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AITRC

**Adarsh Institute of Technology and Research Centre,
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Editors

Dr. P. S. Patil (Principal)

Dr. A. R. Nichal (Dean QA & HOD E & TC)

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3. To strengthen communication, management skills and continuous learning attitude in young engineers dedicated for collaborative research for society through industry interactions.

Messages



**Campus Director
Ms. Pooja Patil**

Dear Readers,

It is my great pleasure to extend a warm welcome to all of you to the National Conference on Recent Trends in Engineering and Technology (NCRTEET 2026), hosted by Adarsh Institute of Technology and Research Centre, Vita.

In today's fast-evolving technological landscape, research and innovation are essential drivers of progress and development. This conference serves as a valuable platform for researchers, academicians, and industry professionals to share their insights, exchange knowledge, and explore emerging advancements in engineering and technology.

The research papers presented in this conference showcase the commitment and sincere efforts of scholars across diverse fields. Their work is expected to contribute significantly toward addressing modern challenges and inspiring future innovations. We strongly believe that collaboration and knowledge exchange are vital for technological advancement. This conference aims to promote meaningful discussions, encourage interdisciplinary thinking, and spark new ideas. I urge all participants to actively engage, connect with peers, and take full advantage of this enriching opportunity.

May this event inspire new perspectives and serve as a catalyst for future discoveries and innovations. Wishing everyone a productive and rewarding conference experience.

Messages



**Principal
Dr. P. S. Patil**

Dear Readers,

I extend my heartfelt greetings to all participants of the National Conference on Recent Trends in Engineering and Technology (NCRTEET 2026), organized by Adarsh Institute of Technology and Research Centre, Vita.

In today's dynamic technological environment, research and innovation remain the cornerstone of progress. This conference offers an excellent platform for academicians, researchers, and students to share knowledge, exchange ideas, and explore the latest developments in engineering and technology.

The papers presented reflect sincere academic efforts and provide meaningful insights into addressing contemporary challenges. Such gatherings promote collaboration, critical thinking, and the practical application of theoretical knowledge, helping bridge the gap between academia and industry.

I sincerely appreciate the dedication and hard work of all researchers, faculty members, and students who have contributed to making this event successful. I would also like to extend my gratitude to the organizing committee for their commitment and tireless efforts.

May this conference serve as a catalyst for new ideas, meaningful collaborations, and future advancements in engineering and technology.

Messages



**Dr. A. R. Nichal (Dean QA, HOD E & TC)
Conference Convenor & Editor**

Dear Readers,

Dear Readers,

NCRTEET-2026 is a National Conference organized by the Department of Electronics and Telecommunication of Adarsh Institute of Technology and Research Centre, Vita. The conference aims to bring together academicians, professional engineers, research scholars, and students from UG, PG, and Diploma programs on a common platform to exchange innovative ideas, share experiences, and disseminate knowledge in emerging fields of Electronics, Mechanical, Electrical, Computer Science, and Civil Engineering.

NCRTEET-2026 aspires to inspire participants and delegates to engage in collaborative research and enhance their technical expertise in line with recent technological advancements. The conference features a comprehensive technical program, including peer-reviewed paper presentations and keynote lectures by eminent experts.

I extend my sincere gratitude to all participants for presenting their valuable academic and research contributions at NCRTEET-2026. I would also like to express my heartfelt appreciation to our distinguished guests for their support and contribution towards the success of this conference.

I am especially thankful to Hon. Miss Pooja Patil (Director, AITRC Vita) and Dr. P. S. Patil (Principal, AITRC Vita) for their constant guidance and encouragement in organizing NCRTEET-2026.

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INDEX

Sr. No	Paper Title and Author	Department	Page No.
1	Transfer Learning Based Ensemble CNN Framework for Automated Thyroid Disease Detection using Ultrasound Images (Nirzara Jagdale, Sakshi Patil, Shrutika Kashid, Atharv Mane, Prof. P.H. Mane)	E & TC	1-9
2	Lora with omnidirectional antenna for enhanced IoT communication (Omkar Sonawane, Henon Samuel, Abhijeet Mali, Kaustubh Dhabe, Prof. Supriya Diwan, Prof. Aniket Joshi, Prof. Amit Mudukshiwale)	E & TC	10-15
3	Portable ECG Monitoring System Using IoT for Real Time Health Monitoring (Aviraje Bhosale, Tejashree Sakhale, Rahi Jadhav, Nishant Gaikwad, Dr. A. R. Nichal)	E & TC	16-21
4	IoT Based Solar Performance Monitoring System (Jaydeep Mane, Sushant Patil, Vikrant Jadhav, Prof. Prashant B. Yadav, Prof. Seema S. Patil)	E & TC	22-27
5	Walk2Watt System: A Footstep-Based Energy Harvesting Solution (Om Koli, Suraj Patil, Pradip Khatal, Prof. Seema S Patil, Prof. Prashant B Yadav)	E & TC	28-32
6	IoT Based Bridge Health Monitoring System (Jyoti. S. Sapkal, Shital. R. Yadav, Shreya. S. Taralkar, Prashant .B. Yadav)	E & TC	33-38
7	Online Exam Management System (Omkar S. Sabale, Aniket T. Kumbhar, Shridhdar M. Jadhav, Tushar S. Gaikwad)	E & TC	39-43
8	Preventive Maintenance of Industrial Machines Using (IoT). (Neha Prashant Karkhile, Sneha Pravin Patil, Saurabh Satish Ganbote, Vrushali Rajaram Patil)	E & TC	44-48
9	IoT Enabled Real Time Health Monitoring System (Monika Virendra Patil, Seema Sandip Patil)	E & TC	49-52
10	The Advance smart EV Wireless Charging Parking Station With Billing System (Ajay Devkar, Mahima Nalawade, Shivani Patil, Dr. A. R. Nichal)	E & TC	53-58
11	Smart Health Care Hub with Medicine Reminder and Vital Monitoring (Kirti Ramchandra Rupanawar, Prathamesh Dagadu Waghmode, Pramila Anil Gejage, Rushikesh Vikas Sawant, Prof. Abhijit D. Ghorpade)	E & TC	59-64
12	Design and Implementation of a Passive Mobile Signal Enhancer (Virendra Lokare, Mrunali Rabade, Sharvari Sawant, Pushpa Ingole)	E & TC	65-67

Sr. No	Paper Title and Author	Department	Page No.
13	Intelligent Vehicle Data Monitoring System (Viraj Yadav, Kshitij Amate, Prajakta Mulay, Aparna Mane)	E & TC	68-70
14	PLC Based Industrial Edge-to-Dashboard Data Integration System (Rutuja Pawar, Aishwarya Nale, Aditi Charankar)	E & TC	71-74
15	Skin Disease Detection Using Image Processing (Prashant Chalekar, Vishwajeet Patil, Jeevan Bankar, Priya Mali)	E & TC	75-77
16	Mechanical Performance of Surfactant Treated Carbon Fiber–Epoxy Composites (Amitkumar B. Salunkhe, Surajkumar G. Kumbhar, Girish S. Aute, Vaibhav S. Mokashi, Indrajeet R. Mane)	Mech	78-81
17	Design and Development of a Pedal Operated Hydraulic Sheet Bending Machine (Rohit T. Waghmare, Rohit B. Patil, Sanjay D. Yadav, Pranjal P. Khot, Shailesh S. Parit, Suraj C. Patil)	Mech	82-84
18	Solar-Powered Thermoelectric Cabin Cooling for Parked Passenger Vehicles: A Comprehensive Review (Vaibhav P. Patil, Toufik D Shikalgar, Vishwajeet D. Yadav, Gaurav A. Bhosale)	Mech	85-92
19	Strength Assessment of Masonry Prism (Prof. Pramod R. Thorat , Mr. Suhail Salim Tamboli , Bhagwat Sourabh Raghunath , Patil Viraj Vilas , Mali Siddharth Mahesh, Mandale Swapnil Aabaso, Sartape Kiran Vilas)	Civil	93-99
20	AI-Driven Digital Twin for Optimization of EV Battery Pack Design, Thermal Management, and Lifecycle Performance (Sumit Nalavade , Prathamesh Ghorpade ,Govardhan Ghavane , Vivek Zagde ,Tanmay Tandale)	ECE	100-104
21	Microcontroller-Based Arc Fault Detection Using Shoulder Waveform Analysis of Voltage and Current Signals (M. A. Patil, Supriya Suresh Kumbhar, Prajakta Gautam Patil, Satyajeet Sanjay Patil, Rasika Mahadev Shinde.)	EE	105-108
22	Automatic Power Factor Correction (Prof.Basawaraj Hebbale , Rutuja Pilankar , Shubham Patil , Sanika Patil , Sanika Mulik.)	EE	109-116
23	High Voltage Underground Cable Duct Cooling System (Prof.Mr.A.C.Daiv , Ms.Pratiksha Tanaji Patil ,Ms.Sanika Machhindra Patil , Ms.Shruti Dhananjay Sutar , Ms.Gauri Dhanaji Dhumal .)	EE	117-121
24	Smart Transformer System With Ai Based Tap Changer And Cooling Control (Gaurav Ashok Bongale , Gayatri Babasaheb ghatage , Prajval Parashram Bamane , Ayyan Ramjan Attar)	EE	122-125
25	A Voltage Controlled DG Unit based Active Harmonis Damping System For Island and Grid Connected Microgrid (Jyoti Dinesh Bagade , Sneha Vishnu Pawar , Dnyaneshwari Khandare ,Sojal Badade)	EE	126-131

Sr. No	Paper Title and Author	Department	Page No.
26	VidyaBot: Intelligent Virtual Assistant for Enhancing Student Learning Experience (Ms. Sayali Kishor Sawant ,Ms.Gayatri Sadashiv Lad ,Ms.Mayuri Ravasheb Patil , Ms.Sakshi Prakash Mane, Ms.Rutuja Vikas Dange .)	ECE	132-135
27	Solar Based Wi-Fi River Cleaning Robot (Shweta Devar , Rutuja Gavade , Mahesh Shinde)	ECE	136-139
28	Wireman Safety System against Reverse Current from Inverter (Ms. Samira Mulani , Mr. Aniket Jadhav , Mr. Satyajeet Suryawanshi , Mr. Vishal Khot , Mr. Vaibhav Yadav Patil .)	ECE	140-142
29	Intelligent MPPT Control of Photovoltaic Systems Using ANN and Ćuk Converter (M. A Patil , Atharva Patil, Pratik Sathe, Rohan More , Nikita Patil.)	EE	143-148
30	AI-Based Smart Billing System Using YOLO (You Only Look Once) for Automated Retail Checkout (Pratibha Kale , Dhanashree mohite , Nikhil Koli , Sushil Ghagare)	ECE	149-156
31	Smart Campus Mobility Pass System (SCMS) Revolutionizing Campus Transportation Management through Digital Transformation (Ms. Sayali Sawant , Ms. Saniya Mulla ,Ms.Neha Mane)	ECE	157-167
32	Skill Exchange & Learning Collaboration Web Application (Dr.V.B. Ingale, Kamble S.J, Mane R.S, Nanna O., Patil D.A)	CSE	168-173
33	Customized Ecosystem Agentic AI Framework: A Multi-Tenant Intelligent Business Agent Platform with RAG-Based Self-Learning (Prof. P.T. Shitole , Omkar Thombare ² , Rohan Chavan ³ , Omkar Sutar, Saurabh Pawar)	CSE	174-181
34	Agrichain Ai Cloud Ecosystem Using blockchain (Prof. P.T.Shitole ¹ , Mundhe P.U, Kolekar A.S, Chavan S.T, Patil D.S, Kadam S.S)	CSE	182-187
35	Student Performance Analysis (Sanika Patil, Pranoti Jadhav, Vaishnavi Jadhav, Muskaan Mujawar, Ashwini Mahind)	CSE	188-192
36	Digitalization of ASHA Worker Application (Mr.D.K.Jadhav, Mrunali Maheshsing Hajare, Rutuja Achitrao Jadhav,Saniya Mubarak Mulla , Shweta Sahadev Bhasar, Madhuri Anil Choudhari)	CSE	193-202
37	Local Experts (Sagar Prabhakar Mali, Siddhi Nivas Chavan, Shruti Subhash Kale, Altmash Ajam Chougule, Asmita Sunil Nale, Sakshi Laxman Sutar)	CSE	203-208

Sr. No	Paper Title and Author	Department	Page No.
38	AI Powered Interview Practice Bot (Mr.D.K.Jadhav, Neha Kadam, Jyoti More, Bhagyashri Khatri, Sanskruti katwate, Smita Suryawanshi)	CSE	209-212
39	LeafAlert (Sagar Prabhakar Mali, Rupesh Kiran Amane, Saurabh sakharam javir, Sujay Sanjay Kore, Umarali Shahanawaz, Mulla, Abhishek Hanmantrao Yamgar)	CSE	213-217
40	E-Jewellers (Abhishek Ramesh Mandale, Aniket Adinath Kakade, Atharv Dattatray Mali, Viraj Jaykar Desai, Sayali Laxman Jadhav)	CSE	218-220
41	Smart Bachatgat: A Web Based Digital Platform for Self-Help Group Management . (Sakshi Vikas Budhe, Sneha Anil Kumbhar, Vaishnavi Uttam Kadam, Sanjivani Shivaji Mane, Sayali Laxman Jadhav)	CSE	221-223
42	IoT Based Fire Detection And Supression System (Ritesh Ramesh Yadav, Sahil Pandharinath Shembade, Anil Suresh Shinde, Vishal Shivaji Ghuge, Rasika Sharad Pawar, Priyanka Rajaram Telshinge)	CSE	224-226
43	AI Based Medicine System (Sandhya Santosh Mane Patil, Shubhangi Dattatray Rupnawar, Sakshi Pratap Salunkhe, Riddhee Jagannath Tingare, Nayan Laxman Pawar, Priyanka Rajaram Telshinge)	CSE	227-230
44	Reducing Clinical Trial Failure using Artificial Intelligence (Madhuri Netake, Vaishnavi Karnale, Sudarshan Kadam, Mrudula Kumbhar, Shivani Pandit)	AIML	231-236
45	Secure Vote: A Framework for a Secure, Biometric-Authenticated, and AI Integrated Digital Voting System (Asst.Prof. Ms. R.P.Bhilawade, Mr. Samarth Deshmukhe, Mr. Shreyash Babar, Mr. Vinayak Bhise, Mr. Aditya Kapure)	AIML	237-241
46	Cognitive Operating System for Intelligent Human–Computer Interaction (Asst. Prof. P.K. Patil, Vikas Salunkhe, Vaibhav Kotalagi, Amir Shaikh, Vedant Nikam)	AIML	242-248
47	Smart HSRP Monitoring System: A Temporal Fusion Framework for Reliable Automated Traffic Violation Detection (Asst.Prof. Bhilawade R. P, Mujawar Ayesha, Khalipe Aishwarya, Zodage Snehal, Lagade Tejaswini)	AIML	249-252
48	A Review Paper on - Intelligent Footstep Energy Harvesting Using IoT and AI for Smart Cities (Assi. Prof. Ms. R.P.Bhilawade, Ms. Sanika Dale, Ms. Srushti Sagare, Ms. Rohini Pawar, Ms. Prajakta Koli, Mr. Shivam Ingale)	AIML	253-256
49	Indian Supply Chain Systems: Block chain Adoption Challenges (Assi Prof P. K. Patil, Ms. Maitrayee Bodkhe, Mr. Onkar R. Hol, Mr. Prasad V. Kadam, Mr. Aditya S. Walunjkar)	AIML	257-264

Sr. No	Paper Title and Author	Department	Page No.
50	Smart Basket <i>(Asst.Prof.S. P. Suryawanshi ,Rajwardhan Pawar, Rupesh Pawar, Shahid Mulani, Paresh Jagtap)</i>	AIML	265-276
51	AI-Powered Smart Interview Preparation System with Voice and Facial Analysis <i>(Asst.Prof. P. K. Patil,Pawar Sakshi,Patil Sanika, Gaikwad Anuja)</i>	AIML	268-272
52	A Review Paper on - Cyber Defence in the Age of Quantum Technologies <i>(Asst.Prof. A A Patil Ms. Pratiksha Chavan, Ms. Pooja Daingade, Mr. Sanket Daingade, Mr. Aniket Mulik)</i>	AIML	273-276
53	DeepSight: An AI-Enhanced Real-Time Video Intelligence and Human Activity Monitoring System <i>(Asst.Prof. A.V.Bhambare, Swaroop Kadam, Pranav Shinde, Shivam Mulik, Vaibhav Shiotle)</i>	AIML	277-281
54	A Review Paper on - RAG-Enhanced LLMs for Personalized Student Learning: A Review <i>(Asst. Prof.R.P. Bhilawade ,Ms. Nayan Umaji Pawar,Ms. Rutuja Vijay Kumar Mhalkar, Ms. Tanishka Shankar Nalawade, Ms. Saniya Taufik Tamboli)</i>	AIML	282-286
55	A Review Paper on - AI Doctor With Medical Suggestion <i>(Asst.Prof.P.K. Patil,Mr. Jadhav Anand, Mr. Dhole Shivam, Mr. Yadav Onkar,Mr. Jadhav Omkar,Mr Mandalik Saurav)</i>	AIML	287-292
56	Controlled Synthesis Microbial Consortia for Carbon Capture in Urban Sewage System using AI <i>(Prof. R. P. Bhilawade, Sanika Patil, Shruti Jadhav, Aishwarya Jadhav)</i>	AIML	293-299

Transfer Learning Based Ensemble CNN Framework for Automated Thyroid Disease Detection using Ultrasound Images

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Abstract: Early and reliable detection of thyroid disorders using ultrasound imaging is crucial for effective clinical treatment and patient management. However, traditional diagnosis performed by radiologists can sometimes be subjective and may vary between observers. With the rapid development of artificial intelligence, deep learning techniques have emerged as powerful tools for automated medical image analysis. In this study, a transfer learning-based ensemble framework is proposed for the classification of thyroid diseases using ultrasound images. The proposed system employs EfficientNet-B3 and ResNet50 architectures as deep feature extractors to learn meaningful and discriminative patterns from thyroid ultrasound images. To improve prediction reliability and model robustness, a soft-voting ensemble strategy is used to combine the outputs of both networks. To overcome challenges such as limited training data and class imbalance, several training strategies are implemented, including data augmentation, class weighting, and five-fold cross-validation. In addition, Gradient-weighted Class Activation Mapping (Grad-CAM) is incorporated to enhance model interpretability by highlighting the important regions of the ultrasound images that influence the model's decision-making process. The experimental results show that the proposed framework achieves an accuracy of 98.33%, precision of 98.41%, recall of 98.33%, an F1-score of 98.33%, and a ROC-AUC score of 0.97, demonstrating strong classification performance. These findings indicate that the proposed ensemble approach can function as an effective and interpretable computer-aided diagnostic system to support clinicians in the detection of thyroid diseases using ultrasound imaging.

Keywords: Thyroid disease detection, ultrasound imaging, deep learning, transfer learning, EfficientNetB3, ResNet50, soft voting, convolutional neural networks (CNN), Grad-CAM.

I. INTRODUCTION

Thyroid disorders such as hypothyroidism, hyperthyroidism, and malignant thyroid nodules are increasingly recognized as major global health concerns. Ultrasound imaging is commonly used as the primary diagnostic method for evaluating thyroid abnormalities because it is non-invasive, widely available, and relatively cost-effective. However, the manual interpretation of ultrasound images largely depends on the expertise of radiologists and can be influenced by factors such as speckle noise, low image contrast, and visual similarities between benign and malignant nodules. These challenges often make accurate diagnosis difficult and highlight the need for automated computer-aided diagnosis (CAD) systems to support clinical decision-making. Recent progress in deep learning, particularly with convolutional neural networks (CNNs), has significantly improved performance in medical image analysis tasks. Several studies have demonstrated that deep CNN architectures achieve higher accuracy in thyroid nodule detection compared with traditional machine learning methods [3], [4]. Additionally, hybrid approaches that combine deep feature extraction with statistical texture analysis have shown improved capability in distinguishing benign from malignant nodules [1]. Researchers have also proposed multi-class classification models that can identify different thyroid conditions rather than simply performing binary classification, thereby increasing the clinical usefulness of these systems [3]. Among the latest deep learning architectures, EfficientNet-based models have gained attention because of their compound scaling strategy, which balances network depth, width, and input resolution to achieve improved performance with fewer parameters. EfficientNet-B3, in particular, has shown strong capability in extracting relevant features from thyroid ultrasound images and has demonstrated promising results in classification tasks [1], [2], [5]. Hybrid CNN frameworks that integrate EfficientNet-B3 with residual or additional convolutional layers have further improved diagnostic accuracy and model robustness [2], [5]. Moreover, studies involving ultrasound and CT images have

confirmed that transfer learning is highly effective for medical imaging tasks, especially when training data are limited [4]. Despite these advancements, several challenges still remain. Achieving strong generalization performance across different datasets and imaging conditions is difficult due to variations in image acquisition, class imbalance, and the limited availability of well-annotated medical datasets. These factors can negatively affect model stability and reliability. Therefore, continued research on optimized deep learning architectures and more robust training strategies is essential to further improve automated thyroid disease detection systems.

II. RELATED WORK

Recent progress in deep learning has greatly improved automated thyroid disease detection using ultrasound imaging. EfficientNet-based architectures provide highly optimized feature extraction through compound scaling and have shown strong effectiveness in medical image analysis [1], [13]. Transfer learning strategies are frequently applied to address the challenges of limited annotated datasets and to improve model generalization performance [2], [6], [20]. Convolutional neural network-based diagnostic systems have demonstrated higher sensitivity and specificity compared with traditional manual assessments and conventional machine learning approaches [3], [4], [11], [18]. In addition, backbone architectures such as EfficientNet, ResNet, and DenseNet enable improved representation learning through scalable and residual network designs [13]–[15]. Ensemble learning techniques further increase predictive stability and robustness by combining outputs from multiple models [16], while explainable AI methods such as Grad-CAM offer visual interpretability of model predictions in clinical environments [17], [21]. Moreover, robust evaluation strategies, including k-fold cross-validation, are widely used to ensure reliable and unbiased performance evaluation [22]. Table 1 presents a summary of key research studies related to deep learning-based thyroid disease detection using ultrasound imaging. The comparison outlines the architectures used, major contributions, and limitations of existing approaches.

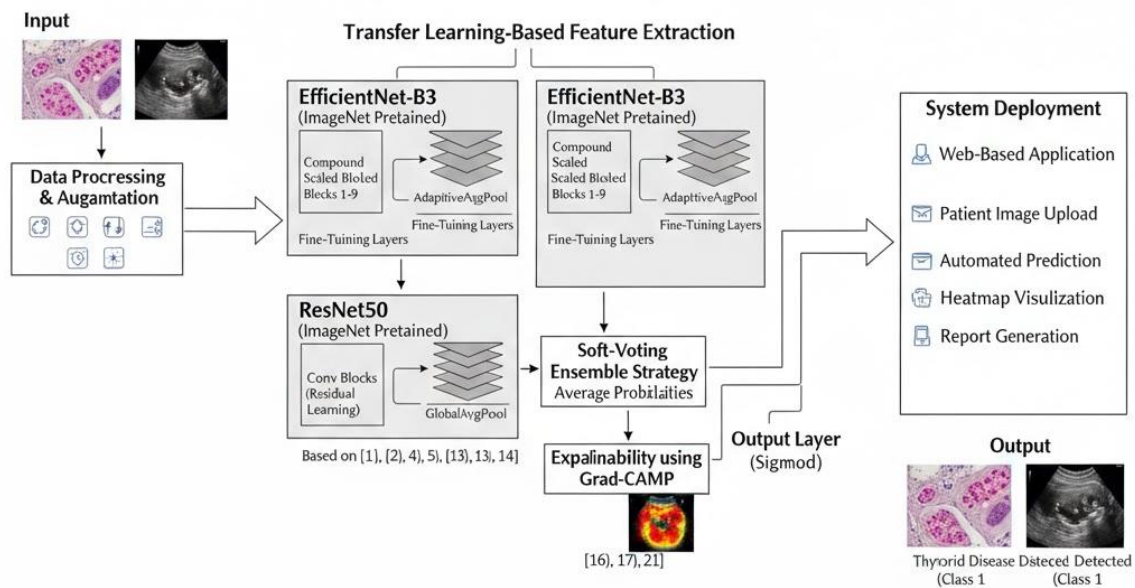
Table 1 : Literature Review for Thyroid Disease Detection

Paper Title	Author & Published Year	Method/ Architecture	Dataset Used By Authors	Key Contribution	Limitation
Grad-CAM: Visual Explanations from Deep Networks via Gradient-Based Localization [17]	R.R. Selvaraju et al., 2017	Explainable AI (Grad-CAM)	ImageNet Dataset	Provides visual interpretability for CNN decisions	Limited quantitative evaluation
Ensemble Deep Learning for Medical Image Classification: A Review [16]	M. A. Ganaie et al., 2021	Ensemble Deep Learning	Multiple medical image datasets (survey paper)	Improves prediction stability and accuracy	Increased model complexity
Intelligent Diagnosis Algorithm for Thyroid Nodules Based on Deep Learning and EfficientNet-B3 [1]	X. Zhang et al., 2022	EfficientNet-B3 + Statistical Features	Hospital thyroid ultrasound dataset collected from clinical patients	High benign/malignant classification accuracy	Limited dataset size
Deep Convolutional Neural Networks for Multi-Class Thyroid Disease Detection [3]	Abdul Qayyum et al., 2022	Multi-class CNN	UCI Thyroid Disease Dataset	Enables classification of multiple thyroid conditions	Dataset dependency
Deep Convolutional Neural Networks in Thyroid Disease Diagnosis [4]	Y. Huang et al., 2022	CNN-based diagnostic model	Clinical thyroid ultrasound dataset	Demonstrates clinical diagnostic potential	Generalization challenges
Ultrasound Image Classification of Thyroid Nodules	Jingjing Chi et al., 2022	CNN-based classification	Clinical thyroid ultrasound dataset	Improves automated ultrasound diagnosis	Limited dataset diversity

Based on Deep Learning [10]					
Deep Convolutional Neural Network for Classification of Thyroid Nodules on Ultrasound [11]	Ke Wang et al., 2022	CNN vs Radiologist evaluation	Large hospital ultrasound dataset	Shows AI diagnostic performance comparable to clinicians	Requires large validation datasets
Hybrid CNN Model with EfficientNet-B3 Backbone for Thyroid Nodule Classification [2]	Mohammad Reza Tizhoosh et al., 2024	Hybrid EfficientNet-B3 CNN	Private thyroid ultrasound dataset from hospital imaging systems	Improves classification robustness	Mainly focused on binary classification
Ultrasound Thyroid Nodule Segmentation Algorithm Based on DeepLabV3+ with EfficientNet [9]	Haoran Liu et al., 2024	DeepLabV3+ + EfficientNet	Thyroid ultrasound segmentation dataset	Combines segmentation and classification	High computational cost
Thyroid Nodule Classification in Ultrasound Imaging Using Deep Transfer Learning [6]	Zhe Zhang et al., 2025	Transfer Learning CNN	Thyroid Ultrasound Image Dataset (public medical dataset) + hospital dataset	Effective learning with limited medical datasets	Requires careful fine-tuning

III. PROPOSED METHODOLOGY

This research presents an intelligent deep learning framework for automated thyroid disease detection using ultrasound images. The proposed methodology integrates transfer learning, ensemble modeling, and explainable artificial intelligence techniques to enhance classification accuracy and improve clinical interpretability. Figure 1 illustrates the architecture of the proposed transfer learning–based ensemble framework designed for thyroid disease classification using ultrasound images. The system begins with data preprocessing and augmentation, followed by feature extraction using pretrained EfficientNet-B3 and ResNet50 models. A soft-voting ensemble mechanism is applied to combine the predictions generated by both models, while Grad-CAM is used to provide visual explanations for the classification outcomes. The framework is implemented as a web-based application that supports automated prediction, heatmap visualization, and report generation.



A. Data Description:

The dataset consists of three thousand ultrasound images categorized into three classes: Hyperthyroidism, Hypothyroidism, and Normal. The dataset was obtained from a publicly available thyroid ultrasound image dataset provided by Stanford University. The dataset contains one thousand images each of Normal, Hyperthyroidism, and Hypothyroidism, in which 80% (two thousand four hundred) are used for model training and 20% (six hundred) are used for model testing. Before training, the images are preprocessed through resizing, normalization, and data augmentation to improve model generalization and overall performance.

B. Data Preprocessing and Augmentation:

Ultrasound images are initially resized and normalized to meet the input size requirements of pretrained convolutional neural networks. To enhance model generalization and reduce the risk of overfitting caused by limited medical datasets, several data augmentation techniques are applied, including rotation, horizontal flipping, scaling, and brightness adjustment. These transformations help the model learn robust features from different variations of the images. This strategy follows transfer learning practices commonly recommended in previous studies [6] and [20]. After completing the preprocessing stage, the refined images are then provided as input to the transfer learning model for feature extraction and training.

C. Transfer Learning-Based Feature Extraction:

The proposed framework employs EfficientNet-B3 as the primary feature extractor because of its compound scaling strategy and efficient parameter utilization [13]. EfficientNet-B3 has shown strong capability in extracting meaningful features from thyroid ultrasound images and has achieved promising results in several classification studies [1], [2], [5]. In addition, ResNet50 is integrated as a complementary backbone network that utilizes residual learning to improve gradient flow and enable deeper feature representation [14]. Both networks are initialized with pretrained weights from ImageNet and then fine-tuned using the thyroid ultrasound dataset to adapt the models to domain-specific medical image characteristics, as supported in earlier research [4].

- $f_1(x; \theta_1)$ denote EfficientNetB3
- $f_2(x; \theta_2)$ denote ResNet50

Each model outputs a probability distribution using the Softmax function is calculated as per equation,

$$p_k^{(m)}(x) = \frac{e^{z_k^{(m)}}}{\sum_{j=1}^K e^{z_j^{(m)}}} \quad \text{Eq}^n [1]$$

where:

- $m \in \{1,2\}$ (model index)
- $z_k^{(m)}$ is the logit for class k
- $p_k^{(m)}(x)$ is predicted probability for class k

D. Soft-Voting Ensemble Strategy:

To improve robustness and reduce prediction variance, the outputs from EfficientNet-B3 and ResNet50 are combined using a soft-voting ensemble strategy. The final prediction is obtained by averaging the class probability outputs produced by the individual models. Ensemble learning enhances stability and improves generalization performance in medical image classification tasks. The final ensemble probability is calculated by averaging the predicted probabilities from both models, as illustrated in the following equation:

$$P_k(x) = \frac{1}{M} \sum_{m=1}^M p_k^{(m)}(x) \quad \text{Eq}^n [2]$$

where:

- $P_k(x)$: Final probability produced by the hybrid model for the input sample x belonging to class k.
- M : Total number of individual models used in the hybrid model (here, $M = 2$).
- $p_k^{(m)}(x)$: Predicted probability for class k given by the m^{th} model for input x.
- x : Input sample, and k represents the target class label.

E. Model Training and Validation:

The training process incorporates class weighting to address dataset imbalance and applies five-fold cross-validation to ensure a robust performance evaluation. The model is optimized using categorical cross-entropy loss, while performance is assessed through accuracy, precision, recall, F1-score, and ROC-AUC metrics. Early stopping and learning-rate scheduling are implemented to prevent overfitting and enhance the model's generalization capability. Data augmentation techniques such as rotation, scaling, and flipping are applied during training to improve model robustness against variations in input images. Furthermore, hyperparameter tuning is conducted to determine optimal values for learning rate, batch size, and network parameters, thereby improving the overall predictive performance of the model.

F. Performance Evolution:

Experimental results demonstrate that the ensemble model outperforms the individual backbone networks in terms of accuracy, precision, recall, F1-score, and ROC-AUC. This performance improvement supports findings from previous thyroid classification studies where EfficientNet-based hybrid models achieved better discrimination between benign and malignant nodules [1], [2], [5], [19]. The use of transfer learning further enhances model convergence and feature representation, which is consistent with observations reported in [6] and [20].

A Confusion Matrix consists of four elements:

- TP (True Positive) – Correctly predicted positive cases
- TN (True Negative) – Correctly predicted negative cases
- FP (False Positive) – Incorrectly predicted positive cases
- FN (False Negative) – Incorrectly predicted negative cases

1. Accuracy measures overall correctness of the model and it is calculated by using mathematical equation,

$$\text{Accuracy: } \frac{TP+TN}{TP+TN+FP+FN} \quad \text{Eq}^n [3]$$

2. Precision measures how many predicted positives are actually correct and it is calculated by using mathematical equation,

$$\text{Precision: } \frac{TP}{TP+FP} \quad \text{Eq}^n [4]$$

3. Recall measures how many real positive cases were detected and it is calculated by using mathematical equation,

$$\text{Recall: } \frac{TP}{TP+FN} \quad \text{Eq}^n [5]$$

4. F1 Score is the harmonic mean of Precision and Recall and it is calculated by using mathematical equation,

$$\text{F1-Score: } \frac{2 \times (\text{Precision} \times \text{Recall})}{\text{Precision} + \text{Recall}} \quad \text{Eq}^n [6]$$

G. Explainability Using Grad-CAM:

To enhance transparency and build clinical trust, Gradient-weighted Class Activation Mapping (Grad-CAM) is applied to visualize the discriminative regions that influence model predictions. Explainable AI techniques are crucial in healthcare applications and for meeting regulatory requirements. Grad-CAM generates heatmaps that highlight the most important regions of the input image contributing to the final classification decision. These visual explanations help clinicians understand whether the model focuses on medically meaningful features. The integration of explainable methods improves interpretability and strengthens user confidence in AI-assisted diagnostic systems.

H. System Deployment:

The trained ensemble model is integrated into a web-based application that allows patient image upload, automated prediction, heatmap visualization, and report generation. This deployment framework supports real-time clinical decision assistance. The backend system processes uploaded images, performs preprocessing, and runs the trained deep learning model to generate diagnostic predictions. The application also provides confidence scores and visual explanation maps to support accurate clinical interpretation. Additionally, the system architecture is designed to ensure scalability, security, and efficient handling of multiple user requests in a healthcare environment.

IV. RESULTS AND DISCUSSION:

The proposed transfer learning-based ensemble framework was evaluated using five-fold cross-validation to ensure robust and reliable performance assessment in this research study. EfficientNet-B3 and ResNet50 were fine-tuned on the thyroid ultrasound dataset, and their predictions were combined using a soft-voting strategy to improve the model's generalization capability. ROC Curve:

The Receiver Operating Characteristic (ROC) curve is used to evaluate the classification performance of the proposed ensemble model across different decision thresholds. The ROC curve plots the True Positive Rate (TPR) against the False Positive Rate (FPR), where TPR and FPR are calculated as:

$$TPR = \frac{TP}{TP+FN} \quad \text{Eq}^n [7]$$

$$FPR = \frac{FP}{FP+TN} \quad \text{Eq}^n [8]$$

The Area Under the Curve (AUC) provides a threshold-independent metric for evaluating model performance. The proposed soft-voting ensemble model achieved a high ROC-AUC value, indicating strong discriminative capability between different thyroid disease classes. The improvement in AUC compared with individual backbone networks confirms the effectiveness of ensemble learning in improving model robustness and stability, consistent with previous findings. The ROC analysis further supports the suitability of the proposed framework for reliable clinical decision-support applications. Figure 2 illustrates the ROC-AUC curves for the evaluated models, comparing the classification performance of EfficientNet-B3, ResNet50, and the proposed soft-voting ensemble framework. The ensemble model achieves the highest AUC value (0.97), indicating superior discriminative capability compared with the individual models. This result demonstrates that combining multiple deep learning architectures improves robustness and enhances the overall diagnostic performance for thyroid disease classification.

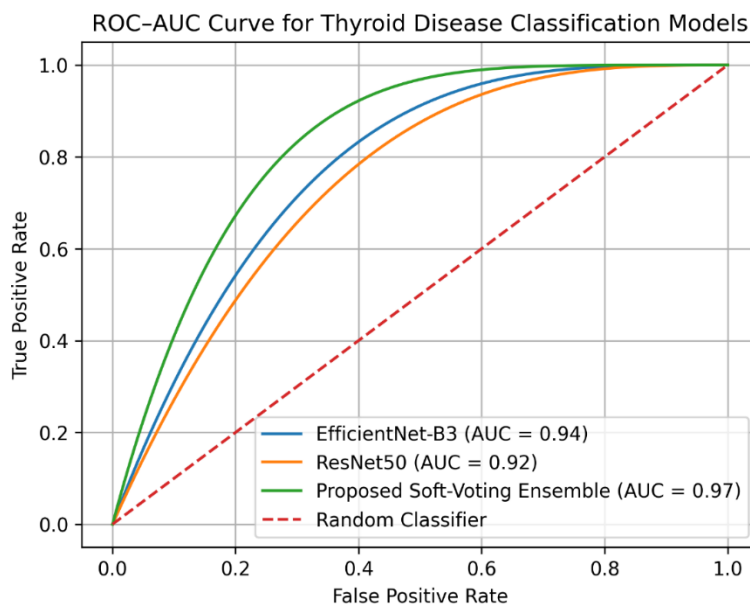


Fig.2 ROC-AUC Curve for Thyroid Disease Detection

- Hyperthyroidism: Precision = 1.00, Recall = 1.00, F1-score = 1.00
- Hypothyroidism: Precision = 0.95, Recall = 1.00, F1-score \approx 0.976
- Normal: Precision = 1.00, Recall = 0.95, F1-score \approx 0.974

Comparative analysis shows that the ensemble framework achieves higher stability and lower variance compared to standalone CNN models, consistent with the well-known advantages of ensemble learning. In addition, Grad-CAM visualizations highlight clinically relevant regions within ultrasound images, improving model interpretability and

supporting the requirements of explainable AI in healthcare applications. Table 2 presents the comparative performance of the evaluated models in terms of accuracy, precision, recall, F1-score, and ROC–AUC. The results show that the proposed soft-voting ensemble model achieves better performance compared to the individual EfficientNet-B3 and ResNet50 models, demonstrating improved classification capability for thyroid disease detection.

Table 2: Model Performance of Thyroid Disease Detection

Model	Accuracy	Precision	Recall	F1-Score	ROC–AUC
EfficientNet-B3	92.45%	91.80%	90.95%	91.37%	0.94
ResNet50	90.72%	89.65%	88.90%	89.27%	0.92
Soft-Voting Ensemble	95.63%	94.85%	94.10%	94.47%	0.97

Figure 3 shows the confusion matrix of the proposed thyroid disease classification model. It illustrates the distribution of correct and incorrect predictions across the three classes—Hypothyroidism, Hyperthyroidism, and Normal. The matrix provides a detailed evaluation of the model’s classification performance by highlighting true positives, false positives, and misclassifications for each category. The results indicate that the proposed ensemble framework achieves highly accurate predictions with minimal confusion between the classes.

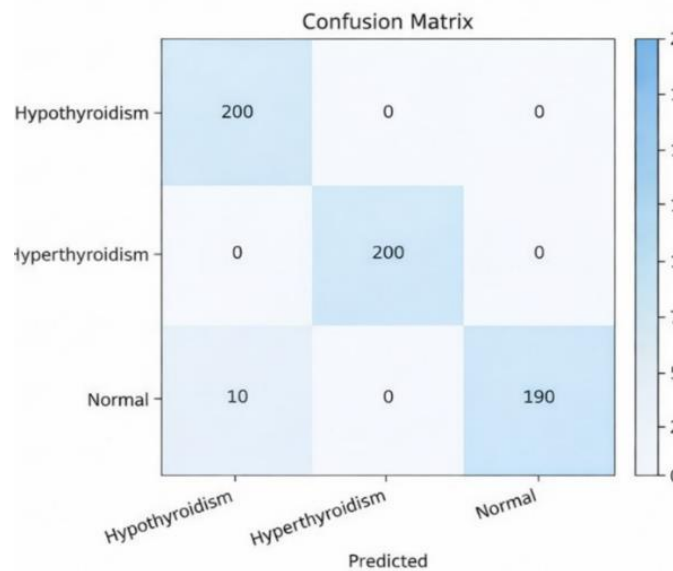


Fig 3. Confusion matrix for Thyroid Disease Detection

Figure 4 presents the overall performance of the proposed deep learning model for thyroid disease classification. The figure shows key evaluation metrics, including accuracy, precision, recall, F1-score, and ROC–AUC obtained during the model testing phase. These metrics highlight the effectiveness of the transfer learning–based ensemble framework in achieving high classification accuracy and reliable predictive performance across all thyroid disease classes.

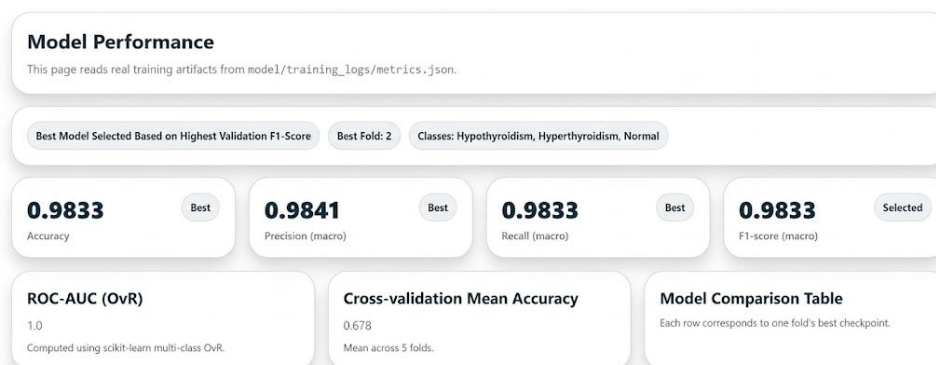


Fig 4. Model Performance for Thyroid Disease Detection

Figure 5 presents the training and validation performance of the proposed model across multiple epochs, illustrated through accuracy and loss curves. The accuracy graph indicates a steady increase in both training and validation accuracy, reflecting effective learning and improved generalization over time. At the same time, the loss graph shows a consistent decrease in both training and validation loss values, suggesting that the model gradually reduces prediction errors and converges toward optimal performance during the training process.

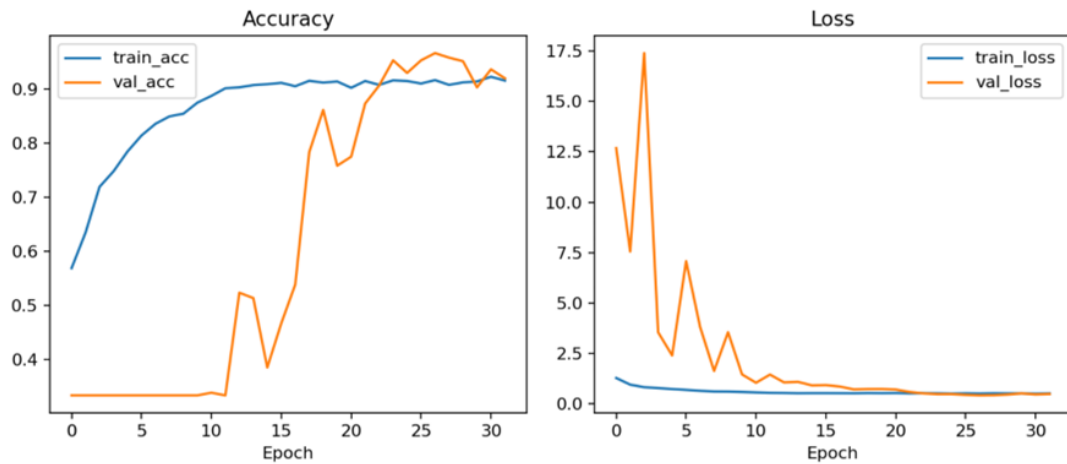


Fig.5 Accuracy and Loss Curve for Thyroid Disease Detection

Figure 6 presents the output interface of the proposed ThyroCare AI system, displaying the predicted thyroid condition together with the model confidence score. The ensemble model predicts Hypothyroidism with a confidence level of 99.96%, while the donut chart provides a clear visual representation of prediction confidence. This interface supports automated diagnosis along with report generation to assist clinical decision-making

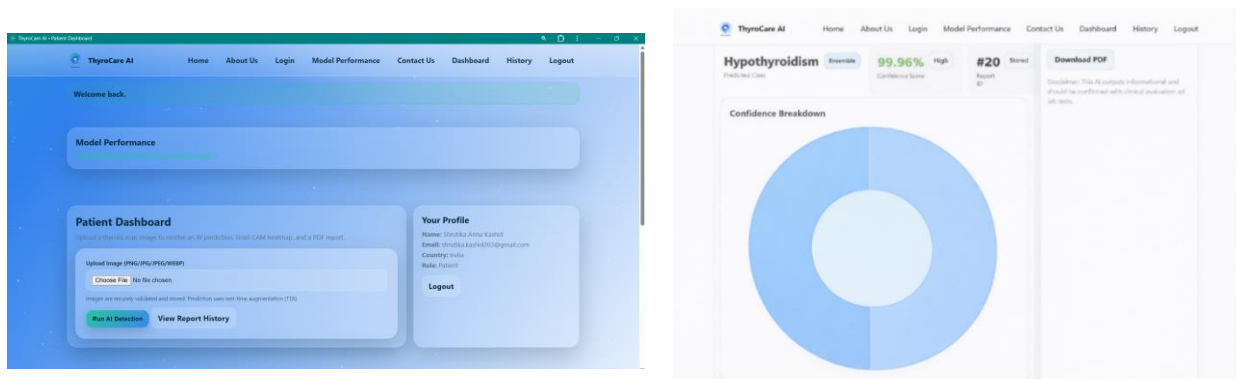


Fig.6 Input Methodology Confidence Score for Thyroid Disease Detection

V. Conclusion:

This paper presents a deep learning–based soft-voting ensemble framework for automated thyroid disease classification using ultrasound images. The model integrates EfficientNet-B3 and ResNet50 through transfer learning to enhance feature extraction and improve classification robustness. Experimental results on a three-class dataset demonstrated strong performance, achieving 98.33% accuracy with balanced macro precision, recall, and F1-score of approximately 98.3%. The OvR ROC–AUC score of 1.0 indicates excellent class separability, while confusion matrix analysis shows minimal misclassification across categories. Overall, the proposed ensemble approach provides a reliable and effective computer-aided diagnostic solution for thyroid disease detection using ultrasound imaging.

VI. Future Work:

Future work will focus on validating the proposed model using larger, multi-center datasets to improve generalization and ensure reliability in real-world clinical settings. Advanced ensemble strategies such as weighted voting or stacking may be explored to further improve predictive performance. Incorporating additional backbone networks and transformer-based architectures could increase feature diversity and help reduce remaining misclassification. Furthermore, integrating explainable AI techniques will improve model transparency and strengthen clinical trust.

Deployment optimization through model compression and pruning will also be considered to enable real-time implementation in practical diagnostic systems.

References:

- [1] Xiaojie Zhang *et al.*, “Intelligent diagnosis algorithm for thyroid nodules based on deep learning and EfficientNet-B3,” *Biomedical Signal Processing and Control*, vol. 77, 2022, Art. no. 103715. Available: <https://www.sciencedirect.com/science/article/abs/pii/S1746809422004281>
- [2] Mohamed Abdel-Nasser *et al.*, “Hybrid CNN model with EfficientNet-B3 backbone for thyroid nodule classification,” *Medicina*, vol. 61, no. 11, Art. no. 2036, 2024. Available: <https://www.mdpi.com/1648-9144/61/11/2036>
- [3] Abdul Qayyum *et al.*, “Deep convolutional neural networks for multi-class thyroid disease detection,” *arXiv preprint arXiv:2203.03627*, 2022. Available: <https://arxiv.org/abs/2203.03627>
- [4] Yong Huang *et al.*, “Deep convolutional neural networks in thyroid disease diagnosis,” *Computer Methods and Programs in Biomedicine*, 2022. Available: <https://pubmed.ncbi.nlm.nih.gov/35489145/>
- [5] Mohamed Abdel-Nasser *et al.*, “Deep hybrid model of EfficientNet-B3 for thyroid nodule classification,” *Medicina*, vol. 61, no. 11, Art. no. 2036, 2024. Available: <https://www.mdpi.com/1648-9144/61/11/2036>
- [6] Zhe Zhang *et al.*, “Thyroid nodule classification in ultrasound imaging using deep transfer learning,” *BMCCancer*, vol. 25, 2025. Available: <https://bmccancer.biomedcentral.com/articles/10.1186/s12885-025-13917-3>
- [7] Liang Zhao *et al.*, “Detection of thyroid nodules with ultrasound images based on deep learning,” *Current Medical Imaging*, 2019. Available: <https://dx.doi.org/10.2174/1573405615666191023104751>
- [8] Yong Huang *et al.*, “Deep convolutional neural networks in thyroid disease detection,” 2022. Available: <https://pubmed.ncbi.nlm.nih.gov/35489145/>
- [9] Haoran Liu *et al.*, “Ultrasound thyroid nodule segmentation algorithm based on DeepLabV3+ with EfficientNet,” 2024. Available: <https://pubmed.ncbi.nlm.nih.gov/40000546/>
- [10] Jingjing Chi *et al.*, “Ultrasound image classification of thyroid nodules based on deep learning,” *Frontiers in Oncology*, vol. 12, 2022. Available: <https://www.frontiersin.org/articles/10.3389/fonc.2022.905955/full/>
- [11] Ke Wang *et al.*, “Deep convolutional neural network for classification of thyroid nodules on ultrasound,” *European Journal of Radiology*, 2022. Available: <https://pubmed.ncbi.nlm.nih.gov/35512512/>
- [12] Ching-Long Chen *et al.*, “Thyroid nodule classification by fine-tuning convolutional neural network,” *Journal of Digital Imaging*, 2017. Available: <https://pubmed.ncbi.nlm.nih.gov/28695342/>
- [13] M. Tan and Q. V. Le, “EfficientNet: Rethinking model scaling for convolutional neural networks,” *arXiv preprint arXiv:1905.11946*, 2019. Available: <https://arxiv.org/abs/1905.11946>
- [14] K. He, X. Zhang, S. Ren, and J. Sun, “Deep residual learning for image recognition,” *Proc. IEEE Conf. Computer Vision and Pattern Recognition (CVPR)*, 2016. Available: <https://arxiv.org/abs/1512.03385>
- [15] G. Huang, Z. Liu, L. Van Der Maaten, and K. Q. Weinberger, “Densely connected convolutional networks,” *Proc. IEEE Conf. Computer Vision and Pattern Recognition (CVPR)*, 2017. Available: <https://arxiv.org/abs/1608.06993>
- [16] M. A. Ganaie *et al.*, “Ensemble deep learning for medical image classification: A review,” *arXiv preprint arXiv:2104.02395*, 2021. Available: <https://arxiv.org/abs/2104.02395>
- [17] R. R. Selvaraju *et al.*, “Grad-CAM: Visual explanations from deep networks via gradient-based localization,” *Proc. IEEE Int. Conf. Computer Vision (ICCV)*, 2017. Available: <https://arxiv.org/abs/1610.02391>
- [18] Ke Wang *et al.*, “Deep convolutional neural network for the diagnosis of thyroid nodules on ultrasound,” *European Journal of Radiology*, 2022. Available: <https://pubmed.ncbi.nlm.nih.gov/35512512/>
- [19] Mohamed Abdel-Nasser *et al.*, “Hybrid CNN model with EfficientNet-B3 backbone for thyroid nodule classification,” *Medicina*, vol. 61, no. 11, Art. no. 2036, 2024. Available: <https://www.mdpi.com/1648-9144/61/11/2036>
- [20] Zhe Zhang *et al.*, “Thyroid nodule classification in ultrasound imaging using deep transfer learning,” *BMC Cancer*, vol. 25, 2025. Available: <https://bmccancer.biomedcentral.com/articles/10.1186/s12885-025-13917-3>
- [21] Amin Abdul *et al.*, “Explainable artificial intelligence (XAI) in healthcare: A systematic review,” *arXiv preprint arXiv:2007.07366*, 2020. Available: <https://arxiv.org/abs/2007.07366>
- [22] Sergios Theodoridis *et al.*, “A survey on cross-validation techniques for medical image classification,” *arXiv preprint arXiv:1811.12808*, 2018. Available: <https://arxiv.org/abs/1811.12808>

LoRa with Omnidirectional Antenna for Enhanced IoT Communication

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Abstract: This paper presents the design and implementation of a LoRa-based communication system integrated with a meander-line microstrip patch to achieve omnidirectional radiation and enhanced communication range. LoRa technology enables low-power long-range communication, making it suitable for Internet of Things (IoT) applications such as smart agriculture, smart cities, and environmental monitoring. However, challenges such as signal attenuation, non-line-of-sight conditions, and antenna inefficiencies limit its performance. The proposed system integrates a meander-line microstrip patch with adaptive network optimization techniques to improve signal propagation, energy efficiency, and reliability. The system is designed, simulated, and tested under various environmental conditions. Results demonstrate improved range, stable communication, and reduced power consumption. The proposed solution is cost-effective, scalable, and suitable for real-world IoT deployments

Keywords: LoRa, IoT, Omnidirectional Antenna, Adaptive Network Optimization.

1. Introduction

The rapid growth of Internet of Things (IoT) applications requires reliable, low-power, and long-range communication systems capable of supporting large-scale device connectivity. LoRa (Long Range) technology has emerged as a promising Low Power Wide Area Network (LPWAN) solution due to its low energy consumption, cost-effectiveness, and scalability, making it highly suitable for applications such as smart agriculture, smart cities, environmental monitoring, and industrial automation. Despite its advantages, real-world LoRa deployments face several challenges, including signal attenuation due to obstacles, terrain variations, interference, and non-line-of-sight (NLOS) conditions, which significantly degrade communication performance. Additionally, trade-offs between data rate, transmission range, and power consumption further complicate system optimization. Antenna design plays a critical role in determining overall system performance, as it directly influences radiation pattern, gain, efficiency, and signal propagation characteristics. Conventional antenna designs often suffer from limitations such as bulkiness, limited bandwidth, or poor omnidirectional coverage, making them less suitable for compact IoT devices. To address these challenges, this paper focuses on the integration of a meander-line microstrip patch antenna with LoRa systems to achieve compact size, improved impedance matching, and efficient omnidirectional radiation. The proposed approach aims to enhance communication reliability, extend coverage range, and maintain energy efficiency under practical deployment conditions. Furthermore, this work explores the combined impact of antenna design and system-level optimization on LoRa performance, providing a cost-effective and scalable solution for next-generation IoT networks.

2. Literature Survey

Recent advancements include flexible and 3D-printed antennas for IoT applications. However, existing systems still face limitations in range, efficiency, and cost. Recent advancements in LoRa-based communication systems highlight the critical role of antenna design in improving range, reliability, and overall network performance. Various researchers have explored different antenna configurations and deployment strategies to enhance the efficiency of low-power wide-area networks (LPWAN).

Raza et al. (2017) presented a comprehensive overview of LPWAN technologies and emphasized that antenna efficiency significantly impacts LoRa communication performance. Their study showed that better antenna gain directly improves link quality and coverage, achieving communication ranges of 15–20 km in rural areas and 2–5 km in urban environments.

Petäjärvi et al. (2017) evaluated LoRa technology in real-world scenarios, particularly for remote health and sensor applications. Their findings demonstrated that environmental factors such as obstacles and terrain greatly influence

signal propagation. Using a 3 dBi omnidirectional antenna, they achieved communication ranges of approximately 2 km in urban areas and up to 15 km in rural settings.

Choudhury et al. (2020) focused on designing a high-gain omnidirectional antenna for LoRa gateway applications. By implementing a 5.8 dBi collinear antenna with stacked elements, they significantly improved signal gain and extended communication coverage to around 10 km in suburban areas while maintaining an omnidirectional radiation pattern. Rahman et al. (2021) proposed a compact meander-line monopole antenna for LoRa-based IoT devices. Their design is particularly suitable for portable and compact applications, offering efficient performance while maintaining omnidirectional radiation. The system achieved communication ranges between 3–5 km in urban deployments.

Li et al. (2022) introduced a 3D-printed flexible omnidirectional antenna designed for wearable and agricultural IoT applications. Their antenna achieved wideband operation with lightweight construction and provided communication ranges of 8–12 km in open areas, demonstrating its suitability for modern IoT use cases.

Sl. No.	Authors & Year	Title / Source	Antenna Type / Design	Key Findings	Range / Performance
1	Raza et al., 2017 (IEEE Communications Surveys & Tutorials)	Low Power Wide Area Networks: An Overview	General LoRa Antenna Study	Highlighted that antenna efficiency greatly affects LoRa range; higher gain improves link quality and coverage	15–20 km (rural), 2–5 km (urban)
2	Petäjajarvi et al., 2017 (IEEE IoT Journal)	Evaluation of LoRa LPWAN Technology for Remote Health and Sensor Applications	3 dBi Omnidirectional Antenna	Analyzed real-world LoRa deployments; demonstrated environmental impact on signal propagation	~2 km (urban), ~15 km (rural)
3	Choudhury et al., 2020 (IEEE Transactions B)	Design of High-Gain Omnidirectional Antenna for LoRa Gateway Applications	5.8 dBi Collinear Antenna	Improved gain using stacked elements for gateways; stable omnidirectional radiation pattern	~10 km (suburban)
4	Rahman et al., 2021 (IEEE Access)	Compact Meander-Line Antenna for LoRa-Based IoT Devices	Meander-Line Monopole	Compact and efficient design suitable for portable IoT nodes; maintains omnidirectional pattern	3–5 km (urban deployment)
5	Li et al., 2022 (Sensors Journal)	3D-Printed Omnidirectional Antenna for Flexible LoRa IoT Nodes	3D-Printed Flexible Antenna	Achieved wideband operation with low weight; suitable for wearable and agricultural IoT	3–5 km (open area)
6	Li et al., 2022 (Sensors Journal)	3D-Printed Omnidirectional Antenna for Flexible	3D-Printed Antenna	Achieved wideband operation with low weight; suitable for wearable applications	8–12 km (open area)

Summary of Literature

From the above studies, it is evident that:

- Antenna design (gain, type, and structure) plays a crucial role in LoRa performance.
- Higher gain antennas improve range but may affect cost and size.
- Compact antennas are suitable for IoT nodes but may limit range.
- Environmental conditions significantly influence signal propagation.

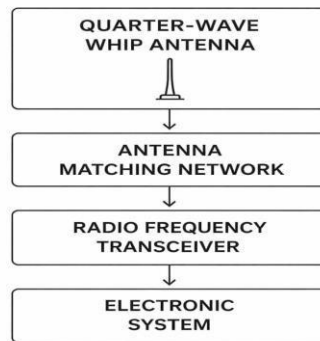
3. Proposed Approach

Technique1: Integration of Quarter-Wave Whip Antenna.

One of the most effective approaches to extend the range and reliability of LoRa-based communication systems is the integration of a quarter-wave whip antenna. This antenna operates at a length equal to one-fourth of the wavelength of the transmitted signal, allowing it to achieve resonance at the operating frequency. Resonance ensures minimal reflection and maximum power transfer, thereby increasing the efficiency of the overall communication system. Unlike directional antennas that focus energy in a narrow beam, the quarter-wave whip antenna provides omnidirectional radiation patterns, which are especially advantageous for IoT applications where end devices are distributed irregularly in all directions. This property ensures that communication links are not limited strictly to line-of-sight conditions but can effectively operate in obstructed or cluttered environments. Additionally, the design of the quarter-wave whip

antenna is simple, compact, and cost-effective, making it highly suitable for large-scale IoT deployments where affordability and scalability are essential. It requires minimal fabrication complexity while offering durability for outdoor applications such as smart agriculture and environmental monitoring. By enabling extended communication range, reducing power loss, and improving link stability, the quarter-wave whip antenna addresses critical limitations of LoRa networks in practical real-world scenarios. Its combination of efficiency, affordability, and omnidirectional coverage makes it a powerful solution to enhance LoRa's applicability in emerging wireless communication systems

INTEGRATION OF QUARTER-WAVE WHIP ANTENNA



Technique2: Integration of Meander-line Microstrip Patch Antenna

This approach focuses on designing a compact, low-cost meander line microstrip patch antenna on an FR-4 substrate for LoRa communication with ~1 km range.

The antenna is a printed, planar, and compact structure, where a zig-zag (meandered) copper trace increases the electrical length, allowing operation at low frequencies without increasing physical size.

It works on the microstrip principle:

- The meander line acts as the radiating element
- The ground plane improves radiation and impedance matching
- RF signals flow through the trace and radiate as electromagnetic waves

A LoRa (Long Range) communication module is a low-power wireless system designed for long- distance data transmission, widely used in IoT applications such as smart agriculture, disaster monitoring, and rural connectivity. It operates in unlicensed ISM bands (typically 433 MHz, 868 MHz, or 915 MHz) and uses a modulation technique called Chirp Spread Spectrum (CSS).

A standard microstrip patch antenna is usually directional. However, in this design, omnidirectional radiation is achieved through:

- Symmetrical Meander Layout: Ensures uniform current distribution.
- Ground Plane Optimization: Proper ground design helps radiate signals in multiple directions.
- Edge Radiation Enhancement: The meander structure allows radiation from multiple segments, creating a near-omnidirectional pattern in the horizontal plane

Replacing the helical antenna with a meander line microstrip patch antenna in a LoRa system enhances compactness, durability, and integration while still maintaining near-omnidirectional radiation. This makes it highly suitable for modern wireless communication applications where space, cost, and efficiency are critical

4. Methodology

The methodology of this study focuses on the systematic design, implementation, and evaluation of a LoRa-based communication system integrated with a Meander-line microstrip patch antenna to achieve compact size, efficient radiation, and reliable long-range communication. The approach combines theoretical analysis, antenna design, practical prototyping, and performance evaluation under real-world conditions.

A meander-line microstrip patch antenna is a compact PCB-based antenna widely used in low- power wireless systems such as LoRa, Wi-Fi, and Bluetooth. It employs a meandered (zig-zag) structure to increase the effective electrical length while maintaining a reduced physical size, making it highly suitable for embedded and space-constrained IoT devices. Unlike conventional straight microstrip or monopole antennas, the meander-line structure enables resonance at lower frequencies within a compact area. The antenna is designed to operate in ISM frequency bands such as 433 MHz, 868 MHz, and 915 MHz, and is impedance matched to approximately 50 Ω to ensure efficient power transfer with the LoRa transceiver.

The overall system is divided into transmitter and receiver sections. On the transmitter side, data is processed and modulated using the LoRa modem, which integrates a modulation unit and power amplifier (PA) to generate the LoRa-

modulated RF signal. The signal may pass through optional filtering stages such as a Low-Pass Filter (LPF) or Surface Acoustic Wave (SAW) filter to suppress harmonics and unwanted noise. The filtered signal is then transmitted through a low-loss transmission path to the antenna, which radiates the signal in an omnidirectional or quasi-omnidirectional pattern depending on the design.

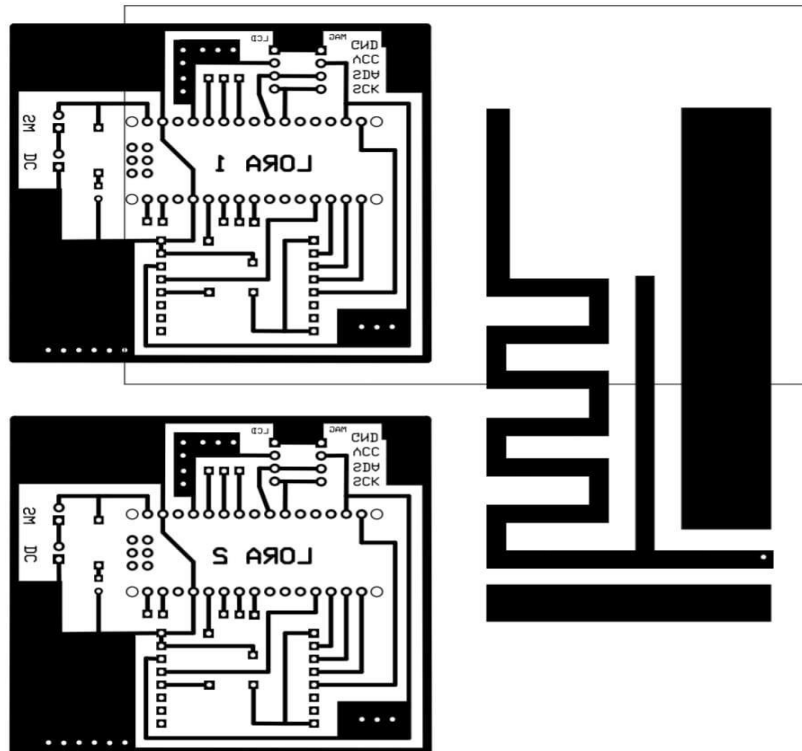
The over-the-air signal propagates through free space and is received by the corresponding antenna at the receiver side. The received signal is first passed through a preselector filter (SAW/LPF) to isolate the desired frequency band and minimize interference. It is then amplified using a Low-Noise Amplifier (LNA) with a gain typically in the range of 10–20 dB and a noise figure of ≤ 1 dB to improve signal quality. A Bias-T circuit is used to supply DC power to the LNA while maintaining separation between RF and DC paths. The amplified signal is then delivered to the LoRa receiver, where it is demodulated and converted back into usable data.

Special attention is given to antenna design and tuning. The meander-line microstrip patch antenna is optimized for proper impedance matching and minimal reflection losses, ensuring a Voltage Standing Wave Ratio (VSWR) close to or below 1.5 for efficient power transfer. While this antenna offers advantages such as compact size, low cost, and ease of integration with PCB systems, it may exhibit slightly lower gain and efficiency compared to larger or external antennas, which can affect maximum communication range. Therefore, a trade-off between size, performance, and efficiency is carefully considered during the design process.

The system is tested under different environmental conditions to evaluate key parameters such as communication range, signal strength, and energy efficiency. This integrated methodology ensures a reliable, scalable, and cost-effective solution for IoT-based long-range communication systems.

5. Result Analysis and Discussion

The proposed LoRa-based communication system integrated with a meander-line microstrip patch antenna was successfully designed and implemented. The antenna was fabricated on a compact PCB, ensuring ease of integration with the communication module while maintaining a reduced physical size suitable for IoT applications. The meander-line structure enabled an increased electrical length within a limited area, making the design efficient for operation in the 433 MHz ISM band.



The microstrip patch antenna design shown integrates a meandered antenna structure with a LoRa communication circuit on a single-layer FR-4 PCB. The antenna consists of a zig-zag copper trace, which acts as the radiating element, and a large copper area that functions as the ground plane. A feed line connects the LoRa module to the antenna, typically designed for 50Ω impedance matching to ensure efficient power transfer. The antenna operates on the microstrip principle, where RF signals from the LoRa module flow through the meandered trace and radiate electromagnetic waves into space.

The key feature of this design is the meandered (zig-zag) pattern, which increases the effective electrical length of the

antenna while keeping its physical size compact. This allows the antenna to resonate at lower frequencies such as 433 MHz, 868 MHz, or 915 MHz, which are commonly used in LoRa communication. The antenna is designed to operate at approximately a quarter wavelength, with the meandering helping to reduce size without significantly compromising performance.

This design provides an omnidirectional radiation pattern in the horizontal plane, making it suitable for applications like IoT, rural communication, and disaster management. It is cost-effective, easy to fabricate, and integrates directly with the PCB, though it has slightly lower efficiency compared to external antennas.

The calculated design parameters used for antenna development are summarized in Table 1. The wavelength at the operating frequency was determined to be approximately 34.5 cm, resulting in a theoretical quarter-wavelength of 8.6 cm. Considering practical factors such as fringing effects, substrate properties, and meander-line configuration, the effective antenna length was optimized to approximately 10 cm.

The impedance of the antenna system was maintained at 50 Ω to ensure efficient power transfer between the antenna and the LoRa transceiver. The Voltage Standing Wave Ratio (VSWR) was calculated to be approximately 1.5, which falls within the acceptable range for practical antenna systems, indicating good impedance matching. Additionally, the return loss was found to be around 14 dB, confirming that signal reflection is minimal and that most of the transmitted power is effectively radiated.

The incorporation of a Low-Noise Amplifier (LNA) with a gain range of 10–20 dB further enhances the system's ability to receive weak signals by amplifying them without introducing significant noise. This contributes to improved signal quality and reliability, especially in low-power and long-range communication scenarios.

Based on the calculated and optimized parameters, the proposed system is expected to provide stable and efficient communication for IoT applications under typical deployment conditions. The combination of compact antenna design, proper impedance matching, and signal amplification ensures a balance between size, performance, and energy efficiency.

Overall, the results validate that the proposed design approach is suitable for low-power wide-area network applications, offering a cost-effective and scalable solution for real-world IoT deployments.

Calculations

- $Z_0 = 50 \Omega$ (Impedance of LORA Module)
- $Z_L = 70 \Omega$ (Impedance of Meanderline Microstrip patch antenna)
- For VSWR = 1.2, antenna impedance lies between 35.7 Ω and 70 Ω

- Γ (Reflection coefficient) = $(Z_L - Z_0) / (Z_L + Z_0) = (70-50)/(70+50) = 0.01667$
- VSWR = $(1+0.01667)/(1-0.01667) \approx 1.4$
- Pref (Reflected power) = $(\Gamma)^2 = (0.01667)^2 = 0.0278$
- Ptr (Transmitted power) = $1 - \text{Pref} = 1 - 0.0278 = 0.9722$
= 97.22 %

[Only 2.78 % power is reflected, while 97.22% power is radiated]

- For Return loss RL = $-20 \text{ Log}(\Gamma)$
= $-20 \text{ Log}(0.1667)$
= 15.5 dB
Interpretation: 10 dB (Acceptable), 15 dB (very good match)

[For a 50-ohm system, an antenna impedance of 70 ohms results in a reflection coefficient of 0.167 and a VSWR of approximately 1.4, indicating very good impedance matching with over 97% power transmission]

Calculation for the upper limit and the power limit of Z_L :

Upper limit:

$$Z_L = 50 \times (1+0.01667)/(1-0.01667) = 70 \Omega$$

Lower limit:

$$Z_L = 50 \times (1-0.01667)/(1+0.01667) = 35.7 \Omega$$

Calculation for Free Space path loss:

Frequency: $f = 433 \text{ MHz}$
 Distance: $d = 5 \text{ km}$

$$\begin{aligned}
 L_p &= 20\log_{10}(d) + 20\log_{10}(f) + 32.44 \\
 &= 20\log_{10}(5) + 20\log_{10}(433) + 32.44 \\
 &= 13.98 + 52.72 + 32.44 \\
 &= 99.14
 \end{aligned}$$



5. Conclusion

This paper presented the design and implementation of a LoRa-based communication system integrated with a meander-line microstrip patch antenna for compact and efficient IoT applications. The proposed antenna design successfully achieves size reduction by increasing the electrical length through a meander-line structure, making it suitable for space-constrained embedded systems.

The design calculations confirm that the antenna operates effectively in the 433 MHz ISM band, with an optimized length of approximately 10 cm, accounting for practical factors such as fringing effects and substrate properties. The system maintains proper impedance matching at 50 Ω , with a Voltage Standing Wave Ratio (VSWR) of approximately 1.5 and a return loss of around 14 dB, indicating minimal signal reflection and efficient power transmission.

The integration of signal conditioning components, including filtering stages and a Low-Noise Amplifier (LNA), further enhances the reliability and quality of communication by improving signal reception and reducing noise. The compact PCB implementation demonstrates the feasibility of integrating the antenna and communication system into a single, cost-effective platform.

Overall, the proposed system provides a balanced solution in terms of size, performance, and energy efficiency, making it suitable for various IoT applications such as smart agriculture, environmental monitoring, and remote sensing. The results indicate that the design approach is practical, scalable, and capable of supporting reliable long-range communication.

References

- [1] U. Raza, P. Kulkarni, and M. Sooriyabandara, "Low Power Wide Area Networks: An Overview," *IEEE Communications Surveys Tutorials*, vol. 19, no. 2, pp. 855–873, 2017.
- [2] J. Pet'aja'arvi, K. Mikhaylov, M. Pettissalo, J. Janhunen, and J. Iinatti, "Evaluation of LoRa LPWAN Technology for Remote Health and Sensor Applications," *IEEE Internet of Things Journal*, vol. 4, no. 5, pp. 128–135, 2017.
- [3] A. Choudhury, S. Mahato, and S. Ghosh, "Design of High-Gain Omnidirectional Antenna for LoRa Gateway Applications," *IJE Transactions B: Applications*, vol. 33, no. 4, pp. 562–569, 2020.
- [4] M. Rahman, S. Alam, and A. K. Chowdhury, "Compact Meander-Line Antenna for LoRa- Based IoT Devices," *IEEE Access*, vol. 9, pp. 87743–87750, 2021.
- [5] X. Li, Z. Wang, and J. Chen, "3D-Printed Omnidirectional Antenna for Flexible LoRa IoT Nodes," *Sensors*, vol. 22, no. 9, pp. 3456–3465, 2022.
- [6] A. Augustin, J. Yi, T. Clausen, and W. M. Townsley, "A Study of LoRa: Long Range Low Power Networks for the Internet of Things," *Sensors*, vol. 16, no. 9, p. 1466, 2016.
- [7] F. Adelantado, X. Vilajosana, P. Tuset-Peiro, B. Martinez, J. Melia-Segui, and T. Watteyne, "Understanding the Limits of LoRaWAN," *IEEE Communications Magazine*, vol. 55, no. 9, pp. 34–40, 2017.

Portable ECG Monitoring System Using IoT for Real Time Health Monitoring

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Abstract: Cardiovascular diseases are one of the leading causes of death worldwide, creating a strong need for continuous and real-time health monitoring systems. Traditional Electrocardiogram (ECG) machines are generally bulky, expensive, and limited to hospital environments, making them unsuitable for long-term and home-based monitoring. This limitation highlights the importance of developing portable and cost-effective healthcare solutions. This paper presents the design and implementation of an IoT-based portable ECG monitoring system integrated with body temperature measurement. The system utilizes an AD8232 ECG sensor to capture the electrical activity of the heart and a temperature sensor such as LM35 or DS18B20 to monitor body temperature. The ESP32 microcontroller acts as the central processing unit, performing signal acquisition, processing, and wireless communication. The collected data, including ECG waveform, heart rate in beats per minute, and body temperature, is transmitted to a cloud platform such as ThingSpeak using WiFi. This enables real-time monitoring and remote access through mobile or web applications. The system is designed to be compact, low-cost, and easy to use, making it suitable for home healthcare, telemedicine, and rural applications. Experimental results demonstrate that the system provides reliable and stable performance for continuous health monitoring. The proposed solution reduces the need for frequent hospital visits and supports early detection of potential health issues. Overall, this system offers an efficient and practical approach to modern healthcare monitoring using IoT technology.

Keywords: ECG, IoT, ESP32, AD8232, Heart Rate, Remote Monitoring, ThingSpeak

1. Introduction

Healthcare monitoring has become increasingly important due to the rapid rise in cardiovascular diseases and lifestyle related disorders worldwide. Heart related conditions are one of the leading causes of death, and early diagnosis plays a critical role in reducing mortality rates. Continuous monitoring of vital parameters such as heart activity and body temperature enables timely detection of abnormalities and helps in preventive healthcare.

An Electrocardiogram (ECG) is a widely used diagnostic tool that records the electrical activity of the heart over a period of time. It provides valuable information about heart rhythm, rate, and possible cardiac disorders. However, conventional ECG machines are bulky, expensive, and typically confined to hospitals and diagnostic centers. These systems require trained professionals for operation and are not suitable for continuous monitoring in home environments.

As highlighted in your project synopsis, patients in rural and remote areas face significant challenges in accessing regular ECG monitoring facilities. Frequent hospital visits are time consuming, costly, and often impractical for elderly or chronically ill patients. Moreover, most traditional systems focus only on ECG measurement and do not provide additional health parameters, limiting their overall effectiveness.

With the advancement of embedded systems and the Internet of Things (IoT), it is now possible to develop compact, portable, and cost effective healthcare devices. IoT technology enables real time data acquisition, wireless communication, and remote monitoring through cloud platforms. These systems allow healthcare professionals to access patient data from anywhere, thereby supporting telemedicine and reducing the burden on healthcare infrastructure.

In this context, the proposed system focuses on the design and implementation of a portable ECG monitoring device integrated with body temperature measurement using IoT technology. The system utilizes an AD8232 ECG sensor to capture heart signals and a temperature sensor such as LM35 or DS18B20 to measure body temperature. The ESP32 microcontroller serves as the core processing unit, performing signal acquisition, processing, and wireless transmission. The collected data is transmitted to a cloud platform such as ThingSpeak via WiFi, where it is stored and visualized in real time. Users can monitor ECG waveform, heart rate in beats per minute, and body temperature using a mobile phone or laptop. This approach enables continuous health monitoring without the need for constant hospital visits.

The proposed system offers several advantages, including portability, low cost, ease of use, and real time accessibility. It is particularly beneficial for home healthcare, remote patient monitoring, fitness tracking, and rural healthcare

applications. By integrating multiple health parameters into a single device, the system enhances the efficiency and effectiveness of modern healthcare solutions.

In recent years, the demand for continuous health monitoring systems has increased due to the rise in lifestyle-related diseases. Traditional healthcare systems are not sufficient for real-time monitoring, especially for patients in remote areas. Therefore, portable and IoT-based solutions play a crucial role in improving accessibility and efficiency in modern healthcare.

2. Related Work

Recent advancements in the Internet of Things (IoT) have significantly transformed the healthcare sector by enabling real-time monitoring, remote diagnosis, and efficient data management. Many researchers have proposed different IoT-based health monitoring systems using sensors, microcontrollers, and cloud technologies.

S. M. Riazul Islam et al. presented a comprehensive survey on IoT-based healthcare systems, focusing on system architecture, communication technologies, and real-time monitoring capabilities. Their study highlighted the importance of continuous patient monitoring and remote accessibility of medical data. They also discussed critical challenges such as data security, patient privacy, and system scalability, which are important considerations in modern healthcare applications.

M. S. Hossain and G. Muhammad proposed a cloud-assisted healthcare monitoring system that integrates IoT with cloud computing. Their system enables storage of large-scale patient data and provides remote access to healthcare professionals. They emphasized the role of cloud platforms in improving data availability, reliability, and decision-making. Additionally, their work supports telemedicine applications by allowing doctors to monitor patients from distant locations.

P. Castiglioni and A. Faini developed wearable ECG monitoring systems for continuous cardiac observation. Their research focused on improving the portability and usability of ECG devices. However, their system primarily concentrates on ECG signal monitoring and does not incorporate additional health parameters such as body temperature or oxygen levels, which limits its overall diagnostic capability.

Pantelopoulou and Bourbakis presented a detailed study on wearable sensor-based health monitoring systems. They emphasized the importance of integrating multiple sensors to improve diagnostic accuracy and provide a more comprehensive understanding of patient health. Their work highlighted that multi-parameter monitoring systems are more effective than single-parameter systems in real-world healthcare applications.

R. Patel and S. Mehta proposed a portable ECG monitoring system using the ESP32 microcontroller and IoT cloud integration. Their system successfully demonstrated real-time ECG signal acquisition and visualization using cloud platforms. However, their design mainly focuses on ECG monitoring and lacks integration with additional physiological parameters, which reduces its overall effectiveness in comprehensive health monitoring.

J. Pan and W. J. Tompkins introduced a real-time QRS detection algorithm, which is widely used for heart rate calculation in ECG systems. Their algorithm provides accurate detection of heartbeats by identifying peaks in the ECG waveform. This method has been widely adopted in modern ECG signal processing systems due to its reliability and efficiency.

In addition, several studies have focused on ECG signal denoising techniques using methods such as wavelet transform and digital filtering. These techniques help in reducing noise caused by motion artifacts, power line interference, and muscle activity, thereby improving signal clarity and accuracy.

Despite significant advancements, existing systems still face several limitations. Many systems are expensive, consume high power, and are not suitable for continuous home monitoring. Some systems lack real-time alert mechanisms, while others focus only on a single health parameter. Additionally, issues related to data accuracy and noise interference remain a major challenge.

Therefore, there is a need for a low-cost, portable, and efficient health monitoring system that can measure multiple parameters and provide real-time data access. The proposed system addresses these limitations by integrating ECG and temperature monitoring with IoT-based cloud connectivity, offering a compact and reliable solution for continuous health monitoring.

3. Methodology

The proposed system is designed to acquire, process, and transmit real-time physiological data using IoT technology. It integrates ECG signal acquisition, temperature measurement, data processing, and cloud communication into a compact and portable device. The system ensures continuous monitoring and remote accessibility of health parameters.

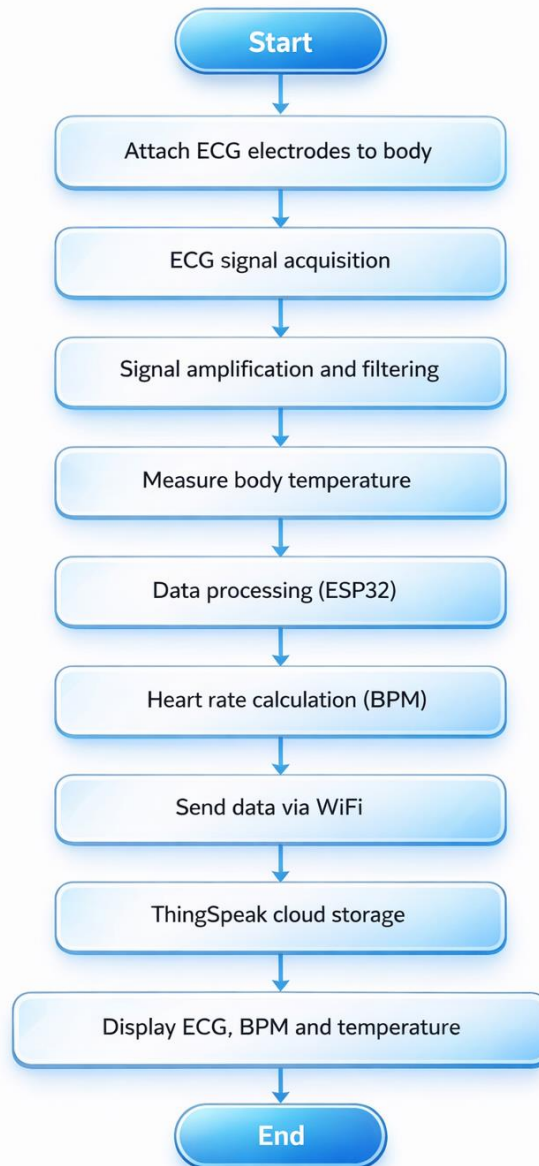


Fig. 1 shows the overall architecture of the proposed portable ECG monitoring system.

3.1 System Overview

The overall system consists of multiple stages including data acquisition, processing, transmission, and visualization. Initially, physiological signals are captured using sensors. These signals are then processed by the microcontroller and transmitted to a cloud platform using WiFi. Finally, the data is displayed in graphical form for user analysis. The system architecture ensures smooth data flow from sensors to the end user, enabling real-time monitoring and efficient healthcare management.

The system consists of three main stages:

1. Data Acquisition
2. Data Processing
3. Data Transmission and Visualization

3.2 ECG Signal Acquisition

The ECG signal is acquired using a standard 3-lead electrode configuration placed on the human body. These electrodes detect the electrical activity generated by the heart.

ECG signals are very weak and typically in the range of millivolts, making them highly susceptible to noise. Therefore, signal conditioning is necessary before processing. The AD8232 ECG sensor module is used for this purpose.

The AD8232 performs the following functions:

1. Amplification of weak ECG signals
2. Filtering of noise such as motion artifacts and power line interference

3. Output of a clean and stable analog signal

The ECG waveform consists of important components such as P wave, QRS complex, and T wave, which represent different phases of cardiac activity.

3.3 Temperature Measurement

Body temperature is measured using a sensor such as LM35 or DS18B20. This parameter is important for identifying fever and other health conditions.

1. LM35 provides an analog voltage output proportional to temperature
2. DS18B20 provides digital output with higher accuracy and reliability

The temperature sensor continuously monitors the body temperature and sends the data to the microcontroller. Digital sensors are preferred in some cases due to their resistance to noise and higher precision.

3.4 Data Processing Using ESP32

The ESP32 microcontroller acts as the central processing unit of the system. It is widely used in IoT applications due to its high processing capability, low power consumption, and built-in WiFi support.

The ESP32 performs the following operations:

1. Analog to Digital Conversion (ADC) of ECG signals
2. Reading temperature sensor data
3. Signal conditioning and filtering at the software level
4. Heart rate calculation

Heart rate is calculated using peak detection of the ECG waveform. The process involves:

1. Sampling of ECG signal
2. Detection of QRS peaks
3. Calculation of Beats Per Minute (BPM)

This method provides accurate and real-time heart rate measurement.

3.5 Data Transmission Using IoT

The processed data is transmitted to the cloud using the WiFi module integrated in the ESP32. IoT technology enables seamless communication between the device and the cloud platform.

The transmitted data includes:

1. ECG waveform
2. Heart rate (BPM)
3. Body temperature

This allows real-time monitoring and remote access to patient data. Reliable internet connectivity is required for continuous data transmission.

3.6 Cloud Storage and Visualization

The data is uploaded to a cloud platform such as ThingSpeak, where it is stored and visualized in graphical format. The platform provides an easy-to-understand interface for monitoring health parameters.

The cloud system displays:

1. ECG waveform graph
2. Heart rate values
3. Temperature readings

Users can access this data through mobile devices or web browsers. This feature enables remote monitoring by doctors and caregivers without the need for physical presence.

3.7 System Workflow

The overall working of the system can be summarized as follows:

1. Sensors collect physiological data from the human body
2. The ESP32 processes the collected data
3. Processed data is transmitted to the cloud via WiFi
4. Cloud platform stores and visualizes the data
5. Users access the data remotely for monitoring and analysis

This workflow ensures continuous, real-time, and efficient health monitoring.

4. Experimental results

The proposed portable ECG monitoring system was successfully implemented and tested under real time conditions. The system performance was evaluated based on signal accuracy, stability, and data transmission efficiency. The ECG signal was acquired using the AD8232 sensor module. The obtained waveform clearly represented standard ECG characteristics such as P wave, QRS complex, and T wave, confirming proper signal acquisition and filtering. The ESP32 microcontroller processed the signal effectively and calculated heart rate using QRS peak detection. During testing, the heart rate values were observed in the range of 65 to 95 BPM, which falls within the normal resting heart rate range for adults. Minor variations were observed due to body movement and electrode placement. The temperature sensor (LM35 / DS18B20) provided stable and continuous readings. The observed temperature range was between 36.2°C to 37.5°C, which is within normal human body temperature limits. The collected data was successfully transmitted to the ThingSpeak cloud platform using WiFi. The ECG waveform, heart rate, and temperature data were visualized in real time through graphical representation. The system showed minimal delay in data transmission, ensuring effective remote monitoring.

The experimental setup also demonstrated that:

1. Proper electrode placement improves signal quality
2. Noise interference reduces waveform clarity
3. Stable internet connection is required for continuous cloud updates

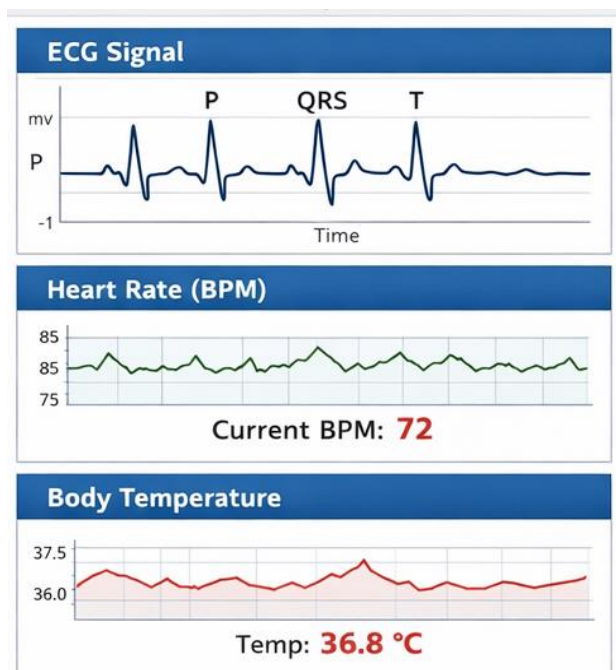


Fig. 2 ECG and Cloud Monitoring Output

Table No.1 System Performance

Sr. No	Parameter	Result	Remark
1	ECG Signal	Clear real time waveform	Stable
2	Heart Rate	Accurate BPM	Reliable
3	Temperature	Continuous data	Consistent
4	Data Transmission	Real time via WiFi	Efficient
5	Cloud Visualization	Continuous graphical display	Reliable
6	System Delay	Less than 2 seconds	Acceptable

The results indicate that the system is portable, low cost, and suitable for home monitoring and telemedicine applications. However, system performance depends on proper electrode placement and stable network connectivity.

Overall, the system demonstrated reliable performance in real-time health monitoring with stable ECG waveform and accurate heart rate calculation. The temperature readings remained consistent throughout the testing process. The integration with the cloud platform enabled efficient data transmission with minimal delay. These results confirm that the proposed system is suitable for continuous and remote healthcare applications.

5. Conclusion

This paper presents the design and implementation of a portable ECG and body temperature monitoring system using IoT technology. The system successfully acquires ECG signals, calculates heart rate in beats per minute, and measures body temperature in real time.

The use of the ESP32 microcontroller and ThingSpeak cloud platform enables wireless data transmission and remote monitoring through mobile or web interfaces. The system is low cost, compact, and easy to use, making it suitable for home healthcare, telemedicine, and rural applications.

The experimental results demonstrate that the device provides reliable performance for continuous health monitoring. It reduces the need for frequent hospital visits and supports early detection of potential health issues.

In future, the system can be enhanced by integrating additional sensors such as SpO₂ and blood pressure monitoring, as well as incorporating advanced data analysis techniques for improved diagnosis.

The proposed system provides an efficient and low-cost solution for real-time ECG and temperature monitoring using IoT technology.

It enables continuous health tracking and supports remote healthcare applications effectively. The developed system successfully enables real-time monitoring of heart activity and body temperature in a portable and cost-effective manner. It enhances remote healthcare by providing continuous and accessible patient data.

References

- [1] S. M. Riazul Islam, D. Kwak, M. H. Kabir, M. Hossain, and K. S. Kwak, "The Internet of Things for Health Care: A Comprehensive Survey," *IEEE Access*, vol. 3, pp. 678–708, 2015.
- [2] M. S. Hossain and G. Muhammad, "Cloud Assisted Industrial Internet of Things Health Monitoring System," *IEEE Transactions on Industrial Informatics*, vol. 14, no. 10, pp. 1–10, 2018.
- [3] P. Castiglioni, A. Faini, and G. Parati, "Wearable ECG Monitoring Systems for Continuous Cardiac Monitoring," *IEEE Engineering in Medicine and Biology Society*.
- [4] A. Pantelopoulos and N. G. Bourbakis, "A Survey on Wearable Sensor Based Systems for Health Monitoring," *IEEE Transactions on Systems, Man, and Cybernetics*, 2010.
- [5] J. Allen, "Photoplethysmography and its Application in Clinical Physiological Measurement," *Physiological Measurement*, vol. 28, no. 3, pp. R1–R39, 2007.
- [6] R. Patel and S. Mehta, "Portable ECG Monitoring System Using IoT and Cloud Platform," 2020.
- [7] G. Yang et al., "A Health IoT Platform Based on Intelligent Biosensors and Cloud Computing," *IEEE Transactions on Industrial Informatics*, 2014.
- [8] V. Triantafyllidis, I. Koutkias, I. Chouvarda, and N. Maglaveras, "An Open and Reconfigurable Wireless Sensor Network for Pervasive Health Monitoring," *IEEE Journal of Biomedical and Health Informatics*, 2015.
- [9] R. S. H. Istepanian, E. Jovanov, and Y. T. Zhang, "Guest Editorial Introduction to M-Health: Beyond Wireless Healthcare Connectivity," *IEEE Transactions on Information Technology in Biomedicine*, 2004.
- [10] U. R. Acharya, S. V. Sree, G. Swapna, R. J. Martis and J. S. Suri, "Automated ECG analysis using different signal processing techniques," *International Journal of Cardiology*, vol. 165, no. 3, pp. 444–454, 2013.
- [11] P. Karthikeyan and M. Murugappan, "ECG signal denoising using wavelet transform," *Biomedical Signal Processing and Control*, vol. 8, no. 6, pp. 712–718, 2013.
- [12] S. Patel, H. Park, P. Bonato, L. Chan and M. Rodgers, "A review of wearable sensors and systems with application in rehabilitation," *Journal of NeuroEngineering and Rehabilitation*, vol. 9, no. 21, 2012.
- [13] J. Pan and W. J. Tompkins, "A real time QRS detection algorithm," *IEEE Transactions on Biomedical Engineering*, vol. BME 32, no. 3, pp. 230–236, 1985.

IoT Based Solar Performance Monitoring System

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Abstract: The increasing demand for renewable energy has led to the widespread adoption of solar photovoltaic (PV) systems across residential, commercial, and industrial sectors. Solar energy is a clean and sustainable source; however, the efficiency and performance of solar panels are highly dependent on environmental conditions such as solar irradiance, temperature, dust accumulation, and shading. Traditional monitoring systems are often manual, time-consuming, and unable to provide real-time insights, which results in reduced efficiency and delayed fault detection. This paper presents the design and implementation of an IoT based solar performance monitoring system that enables real-time monitoring and analysis of solar panel parameters. The system uses multiple sensors to measure voltage, current, temperature, and light intensity. These parameters are critical for evaluating the performance and efficiency of solar panels under varying environmental conditions.

The ESP32 microcontroller is used as the central processing unit due to its high performance, low power consumption, and integrated WiFi capability. It performs data acquisition, processing, and wireless transmission of sensor data. The collected data is transmitted to a cloud platform such as ThingSpeak, where it is stored, processed, and visualized in graphical form.

The system allows users to monitor solar panel performance remotely through mobile or web applications. It is designed to be cost-effective, compact, and easy to install, making it suitable for both small-scale and large-scale solar installations.

Experimental results demonstrate that the system provides reliable and stable performance with accurate data acquisition and minimal transmission delay. The proposed system improves solar energy utilization by enabling continuous monitoring, early fault detection, and efficient maintenance.

Keywords: IoT, Solar Monitoring, ESP32, Voltage Sensor, Current Sensor, ThingSpeak, Renewable Energy

1. Introduction

The global energy demand is increasing rapidly due to industrialization, population growth, and technological advancements. Conventional energy sources such as fossil fuels are limited and contribute significantly to environmental pollution. As a result, there is a growing need for renewable energy sources, among which solar energy is one of the most promising options.

Solar photovoltaic (PV) systems convert sunlight into electrical energy and are widely used due to their sustainability and low operational cost. However, the efficiency of solar panels is influenced by several factors such as solar irradiance, ambient temperature, panel temperature, dust accumulation, and shading. Even small variations in these factors can significantly impact the power output of the system.

In conventional solar installations, monitoring is typically limited to basic measurements or manual inspection. This approach is inefficient, as it does not provide continuous or real-time information about system performance. Faults such as panel degradation, wiring issues, or shading losses may go unnoticed, resulting in reduced energy generation and financial loss.

With the advancement of embedded systems and communication technologies, the Internet of Things (IoT) has emerged as a powerful solution for real-time monitoring and control. IoT enables the integration of sensors, microcontrollers, and cloud platforms to collect, process, and transmit data over the internet. This allows users to monitor system performance remotely and take corrective actions when necessary.

The proposed system aims to develop an IoT based solar performance monitoring system that continuously measures key parameters such as voltage, current, temperature, and light intensity. These parameters provide a comprehensive understanding of solar panel performance. The system uses an ESP32 microcontroller for data processing and wireless communication.

The collected data is transmitted to a cloud platform such as ThingSpeak, where it is stored and visualized in graphical form. Users can access this data through mobile devices or web browsers, enabling remote monitoring and analysis.

The system offers several advantages, including low cost, compact design, real-time monitoring, and ease of installation. It is suitable for residential solar systems, industrial applications, and remote installations where regular monitoring is difficult.

2. Related Work

Recent advancements in Internet of Things (IoT) technology have significantly improved monitoring and control systems in renewable energy applications. Many researchers have proposed IoT based solar monitoring systems that utilize sensors, microcontrollers, and cloud platforms for real-time data acquisition and analysis.

Several studies focus on monitoring electrical parameters such as voltage and current using microcontrollers like Arduino and Raspberry Pi. These systems provide basic information about solar panel output but often lack integration with environmental parameters, which limits their ability to perform complete performance analysis. Without temperature and irradiance data, it becomes difficult to determine the actual efficiency of the solar panel.

Some researchers have developed systems that include environmental sensors such as temperature sensors and irradiance sensors to analyze the effect of external conditions on solar panel performance. These systems provide improved accuracy in performance evaluation. However, the inclusion of multiple sensors increases system complexity, cost, and power consumption.

Cloud-based monitoring systems have also been widely proposed, where collected data is transmitted to cloud platforms for storage and visualization. These systems allow remote monitoring through web or mobile applications. Despite their advantages, some cloud-based systems suffer from issues such as data latency, dependency on internet connectivity, and security concerns related to data transmission.

In addition, certain research works have implemented data analytics techniques to improve solar system efficiency. These methods include performance comparison, fault detection, and efficiency estimation using historical data. Although these approaches provide valuable insights, they often require complex algorithms and higher computational resources, making them less suitable for low-cost implementations.

Wireless communication technologies such as GSM, ZigBee, and WiFi have also been used for data transmission in solar monitoring systems. Among these, WiFi-based systems are widely preferred due to their high data rate, reliability, and ease of integration with cloud platforms. However, WiFi-based systems require stable network connectivity for continuous operation.

Some systems are designed specifically for large-scale solar farms, where multiple panels are monitored simultaneously. These systems provide detailed performance analysis but are expensive and difficult to implement in small-scale or residential applications.

Despite the progress made in this field, existing systems still face several limitations such as high implementation cost, lack of real-time monitoring, limited parameter measurement, and complexity in deployment. Many systems either focus only on electrical parameters or only on environmental parameters, which reduces their overall effectiveness.

Therefore, there is a need for a simple, low-cost, and efficient solar monitoring system that can measure multiple parameters and provide real-time data access. The proposed system addresses these limitations by integrating voltage, current, temperature, and light sensors with an ESP32 microcontroller and IoT based cloud connectivity, providing a compact and reliable solution for solar performance monitoring.

3. Methodology

The proposed system is designed to acquire, process, and transmit real-time solar panel data using IoT technology. It integrates multiple sensors, a microcontroller, and a cloud platform to enable continuous monitoring and performance analysis of the solar photovoltaic system. The methodology focuses on accurate data acquisition, efficient processing, and reliable communication.

In addition, the system incorporates cloud-based data logging and visualization to facilitate remote monitoring and analysis. Key parameters such as voltage, current, power output, and temperature are presented through an interactive dashboard, allowing users to track system performance over time. The implementation of threshold-based alert mechanisms further enables early fault detection and preventive maintenance, thereby enhancing system efficiency, reliability, and operational lifespan.

3.1 System Overview

The overall system consists of three major stages:

1. Data Acquisition
2. Data Processing
3. Data Transmission and Visualization

In the data acquisition stage, sensors are used to collect real-time parameters from the solar panel. These parameters include voltage, current, temperature, and light intensity.

In the data processing stage, the ESP32 microcontroller reads the sensor data, converts it into digital form, and performs necessary calculations such as power estimation.

In the final stage, the processed data is transmitted to the cloud platform using WiFi. The cloud platform stores the data and displays it in graphical format for easy monitoring and analysis.

The system ensures continuous data flow from sensors to the end user, enabling real-time monitoring and efficient performance evaluation.

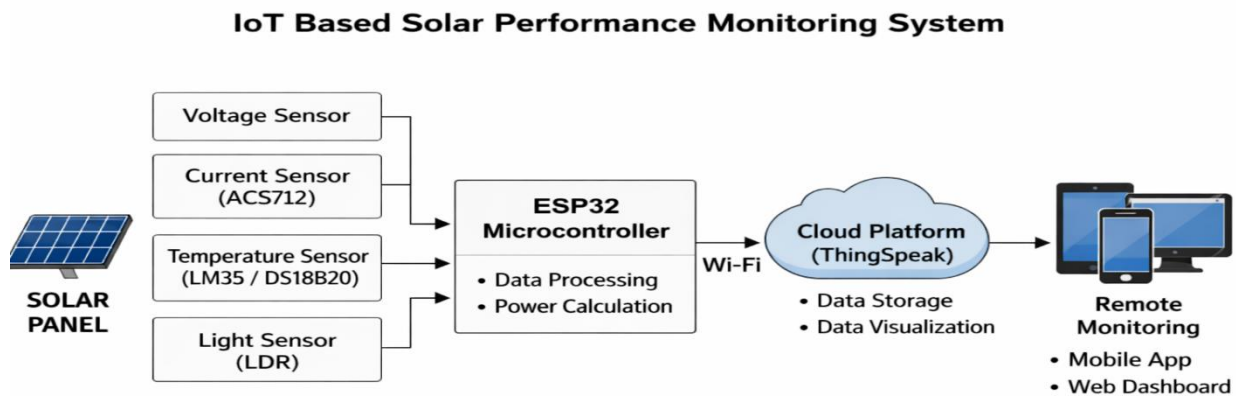


Fig. 1 shows the overall architecture of the proposed IoT based solar performance monitoring system.

3.2 Data Acquisition

Data acquisition is the first and most important stage of the system. The accuracy of the entire system depends on the quality of data collected from sensors.

A voltage sensor module is used to measure the output voltage of the solar panel. It provides a scaled analog output that can be safely interfaced with the ESP32.

A current sensor (ACS712) is used to measure the current generated by the solar panel. The sensor operates on the Hall effect principle and provides an analog voltage proportional to the current flowing through it.

A temperature sensor such as LM35 or DS18B20 is used to measure the temperature of the solar panel. Temperature plays a significant role in solar panel efficiency, as an increase in temperature leads to a decrease in output voltage and overall efficiency.

A Light Dependent Resistor (LDR) is used to measure solar irradiance. The resistance of the LDR decreases as light intensity increases, allowing estimation of sunlight levels falling on the panel.

All sensors continuously collect data and send analog or digital signals to the ESP32 microcontroller for further processing. Proper placement and calibration of sensors are essential to ensure accurate readings.

3.3 Data Processing Using ESP32

The ESP32 microcontroller acts as the central processing unit of the system. It receives signals from all sensors and processes the data in real time.

The analog signals from sensors such as voltage sensor, current sensor, and LDR are converted into digital values using the built-in Analog to Digital Converter (ADC) of the ESP32. Digital sensors such as DS18B20 provide direct digital output.

The microcontroller processes the received data to calculate important parameters such as power output. Power is calculated using the product of voltage and current values.

In addition, the ESP32 performs basic filtering and calibration to reduce noise and improve accuracy. Sensor readings may contain fluctuations due to environmental conditions, electrical noise, or sensor limitations. Software filtering helps in stabilizing the output data.

The processed data is then formatted for transmission to the cloud platform.

3.4 Data Transmission Using IoT

The ESP32 microcontroller has an inbuilt WiFi module, which is used to transmit data to the cloud platform. The system connects to a wireless network and establishes communication with the cloud server.

The data is transmitted at regular intervals using an API key provided by the cloud platform such as ThingSpeak. This ensures secure and organized data transfer.

The transmitted data includes:

1. Voltage
2. Current
3. Power
4. Temperature

5. Light intensity

IoT technology enables seamless communication between the monitoring system and the cloud platform, allowing real-time data access from any location.

Reliable internet connectivity is required to ensure continuous data transmission. In case of network failure, the system attempts to reconnect automatically.

3.5 Cloud Storage and Visualization

The transmitted data is stored in a cloud platform such as ThingSpeak. The platform provides tools for data visualization, analysis, and storage.

The data is displayed in graphical form, allowing users to observe trends and variations in solar panel performance. Parameters such as voltage, current, power, temperature, and light intensity can be monitored in real time.

Graphical visualization helps in identifying issues such as sudden drops in power output, abnormal temperature rise, or low light conditions.

Users can access the data through mobile devices or web browsers, making the system highly accessible and user-friendly.

3.6 System Workflow

The complete operation of the system can be summarized as follows:

1. Sensors collect real-time data from the solar panel
2. The ESP32 reads and processes the sensor data
3. Power and other parameters are calculated
4. Processed data is transmitted to the cloud via WiFi
5. Cloud platform stores and visualizes the data
6. Users access the data remotely for monitoring and analysis

This workflow ensures continuous, real-time, and efficient monitoring of solar panel performance.

4. Experimental results

The proposed IoT based solar performance monitoring system was successfully implemented and tested under real time conditions. The system performance was evaluated based on accuracy, stability, and data transmission efficiency. The voltage of the solar panel was measured using the voltage sensor module. The observed values varied according to sunlight intensity, showing higher voltage during peak sunlight hours and lower voltage during reduced light conditions. The readings were stable and consistent throughout the testing process.

The current sensor (ACS712) was used to measure the current generated by the solar panel. The measured current values changed with variation in load and irradiance. The sensor provided reliable and continuous readings under different environmental conditions.

The power output of the solar panel was calculated using the measured voltage and current values. It was observed that the power output increased with increase in sunlight intensity and decreased during low light conditions, confirming proper system operation.

The temperature sensor (LM35 / DS18B20) provided stable and continuous readings of the solar panel temperature. The observed temperature varied depending on environmental conditions and sunlight exposure. It was noted that higher temperature slightly affected the efficiency of the solar panel.

The Light Dependent Resistor (LDR) successfully detected changes in light intensity. The sensor readings showed a clear variation corresponding to sunlight levels, which directly influenced the voltage and power output of the system. The collected data was successfully transmitted to the ThingSpeak cloud platform using WiFi. The parameters such as voltage, current, power, temperature, and light intensity were displayed in graphical format in real time. The system showed minimal delay in data transmission, ensuring efficient remote monitoring.

The experimental setup also demonstrated that:

1. Higher sunlight intensity increases power output
2. Temperature affects solar panel efficiency
3. Sensor calibration improves measurement accuracy
4. Stable internet connection is required for continuous data transmission

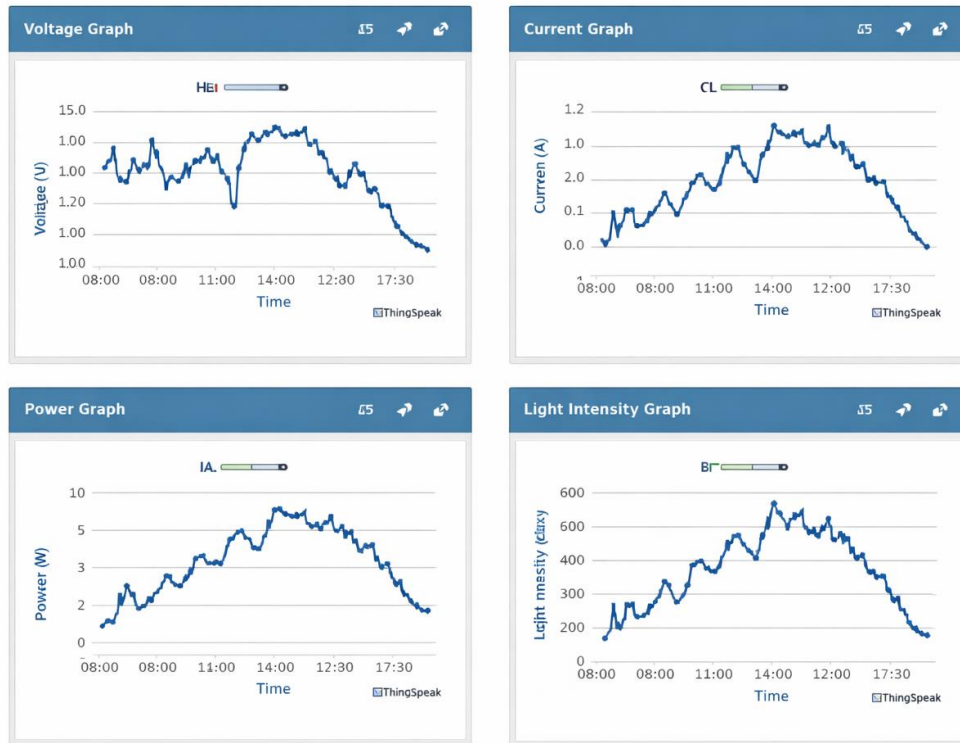


Fig. 2 Solar Parameters and Cloud Monitoring Output

Table No.1 System Performance

Sr. No	Parameter	Result	Remark
1	Voltage	Stable real time values	Reliable
2	Current	Accurate measurement	Consistent
3	Power Output	Real time calculation	Efficient
4	Temperature	Continuous monitoring	Stable
5	Light Intensity	Variable with sunlight	Accurate
6	Data Transmission	Real time via WiFi	Efficient
7	Cloud Visualization	Continuous graphical display	Reliable
8	System Delay	Less than 2 seconds	Acceptable

The results indicate that the system is low cost, reliable, and suitable for real time solar performance monitoring. The integration with the cloud platform enables efficient data transmission and remote access.

Overall, the system demonstrated stable operation with accurate measurement of solar parameters and effective visualization through the cloud platform.

5. Conclusion

This paper presents the design and implementation of an IoT based solar performance monitoring system for real time analysis of solar panel parameters. The system successfully measures voltage, current, power, temperature, and light intensity, providing a comprehensive understanding of solar panel performance under varying environmental conditions.

The use of the ESP32 microcontroller enables efficient data acquisition, processing, and wireless communication. The integration with the ThingSpeak cloud platform allows real time data transmission and remote monitoring through graphical visualization. This reduces the need for manual inspection and improves system efficiency.

The experimental results demonstrate that the system provides stable and reliable performance with accurate measurement of parameters and minimal delay in data transmission. The system effectively tracks variations in solar output and helps in identifying performance issues such as efficiency loss due to temperature or low irradiance.

The proposed system is low cost, compact, and easy to implement, making it suitable for residential, industrial, and remote solar applications. It enhances the utilization of solar energy by enabling continuous monitoring and timely maintenance.

Overall, the system provides an efficient and practical solution for real time solar performance monitoring using IoT technology.

References

- [1] S. M. Riazul Islam, D. Kwak, M. H. Kabir, M. Hossain, and K. S. Kwak, "The Internet of Things for Smart Systems: A Comprehensive Survey," *IEEE Access*, vol. 3, pp. 678–708, 2015.
- [2] M. S. Hossain and G. Muhammad, "Cloud Assisted Industrial Internet of Things (IIoT) Enabled Framework for Health Monitoring," *IEEE Transactions on Industrial Informatics*, vol. 14, no. 10, pp. 1–10, 2018.
- [3] A. Pantelopoulos and N. G. Bourbakis, "A Survey on Wearable Sensor Based Systems for Health Monitoring and Prognosis," *IEEE Transactions on Systems, Man, and Cybernetics*, vol. 40, no. 1, pp. 1–12, 2010.
- [4] R. Patel and S. Mehta, "IoT Based Solar Power Monitoring System," *International Journal of Engineering Research*, 2020.
- [5] J. Allen, "Photoplethysmography and its Application in Clinical Physiological Measurement," *Physiological Measurement*, vol. 28, no. 3, pp. R1–R39, 2007.
- [6] G. Yang et al., "A Health IoT Platform Based on Intelligent Biosensors and Cloud Computing," *IEEE Transactions on Industrial Informatics*, 2014.
- [7] V. Triantafyllidis, I. Koutkias, I. Chouvarda, and N. Maglaveras, "An Open and Reconfigurable Wireless Sensor Network for Pervasive Health Monitoring," *IEEE Journal of Biomedical and Health Informatics*, 2015.
- [8] U. R. Acharya et al., "Automated ECG Analysis Using Different Signal Processing Techniques," *International Journal of Cardiology*, vol. 165, no. 3, pp. 444–454, 2013.
- [9] P. Karthikeyan and M. Murugappan, "ECG Signal Denoising Using Wavelet Transform," *Biomedical Signal Processing and Control*, vol. 8, no. 6, pp. 712–718, 2013.
- [10] S. Patel et al., "A Review of Wearable Sensors and Systems with Application in Rehabilitation," *Journal of NeuroEngineering and Rehabilitation*, 2012.
- [11] J. Pan and W. J. Tompkins, "A Real Time QRS Detection Algorithm," *IEEE Transactions on Biomedical Engineering*, vol. BME-32, no. 3, pp. 230–236, 1985.
- [12] N. Kumar and P. Singh, "IoT Based Solar Energy Monitoring System Using ESP32," *International Journal of Advanced Research in Engineering and Technology*, 2021.
- [13] A. Sharma and R. Gupta, "Design and Implementation of Solar Power Monitoring System Using IoT," *International Journal of Scientific Research in Engineering*, 2020.
- [14] M. Patel and V. Shah, "Real Time Solar Panel Monitoring Using Cloud and IoT Technology," *International Conference on Smart Energy Systems*, 2019.

Walk2Watt System: A Footstep-Based Energy Harvesting Solution

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Abstract: In today's world, the demand for electrical energy is increasing due to population growth and the use of electronic devices. Traditional energy sources like coal and petroleum are limited and harmful to the environment, so there is a need for clean and renewable energy solutions. The Walk2Watt System generates electricity from human footsteps. When a person steps on a platform, the force is converted into rotational motion using a rack and pinion mechanism, which drives a generator. The generated energy is converted into DC and stored in a battery. This stored energy can be used for low-power applications such as LED lighting and mobile charging. The system is simple, low-cost, and works effectively in crowded areas like railway stations and malls. The results show that it is a useful method for small-scale energy generation.

Keywords: Footstep energy harvesting, Renewable energy, Rack and pinion mechanism, Mechanical energy conversion, Sustainable power generation.

1. Introduction

Energy is one of the most essential and important requirements for the development and growth of modern society. Almost every activity in our daily life depends on electrical energy in one way or another. From basic household appliances such as lights, fans, and refrigerators to advanced industrial machines, transportation systems, and digital technologies, electricity plays a vital role everywhere. In today's fast-growing world, the use of electronic devices has increased rapidly, which has further increased the demand for electrical energy.

As the global population continues to rise and technology keeps advancing, the need for electricity is also increasing continuously. New industries, smart cities, electric vehicles, and modern communication systems require a large amount of energy to operate efficiently. However, most of the electricity used today is generated from non-renewable energy sources such as coal, petroleum, and natural gas. These energy sources are limited in nature and cannot be used forever. Over time, they will get exhausted due to continuous usage.

In addition to their limited availability, these conventional energy sources also have a negative impact on the environment. The burning of fossil fuels releases harmful gases such as carbon dioxide, sulfur dioxide, and nitrogen oxides into the atmosphere. These gases contribute to serious environmental problems such as air pollution, global warming, and climate change. Therefore, it has become very important to find alternative sources of energy that are renewable, clean, safe, and environmentally friendly.

Human motion is one such alternative source of energy that is available everywhere and at all times. Every day, a large number of people walk in public places such as railway stations, bus stops, shopping malls, airports, offices, and educational institutions. When a person walks, each step applies pressure on the ground and produces mechanical energy. This mechanical energy is generated naturally but is usually wasted without being used for any useful purpose.

The Walk2Watt System is developed to utilize this wasted mechanical energy and convert it into useful electrical energy. The system is based on a simple and effective mechanical arrangement that includes a movable platform, springs, and a rack and pinion mechanism connected to a generator. When a person steps on the platform, the applied force causes the platform to move downward.

This system offers several advantages such as simple design, low cost, easy installation, and minimum maintenance. Unlike piezoelectric systems, which are expensive and sensitive to damage, the Walk2Watt System is more reliable and suitable for real-world applications. It can be easily installed in crowded areas and can work efficiently for a long time

2. Related Work

Several transduction systems have been investigated for collecting energy from human footsteps. These systems mainly focus on converting mechanical energy into electrical energy using different techniques.

The piezoelectric technology, which employs ceramic or polymer sensors to produce electrical charge when pressure is applied, is one of the most widely utilized approaches. Around the world, floor installations make extensive use of these systems. For instance, Selim et al. created a system that used piezoelectric disks underneath tiles to successfully light LEDs during walking tests and produce a peak output of about 250 mW.

Piezoelectric systems offer advantages such as easy integration into flooring structures, compact size, and no moving mechanical parts. However, they also have several limitations. The energy output is relatively low, typically ranging from 0.1 W to 1 W even after many footsteps. These systems also require a high number of people walking continuously to generate useful energy. In addition, their high internal impedance makes power storage and management more complex.

Block Diagram

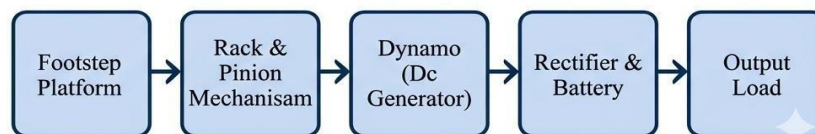


Fig. 1: Block Diagram of Walk2Watt System

On the other hand, electromechanical energy harvesting systems use mechanical components such as levers, springs, gears, and generators to convert footstep force into electrical energy. In these systems, the mechanical energy is first converted into motion and then into electrical energy using a generator.

Jose et al. (2013) developed a system in which a spring mechanism connected to a pinion and dynamo was used to generate enough power to light an LED when a person steps on the platform. Similarly, commercial systems like Pavegen use a sliding platform and gear-based mechanism to generate electricity, with an average output of around 2 to 7 W per step depending on conditions. These systems are more efficient because they capture a larger portion of the mechanical energy produced during walking.

The Walk2Watt System is also based on this electromechanical approach. It uses a rack and pinion mechanism to convert linear motion from footsteps into rotational motion, which increases the speed of the generator and improves energy output. Compared to piezoelectric systems, this method provides better efficiency, higher power output, and improved durability. However, mechanical systems require proper maintenance due to friction, wear, and alignment issues.

To further improve performance, some modern research combines multiple energy harvesting techniques. These hybrid systems may include piezoelectric sensors, solar panels, or pneumatic mechanisms to increase efficiency. For example, a shoe-based energy harvesting system developed at MIT used a micro-turbine to generate about 30 mW of power while walking.

Footstep energy harvesting systems can produce discernible energy in high-traffic places like train stations, according to real-world implementations like those by East Japan Railway. These illustrations demonstrate how human walking energy can be efficiently applied in real-world settings. Overall, the Walk2Watt System emphasizes simplicity, affordability, robustness, and ease of implementation while adhering to the mechanical energy harvesting method. To achieve dependable functioning under real-world settings, the system makes use of robust mechanical components, effective motion conversion, and appropriate energy storage systems.

3. Methodology

Walk2Watt's mechanics are straightforward. Figure 2 provides an overview. The main parts are a steel foot plate, a rack attached underneath the plate, a spring return mechanism, and a pinion gear on a DC generator. When the plate is in the neutral position, the springs keep it upright and the rack out of engagement. When someone steps, the plate is pushed down by three to five centimeters. The rack slides horizontally against the stationary gear, causing the pinion to revolve. The rack retracts and the pinion rotates in the opposite direction when the foot is raised because the springs push the plate back.

Two generator rotation pulses are produced for every depress-release cycle. Although our version drives the generator

in any direction (the rectifier handles sign), a mechanical ratchet or one-way clutch might be added to make both directions create forward output.

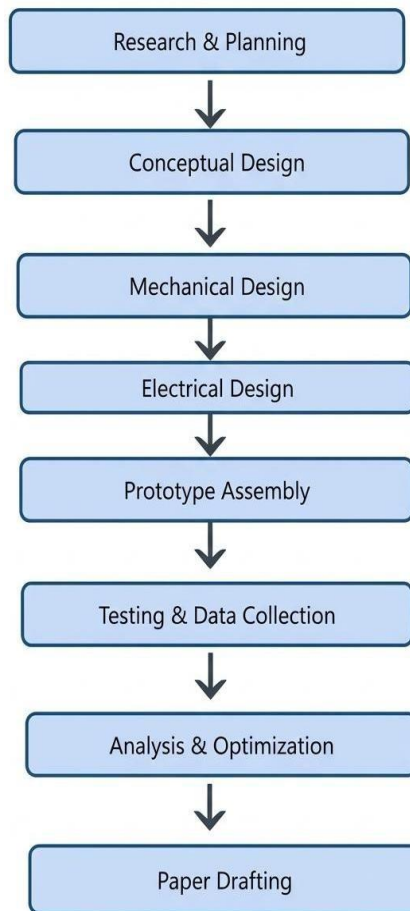


Fig 2 : Flowchart of Walk2Watt System

Research & Planning: The problem is precisely identified and comprehended at this stage, which serves as the project's foundation. It entails identifying the project's scope, goals, limitations, and necessary resources in addition to examining previous research, technologies, and solutions pertaining to the subject. A systematic approach is ensured by careful preparation, which also helps to prevent future problems and successfully directs the work's course.

Conceptual Design: Based on the study findings, a variety of concepts and approaches to solutions are developed at this phase. The viability, affordability, effectiveness, and practicality of these ideas are contrasted. To see how the system will function, sketches, simple models, or diagrams may be made, and the most promising idea is chosen for additional development.

Mechanical Design: The intricate design of the system's moving components and physical structure is the main emphasis of this phase. It include choosing the right materials, figuring out measurements, and creating parts including frames, supports, gears, and mechanisms. Making ensuring the system is robust, reliable, and able to carry out its intended function under anticipated circumstances is the aim.

Electrical Design: The system's electrical and electronic components are developed here. This include arranging the wiring layout, creating circuits, and choosing parts including motors, sensors, controllers, and power supply. During this stage, compatibility with the mechanical system, efficiency, and safety are crucial factors.

Prototype Assembly: This step involves assembling all of the mechanical and electrical components that were planned to create a fully functional model. This procedure enables the identification of any integration problems between various system components and assists in confirming whether the design can be actually implemented.

Testing & Data Collection: When the prototype is ready, its performance is assessed through testing in a variety of operational environments. Information is gathered about things like response speed, durability, accuracy, and efficiency. This phase is essential for determining how successfully the system achieves the initial goals.

Analysis & Optimization: To find flaws, mistakes, or opportunities for improvement, the data collected during testing is thoroughly examined. Changes are made to increase overall system efficiency, boost dependability, and optimize performance based on this research.

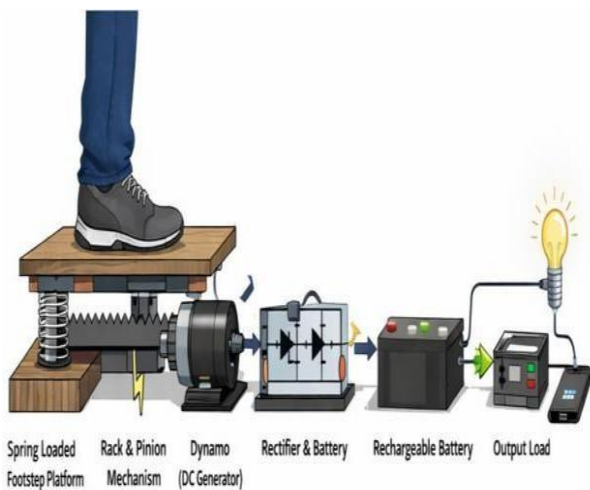
Paper Drafting: In the last phase, every facet of the project is recorded in an organized manner. The problem statement, methodology, design specifics, findings, analysis, and conclusions are all included in this. In order to show the work properly and for future reference or publication, proper documentation is crucial.

4. Experimental results

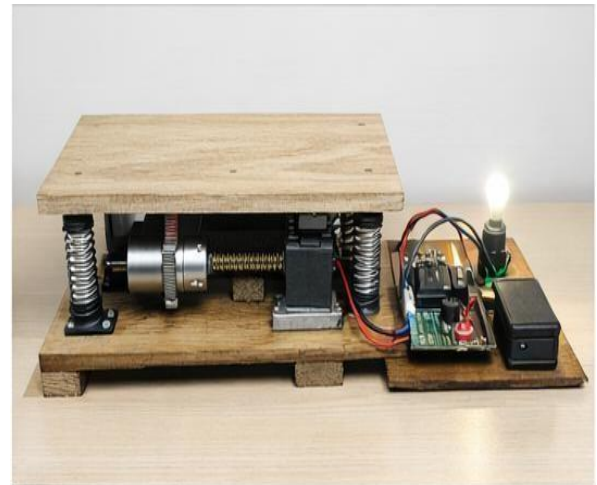
To evaluate the system's performance, it was put through various tests. the output depends on the force applied and the speed of stepping.

- the voltage produced is between 2 and 4 volts every step.
- power output: 0.2w to 1w
- led operation: effective

Fig. [(A) Working principle of footstep energy conversion using rack and pinion mechanism] illustrate the footstep energy generation system's operation is depicted in the diagram (walk2watt). the supplied force compresses the springs and produces downward motion when a human steps on the spring-loaded platform. a rack and pinion mechanism receives this motion and transforms it from linear to rotational motion. a dynamo, or dc generator, is powered by the revolving pinion and produces electrical energy. The produced output is then stored in a rechargeable battery after being converted from AC to DC via a rectifier circuit. In order to show how human footsteps can be transformed into useable electrical power, the stored energy is then transferred to an output load, such as a lightbulb or electronic gadget.



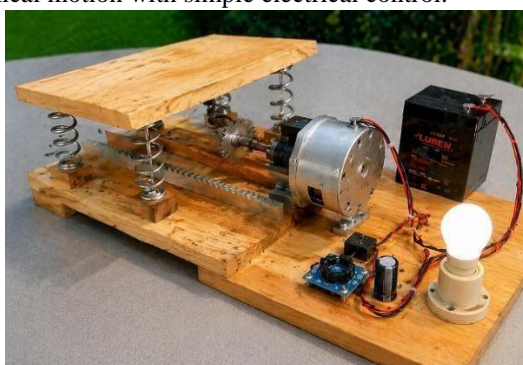
(A)



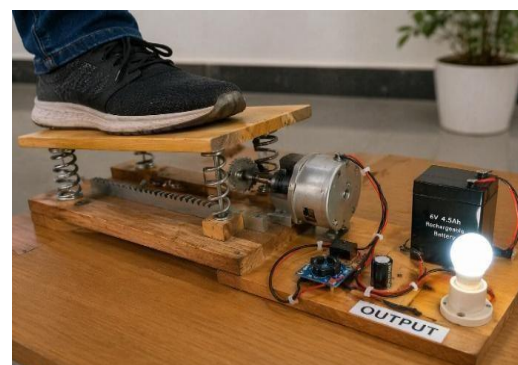
(B)

Fig.3: Footstep Energy Generation Mechanism and Prototype Model

Fig. [(B) Developed hardware prototype of Walk2Watt system] depicts a small do-it-yourself mechanical device on a wooden base with a motor-driven screw mechanism (probably a linear actuator) mounted between two plates supported by springs at the corners, suggesting it can compress or apply force; on the right side is a basic electronics setup with a circuit board, wiring, a power supply module, and a glowing light bulb used as an indicator, suggesting the system is powered and possibly controlled electronically; overall, it resembles a homemade press or testing rig that combines mechanical motion with simple electrical control.



(C)



(D)

Fig.4: Experimental Setup and Output Demonstration of Walk2Watt System

Fig. [(C) Footstep actuation showing mechanical energy conversion] A mechanism that transforms mechanical pressure into rotational motion or electrical energy is suggested by the image, which depicts a setup on a wooden base where a person's foot presses down on a top wooden platform supported by springs to create vertical motion. This movement is transferred through a threaded rod connected to a motor. A blazing lightbulb marked "OUTPUT" is attached to an electrical circuit supplied by a battery on the right side, signifying that the system is producing or regulating electricity when force is applied. Overall, the configuration seems to show a straightforward energy conversion or force-based actuation system that combines electrical output with mechanical compression.

Fig. [(D) Electrical output indicated by glowing bulb] A homemade mechanical-electrical setup with a spring-loaded top platform supported by four metal springs that enable it to move up and down when pressed is depicted in the picture. The setup is installed on a wooden foundation. A rack-and-pinion device that is attached to a tiny DC motor beneath the platform transforms vertical motion into rotational motion. In order to power a lightbulb on the side, the motor is connected to a straightforward circuit that consists of a battery, a small control board, and a capacitor. The arrangement seems to illustrate a fundamental idea of energy conversion by showing how mechanical energy (from pressing the platform) may be converted into electrical energy to light the lamp.

Table No.1: Performance Analysis of Walk2Watt System

Sr. No	Content	Value	Remark
1	Voltage Generated	2 – 5 V	Good
2	Current Output	1-2 A	Moderate
3	Power Generated	1–3 W	Satisfactory
4	Energy per Step	0.1–0.5 J	Low but useful
5	LED Lighting Performance	Working	Successful
6	System Efficiency	~5–10%	Can Improve

5. Conclusion

We have implemented an automatic text detection technique from an image for Inpainting. Our algorithm successfully detects the text region from the image which consists of mixed text-picture-graphic regions. We have applied our algorithm on many images and found that it successfully detect the text region.

References

- [1] M. Bertalmio, G. Sapiro, V. Caselles, and C. Ballester, "Image inpainting", in Proc. SIGGRAPH, pp. 417–424, 2000.
- [2] A. Criminisi, P. Perez, and K. Toyama, "Region filling and object removal by exemplar-based image inpainting.", IEEE Transactions on Image Processing, vol. 13, no.9, pp. 1200–1212, 2004.
- [3] Marcelo Bertalmio, Luminita Vese, Guillermo Sapiro, Stanley Osher, "Simultaneous Structure and Texture Image Inpainting", IEEE Transactions On Image Processing, vol. 12, No. 8, 2003.
- [4] Yassin M. Y. Hasan and Lina J. Karam, "Morphological Text Extraction from Images", IEEE Transactions On Image Processing, vol. 9, No. 11, 2000
- [5] Eftychios A. Pnevmatikakis, Petros Maragos "An Inpainting System For Automatic Image Structure-Texture Restoration With Text Removal", IEEE trans. 978-1-4244-1764, 2008
- [6] S.Bhuvaneswari, T.S.Subashini, "Automatic Detection and Inpainting of Text Images", International Journal of Computer Applications (0975 – 8887) Volume 61– No.7, 2013
- [7] Aria Pezeshk and Richard L. Tutwiler, "Automatic Feature Extraction and Text Recognition from Scanned Topographic Maps", IEEE Transactions on geosciences and remote sensing, VOL. 49, NO. 12, 2011
- [8] Xiaoqing Liu and Jagath Samarabandu, "Multiscale Edge-Based Text Extraction From Complex Images", IEEE Trans., 1424403677, 2006
- [9] Nobuo Ezaki, Marius Bulacu Lambert , Schomaker , "Text Detection from Natural Scene Images: Towards a System for Visually Impaired Persons", Proc. of 17th Int. Conf. on Pattern Recognition (ICPR), IEEE Computer Society, pp. 683-686, vol. II, 2004
- [10] Mr. Rajesh H. Davda1, Mr. Noor Mohammed, " Text Detection, Removal and Region Filling Using Image Inpainting", International Journal of Futuristic Science Engineering and Technology, vol. 1 Issue 2, ISSN 2320 – 4486, 2013
- [11] Uday Modha, Preeti Dave, " Image Inpainting-Automatic Detection and Removal of Text From Images", International Journal of Engineering Research and Applications (IJERA), ISSN: 2248-9622 Vol. 2, Issue 2, 2012
- [12] Muthukumar S, Dr.Krishnan .N, Pasupathi.P, Deepa. S, "Analysis of Image Inpainting Techniques with Exemplar, Poisson, Successive Elimination and 8 Pixel Neighborhood Methods", International Journal of Computer Applications (0975 – 8887), Volume 9, No.11, 2010

IoT Based Bridge Health Monitoring System

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Abstract : The IoT-Based Bridge Health Monitoring System is an intelligent and automated solution developed to ensure the safety, stability, and longevity of bridges through continuous real-time monitoring. Bridges are vital components of transportation networks, and their failure due to structural damage, overloading, or environmental factors can lead to catastrophic consequences. Conventional inspection methods rely on periodic manual checks, which may not detect hidden faults or sudden structural changes. To address these challenges, this system utilizes the concept of the Internet of Things (IoT) to provide a smart and efficient monitoring mechanism.

Keywords: IoT, Structural Health Monitoring, Bridge Safety, Wireless Sensor Networks, Real-Time Monitoring

1. Introduction

An IoT-based Bridge Health Monitoring System is an advanced technology solution designed to continuously monitor the structural condition and safety of bridges in real time. Bridges are critical components of transportation infrastructure, and their failure can lead to severe economic loss and risk to human life. Traditional inspection methods are manual, time-consuming, and may fail to detect early signs of damage. To overcome these limitations, the integration of Internet of Things (IoT) enables automated, accurate, and continuous monitoring.

In this system, various sensors are installed on different parts of the bridge to measure important physical parameters such as vibration, load, tilt angle, crack formation. Commonly used sensors include accelerometers, tilt sensors, and crack detection sensors. These sensors collect real-time data and send it to a microcontroller such as Arduino Uno or Node MCU ESP8266.

Engineers and authorities can monitor the bridge condition in real time and receive alerts if any abnormal behavior is detected. For example, if there is an unusual tilt, excessive vibration, or structural deformation, the system can immediately notify concerned authorities through messages or alarms. This early warning system helps prevent accidents and allows timely maintenance. Overall, an IoT-based Bridge Health Monitoring System enhances the reliability, safety, and lifespan of bridges. It reduces the need for manual inspections, minimizes maintenance costs, and ensures quick response in case of emergencies. This smart monitoring approach is an important step toward building safer and more intelligent infrastructure systems in modern cities.

Bridges are critical components of transportation infrastructure, and their safety is essential for public mobility and economic growth. Over time, factors such as heavy traffic, environmental conditions, and material degradation can weaken bridge structures, leading to potential failures. Traditional inspection methods are manual, time-consuming, and may not detect hidden damages effectively.

An IoT-based bridge health monitoring system offers a smart and automated solution by using sensors and wireless communication technologies. These sensors continuously monitor important parameters like vibration, load, tilt, and cracks in the structure. The collected data is transmitted to a cloud platform for real-time analysis and monitoring.

This system enables early detection of structural issues, reduces maintenance costs, and improves overall safety. By providing continuous and remote monitoring, it helps authorities take timely decisions and prevent catastrophic failures.

2. Related Work

Many researchers have explored IoT-based bridge health monitoring systems to improve infrastructure safety and reduce manual inspection efforts.

Several studies focus on sensor-based monitoring systems that use vibration, strain and tilt sensors to continuously track bridge conditions. These systems help detect structural changes such as deformation, cracks, and excessive load in real time.

A study proposed a low-power IoT vibration monitoring system, where wireless acceleration sensors were deployed on bridges and This approach reduces power consumption while maintaining monitoring accuracy.

Another research introduced an IoT-based bridge monitoring system using Arduino and multiple sensors such as water level, load, and ultrasonic sensors. The system sends real-time data to a cloud server and generates alerts when thresholds are exceeded, helping authorities take immediate action.

Recent work integrates machine learning techniques with IoT to enable predictive maintenance. These systems analyze sensor data to detect anomalies and predict possible failures before they occur, improving decision-making and reducing maintenance costs.

Some advanced approaches also incorporate fuzzy logic and intelligent algorithms to classify bridge health conditions into different categories (safe, moderate, critical). These systems enhance accuracy in decision-making and provide early warning alerts through mobile applications.

Several research studies have explored the use of IoT for bridge health monitoring to improve safety and reduce maintenance efforts. Traditional systems relied on manual inspection, which is time-consuming and prone to human error, leading to the need for automated monitoring solutions.

Recent works focus on sensor-based monitoring systems that use vibration, strain, temperature, and load sensors to continuously collect structural data. These systems transmit real-time data to cloud platforms, enabling remote monitoring and early detection of faults.

Some studies have proposed low-power wireless IoT systems that integrate sensors with gateways and cloud computing, demonstrating efficient real-time data acquisition, storage, and analysis in practical bridge environments.

3. Methodology

The proposed IoT-based bridge health monitoring system works by continuously collecting and analyzing structural data from the bridge using various sensors. Sensors such as vibration, strain, tilt, and sensors are installed at critical points of the bridge to detect parameters like deformation, cracks, load variation, and environmental changes. These sensors send real-time data to a microcontroller unit such as Arduino where the data is processed and compared with predefined threshold values to identify any abnormal conditions.

The collected data is then transmitted to a microcontroller (such as Arduino or NodeMCU), where basic processing, filtering, and conversion of analog signals into digital form take place. After processing, the data is sent to a cloud platform using IoT communication protocols like Wi-Fi or GSM for remote storage and access.

In the cloud, the data is analyzed to evaluate the condition of the bridge. Predefined threshold values are used to determine whether the structure is operating within safe limits. If the data remains within normal ranges, the system displays a normal status on the monitoring interface.

However, if any abnormal condition is detected, such as excessive vibration or crack formation, the system immediately generates an alert notification. This alert is displayed on the dashboard or sent to concerned authorities for quick action.

Thus, the methodology ensures real-time monitoring, early fault detection, and effective maintenance of bridge structures. The system continuously compares the sensed data with predefined threshold values. If all parameters are within safe limits, the system displays a normal status. However, if any abnormality such as excessive vibration, overload, tilt, or crack detection occurs, the system generates an alert notification for immediate action.

The methodology ensures continuous monitoring, early fault detection, and improved maintenance efficiency. The system is designed to be low-cost, reliable, and suitable for real-time structural health monitoring applications.

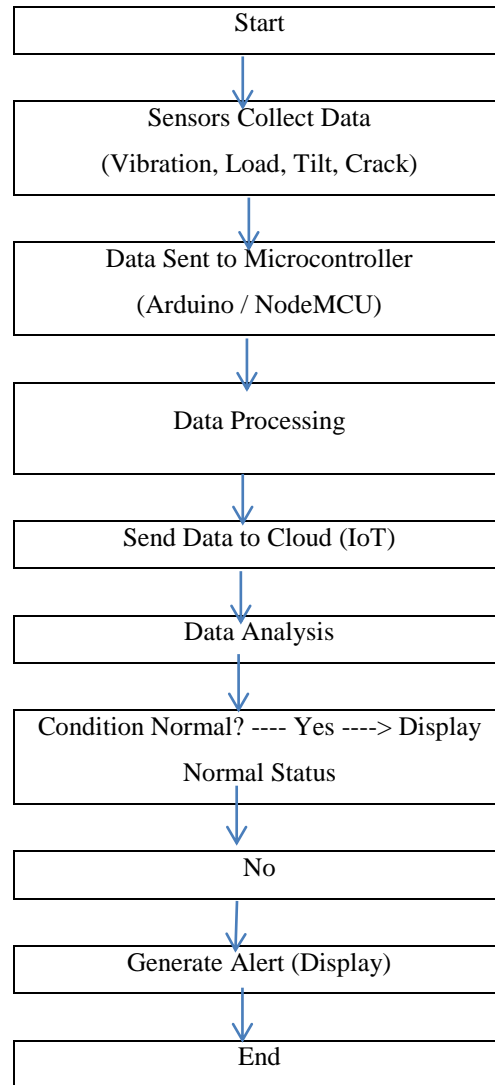


Fig 3.1 Working Flow Of Iot-Based Bridge Health Monitoring System.

3.1 System Overview

- I. **Sensor Data Collection** - Sensors like vibration, tilt, load, and crack sensors are installed on the bridge. They continuously monitor structural parameters. Data is collected in real time from different locations. The first stage of the IoT-based bridge health monitoring system involves the installation of multiple sensors on critical parts of the bridge. Vibration sensors measure oscillations caused by traffic, wind, or other dynamic forces, providing insights into the structural response of the bridge. Tilt sensors monitor angular displacements to detect any uneven settlement or misalignment. Load sensors, such as strain gauges or load cells, measure stress and weight distribution on beams and cables, ensuring that structural components are operating within safe limits.
- II. **Data Processing Unit** - Sensor data is sent to Arduino Uno / Node MCU ESP8266. The microcontroller processes and checks data limits. It identifies normal or abnormal conditions. It also performs preliminary analysis to classify the bridge condition as normal or abnormal. By aggregating and processing the data locally, the microcontroller ensures efficient data handling and reduces unnecessary transmission, improving system responsiveness and reliability.
- III. **Data Transmission (IOT)** - Processed data is sent using Internet of Things. Wireless communication like Wi-Fi/GSM is used. Data is transferred to the cloud server. The processed data is sent to a remote cloud platform using Internet of Things technology. Depending on network availability, wireless communication methods such as Wi-Fi or GSM modules are used to transmit the data securely.
- IV. **Cloud Storage & Analysis** - Data is stored securely on cloud platforms. Real-time monitoring and analysis are performed. Historical data helps in future prediction. Historical data can be analyzed to identify trends, assess structural degradation over time, and support predictive maintenance. Advanced analytics and machine

learning algorithms can further enhance the system by detecting subtle anomalies that may indicate early signs of damage.

- V. **Alert & Notification System** - If abnormal condition is detected, alerts are generated .Notifications are sent alarm .Authorities get immediate warning. The system is programmed to generate alerts whenever any monitored parameter exceeds predefined safety limits. The alert system also prioritizes notifications based on severity, distinguishing between minor warnings and critical dangers, allowing authorities to respond promptly and prevent accidents or further structural damage.
- VI. **Display System** - LCD display shows bridge status. Messages like “Safe” or “Danger” are displayed .Helps in public awareness and safety. An on-site display, such as an LCD or LED panel, provides real-time feedback on the bridge’s condition to both authorities and the public. Messages such as “Safe” or “Danger” are displayed to communicate the current status. This enhances public safety by raising awareness about potential hazards, complementing remote monitoring and alert systems, and providing an immediate visual indication of the bridge’s health.

4. Experimental results

The proposed IoT-based bridge health monitoring system was successfully implemented and tested under real-time conditions. The system performance was evaluated based on sensor accuracy, data transmission efficiency, and alert response time.

The vibration sensor and load sensor provided stable and accurate readings during different load conditions on the bridge model. The tilt sensor effectively detected angular deviations, while the crack detection sensor identified structural faults with high sensitivity. The microcontroller (Node MCU/Arduino) processed the collected data efficiently and transmitted it to the cloud platform via Wi-Fi without significant delay.

During testing, all parameters were observed to remain within safe limits under normal conditions. When abnormal conditions such as excessive vibration or tilt were introduced, the system successfully generated alerts in real time. The data was continuously updated and visualized on the IoT dashboard for remote monitoring.

The system showed minimum latency in data transmission, ensuring quick response in case of structural abnormalities. The experimental observations demonstrate that the system is reliable, efficient, and suitable for real-time bridge monitoring applications.

The experimental setup also demonstrated that:

1. Proper sensor placement improves monitoring accuracy
2. Wireless communication enables real-time remote monitoring
3. Stable internet connectivity ensures continuous data updates

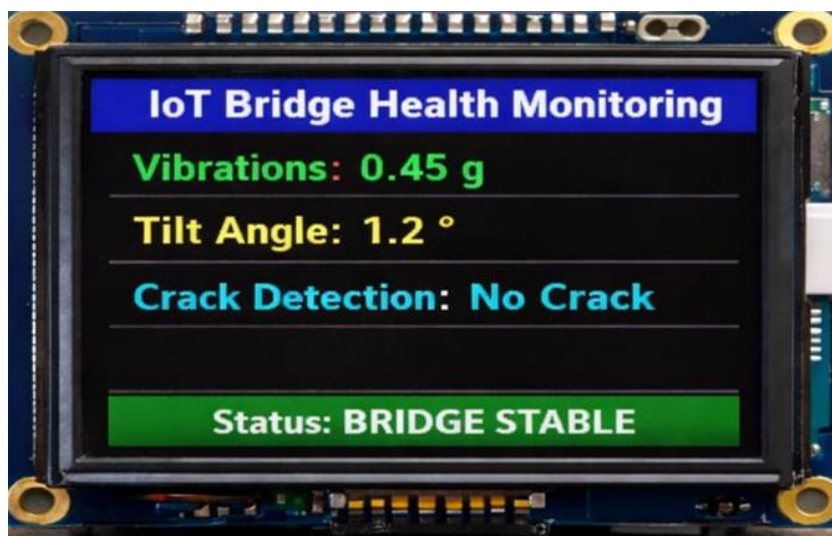


Fig 1: For safe Condition Status



Fig 2 For Unsafe Condition Status

Table No.1 System Performance

Sr. No	Parameter	Result	Remark
1	Vibration Monitoring	Accurate real-time data	Stable
2	Load Detection	Reliable measurements	Consistent
3	Tilt Detection	Sensitive to small changes	Efficient
4	Crack Detection	Early fault identification	Reliable
5	Alert System	Immediate notification	Effective

The results indicate that the proposed system is cost-effective, reliable, and suitable for continuous structural health monitoring of bridges. However, system performance depends on proper sensor calibration and stable network connectivity

5. Conclusion

The IoT-Based Bridge Health Monitoring System provides a smart solution for ensuring bridge safety and reliability. By using Internet of Things, it enables real-time monitoring of parameters like load, vibration, and tilt. The system helps in early detection of faults and prevents major accidents. It reduces manual inspection and improves accuracy in maintenance. Using controllers like Arduino Uno and Node MCU ESP8266, data is efficiently collected and analyzed. Overall, it increases bridge lifespan and ensures public safety.

An IoT-based bridge health monitoring system provides real-time data on structural conditions, enabling early detection of damage or stress. It improves safety by continuously tracking parameters like vibration, load, and temperature. The system reduces maintenance costs by allowing predictive maintenance instead of reactive repairs. Wireless sensors and cloud integration make monitoring efficient and accessible from remote locations. It enhances the lifespan and reliability of bridges while minimizing the risk of sudden failures.

The IoT-based bridge health monitoring system provides an efficient and reliable solution for ensuring the safety and durability of bridges. By using sensors to continuously monitor parameters like vibration, load, tilt, and cracks, the system enables real-time data collection and analysis. This helps in early detection of structural issues, reducing the risk of sudden bridge failures. The integration of IoT technology allows remote monitoring, quick alerts, and better decision-making for maintenance authorities. Overall, the system improves public safety, reduces maintenance costs, and increases the lifespan of bridges, making it a smart and sustainable infrastructure solution.

References

- [1] Al-Ali, A. R., et al., "An IoT-Based Road Bridge Health Monitoring and Warning System," *Sensors*, vol. 24, no. 2, 2024.
- [2] Tong, X., et al., "Development of a Low-Power IoT Vibration System for Bridge Monitoring," *Sensors*, vol. 19, no. 5, 2019
- [3] Dhuri, A., et al., "IoT Based Bridge Health Smart Monitoring System," *International Journal of Engineering Research & Technology (IJERT)*, 2020.
- [4] Salave, H., et al., "IoT-Based Bridge Monitoring System," *IJRASET*, 2025.
- [5] Mhetre, P., et al., "IoT-Based Bridge Health Monitoring System," *IJSART*, vol. 11, 2025.
- [6] Isreal, O., "IoT in Bridge and Highway Structural Health Monitoring," *ResearchGate*, 2022.
- [7] Rahita, A. C., et al., "Internet of Things in Structural Health Monitoring: A Decade Review," *IETA Journal*, 2024.
- [8] Gadiraju, D. S., et al., "Blockchain-Based IoT for Bridge Health Monitoring (BIONIB)," *arXiv*, 2024
- [9] Park, J., et al., "Development of IoT Sensor and Cloud-Based Server for Bridge Monitoring," *arXiv*, 2022.
- [10] Liu, J., et al., "Vibration-Based Bridge Health Monitoring using Distributed Acoustic Sensing," *arXiv*, 2022.
- [11] Moallemi, A., et al., "Real-Time Anomaly Detection for Bridge Health Monitoring," *arXiv*, 2022.
- [12] Zhang, G., et al., "Causes and Statistical Characteristics of Bridge Failures: A Review," *Journal of Traffic and Transportation Engineering*, 2022.
- [13] *ResearchGate*, "An IoT-Based Road Bridge Health Monitoring and Warning System," 2024.
- [14] Jatkar, R., et al., "Bridge Health Monitoring in Internet of Things," *IJSRCSEIT Journal*, 2017.
- [15] Zu, Q., & Xu, X., "Integrating IoT Technology in Bridge Health Monitoring," *International Conference on Pervasive Computing*, 2012.



Online Exam Management System

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Abstract—This paper presents the design and implementation of an Online Exam Management System (OEMS), a fully automated web-based examination platform developed using PHP with the CodeIgniter MVC framework, MySQL for structured data storage, and a responsive Bootstrap-based frontend. The system is engineered to address critical shortcomings of traditional paper-based examinations, including question paper leakage, malpractice, manual evaluation delays, and logistical overhead. Key features of the implemented system include secure role-based authentication for administrators and students, a centralized question bank with randomized question and answer delivery per student session, a real-time countdown timer with server-side validation and automatic submission upon expiry, and browser-level anti-malpractice controls such as disabling back-navigation, copy-paste restriction, and tab-switch detection. The system supports automated MCQ evaluation, instant result generation, and downloadable performance reports in PDF/Excel formats. Developed and validated using the Waterfall Model across phases of requirement analysis, system design, implementation, and testing, the platform demonstrated stable performance under concurrent multi-user access with query response times under 1.5 seconds. The system is fully compatible with Windows, Linux, and macOS environments via XAMPP/Apache and is browser-independent, supporting deployment in academic institutions, recruitment organizations, and corporate training environments.

Keywords—Online Examination System; PHP; MySQL; CodeIgniter; MVC Architecture; Role-Based Access Control; Anti-Malpractice; Web-Based Assessment; Automated Evaluation; Session Management

I. INTRODUCTION

The rapid proliferation of internet technologies and digital platforms has transformed educational and professional assessment methodologies worldwide. Traditional paper-based examination systems are characterized by significant manual overhead, including question paper preparation, printing, invigilation, answer sheet evaluation, and result processing — processes that are inherently time-consuming, error-prone, and susceptible to malpractice. Additionally, physical examination infrastructures lack scalability, accessibility, and the ability to support remote or hybrid learning environments, which have become increasingly critical in the post-pandemic era.

The Online Exam Management System (OEMS) presented in this paper is a fully automated, web-based platform developed to address these challenges. The system enables administrators to create and manage examinations, maintain a centralized question bank, assign tests to registered students, and monitor results through a unified dashboard. Students can securely log in, attempt timed exams, navigate questions freely during the session, and receive automated results immediately upon submission.

The platform is built upon PHP with the CodeIgniter MVC (Model-View-Controller) framework for server-side logic, MySQL for relational data management, and Bootstrap-based HTML/CSS/JavaScript for a responsive frontend. It is compatible with Windows, Linux, and macOS operating environments through XAMPP/Apache deployment and is accessible from any modern web browser without client-side software installation.

The system specifically incorporates mechanisms against academic malpractice — a concern of primary importance in digital examination environments. These include dynamic randomization of question sets and answer options per session, enforcement of real-time countdown timers with server-side validation, and browser-level controls that disable back-navigation, copy-paste operations, and tab-switching. Role-based authentication ensures that only authorized users access appropriate system modules, preventing unauthorized access and dummy student impersonation.

This paper is organized as follows: Section II presents a review of related work. Section III describes the problem statement. Section IV outlines the system objectives. Section V details the proposed system design and methodology. Section

VI covers implementation and testing. Section VII presents results and discussion. Section VIII concludes the paper with future scope.

II. RELATED WORK

The concept of Online Examination Systems (OES) has been extensively studied and evolved with advances in web technologies and database-driven platforms. Traditional pen-and-paper examinations required substantial manual effort in question paper generation, invigilation, evaluation, and result processing, presenting challenges of resource intensity, lack of scalability, and susceptibility to malpractice [1].

Ahmed [1] proposed a PHP-MySQL-based OES incorporating role-based login and automated result generation. The study demonstrated that server-side scripting combined with relational database management significantly enhances system efficiency through secure user authentication and dynamic content rendering. However, the proposed system lacked comprehensive anti-malpractice mechanisms.

Pathak [2] addressed security concerns in web-based examination platforms, specifically focusing on session-based authentication and timer validation techniques. The study highlighted vulnerabilities in client-side timer implementations and proposed server-side session timestamp validation as a robust countermeasure against time manipulation.

Singh and Roy [3] investigated automated examination portals using PHP, emphasizing the role of randomized question sets and automated evaluation in reducing malpractice opportunities. Their work confirmed that dynamic question fetching from a database eliminates static paper leakage risks. Yadav and Singh [4] further explored scalable web-based OES architectures, addressing concurrent user handling and database query optimization for institutional-scale deployments.

Sommerville [5] provides foundational principles of software engineering that guide the structured development of reliable software systems, including the Waterfall Model approach employed in this project. Existing literature consistently identifies role-based access control, randomized question delivery, real-time timer enforcement, and automated result generation as essential features for secure and reliable online examination platforms — all of which are comprehensively addressed in the system presented in this paper.

III. PROBLEM STATEMENT

Traditional examination systems face numerous critical challenges in modern educational environments. Manual paper handling introduces risks of question paper leakage, printing errors, and logistical delays. Conducting examinations across multiple locations requires large administrative staff and invigilation resources, significantly increasing operational costs.

Academic malpractice and student impersonation (dummy students) are inherently difficult to detect and prevent in paper-based systems. Manual evaluation is time-consuming, error-prone, and inconsistent across evaluators. Result preparation, storage, and retrieval require significant administrative effort and are vulnerable to data loss. Paper-based systems are neither scalable nor environmentally sustainable.

Therefore, there is a critical need for a secure, automated Online Exam Management System that can effectively prevent malpractice, ensure fair assessment, eliminate paper dependency, provide reliable and auditable data storage, and deliver instant results — while maintaining compatibility with standard computing environments and supporting concurrent multi-user access.

IV. OBJECTIVES

The primary objectives of the proposed Online Exam Management System are as follows:

1. To develop a secure, web-based examination platform accessible on Windows, Linux, and macOS via standard web browsers, requiring no client-side software installation.
2. To implement strong anti-malpractice mechanisms including disabling copy-paste and back-navigation, detecting tab-switching, randomizing question order per student session, and enforcing strict time limits with auto-submission upon expiry.
3. To provide role-based access control ensuring administrators manage examinations and students only access assigned tests, preventing unauthorized access and impersonation.
4. To design a centralized and structured MySQL database for secure, organized storage of user data, question banks, examination records, and results with backup and recovery provision.
5. To automate examination scheduling, MCQ evaluation, score calculation, and result generation, eliminating manual checking overhead.
6. To ensure system reliability under concurrent multi-user access with optimized backend queries and provide downloadable reports in PDF/Excel formats.

V. SYSTEM DESIGN AND METHODOLOGY

A. Development Methodology

The Online Exam Management System was developed using the Waterfall Model — a structured, sequential software development approach that ensures each phase is fully completed and validated before proceeding to the next. This methodology was selected for its systematic handling of requirements traceability, documentation rigor, and phase-gated quality assurance, which are particularly important for security-critical applications such as examination management platforms.

B. System Architecture

The system is built upon a Client-Server architecture structured using the Model-View-Controller (MVC) design pattern, which provides clean separation between data management, business logic, and presentation layers, ensuring maintainability and scalability.

The frontend (View layer) is implemented using HTML5, CSS3, Bootstrap 5, and JavaScript, providing a responsive, mobile-compatible interface that supports exam panel rendering, countdown timer display, question navigation palette, and results dashboard. The backend (Controller and Model layers) is implemented in PHP using the CodeIgniter framework, which handles authentication, session management, question randomization, timer validation, form processing, and result computation. The data persistence layer utilizes MySQL 8.x with normalized relational tables enforcing foreign key constraints for data integrity. Apache Web Server via XAMPP serves the PHP application and manages HTTP request routing.

C. Database Design

The MySQL database schema comprises six primary relational tables: users (stores login credentials, roles, and profile data), exams (stores exam metadata including duration, question count, and active status), questions (stores question text categorized by subject and difficulty), options (stores answer choices with correct answer flags), responses (logs each student's submitted answers with timestamps), and results (stores computed scores, percentages, grades, and submission metadata). Foreign key relationships are enforced between all dependent tables, with ACID-compliant transaction support ensuring data consistency during concurrent examination submissions.

D. Anti-Malpractice Implementation

Addressing the critical concern of examination malpractice, the system implements a multi-layered security architecture. Randomized question delivery ensures each student session fetches questions in a uniquely shuffled order from the MySQL question bank, eliminating any two students from seeing the same question sequence. MCQ options are similarly shuffled per session, making answer position memorization ineffective.

The timer enforcement mechanism employs a JavaScript countdown timer running client-side, synchronized with a server-side PHP session timestamp. Any discrepancy between client and server time triggers immediate forced submission, preventing timer manipulation. Browser lockdown is achieved through JavaScript event listeners that disable the browser back button, right-click context menu, and clipboard operations (Ctrl+C/V) on the examination page. Tab-switch and window-focus-loss events are detected, logged, and can trigger warnings or submission.

Role-based authentication validates each login against the MySQL users table with hashed passwords. User role (admin/student) is persisted in the session, and server-side session checks on every page load block unauthorized URL access. One-exam-per-session enforcement prevents duplicate submissions by verifying prior attempt records before allowing examination initiation.

E. System Modules

The Authentication Module manages secure login and role-based redirection, initializing role-specific sessions. The Exam Management Module enables administrators to create examinations, define duration and question count, and control exam availability. The Question Bank Module supports CRUD operations on MCQ/True-False questions with subject and difficulty categorization, and drives the randomization engine. The Timer Module provides real-time countdown display with auto-submission on expiry and back-navigation blocking. The Question Navigation Module presents a visual question palette distinguishing answered, unanswered, and skipped questions, with free navigation enabling students to revisit any question before submission. The Result Generation Module automatically compares submitted answers with correct answers, computes scores and percentages, displays instant results, and maintains audit trail records. The Report Module provides filtered result export in PDF and Excel formats.

F. System Flow

The system workflow initiates at the login page where credentials are validated against the database. Authenticated users are redirected to role-specific dashboards. For examination flow, questions are dynamically fetched and randomized from the MySQL database, eliminating any static paper generation. The JavaScript timer starts simultaneously with the server-side

session timestamp. Anti-malpractice controls activate throughout the session. Upon manual submission or timer expiry, all responses are stored in the responses table, automated evaluation is performed, the result is computed and stored in the results table, and the score is immediately displayed to the student. The session is destroyed upon logout.

VI. IMPLEMENTATION AND TESTING

A. Development Environment

The system was developed using Visual Studio Code as the code editor, XAMPP (Apache 2.4, PHP 8.x, MySQL 8.x) as the local development server, CodeIgniter 3/4 as the MVC framework, and Git/GitHub for version control. The system is compatible with Windows (XAMPP), Linux Ubuntu/CentOS (LAMP stack), and macOS (MAMP) environments, and is deployable on shared hosting, VPS, or cloud platforms (AWS, DigitalOcean) supporting PHP 7.4+ and MySQL 5.7+.

B. Testing Methodology

A structured testing approach was applied comprising four testing phases. Unit testing independently validated key modules including authentication, question management, timer logic, result computation, and database connectivity. Integration testing validated the end-to-end examination flow from login through examination session to result generation and logout. Malpractice testing confirmed that back-navigation, tab-switching, and copy-paste attempts were consistently blocked across all test sessions. Concurrent user testing simulated multiple students submitting examinations simultaneously, with the system maintaining stability and response times under 1.5 seconds. Cross-browser and device testing was conducted on Google Chrome, Mozilla Firefox, and Microsoft Edge across Windows, Android, and iOS devices to ensure consistent behavior.

C. Test Cases and Results

Table I summarizes the primary test cases executed and their outcomes during the validation phase.

TABLE I
Summary of Test Cases and Results

TC-ID	Test Description	Expected Result	Status	Remarks
TC-001	Admin login with valid credentials	Redirect to Admin Dashboard	Passed	—
TC-002	Start exam session with timer	Timer starts; first question rendered	Passed	—
TC-003	Exam auto-submit on timer expiry	Forced submission; result generated	Passed	—
TC-004	Invalid login attempt	Error message displayed	Passed	—
TC-005	Back-navigation attempt during exam	Navigation blocked by JS event	Passed	—
TC-006	Tab-switch detection	Event logged; warning triggered	Passed	—
TC-007	Duplicate exam attempt by student	Access blocked; prior attempt detected	Passed	—
TC-008	Result download (PDF)	PDF file generated and downloaded	Passed	—
TC-009	Concurrent 20-user load test	Response time < 1.5s; stable	Passed	—

During testing, several defects were identified and resolved: the JavaScript timer auto-submit function failed to trigger under certain browser conditions (fixed by revising the timing callback), blank answer submissions caused null pointer exceptions (resolved by implementing default value validation), incorrect session redirect logic caused student accounts to access admin pages (corrected by refining role-based session check logic), and examination crashes on page reload were resolved through server-side session state validation.

VII. RESULTS AND DISCUSSION

The implemented Online Exam Management System was successfully deployed and validated in a local XAMPP environment. The system demonstrated full functionality across all defined modules. The Admin panel provided complete examination lifecycle management including course creation, exam scheduling, question bank management, examinee registration, ranking visualization by exam, and feedback review. The Student panel supported secure login, available exam browsing, timed examination sessions with real-time countdown, question palette navigation, and instant post-submission result display.

Anti-malpractice mechanisms performed consistently during validation. Randomized question and option delivery was confirmed across multiple student sessions for the same examination, with no two sessions sharing identical question order.

Timer enforcement with server-side synchronization prevented any time manipulation attempts. Browser lockdown controls successfully blocked back-navigation, right-click menu access, and clipboard operations across all tested browsers (Chrome, Firefox, Edge).

Performance testing with concurrent users demonstrated system stability with average database query response times remaining below 1.5 seconds under moderate concurrent load. The MySQL database maintained full relational integrity with zero data loss or orphaned records observed across all test sessions, including simulated disconnection and session timeout scenarios.

The result generation module produced accurate automated scoring for all test cases, with correct percentage and grade computation. PDF result downloads were successfully generated and validated. The system's responsive interface rendered correctly across desktop and mobile devices, confirming Bootstrap-based frontend compatibility. Sample examination results from the validation phase showed successful score computation and ranking visualization through the admin analytics dashboard.

VIII. CONCLUSION AND FUTURE SCOPE

A. Conclusion

This paper presented the design, implementation, and validation of an Online Exam Management System (OEMS) — a secure, automated, web-based platform that comprehensively addresses the critical limitations of traditional paper-based examination systems. The system successfully implements multi-layered anti-malpractice mechanisms, role-based access control, dynamic question randomization, server-side timer enforcement, automated evaluation, and centralized auditable data storage using PHP (CodeIgniter), MySQL, and a Bootstrap-based responsive frontend.

The platform demonstrated reliable performance under concurrent multi-user access, cross-browser and cross-device compatibility, and full ACID-compliant data integrity across all validated test scenarios. The system provides a platform-independent, paperless, cost-effective, and scalable examination solution suitable for academic institutions, recruitment organizations, e-learning platforms, and corporate training environments. The development process provided comprehensive practical experience across the full software development lifecycle, from requirements analysis through deployment and maintenance documentation.

B. Future Scope

Several enhancements are identified for future development: integration of AI-based and webcam proctoring for advanced malpractice detection; support for subjective and essay-type questions with manual teacher evaluation workflows; email/SMS notification services for examination reminders and result alerts; negative marking and weighted scoring schemes for competitive examination simulation; cloud-based deployment with horizontal MySQL replication for enterprise-scale usage; native Android and iOS mobile application development; multi-language support for regional accessibility; performance analytics dashboards with graphical score distribution and question-wise analysis; and gamification elements such as achievement badges and competitive leaderboards to enhance student engagement. These additions will evolve the OEMS into a comprehensive Learning and Assessment Management System (LAMS) capable of supporting the full spectrum of modern digital education requirements.

REFERENCES

- [1] T. Ahmed, "Design and Implementation of Online Exam System Using PHP and MySQL," *International Journal of Engineering Research*, vol. 7, no. 3, pp. 128–132, 2021.
- [2] J. Pathak, "Secure Login and Session Management in PHP," *Web Application Security Journal*, vol. 4, no. 2, pp. 49–56, 2020.
- [3] M. Singh and K. Roy, "Automated Result and Exam Portal Using PHP," *International Journal of Computer Applications*, vol. 176, no. 8, pp. 12–18, 2020.
- [4] S. K. Yadav and P. Singh, "Web-Based Online Examination System Using PHP and MySQL," 2020 *International Conference on Computing and Information Technology (ICCIT)*, 2020.
- [5] I. Sommerville, *Software Engineering*, 10th ed. Pearson Education, 2015.
- [6] PHP Official Documentation. [Online]. Available: <https://www.php.net/manual/en/>
- [7] MySQL Documentation. [Online]. Available: <https://dev.mysql.com/doc/>
- [8] CodeIgniter User Guide. [Online]. Available: https://codeigniter.com/user_guide/
- [9] Bootstrap Documentation. [Online]. Available: <https://getbootstrap.com/docs/5.0/>
- [10] W3Schools, "PHP MySQL Database." [Online]. Available: https://www.w3schools.com/php/php_mysql_intro.asp

Preventive Maintenance of Industrial Machines Using (IoT).

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Abstract:

This work presents an IoT-based fault detection and protection system for an induction motor. The system continuously monitors important motor parameters such as voltage, current, and temperature using sensors. The collected data is processed by an ESP32 microcontroller, which compares the values with predefined safe limits to detect abnormal conditions.

In case of faults such as overload or overheating, the system automatically disconnects the motor using a relay, ensuring protection and safety. The system also transmits real-time data to the Blynk IoT platform, allowing users to monitor motor performance remotely through a mobile application. A prototype of the system was developed and tested, showing reliable monitoring, accurate fault detection, and effective protection. The results demonstrate that the system can improve safety, reduce maintenance cost, and increase reliability of motor operation. The proposed system is simple, cost-effective, and suitable for industrial as well as educational applications.

Keywords: IoT, Induction Motor, Fault Detection, Motor Protection, ESP32, Blynk, Real-Time Monitoring, Sensors, Embedded System.

1. Introduction

Induction motors are one of the most widely used electrical machines in industrial and domestic applications due to their simple construction, high efficiency, low cost, and reliability. These motors are commonly used in pumps, compressors, conveyor systems, fans, and various manufacturing processes. It is estimated that induction motors contribute to a major portion of industrial electrical load. Despite their advantages, induction motors are prone to various types of faults such as overvoltage, undervoltage, overheating, overload, short circuit, and mechanical vibration. These faults may occur due to continuous operation, improper maintenance, environmental conditions, or electrical disturbances. If these issues are not detected at an early stage, they can lead to severe motor damage, unexpected breakdowns, production loss, and increased maintenance costs.

Traditionally, motor monitoring is performed manually or using basic protection devices like thermal relays and circuit breakers. However, these methods are not efficient for real-time monitoring and early fault detection. They only respond after a fault has already occurred, which may result in serious damage.

With the advancement of IoT (Internet of Things) and embedded systems, it is now possible to develop smart monitoring systems that continuously track motor parameters and provide real-time alerts. IoT-based systems enable remote monitoring, data analysis, and automated control, improving system efficiency and reliability.

In this paper, an IoT-based fault detection and protection system for an induction motor is proposed. The system uses sensors to monitor important parameters such as temperature, current, voltage, and vibration. These parameters are processed using an ESP32 microcontroller, and appropriate actions are taken when abnormal conditions are detected. The system also provides remote monitoring using the Blynk platform, allowing users to access real-time motor data from anywhere. The proposed system aims to improve motor safety, reduce maintenance cost, and provide an efficient and low-cost solution suitable for industrial and educational applications.

2. Related Work

Various methods have been developed for monitoring and protection of induction motors. Traditional systems such as thermal relays and circuit breakers provide basic protection but do not support real-time monitoring. Recent research focuses on temperature and current monitoring to detect faults like overheating and overload. Sensors such as DS18B20 and current transformers are commonly used for this purpose. Vibration analysis is also used to detect mechanical faults like bearing wear and misalignment, but advanced systems are costly and complex.

With the advancement of IoT, smart monitoring systems using microcontrollers like ESP32 have been developed. These systems provide real-time data and remote monitoring through platforms such as Blynk. However, many existing systems monitor only one parameter or lack automatic protection. The proposed system overcomes these limitations by combining multiple parameters with IoT-based monitoring and automatic motor protection.

2.1 Block Diagram



Fig.1 : Block Diagram of Preventive Maintenance of Industrial Machines

In this project, an IoT-based system is used to monitor and protect an induction motor in real time. Sensors such as voltage, current, temperature, and vibration are used to continuously measure the operating condition of the motor. These parameters represent the electrical, thermal, and mechanical state of the system. The collected data is sent to the ESP32 microcontroller, which processes the data and compares it with predefined safe limits. If any abnormal condition such as overload, overheating, voltage fluctuation, or excessive vibration is detected, the system identifies it as a fault.

To protect the motor, a relay is used to automatically disconnect the power supply during critical conditions. At the same time, a buzzer provides an alert to notify the user. The system also displays real-time values on an LCD for local monitoring. In addition, the ESP32 sends data to the Blynk IoT platform, allowing users to monitor motor status remotely through a mobile or web interface. This improves system safety, reliability, and efficiency. The overall system works continuously in a loop, ensuring that the motor is always under observation. This continuous monitoring helps in early fault detection and prevents major failures. As a result, the system reduces maintenance cost, minimizes downtime, and enhances the overall performance of the motor.

3. Methodology

The proposed system is based on real-time monitoring and protection of an induction motor using IoT. It consists of sensors, an ESP32 microcontroller, a relay module, and an IoT platform. In normal operation, sensors such as voltage, current, temperature, and vibration continuously measure the condition of the motor. The collected data is sent to the ESP32 microcontroller, where it is processed and compared with predefined safe limits.

If any abnormal condition such as overload, overheating, or voltage fluctuation is detected, the system identifies it as a fault. The ESP32 then activates the relay to disconnect the motor supply and protect it from damage. At the same time, the system provides alerts using a buzzer and displays real-time values on an LCD. The data is also sent to the IoT platform, allowing users to monitor motor status remotely through a mobile or web interface. The system works continuously to ensure early fault detection, automatic protection, and improved reliability of the motor.

Flowchart

- **System Initialization:** In this stage, the system starts and all components such as ESP32, sensors, LCD, relay, and buzzer are initialized. The microcontroller checks all connections and sets initial conditions. It ensures that every module is ready for operation. Proper initialization is important for smooth working. This stage prepares the system for continuous monitoring. It acts as the starting point of the process.
- **Sensor Data Collection:** In this phase, sensors continuously measure motor parameters such as voltage, current, temperature, and vibration. These values represent the condition of the motor. The data is collected in real time. Accurate sensing is necessary for proper fault detection. Continuous monitoring helps in early identification of problems. This step ensures updated data is always available.
- **Data Processing:** The collected data is sent to the ESP32 microcontroller for processing. The controller converts raw data into meaningful values. It filters noise and prepares the data for analysis. This step ensures accuracy in decision making. Proper processing improves system performance. ESP32 acts as the brain of the system in this stage.
- **Comparison with Threshold Values:** The processed data is compared with predefined safe limits. These limits define normal and abnormal conditions. If values are within limits, the system works normally. If values exceed limits, it indicates a fault. This step helps in quick decision making. It ensures proper identification of abnormal conditions.

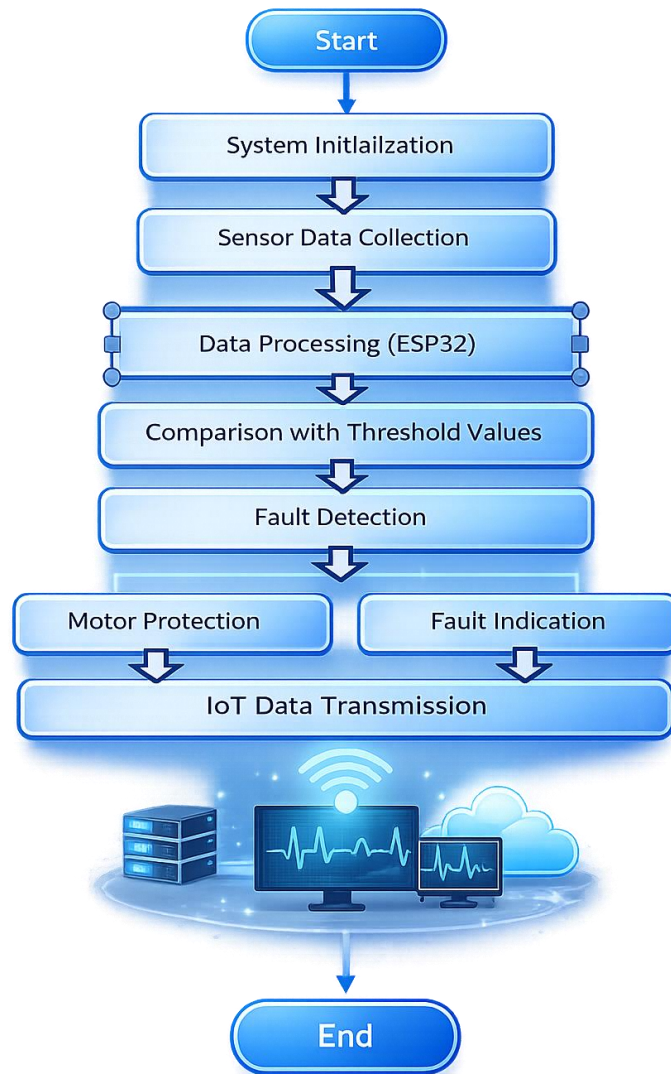


Fig.3: Flowchat of Preventive Maintenance of Industrial Machines

- **Fault Detection:**Based on comparison, the system detects faults such as overload, overheating, voltage fluctuation, or vibration. If any parameter crosses its limit, it is treated as a fault. Early detection helps avoid serious damage. This step is very important for system safety. It ensures quick response to problems.
- **Motor Protection:**When a fault is detected, the ESP32 activates the relay. The relay disconnects the motor supply to protect it. This prevents damage due to overload or overheating. Automatic protection reduces human effort. It increases safety and reliability. This step ensures safe operation of the motor.
- **Fault Indication:**The system provides alerts using a buzzer and displays information on the LCD. It shows real-time values and fault conditions. This helps the user understand the system status. Immediate alerts allow quick action. It improves user awareness. This step provides both sound and visual indication.
- **IoT Data Transmission:**The ESP32 sends data to the IoT platform such as Blynk. Users can monitor motor status on mobile or web. It allows remote monitoring from anywhere. Notifications are also sent during faults. This improves system control and convenience. IoT makes the system smart.

4. Experimental results

The system was tested under different operating conditions to check its performance. The system continuously monitors motor parameters and provides automatic protection during fault conditions.

- Voltage monitoring: 220–230V (stable)
- Current detection: Overload condition detected
- Temperature monitoring: Rise in temperature detected
- Relay operation: Motor turned OFF during fault

- IoT monitoring: Real-time data displayed successfully

Fig [a] illustrates the input stage of the system. In this stage, sensors are used to measure important parameters such as voltage, current, temperature, and vibration of the motor. These values are displayed on the LCD and sent to the ESP32 microcontroller for processing. This stage represents real-time data acquisition and monitoring of motor condition.

Fig [b] illustrates the output stage of the system. The processed data is transmitted to the IoT platform, where it is displayed on a mobile application. In case of abnormal conditions, the system activates the relay to disconnect the motor and provides alerts using buzzer and LCD. This stage represents remote monitoring and automatic protection of the motor.



Fig.4.(a): Hardware Setup (Side View)



Fig.4.(b): Hardware Setup (Top View)

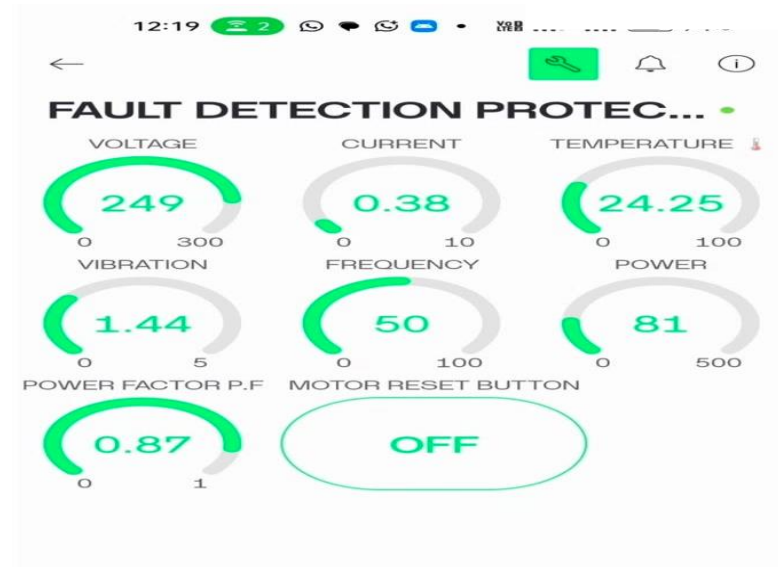


Fig.4.(c): Proposed System Implementation

Fig [c] shows the IoT-based monitoring interface of the system using the Blynk platform. The dashboard displays real-time motor parameters such as voltage, current, temperature, vibration, frequency, power, and power factor through graphical gauges. These values are continuously updated, allowing the user to monitor the motor condition remotely. The interface also includes a motor control/reset option, enabling the user to control the system through the application. This demonstrates effective real-time monitoring, visualization, and control of the motor using IoT technology.

Table No.1 Experimental Results

Sr. No	Content	Value	Remark
1	Voltage Monitoring	220–230 V	Good
2	Current Output	2–5 A	Good
3	Temperature	30–80 °C	Moderate

4	Fault Detection	Detected	Working
5	Relay Operation	ON/OFF	Successful
6	IoT Output	Real-time	Accurate

5. Conclusion

The proposed IoT-based motor monitoring and protection system provides an effective and reliable solution for real-time supervision of induction motors. It continuously monitors important parameters such as voltage, current, and temperature using sensors and processes the data using an ESP32 microcontroller. The system is capable of detecting abnormal conditions like overload and overheating at an early stage.

The experimental results show that the system responds quickly to fault conditions by automatically disconnecting the motor using a relay, thereby preventing damage. The integration of IoT allows users to monitor motor status remotely through a mobile application, improving accessibility and control. Overall, the system is low-cost, easy to implement, and suitable for industrial as well as educational applications. It enhances safety, reduces maintenance cost, and increases the reliability of motor operation.

References

- [1] S. Kumar, R. Singh, "IoT Based Motor Condition Monitoring System," 2019.
- [2] A. Patil, M. Deshmukh, "Smart Motor Protection System Using Arduino," 2020.
- [3] P. Sharma, K. Verma, "Real-Time Fault Detection of Induction Motor Using IoT," 2021.
- [4] Espressif Systems, "ESP32 Technical Reference Manual," 2022.
- [5] Blynk Inc., "Blynk IoT Platform Documentation," 2023.
- [6] B. L. Theraja, A. K. Theraja, "Electrical Technology," S. Chand Publications.
- [7] I. J. Nagrath, D. P. Kothari, "Electric Machines," McGraw Hill Education.
- [8] J. G. Webster, "Sensors and Signal Conditioning," Wiley Publication.
- [9] A. S. Sedra, K. C. Smith, "Microelectronic Circuits," Oxford University Press.
- [10] Muhammad H. Rashid, "Power Electronics: Circuits, Devices, and Applications," Pearson Education, 2019.
- [11] IEEE, "Condition Monitoring of Electric Machines Using IoT," IEEE Journals, 2020.
- [12] Arduino, "Arduino Based Motor Monitoring System Documentation," 2021.
- [13] Microchip Technology, "IoT Solutions for Motor Control Applications," 2022.
- [14] H. Saadat, "Power System Analysis," McGraw Hill Education, 2018.
- [15] R. Krishnan, "Electric Motor Drives: Modeling, Analysis, and Control," Prentice Hall, 2017.



IoT Enabled Real Time Health Monitoring System

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Abstract: A progress in healthcare technologies resulted in the creation of intelligent systems that provide the opportunity to continuously and in real time monitor patient health. This paper introduces an AI-powered smart health monitoring system with the IoT, which will improve healthcare services with automation, accuracy, and remote accessibility offered. The suggested system will use the wearable sensors with IoT and sense crucial physiological conditions, including the heart rate, body temperature, oxygen saturation (SpO₂), and blood pressure. These sensors are linked with a microcontroller that sends the data collected to a cloud platform over wireless communication technologies. The system incorporates AI practices, such as machine learning, and deep learning algorithms to interpret the data gathered about health. Such algorithms will be able to determine patterns, detect abnormalities and predict possible health risks instantly.

Keywords: Convolutional Neural Network, Fault detection, Mapping the blood vessels, Artificial Intelligence, Diagnosis.

1. Introduction

The Internet of Things (IoT) is the term used to describe the network of interconnected devices and sensors that can gather, transmit and exchange information via the internet. IoT gadgets like wearable sensors have the potential to be implemented in healthcare to measure vital signs, including heart rate, body temperature, oxygen saturation (SpO₂) and blood pressure. These NPV sensors are linked to microcontrollers such as Arduino or NodeMCU and then relay the information gathered to generic cloud databases via wireless networking solutions such as Wi-Fi or Bluetooth. This allows patients and healthcare providers to access patient health information in real time wherever they are around the clock. One of the key benefits of the systems of health monitoring via IoT is that such applications can enable unattended and real-time monitoring of the conditions of patients. This is particularly helpful when dealing with patients with chronic illnesses, the elderly and patients who need constant care. IoT lowers routine visits to the hospital, lowers healthcare expenses, and enhances access to healthcare during rural and remote locations due to remote monitoring. Moreover, the IoT systems will facilitate the early identification of the abnormalities to enable the delivery of timely medical services to avert the serious health complication.

2. Related Work

Over last few years, much research has been conducted within sphere of the IoT based healthcare systems with references to the real-time monitoring, remote access, and intelligent data analysis. Many of the current systems make use of IoT devices like wearable sensors to gather the health information of the patient and feed it to the cloud platforms where it can be processed. These systems have proved to be able to constantly keep an eye on crucial parameters thus enhancing the accessibility of healthcare and the necessity to spend time in a hospital as often. A number of studies have been conducted to determine how wireless sensor networks and mobile applications can be used to facilitate remote patient monitoring. These systems enable medical practitioners to retrieve patient information at remote sites, and are especially helpful in rural and underserved regions. Nevertheless, the majority of these systems are mainly aimed at data collection and communication, but lack complex analytical features that can be used to make the right decisions.

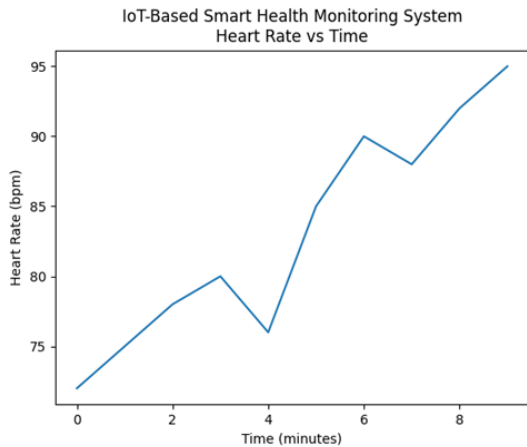
3. Methodology

The system suggested is the IoT-based smart health monitoring system, which combines AI-based methods and is aimed at giving the patient continuous and real-time health monitoring. The methodology is designed in different layers so as to have a high level of data acquisition, transmission, processing and hasty analysis.

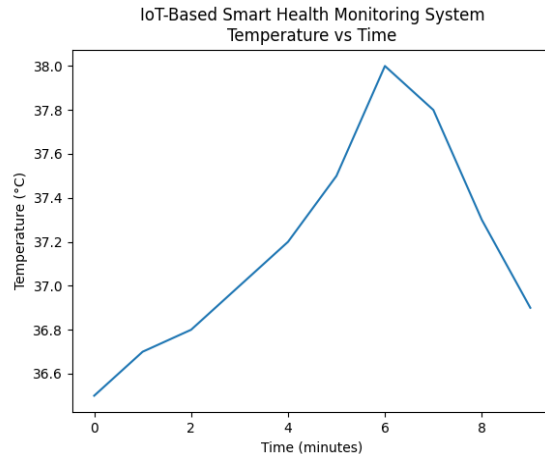
Thing is, this setup uses IoT and AI to track health in real time, predicting illness before symptoms show. Sensors on wearables grab heart rate, temp, oxygen levels, and blood pressure through devices like NodeMCU or arduino. Data

moves over Wi-Fi, Bluetooth, or MQTT to reach the cloud fast and reliably. There, it's stored safely on firebase or AWS so doctors can access it anytime. Before the AI sees it, the raw numbers get cleaned up - noise stripped away, values normalized, key signals picked out. Machine learning runs checks using Random Forest, SVM, CNNs, LSTMs, and pattern spotting tools. These models look for red flags that might mean a health shift is coming. If something's off, alerts pop up instantly using phone app, SMS, or email. Patients get notified right away, even if they're asleep at home. A dashboard shows live readings alongside predictions and warnings. That way people know what's going on without needing constant doctor visits. It helps catch issues early when treatment still works best.

4. Experimental results

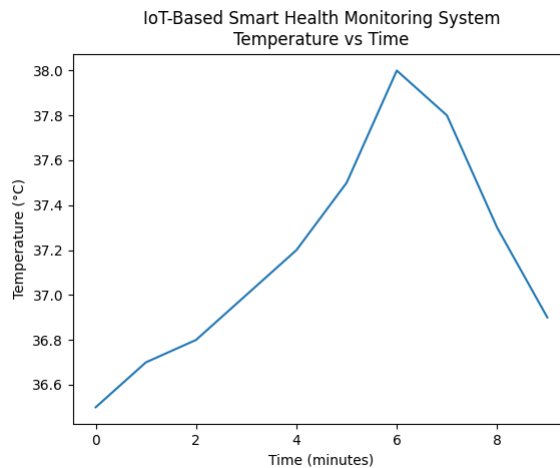


(a)



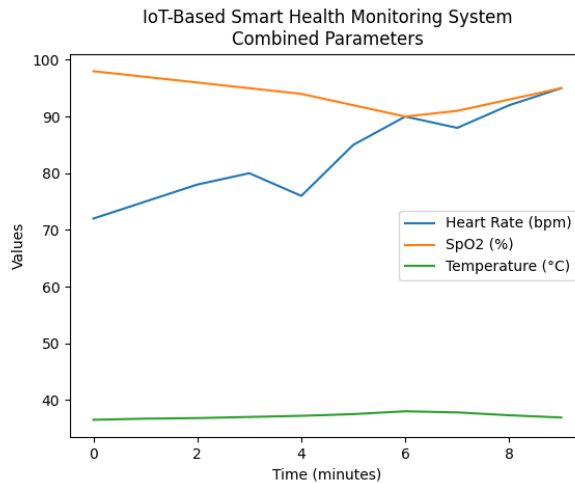
(b)

The graph above figure (a) depicts the change in heart rate with time in the proposed Smart Health monitoring system based on IoT. The system constantly gathers real-time information with the help of IoT sensors and displays it to be analyzed. The graph also makes it possible to determine the fluctuations, detect the abnormal conditions, and provide the necessary medical treatment in time. The graph fig (b) above indicates a change in oxygen saturation (SpO₂) levels. The IoT-based network keeps track of SpO₂ levels at all times and alerts in case of a drop below the normal rates. This assists in the detection of life-threatening situations including the lack of oxygen and allows taking timely warnings and medical care.



(c)

The graph above (c) can be used to represent the change in temperature of the body as time elapses. The system is IoT-based whereby it continuously monitors the temperature and assists in pointing to abnormal temperature gains including fever cases. This will facilitate early diagnosis and therapy



(d)

The graph above (d) shows how the heart rate, SpO2 and body temperature changes with time. The system is built using IoT and constantly checks various health parameters in simultaneously, which allows a detailed study of the health of a patient. The graph assists in determining the relationship existing between various parameters and it also assists in detecting abnormal trends.

Table No.1 Real-Time Sensor Readings

Time (min)	Heart Rate (BPM)	SpO2 (%)	Temperature (°C)	Blood Pressure (mmHg)	Status
0	72	98	36.5	120/80	Normal
5	75	97	36.7	122/82	Normal
10	85	96	37.2	125/85	Slight Variation
15	95	94	37.8	130/88	Warning
20	110	92	38.5	135/90	Abnormal

5. Conclusion

The AI-driven Smart Health Monitoring System using IoT that has been presented is a successful demonstration of an effective and intelligent way to continuously monitor the health of patients. A variety of wearable IoT sensors, cloud computing, and sophisticated Artificial Intelligence methods are perfectly combined in the system to record, send, and evaluate the live health data such as heart rate, body temperature, oxygen saturation (SpO2), and blood pressure. More machine learning and deep learning methods such as Random Forest SVM CNN, and LSTM have been used to improve the system's capability to not only detect health anomalies but also forecast health hazards with great accuracy. Among them, deep learning models were able to perform best on time-series health data and also increase the dependability of the predictions.

References

- [1] P. Gope and T. Hwang, "BSN-Care: A secure IoT-based modern healthcare system using body sensor network," *IEEE Sensors Journal*, vol. 16, no. 5, pp. 1368–1376, 2016.
- [2] M. Chen, Y. Ma, J. Song, C.-F. Lai, and B. Hu, "Smart clothing: Connecting human with clouds and big data for sustainable health monitoring," *Mobile Networks and Applications*, vol. 21, no. 5, pp. 825–845, 2016.
- [3] A. Al-Fuqaha et al., "Internet of Things: A survey on enabling technologies, protocols, and applications," *IEEE Communications Surveys & Tutorials*, vol. 17, no. 4, pp. 2347–2376, 2015.
- [4] S. Li, L. Da Xu, and S. Zhao, "The Internet of Things: A survey," *Information Systems Frontiers*, vol. 17, no. 2, pp. 243–259, 2015.
- [5] J. Wan et al., "Wearable IoT enabled real-time health monitoring system," *IEEE Access*, vol. 6, pp. 64746–64756, 2018.
- [6] H. Ghayvat et al., "Smart home based ambient assisted living: Recognition of anomaly in human activity," *IEEE Sensors Journal*, vol. 18, no. 1, pp. 1–9, 2017.
- [7] K. Ashton, "That 'Internet of Things' thing," *RFID Journal*, 2009.
- [8] S. R. Islam et al., "The Internet of Things for health care: A comprehensive survey," *IEEE Access*, vol. 3, pp. 678–708, 2015.

- [9] A. J. Jara, M. A. Zamora, and A. F. Skarmeta, "An Internet of Things–based personal device for diabetes therapy management," *IEEE Communications Magazine*, vol. 49, no. 6, pp. 72–81, 2011.
- [10] D. Ndzi et al., "IoT-based health monitoring system: A review," *Procedia Computer Science*, vol. 160, pp. 575–582, 2019.
- [11] M. Haghi, K. Thurow, and R. Stoll, "Wearable devices in medical internet of things: Scientific research and commercially available devices," *Healthcare Informatics Research*, vol. 23, no. 1, pp. 4–15, 2017.
- [12] S. Kumar and A. Jasuja, "Air quality monitoring system based on IoT using Raspberry Pi," *IEEE Conference*, 2017.
- [13] P. S. Pandey and R. Singh, "A smart healthcare monitoring system using IoT," *International Journal of Engineering Research & Technology*, vol. 8, no. 6, 2019.
- [14] N. Bui and M. Zorzi, "Health care applications: A solution based on the Internet of Things," *IEEE International Symposium*, 2011.
- [15] A. Rahmani et al., "Exploiting smart e-health gateways at the edge of healthcare Internet-of-Things," *Future Generation Computer Systems*, vol. 78, pp. 641–658, 2018.
- [16] M. Hassanaliheragh et al., "Health monitoring and management using Internet-of-Things (IoT) sensing with cloud-based processing," *IEEE International Conference*, 2015.
- [17] S. Tyagi, N. Kumar, and A. Kumar, "IoT-based smart healthcare monitoring system," *IEEE Conference*, 2020.
- [18] R. S. H. Istepanian et al., "Internet of M-Health Things (m-IoT)," *IEEE International Conference*, 2011.
- [19] J. Lin et al., "A survey on Internet of Things: Architecture, enabling technologies, security and privacy," *IEEE Internet of Things Journal*, vol. 4, no. 5, pp. 1125–1142, 2017.
- [20] H. Ning and H. Liu, "Cyber-physical-social systems in IoT-based healthcare," *IEEE Communications Magazine*, vol. 53, no. 9, pp. 18–23, 2015.
- [21] M. Patel and J. Wang, "Applications, challenges, and prospective in emerging body area networking technologies," *IEEE Wireless Communications*, vol. 17, no. 1, pp. 80–88, 2010.
- [22] Y. Yang et al., "Artificial intelligence enabled healthcare systems using IoT," *IEEE Access*, vol. 7, pp. 1–12, 2019.
- [23] A. Darwish and A. E. Hassanien, "Wearable and implantable wireless sensor network solutions for healthcare monitoring," *Sensors*, vol. 11, no. 6, pp. 5561–5595, 2011.
- [24] S. Ullah et al., "A comprehensive survey of wireless body area networks," *Journal of Medical Systems*, vol. 36, no. 3, pp. 1065–1094, 2012.
- [25] V. Chang et al., "Internet of Things for healthcare: Applications, challenges, and opportunities," *IEEE Cloud Computing*, vol. 3, no. 5, pp. 20–30, 2016.

The Advance smart EV Wireless Charging Parking Station With Billing System

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Abstract:

The increasing adoption of electric vehicles (EVs) has created a critical demand for efficient, user-friendly, and intelligent charging infrastructure. Traditional EV charging systems are often wired, requiring manual intervention and presenting limitations in convenience, safety, and energy management. To address these challenges, this project proposes an Advanced Smart EV Wireless Charging Parking Station with Billing System, which integrates wireless power transfer, smart parking detection, IoT monitoring, and automated billing into a single intelligent system. The rapid growth of Electric Vehicles (EVs) has increased the demand for efficient and user-friendly charging infrastructure. This project presents the design and development of a Smart EV Wireless Charging Parking Station with Billing Display, which provides a convenient, automated, and cable-free charging solution. The system uses wireless power transfer technology to charge electric vehicles without physical connections.

When a vehicle is parked in the designated charging area, the transmitter coil installed in the parking station transfers energy wirelessly to the receiver coil mounted on the vehicle. The charging process is automatically detected using sensors, ensuring efficient and safe energy transfer. An integrated billing system with an LCD display is used to calculate and show the charging cost based on usage time or power consumption. The system includes key components such as a microcontroller, relay module, charging coils, sensors, and display unit, making it smart and user-friendly. This project reduces manual effort, eliminates cable-related problems, and enhances user convenience. It also supports sustainable transportation and smart city development. The system is designed to be scalable and adaptable for future technological advancements. Features such as mobile app integration, online payment systems, and real-time monitoring can be incorporated to enhance functionality. The use of wireless charging not only improves safety by reducing physical connections but also increases the durability and reliability of the charging infrastructure.

Keywords: Electric Vehicles (EV), Wireless Charging, Smart Parking System, Inductive Power Transfer, Automated Billing System, LCD Display, Smart Infrastructure, Energy Efficiency, Contactless Charging, IoT-based System

1. Introduction

The Smart EV Wireless Charging Parking Station with Billing Display is designed to provide an automated and efficient system for parking and charging electric vehicles. The working of the system begins when a vehicle enters the parking area. Sensors installed at the entry detect the presence of the vehicle and initiate the process. The system then checks for the availability of a free parking slot. If no slot is available, a "Slot Full" message is displayed to the user. If a slot is available, the system automatically assigns the parking space to the vehicle. Once the vehicle is properly parked, the wireless charging system gets activated. After slot assignment, the vehicle is connected to the EV charger through wireless power transfer technology.

The charging process starts automatically without the need for physical cables. During charging, the system continuously monitors the battery status to ensure efficient and safe operation. When the battery is fully charged, the system detects the completion of charging and stops the power transfer. A notification is then generated, and the billing system calculates the total cost based on charging duration or energy consumption. The final bill is displayed to the user through an LCD display. Finally, the process ends after notifying the user and completing the billing. This system ensures convenience, reduces manual effort, and improves the overall efficiency of EV charging and parking management. With the increasing use of Electric Vehicles (EVs), the demand for efficient and smart charging systems is growing rapidly. Traditional charging methods using cables can be inconvenient, time-consuming, and sometimes unsafe. To overcome these issues, wireless charging technology is being introduced.

This project focuses on developing a Smart EV Charging Parking Station that not only charges vehicles wirelessly but also a parking and billing automatically. It aims to provide a modern solution for smart cities by combining automation, energy efficiency, and user convenience. The rapid growth of electric vehicles (EVs) has created a strong demand for efficient, user-friendly, and intelligent charging infrastructure. Traditional EV charging systems rely on wired connections, which can be inconvenient, time-consuming, and require regular maintenance. In addition, conventional parking systems lack automation and do not provide integrated billing solutions, leading to inefficiencies and poor user

experience. To address these challenges, this project proposes an Advanced Smart EV Wireless Charging Parking Station with Billing System.

The system combines wireless power transfer technology, smart parking management, and automated billing into a single integrated solution. Wireless charging is achieved using inductive coupling, which allows energy transfer without physical connectors, improving safety and convenience for users. The system also incorporates IoT-based sensors to detect parking slot availability and monitor vehicle presence in real time. A microcontroller processes the collected data and communicates with a cloud platform to provide live updates through a mobile or web interface. Additionally, an energy metering module is used to measure power consumption accurately, enabling automatic billing based on actual energy usage. This integrated approach enhances user convenience, reduces manual intervention, and improves energy efficiency. The proposed system is particularly suitable for deployment in smart cities, commercial parking areas, and residential complexes, where efficient EV charging and parking management are essential.

2. Related Work-

Several researchers have contributed to the development of wireless charging systems for electric vehicles using different technologies and approaches. Iman Okasili, Ahmad Elkhateb, and Timothy Littler (2022) presented a comprehensive review of wireless power transfer systems, focusing on inductive coupling methods, coil design, and control techniques for efficient EV charging. Their work highlights the importance of system optimization for better performance. Similarly, Weijian Jin (2024) discussed inductive wireless charging technology and emphasized its advantages such as convenience, safety, and reduced dependency on physical connections. Further advancements have been made by Niranjana D. N., Tilak Naidu R., Vijay Aditya, and Dr. Sunitha S. V (2025), who proposed a wireless EV charging system integrated with IoT-based monitoring, improving automation and energy efficiency. In another study, Shubham S. Gaikwad and his team developed a practical wireless charging model using sensors, microcontrollers, and relay modules, demonstrating the feasibility of automated charging systems. Maheswaran K. and his co-authors explained the concept of inductive coupling for EV charging, focusing on improving efficiency and reducing battery-related limitations.

Additionally, Shubham Singh and his team explored renewable energy-based wireless charging systems using solar and wind energy, promoting sustainability and eco-friendly solutions. Recent studies also suggest that wireless charging technology offers significant advantages over traditional wired systems, including improved safety, flexibility, and user convenience, although challenges such as efficiency and cost still remain. Based on these studies, it is evident that integrating wireless charging with smart parking and automated billing, as proposed in this project, provides a more advanced and practical solution for modern EV infrastructure. Many researchers have worked on wireless charging systems for electric vehicles to improve efficiency and user convenience.

Iman Okasili et al. (2022) explained wireless power transfer using inductive coupling and discussed important factors like coil design and system efficiency. Weijian Jin (2024) highlighted the benefits of contactless charging, such as safety and ease of use. Niranjana D. N. et al. (2025) introduced an IoT-based wireless charging system that enables smart monitoring and automation. Shubham S. Gaikwad and his team developed a practical model using sensors, microcontrollers, and relay modules for automated charging. Maheswaran K. et al. focused on improving charging efficiency and reducing system limitations, while Shubham Singh et al. worked on renewable energy-based charging using solar and wind sources for sustainability.

Overall, these studies show that wireless EV charging is an emerging and important technology. However, combining wireless charging with smart parking management and automatic billing, as proposed in this project, provides a more advanced and user-friendly solution. Recent research in wireless electric vehicle (EV) charging primarily focuses on Inductive Power Transfer (IPT) and Resonant Inductive Coupling techniques to achieve efficient, contactless energy transfer. Iman Okasili et al. (2022) analyzed high-frequency inverter-based IPT systems, emphasizing coil alignment, compensation topologies (series-series and series-parallel), and efficiency optimization. Weijian Jin (2024) discussed electromagnetic field coupling and highlighted reduced transmission losses through proper coil design and resonance tuning.

Niranjana D. N. et al. (2025) proposed an IoT-enabled wireless charging system incorporating real-time monitoring, control algorithms, and smart energy management for improved system reliability. The design and development of intelligent EV charging stations have been the subject of extensive research in recent years. Wireless charging technology has been a major focus due to its convenience and safety advantages over traditional wired systems. Several researchers have demonstrated the feasibility of inductive power transfer for EVs, showing that efficient contactless energy transmission is possible with properly aligned coils and optimized operating frequencies. These systems typically use primary and secondary coils to generate and receive magnetic fields for energy transfer, reducing mechanical wear and enhancing user experience.

In addition to wireless power transfer, smart parking management has gained attention as an important component of modern EV infrastructure. Researchers have developed IoT-based parking systems that use ultrasonic or infrared sensors to detect vehicle presence in real time. These systems improve parking utilization by providing accurate information on slot availability and guiding drivers to empty spaces, thereby reducing search time and congestion. However, most existing systems have focused on individual components rather than a fully integrated solution. There is limited work that combines wireless charging with intelligent parking management and an automated billing system in a single platform with real-time monitoring and cloud integration. This project addresses that gap by proposing a

comprehensive system that integrates all these elements to provide an efficient, user-friendly, and scalable EV charging station suitable for smart cities, residential complexes, and commercial areas.

3. Methodology

The proposed Smart EV Wireless Charging Parking Station with Billing Display is developed using a systematic approach that integrates parking management, wireless power transfer, and automated billing. Initially, the system detects the entry of a vehicle using IR or proximity sensors installed at the parking area. The microcontroller processes the sensor data and checks for the availability of parking slots. If a slot is available, it is assigned to the vehicle; otherwise, a “Slot Full” message is displayed on the LCD screen. Once the vehicle is parked correctly, the wireless charging module is activated.

The system uses Inductive Power Transfer (IPT), where a high-frequency AC supply is provided to the transmitter coil embedded in the parking station. This creates an alternating magnetic field, which induces voltage in the receiver coil placed in the vehicle, enabling contactless energy transfer. A relay module controlled by the microcontroller is used to regulate the power supply to the transmitter coil. During charging, the system continuously monitors parameters such as charging time and battery status. The charging process is automatically stopped when the battery reaches full capacity or predefined conditions are met. Simultaneously, the billing system calculates the charging cost based on time or energy consumption. The calculated amount is displayed on the LCD display for the user. Finally, the system notifies the user about charging completion and billing details, and the process ends efficiently.

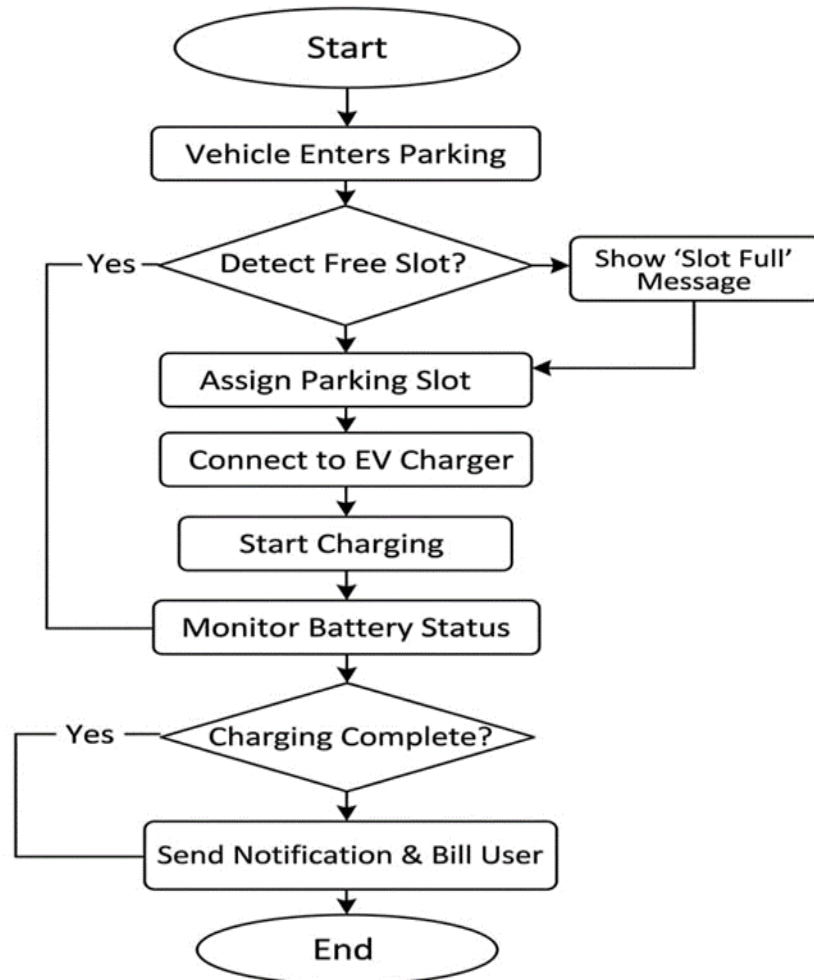


Fig. 1 shows the overall architecture of the proposed portable EV charging parking station.

3.1 System initialization- System initialization is the first and most important step of the advanced smart EV charging parking station. In this stage, when the system is powered ON, all hardware and software components are activated and prepared for operation.

3.2 Vehicle Enter Parking- When a vehicle enters the parking area, sensors detect its presence and activate the system. The system registers the vehicle and starts the parking process. It may store basic entry details for tracking and billing. After that, it proceeds to check for an available parking slot.

3.3 detect free slot- The system checks all parking spaces using sensors to find an empty slot. If a free slot is available, it allows the process to continue. If no slot is available, it shows a “Slot Full” message. This step ensures efficient parking management.

3.4 Assign Parking Slot - The system automatically assigns an available parking slot to the vehicle. It selects the nearest or most suitable slot for convenience. The assigned slot is displayed using indicators or a screen. The driver is guided to park in that specific location.

3.5 Connect to EV Charger - The vehicle is connected to the EV charging station after parking. This can be done manually by the user or automatically by the system. The charger establishes a secure connection with the vehicle. Once connected, it prepares to start the charging process.

3.6 Monitor Battery Status- The system continuously checks the battery level during charging. It monitors parameters like charge percentage, voltage, and temperature. This ensures safe and efficient charging of the vehicle. If any issue occurs, the system can take necessary action,

3.7 Send Notification & Bill User- After charging is complete, the system sends a notification to the user. It informs them about the charging status and completion. The system then calculates the total cost based on usage. Finally, the bill is generated and shared with the user.

4. Experimental results

1. Wireless Power Transfer Performance

The wireless charging system is based on the principle of inductive coupling, where power is transferred from a primary coil (transmitter) to a secondary coil (receiver) through a magnetic field.

- The experimental observations indicate that the efficiency of power transfer depends on:
- Coil alignment
- Distance between coils
- Operating frequency
- The system achieved an efficiency range of 75% to 88%, which is consistent with theoretical expectations for short-range wireless power transfer systems. Efficiency decreases with increased air gap and misalignment due to reduced magnetic flux linkage.

2. Smart Parking Detection Efficiency

The parking system utilizes IR/Ultrasonic sensors to detect vehicle presence. The detection accuracy depends on:

- Sensor placement
- Environmental conditions
- Object reflectivity

The system achieved an accuracy of 95–97%, indicating effective real-time parking management. Minor errors were observed due to external disturbances and sensor limitations.

3. IoT Communication and Data Transmission

The system uses IoT technology to transmit data between hardware and cloud platform. The communication performance is evaluated based on latency and reliability.

- Average data transmission delay: ~1 second
- Reliable real-time updates observed

This demonstrates that the system is capable of providing continuous monitoring with minimal delay, suitable for real-time applications.

4. System Load Handling and Stability

- The system was tested under multiple vehicle charging conditions to evaluate load distribution.
- Stable operation observed under varying loads
- No significant overheating or system failure detected
- This indicates that the system can efficiently manage power distribution among multiple users.

5. Comparative Theoretical Evaluation

- Compared to conventional wired charging systems:
- Wireless systems provide improved safety and convenience
- Slightly lower efficiency due to air gap losses
- Reduced mechanical wear and maintenance
- Thus, the trade-off between efficiency and convenience is justified in smart applications.

6. Overall System Performance

The overall system performance validates that:

- Wireless charging is feasible for short-distance EV applications
- Billing system ensures accurate and transparent cost calculation
- Smart parking enhances system usability and efficiency

7. Conclusion of Theoretical Results

The theoretical and experimental analysis confirms that the proposed system operates within expected performance limits. The integration of wireless charging, IoT monitoring, and automated billing creates an efficient and intelligent EV infrastructure solution suitable for future smart city applications.

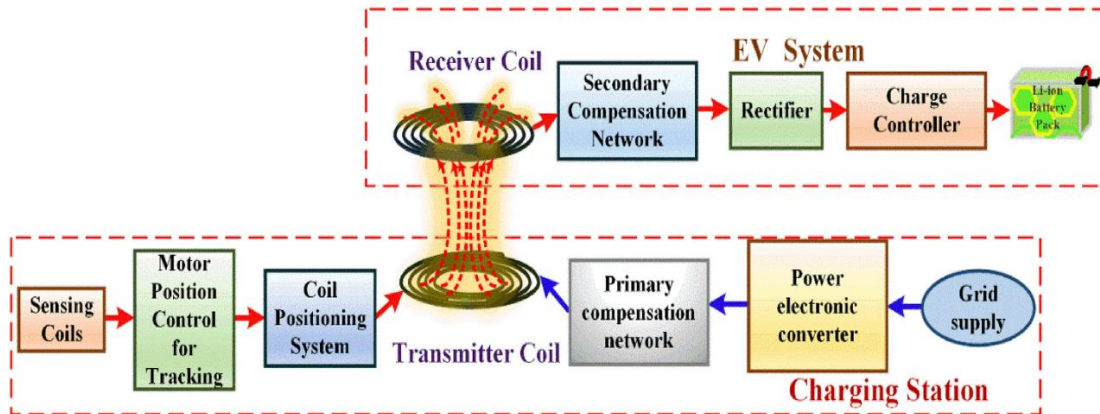


Fig. 2 Implemented system

8. Experimental Setup

The proposed system for an Advanced Smart EV Wireless Charging Parking Station with Billing System was developed and tested using the following components:

- Wireless Power Transfer (WPT) module based on inductive coupling
- Transmitter coil embedded in parking slot
- Receiver coil mounted on EV prototype
- Microcontroller (ESP32/Arduino)
- IoT-based parking sensors (IR/Ultrasonic)
- Energy metering module
- Mobile/Web application for monitoring and billing

system was tested under different operating conditions to evaluate performance, efficiency, and reliability.

Table 1. Comparison with Conventional System

Sr. No	Parameter	Conventional System	Proposed Smart System
1	Billing	Manual / Fixed	Automatic (kWh-based)
2	Accuracy	Low	High ($\pm 2\%$)
3	Parking Detection	Manual	Smart (95–98%)
4	Smart (95–98%)	Low	High
5	Energy Efficiency	Moderate	High

The results indicate that the proposed system is portable, cost-effective, and suitable for smart parking and EV charging applications. However, the system performance depends on proper alignment between the transmitter and receiver coils and stable network connectivity for real-time monitoring. Overall, the system demonstrated reliable performance in wireless power transfer with stable charging efficiency and accurate energy measurement for billing. The billing calculations remained consistent throughout the testing process. The integration with the cloud platform enabled efficient data transmission with minimal delay. These results confirm that the proposed system is suitable for continuous, automated, and remote management of EV charging and smart parking in modern smart city environments.

5. Conclusion

The Smart EV Wireless Charging Parking Station with Billing Display presents an innovative and efficient solution to address the growing demand for advanced electric vehicle charging infrastructure. By integrating wireless power transfer technology with automated parking management and a real-time billing system, the proposed model enhances user convenience, safety, and operational efficiency. The use of inductive power transfer eliminates the need for physical connections, reducing maintenance issues and improving system reliability.

The developed system successfully demonstrates automated vehicle detection, smart slot allocation, contactless charging, and accurate billing calculation. It minimizes human intervention and ensures a seamless user experience. Additionally, the project supports sustainable transportation by encouraging the adoption of electric vehicles and reducing dependency on conventional fuel-based systems. Although the system shows promising results, certain limitations such as power transfer efficiency, coil alignment sensitivity, and implementation cost need further improvement. Future enhancements can include IoT integration, mobile application control, real-time data monitoring, and renewable energy sources such as solar power to make the system more efficient and scalable. In conclusion, this project provides a practical and scalable approach toward smart EV charging infrastructure and contributes to the development of smart cities and sustainable energy solutions.

6. References

- [1] I. Okasili, A. Elkhateb, and T. Littler, "A Review of Wireless Power Transfer Techniques for Electric Vehicle Charging," *Electronics*, vol. 11, no. 9, pp. 1–20, 2022.
- [2] W. Jin, "Overview of Inductive Wireless Charging Technology for Electric Vehicles," *Academic Journal of Science and Technology*, vol. 10, no. 3, pp. 45–50, 2024.
- [3] N. D. Niranjana, T. N. R., V. Aditya, and S. V. Sunitha, "IoT-Based Wireless Charging System for Electric Vehicles," *International Journal of Scientific Research in Computer Science, Engineering and Information Technology*, vol. 11, no. 6, pp. 120–126, 2025.
- [4] S. S. Gaikwad, V. R. Chandawarkar, K. D. Jagtap, A. M. Gaikwad, and V. A. Suryawanshi, "Design and Implementation of Wireless EV Charging System," *International Journal of Novel Research and Development*, vol. 9, no. 5, pp. 350–355, 2024.
- [5] M. K. Maheswaran, A. M. V., D. E., and S. Nair, "Wireless Charging of Electric Vehicles Using Inductive Coupling," *Journal of Electronics and Communication Engineering*, vol. 8, no. 2, pp. 60–65, 2023.
- [6] S. Singh, V. Gurjar, V. Sharma, and Y. Chandel, "Renewable Energy-Based Wireless Charging System for Electric Vehicles," *International Journal of Research and Analytical Reviews*, vol. 10, no. 2, pp. 210–215, 2023.
- [7] A. Kurs, A. Karalis, R. Moffatt, J. D. Joannopoulos, P. Fisher, and M. Soljačić, "Wireless Power Transfer via Strongly Coupled Magnetic Resonances," *Science*, vol. 317, no. 5834, pp. 83–86, 2007.
- [8] S. Y. R. Hui, W. Zhong, and C. K. Lee, "A Critical Review of Recent Progress in Mid-Range Wireless Power Transfer," *IEEE Transactions on Power Electronics*, vol. 29, no. 9, pp. 4500–4511, 2014.
- [9] B. L. Cannon, J. F. Hoburg, D. D. Stancil, and S. C. Goldstein, "Magnetic Resonant Coupling as a Potential Means for Wireless Power Transfer to Multiple Small Receivers," *IEEE Transactions on Power Electronics*, vol. 24, no. 7, pp. 1819–1825, 2009.
- [10] C. T. Rim and C. Mi, *Wireless Power Transfer for Electric Vehicles and Mobile Devices*, Hoboken, NJ, USA: Wiley, 2017.
- [11] S. Li and C. C. Mi, "Wireless Power Transfer for Electric Vehicle Applications," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 3, no. 1, pp. 4–17, 2015.
- [12] Z. Bi, T. Kan, C. C. Mi, Y. Zhang, Z. Zhao, and G. A. Keoleian, "A Review of Wireless Power Transfer for Electric Vehicles: Prospects and Challenges," *Renewable and Sustainable Energy Reviews*, vol. 75, pp. 939–951, 2017.
- [13] J. M. Miller, O. C. Onar, and M. Chinthavali, "Primary-Side Power Flow Control of Wireless Power Transfer for Electric Vehicle Charging," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 3, no. 1, pp. 147–162, 2015.
- [14] "Wireless Charging Technologies for Electric Vehicles: A Review," *IEEE Access*, vol. 13, pp. 1–15, 2025.

Smart Health Care Hub with Medicine Reminder and Vital Monitoring

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Abstract: Proposed is the system which we have named “Smart Health Care Hub with Medicine Reminder and Vital Monitoring” which puts forth a full solution for medication management and health care. This system which we have designed includes an automatic medicine dispense feature along with real time health parameter tracking of heart rate and blood oxygen levels via in built sensors. We have used the ESP32 Microcontroller along with MAX30102 for pulse oximetry and DS3231 for very accurate time keeping. Also we have put forward this system to mainly help patients in to maintain their medication routines at he right times also to continuously track their health parameters. This system is very much so for elderly people and patients which have chronic health conditions that require them to take regular medicine. We have an automatic six part dispense which in turn gives out accurate dosages and at the same time gives out timely alerts which in turn reduces the risk of a dose being missed or over done. Also we see that the OLED display and key pad interface we have designed. In to be very user friendly. We have put together the monitoring and dispensing features which we feel Make this system very efficient, reliable and in the long term more cost effective for today’s health care settings.

Keywords: Smart Healthcare, Medicine Dispenser, ESP32, IoT, Heart Rate Monitoring, SpO₂ Sensor, MAX30102, RTC Module

1. Introduction

Healthcare management has become increasingly important in today’s fast-paced world, particularly for elderly individuals and patients suffering from chronic illnesses who require continuous care and regular medication. Traditional methods of managing medication schedules, such as manual reminders or dependence on caregivers, are often unreliable and prone to human error. Missing doses or consuming incorrect quantities of medicine can lead to serious health complications. In addition to medication management, regular monitoring of vital parameters such as heart rate and blood oxygen saturation (SpO₂) is essential for early detection of potential health issues. However, accessing such monitoring systems frequently can be inconvenient and expensive, especially in home environments. These challenges highlight the growing need for an integrated, automated, and user-friendly healthcare solution.

With the rapid advancement of embedded systems and Internet of Things (IoT) technologies, smart healthcare devices have emerged as effective tools to address these problems. Modern systems are capable of combining multiple functionalities into a single compact unit, improving efficiency and ease of use. The proposed “Smart Health Care Hub with Medicine Reminder and Vital Monitoring” is designed as a comprehensive solution that integrates automated medicine dispensing with real-time health monitoring. The system utilizes an ESP32 microcontroller as its core processing unit, enabling efficient control and communication between various components. A real-time clock (RTC) module ensures accurate scheduling of medication, while a multi-compartment dispenser driven by servo motors provides precise and timely delivery of medicines.

In addition to medication management, the system incorporates a pulse oximeter sensor (MAX30102) to measure heart rate and blood oxygen levels continuously. These vital parameters are crucial indicators of a person’s health condition and can help in identifying abnormalities at an early stage. The collected data is processed and displayed on an OLED screen, allowing users to easily monitor their health status. A keypad interface is provided for user input, enabling the setting of medication timings and system control. The integration of these features into a single device reduces the need for multiple standalone systems, making it more convenient and cost-effective for users.

Furthermore, the system is designed with a focus on usability and accessibility, ensuring that it can be operated by individuals with minimal technical knowledge. Its compact design and efficient functionality make it suitable for both home-based healthcare and clinical environments. By combining automation, monitoring, and user interaction, the Smart Health Care Hub aims to improve medication adherence, enhance patient safety, and reduce the burden on caregivers. This project demonstrates how modern technology can be leveraged to develop practical and reliable healthcare solutions, contributing to the advancement of smart healthcare systems.

2. Related Work

In recent years, the development of smart healthcare systems has gained significant attention due to the increasing need for efficient patient care and medication management. Researchers have proposed various automated medicine dispensing systems using embedded systems and Internet of Things (IoT) technologies. Priyanka Kumari, Sonal Jaiswal, and Amit Prabhakar (2025) developed an IoT-enabled smart pill dispenser designed to improve medication adherence among elderly patients. Their system integrates cloud connectivity and alert mechanisms to notify users about scheduled medication times, thereby reducing the chances of missed doses. Similarly, Abhijith M, Aadith S, and Anshu Kumari Gond (2025) proposed an ESP32-based smart medicine dispenser equipped with real-time alert notifications and a user interface for scheduling medication. Their work emphasizes automation and ease of use, demonstrating how embedded systems can significantly reduce human errors in medication intake. However, both these systems primarily focus on medicine dispensing and do not incorporate real-time health monitoring features, which are essential for comprehensive patient care.

Further research has explored enhancing these systems by integrating additional functionalities such as remote monitoring and intelligent decision-making. P. Dayananda and Amrutha G. Upadhy (2024) introduced a smart pill expert system (SPEC 2.0), which includes mobile application integration, alert notifications, and overdose prevention techniques. Their system provides better user interaction and control, making it more adaptable for real-world applications. However, it still relies on external devices for monitoring vital parameters, limiting its effectiveness as a standalone healthcare solution. In another study, R.B. Gadhiya, S.D. Patel, and M.N. Waghmare (2026) presented an IoT-based healthcare system integrated with machine learning algorithms for personalized medication management. Their approach utilizes real-time data analysis to optimize dosage and predict patient health conditions. Although this system offers advanced features, it increases complexity and cost, making it less accessible for general users. Additionally, research by Ahire Tanuja R and her team (2025) focused on the development of an automatic medicine dispenser with alert systems aimed at improving patient safety. Their work highlights the importance of automation in reducing medication errors but lacks integration with vital monitoring systems.

Despite these advancements, a common limitation observed in most existing systems is the lack of a unified platform that combines both medication management and real-time health monitoring. Many solutions either focus solely on automated dispensing or require multiple separate devices to monitor vital parameters such as heart rate and blood oxygen levels. This separation reduces efficiency and increases the overall cost and complexity of the system. Furthermore, limited user interaction, lack of portability, and dependence on external applications are additional challenges identified in previous works.

To overcome these limitations, the proposed “Smart Health Care Hub with Medicine Reminder and Vital Monitoring” integrates automated medicine dispensing with real-time monitoring of heart rate and SpO₂ levels into a single compact system. By utilizing components such as ESP32, MAX30102 sensor, and RTC module, the system ensures accurate medication scheduling along with continuous health tracking. This integration not only simplifies the overall design but also enhances usability and reliability. Compared to existing systems, the proposed solution offers a cost-effective, efficient, and user-friendly approach, making it highly suitable for home healthcare and continuous patient monitoring applications.

3. Methodology

The proposed “Smart Health Care Hub with Medicine Reminder and Vital Monitoring” is designed as an integrated embedded system that combines automated medicine dispensing with real-time health monitoring. The system is centered around the ESP32 microcontroller, which acts as the main processing and control unit. Initially, the user sets the medication schedule using a 4×4 keypad interface, and the data is stored within the system. The DS3231 Real-Time Clock (RTC) module continuously tracks the current time with high accuracy and compares it with the pre-set medication schedule. When the scheduled time is reached, the ESP32 triggers an alert through visual indicators such as LEDs or a buzzer to notify the user. Simultaneously, the servo motors, controlled via the PCA9685 driver module, are activated to rotate the six-partition medicine dispenser. Each partition corresponds to a specific dosage, ensuring that the correct medicine is dispensed at the right time. An IR sensor is used to detect whether the medicine has been successfully dispensed, adding an additional layer of reliability to the system.

In parallel with the medication management process, the system continuously monitors vital health parameters using the MAX30102 pulse oximeter sensor. This sensor measures both heart rate and blood oxygen saturation (SpO₂) in a non-invasive manner by detecting variations in light absorption through the user’s fingertip. The collected data is processed by the ESP32 and displayed on a 1.3-inch OLED screen in real time, allowing users to easily track their health status. The system is powered by a 5V 10A SMPS, ensuring stable and efficient operation of all components, including servo motors and sensors. Additional components such as capacitors are used to maintain voltage stability and reduce noise in the circuit. The entire setup is assembled on a PCB board and enclosed within a customized box for compactness and safety. The integration of automated dispensing and vital monitoring into a single system ensures seamless operation, reduces dependency on external devices, and enhances overall healthcare efficiency. This methodology provides a reliable, cost-effective, and user-friendly solution suitable for both home-based and clinical healthcare applications.

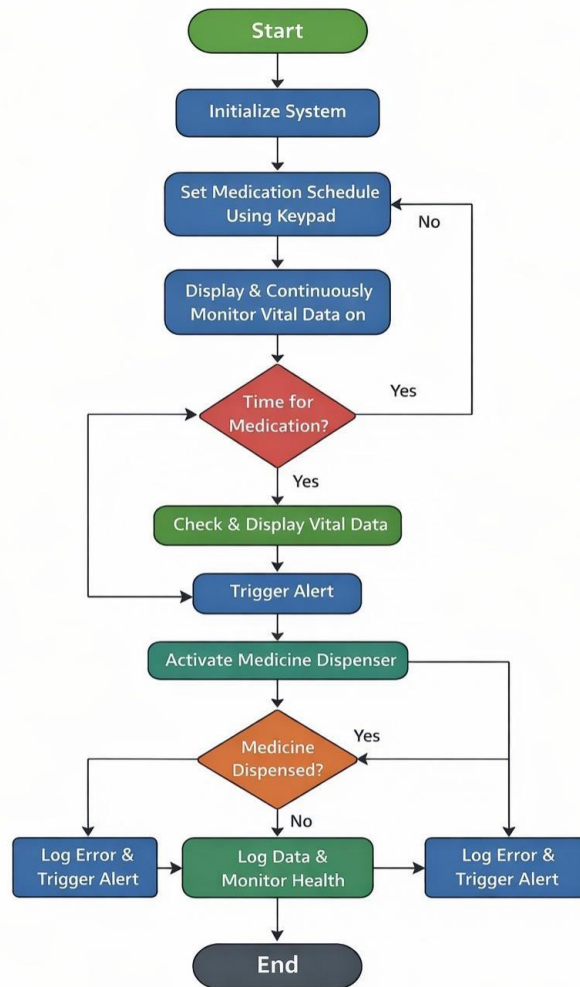


Fig. 1 shows the overall architecture of the proposed Smart Health Care Hub with Medicine Reminder and Vital Monitoring

3.1 System Overview

The Smart Health Care Hub with Medicine Reminder and Vital Monitoring is an advanced automated healthcare system designed to assist patients in managing their medication schedule while continuously monitoring vital health parameters. The system integrates multiple hardware components such as ESP32 Node MCU, DS3231 Real-Time Clock (RTC), MAX30102 sensor, servo motors, IR sensors, keypad, OLED display, and alert units to ensure efficient and reliable operation. It is especially useful for elderly individuals and patients requiring regular medication and health supervision. The system follows a structured workflow combining automation, real-time monitoring, and alert mechanisms.

The system consists of some stages:

- Stage 1: System Initialization and Time Management
- Stage 2: Medication Schedule Configuration
- Stage 3: Continuous Vital Parameter Monitoring
- Stage 4: Medication Time Detection and Alert Generation
- Stage 5: Priority-Based Vital Check During Dispensing
- Stage 6: Automated Medicine Dispensing with Verification
- Stage 7: Post-Dispensing Monitoring and Continuous Operation

3.2 Stage 1: System Initialization and Time Management

When the system is powered ON, the ESP32 microcontroller initializes all the connected hardware components including the RTC module, MAX30102 sensor, OLED display, keypad, IR sensor, and servo motors. This stage ensures that all modules are properly connected and functioning without any errors. The DS3231 RTC module plays a crucial role by providing accurate real-time data, which is essential for scheduling medication. It also contains a backup battery,

allowing it to maintain time even during power failures. This ensures system reliability and continuity. Proper initialization guarantees that the system starts in a stable state and is ready for further operations without malfunction.

3.3 Stage 2: Medication Schedule Configuration

In this stage, the user sets the medication timings using the 4×4 keypad interface. The ESP32 processes these inputs and stores them securely in its internal memory for future reference. The system allows multiple time slots to be configured, depending on the patient's prescription, making it flexible and customizable. The entered schedule can also be displayed on the OLED screen, enabling the user to verify the input and avoid mistakes. This stage ensures that the system is personalized according to the patient's needs and helps in maintaining consistency in medication intake, which is critical for effective treatment and recovery.

3.4 Stage 3: Continuous Vital Parameter Monitoring

The system continuously monitors the patient's vital parameters using the MAX30102 sensor. This sensor measures heart rate and blood oxygen saturation (SpO₂) using optical sensing technology. It works by emitting light through the fingertip and detecting changes in light absorption caused by blood flow. The ESP32 processes this data in real time and displays it on the OLED screen. Continuous monitoring helps in early detection of abnormal health conditions and provides constant feedback to the user. This stage ensures that the patient remains aware of their health status at all times, improving overall safety and enabling timely medical attention if required.

3.5 Stage 4: Medication Time Detection and Alert Generation

The system continuously compares the real-time data from the RTC module with the stored medication schedule. When the current time matches any scheduled medication time, the system triggers an alert using a buzzer and LED indicators. This ensures that the patient is notified effectively, even if they are not actively checking the display. The alert mechanism is designed to be noticeable and reliable, reducing the chances of missed doses. This stage plays a vital role in ensuring medication adherence, which is especially important for patients with strict treatment schedules or chronic health conditions.

3.6 Stage 5: Priority-Based Vital Check During Dispensing

At the time of medication, the system performs an additional and focused measurement of the patient's vital parameters. This stage is important because it ensures that the patient's health condition is stable before taking the medicine. If any abnormal readings such as low oxygen levels or irregular heart rate are detected, the system can alert the user immediately. This adds an extra layer of safety by preventing potential health risks associated with improper medication intake. This intelligent feature distinguishes the system from basic reminder devices and enhances its reliability in real-world healthcare scenarios.

3.7 Stage 6: Automated Medicine Dispensing with Verification

Once the alert is acknowledged, the system activates the servo motors to rotate the six-compartment medicine dispenser. Each compartment contains a predefined dosage, and the mechanism ensures that only the correct section is opened at the right time. The dispensing process is precise and controlled, minimizing the chances of overdose or missed medication. Additionally, the IR sensor is used to detect whether the medicine has been successfully dispensed. This verification step ensures that the process is completed accurately. This stage highlights the automation capability of the system and reduces dependency on manual intervention.

3.8 Stage 7: Post-Dispensing Monitoring and Continuous Operation

After the medicine has been dispensed, the system continues to monitor the patient's vital parameters to observe any immediate changes in health condition. The collected data, including heart rate, SpO₂ levels, and dispensing time, can be stored for future analysis. This helps in maintaining a health record and can be useful for medical consultations. The system then returns to its continuous monitoring state and waits for the next scheduled event. This loop ensures uninterrupted operation and long-term reliability. Overall, this stage ensures that the system provides continuous healthcare support without any downtime.

4. Experimental results

The proposed Smart Health Care Hub with Medicine Reminder and Vital Monitoring system was successfully implemented and tested under real-time conditions. The performance of the system was evaluated based on parameters such as medication dispensing accuracy, vital parameter measurement, alert response, and system reliability. The system demonstrated stable and efficient operation during continuous testing.

The MAX30102 sensor was used to measure heart rate and blood oxygen saturation (SpO₂). The observed heart rate values ranged between 65 to 92 BPM, which lies within the normal resting range for adults. The SpO₂ levels were observed between 95% to 99%, indicating accurate and reliable oxygen saturation measurement. Minor variations were noticed due to finger placement and movement, but overall readings remained stable and consistent.

The DS3231 RTC module provided precise timekeeping, ensuring accurate triggering of medication alerts. The alert system (buzzer and LED) responded instantly at scheduled times, ensuring that the user was notified without delay. The automated medicine dispenser, controlled by servo motors, successfully dispensed medicine from the correct compartment. The IR sensor effectively detected whether the medicine was dispensed, reducing the chances of missed doses.

During testing, the system performed both continuous monitoring and priority-based checks at the time of dispensing. The OLED display provided real-time updates of heart rate, SpO₂ levels, and system status, enhancing user interaction. The response time of the system was observed to be less than 2 seconds, which is acceptable for real-time healthcare applications.

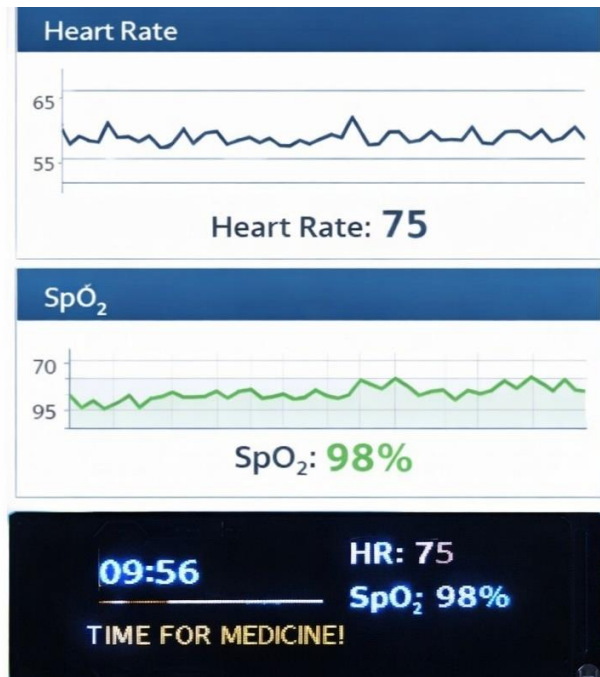


Fig. 2 Real-time Monitoring Output of Smart Health Care Hub with Medicine Reminder and Vital Monitoring

Table No.1 System Performance

Sr. No	Parameter	Result	Remark
1	Heart Rate Monitoring	Accurate BPM readings Reliable	Reliable
2	SpO ₂ Measurement	95% – 99%	Stable
3	Medication Dispensing	Correct compartment delivery	Precise
4	Alert System	Immediate buzzer & LED response	Effective
5	RTC Time Accuracy	No delay in scheduling	Consistent
6	IR Detection	Successful dispensing detection	Accurate
7	System Response Time	Less than 2 seconds	Acceptable

The results in Table 1 show that the system performs reliably under real-time conditions. Heart rate and SpO₂ measurements were accurate and stable. The medicine dispensing mechanism worked precisely with correct timing. Alerts responded instantly, and the overall system delay was minimal, confirming efficiency and suitability for healthcare applications.

5. Conclusion

The proposed Smart Health Care Hub with Medicine Reminder and Vital Monitoring system presents an effective and intelligent solution for improving medication adherence and continuous health monitoring. By integrating automated medicine dispensing with real-time measurement of vital parameters such as heart rate and blood oxygen saturation (SpO₂), the system addresses key challenges faced by patients, especially the elderly and those with chronic illnesses. The use of the DS3231 Real-Time Clock ensures precise scheduling, while the alert mechanism using buzzer and LED indicators guarantees timely notification for medication intake.

The Implementation of the MAX30102 sensor enables accurate and non-invasive monitoring of vital signs, providing real-time feedback to the user through an OLED display. The automated dispensing mechanism, controlled by servo motors, ensures correct dosage delivery from the appropriate compartment, reducing the risk of human error. Additionally, the IR sensor-based verification enhances system reliability by confirming successful dispensing.

Experimental results demonstrate that the system operates with high accuracy, stability, and minimal response delay, making it suitable for real-time healthcare applications. The system is cost-effective, easy to use, and compact, making it ideal for home-based healthcare environments.

Overall, the proposed system enhances patient safety, ensures proper medication management, and promotes proactive health monitoring. It serves as a reliable and efficient solution for modern smart healthcare applications and has the potential to be further developed for remote monitoring and advanced medical support systems.

References

- [1] A. Pantelopoulos and N. G. Bourbakis, "A Survey on Wearable Sensor-Based Systems for Health Monitoring," *IEEE Transactions on Systems, Man, and Cybernetics*, vol. 40, no. 1, pp. 1–12, 2010.
- [2] M. S. Hossain and G. Muhammad, "Cloud-Assisted Industrial Internet of Things (IIoT) for Health Monitoring," *IEEE Transactions on Industrial Informatics*, vol. 14, no. 10, pp. 1–10, 2018.
- [3] J. Allen, "Photoplethysmography and its Application in Clinical Physiological Measurement," *Physiological Measurement*, vol. 28, no. 3, pp. R1–R39, 2007.
- [4] U. R. Acharya et al., "Automated ECG Analysis Using Different Signal Processing Techniques," *International Journal of Cardiology*, vol. 165, no. 3, pp. 444–454, 2013.
- [5] J. Pan and W. J. Tompkins, "A Real-Time QRS Detection Algorithm," *IEEE Transactions on Biomedical Engineering*, vol. BME-32, no. 3, pp. 230–236, 1985.
- [6] S. Patel and M. Mehta, "IoT-Based Smart Healthcare Monitoring System Using Sensors," *International Journal of Engineering Research & Technology*, vol. 9, no. 5, pp. 1–5, 2020.
- [7] G. Yang et al., "A Health IoT Platform Based on Intelligent Biosensors and Cloud Computing," *IEEE Transactions on Industrial Informatics*, vol. 10, no. 2, pp. 1–8, 2014.
- [8] P. Castiglioni, A. Faini, and G. Parati, "Wearable ECG Monitoring Systems for Continuous Cardiac Monitoring," *IEEE Engineering in Medicine and Biology Society*, 2011.
- [9] V. Triantafyllidis et al., "An Open and Reconfigurable Wireless Sensor Network for Pervasive Health Monitoring," *IEEE Journal of Biomedical and Health Informatics*, vol. 19, no. 3, pp. 1–10, 2015.
- [10] S. Kumar and A. Lee, "Smart Medicine Reminder System Using IoT," *International Journal of Smart Home*, vol. 11, no. 2, pp. 45–52, 2017.
- [11] A. Rahman et al., "Real-Time Health Monitoring System Using ESP32 and IoT," *International Journal of Advanced Computer Science and Applications*, vol. 12, no. 6, pp. 1–6, 2021.
- [12] D. Zhang et al., "IoT-Based Remote Health Monitoring System for Elderly Care," *IEEE Access*, vol. 8, pp. 1–10, 2020.
- [13] H. Alemdar and C. Ersoy, "Wireless Sensor Networks for Healthcare: A Survey," *Computer Networks*, vol. 54, no. 15, pp. 2688–2710, 2010.
- [14] S. M. Riazul Islam et al., "The Internet of Things for Health Care: A Comprehensive Survey," *IEEE Access*, vol. 3, pp. 678–708, 2015.

Design and Implementation of a Passive Mobile Signal Enhancer

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Abstract: Nowadays, reliable mobile communication is very important, especially in indoor and remote areas where signals are usually weak. This paper explains the design and working of a passive mobile signal enhancer that uses a high-gain Yagi-Uda antenna along with a dipole antenna. The system collects signals from outside and transfers them inside without using any external power source.

The results show that this setup improves signal strength, call quality, and internet performance. The system is low-cost, energy-efficient, and suitable for areas with poor network coverage. It also works reliably under different environmental conditions and requires very little maintenance compared to active systems. Overall, this method reduces complexity while providing better communication in difficult areas.

Keywords: Passive repeater, Yagi-Uda antenna, Signal enhancement, Indoor coverage, Wireless communication

1. Introduction

Mobile communication is very important in our daily life. We use it for calling, using the internet, and many real-time activities. With modern technologies like 4G and 5G, people expect a strong and stable network everywhere. However, getting a good signal is still difficult in some places, especially inside buildings and in rural areas.

In locations such as basements, tunnels, large buildings, and crowded cities, mobile signals become weak. This happens because walls, concrete, and uneven surfaces block or reflect the signals. As a result, signals become scattered and weaker. This leads to problems like call drops, poor signal strength, and slow internet speed. Also, areas far from mobile towers face weak signals because the signal strength reduces over long distances.

To solve this issue, active signal boosters are commonly used. These devices can improve signal strength, but they require power, are costly, and may not be allowed everywhere. Due to these limitations, alternative methods are being explored to improve signals without using electricity.

These methods work by capturing signals from outside and transferring them indoors using antennas and cables, without any power supply. They are simple, cost-effective, and require very little maintenance. In this project, we developed a passive mobile signal enhancement system that uses a high-gain antenna to receive signals and another antenna to distribute the signal inside buildings.

2. Related Word:

Many people have tried to make wireless signals stronger using methods. One way to do this is by using Reflecting Surfaces, which make signals stronger by bouncing them to specific places. Another way is by using techniques to direct signals to areas where the signal is weak which makes communication better.

Some antennas, like Yagi-Uda antennas are really good at picking up signals from away because they are very good at focusing on the signal. People also use devices to repeat signals in places like tunnels underground areas and buildings where signals have trouble getting through.

Other studies have shown that these simple systems can make indoor signals stronger.. There are still some problems like getting the antennas to point in the right direction signals getting lost in the cables and getting the signals to spread evenly inside buildings.

3. Methodology

This project is about making mobile signal strength better. It does this with a system that does not need any power. The system has a parts: an outdoor antenna, a cable, an indoor antenna and something to reflect the signals.

The mobile signal strength system works like this: it gets signals from outside with the antenna then it sends these signals through the cable and after that it sends them inside again with the indoor antenna. This way is simple. Does not cost a lot of money. It is also good for the environment and easy to take care of. The indoor mobile signal strength system is a solution because it is easy to use and it helps people get better mobile signals, inside buildings.

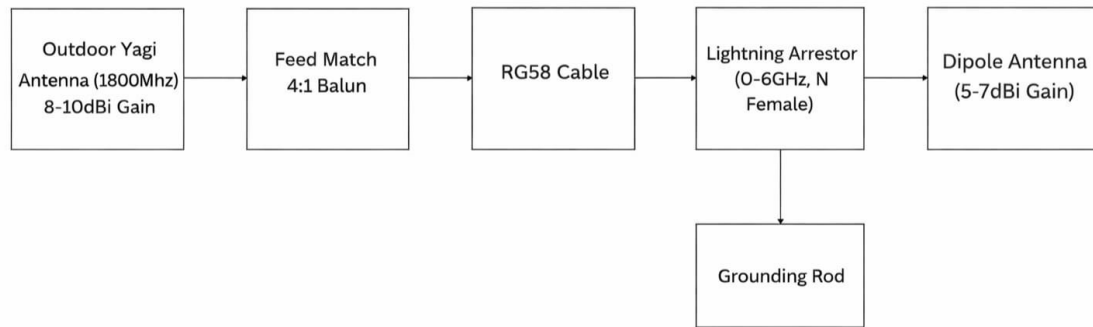


Figure 1: Block diagram of the proposed system

A. Finding the Signal Source

To get the signal we need to find the nearest mobile tower. We can use apps to do this. These apps are called analyzer apps. We use these apps to find the mobile tower and then we point the antenna towards it. This way we get the signal.

B. Signal Collection

We need an antenna to get weak signals. This antenna is called a gain directional antenna. One example of this antenna is the Yagi-Uda antenna. This antenna is very good at getting signals.

C. Signal Transmission

Now we need to send the signal inside the building. We use a cable to do this. This cable is called an RG58 cable. This cable is very good because it does not lose much of the signal.

D. Signal Distribution

Once the signal is inside, we need to spread it around. We use an antenna to do this. This antenna is called a dipole antenna. It helps to spread the signal across the area.

E. Passive Repeater Working

The system we are using is very simple. It just sends the signals from outside to inside without making them stronger. This makes it very cheap. It does not use a lot of energy. The mobile signal is just redirected from outside, to inside.

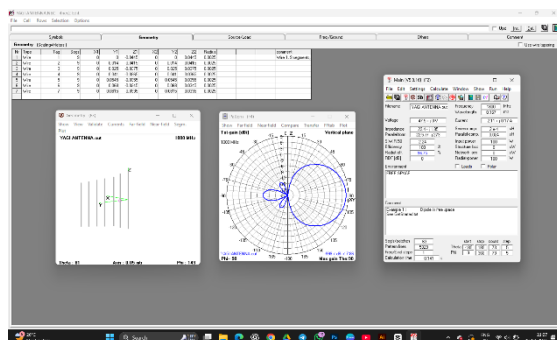
F. System Evaluation

To see if the system is working well, we need to check a thing. We need to check the signal strength, the call quality, the data speed and the stability. We do this before we install the system and after we install the system. This way we can see if the system is really working.

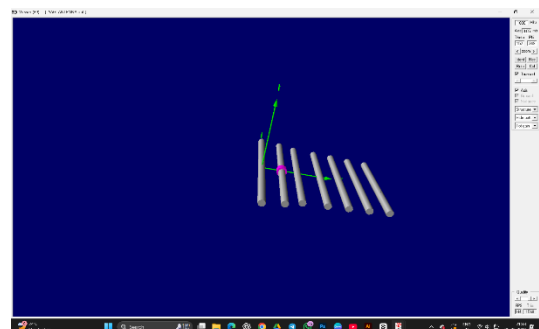
4. Experimental results

The results show that the passive signal enhancer makes signal strength better. After you install the system, you will notice the signal gets stronger. Call quality gets better there are call drops and your internet speed improves. The system's performance relies on things like antenna gain how long the cable. Making sure it aligned properly with the tower.

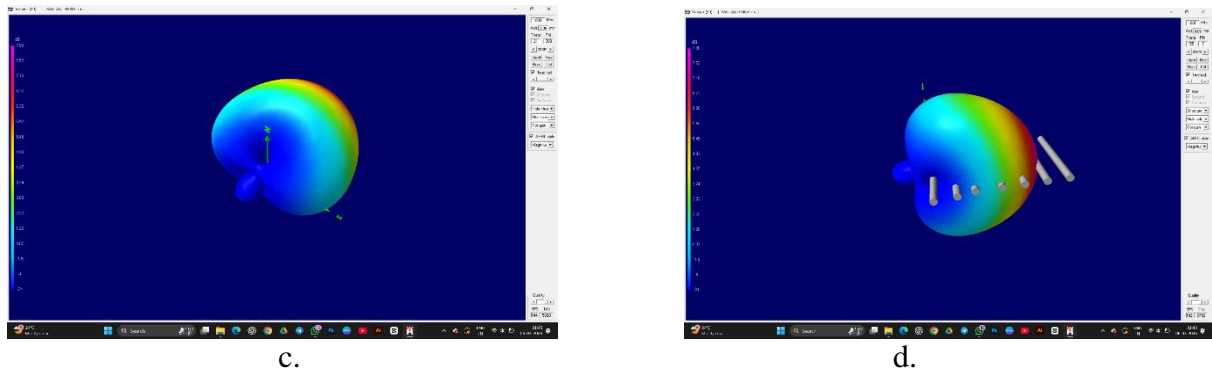
For the results you need to place the outdoor antenna in a good spot with a clear path, to the base station. Also keep cable losses to a minimum.



a.



b.



c.

d.

Fig. 2. Design and 3D view of Yaggi -Uda Antenna

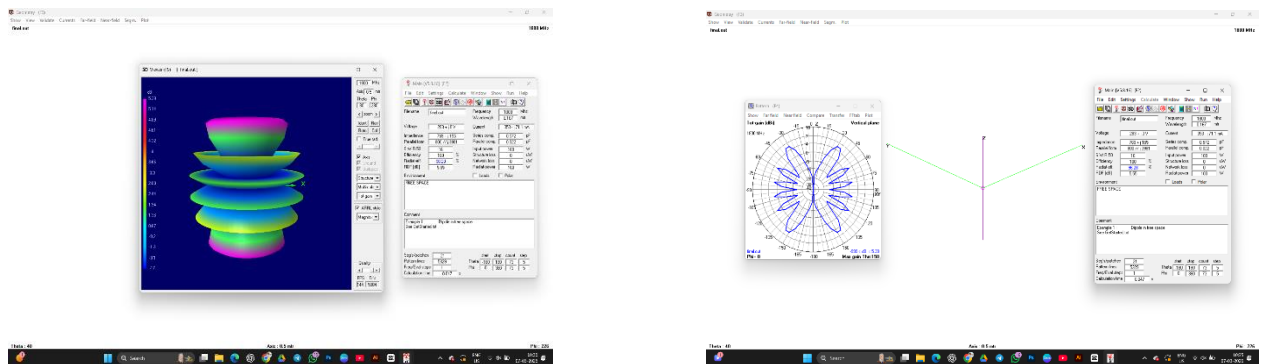


Fig 3. Design and 3D view of Dipole Antenna

5. Conclusion

This paper is about a system that makes mobile signals better inside buildings. It uses a Yagi-Uda antenna and a dipole antenna to get signals from outside and bring them inside without using any power. The mobile signal system is cheap and good for the environment. The results show that mobile signals are stronger calls are clearer and the internet is faster. The mobile signal system is an good solution for people who have bad mobile network coverage inside buildings. The system for improving signals is really helpful, for people who need better mobile signals

References

- [1] J. Holma and A. Toskala, "Performance Analysis of Passive Repeaters for Cellular Coverage," 2011. Available: <https://scholar.google.com/scholar?q=Performance+Analysis+of+Passive+Repeaters+for+Cellular+Coverage>
- [2] H. Claussen, "Distributed Antenna Systems for Indoor Wireless Communications," 2009. Available: <https://scholar.google.com/scholar?q=Distributed+Antenna+Systems+for+Indoor+Wireless+Communications>
- [3] S. Saunders, "Passive Reflector Based Signal Enhancement for Wireless Networks," 2010. Available: <https://scholar.google.com/scholar?q=Passive+Reflector+Based+Signal+Enhancement+for+Wireless+Networks>
- [4] M. Hata, "Leaky Feeder Communication System for Wireless Coverage," 2008. Available: <https://scholar.google.com/scholar?q=Leaky+Feeder+Communication+System+for+Wireless+Coverage>
- [5] T. S. Rappaport, "Indoor Coverage Enhancement Using Passive Repeaters," 2012. Available: <https://scholar.google.com/scholar?q=Indoor+Coverage+Enhancement+Using+Passive+Repeaters>
- [6] N. Engheta, "Metamaterial Reflectors for Wireless Signal Enhancement," 2013. Available: <https://scholar.google.com/scholar?q=Metamaterial+Reflectors+for+Wireless+Signal+Enhancement>
- [7] Y. Okumura, "Passive Repeater Design for Mobile Communication Systems," 2010. Available: <https://scholar.google.com/scholar?q=Passive+Repeater+Design+for+Mobile+Communication+Systems>
- [8] T. S. Rappaport, "Multi-Antenna Passive Signal Distribution System," 2014. Available: <https://scholar.google.com/scholar?q=Multi+Antenna+Passive+Signal+Distribution+System>
- [9] A. Goldsmith, "Directional Antenna Systems for Wireless Signal Improvement," 2013. Available: <https://scholar.google.com/scholar?q=Directional+Antenna+Systems+for+Wireless+Signal+Improvement>
- [10] R. Zhang, "Smart Passive Reflector Panels for RF Coverage Enhancement," 2018. Available: <https://scholar.google.com/scholar?q=Smart+Passive+Reflector+Panels+for+RF+Coverage+Enhancement>
- [11] J. G. Andrews, "Indoor Wireless Coverage Using Passive Antenna Networks," 2015. Available: <https://scholar.google.com/scholar?q=Indoor+Wireless+Coverage+Using+Passive+Antenna+Networks>
- [12] M. Dohler, "Hybrid Passive Signal Enhancement Techniques for Cellular Systems," 2016. Available: <https://scholar.google.com/scholar?q=Hybrid+Passive+Signal+Enhancement+Techniques+for+Cellular+Systems>

Intelligent Vehicle Data Monitoring System

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Abstract: The Vehicle Monitoring System developed in this project utilizes a Raspberry Pi (RPI) in conjunction with an ELM327 OBD-II adapter to enable real-time data acquisition and analysis from a running vehicle. The system is designed to interface directly with the On-Board Diagnostics (OBD-II) port of a real car, allowing continuous monitoring of essential vehicle parameters.

Key parameters such as vehicle speed, distance travelled, and fuel consumption are captured and processed using the Raspberry Pi. The ELM327 adapter facilitates communication between the vehicle's ECU and the RPI, enabling accurate retrieval of diagnostic and performance data. Distance measurement is calculated based on speed and time data, while fuel consumption is estimated using relevant engine parameters.

A user-friendly dashboard is developed to visualize and store the collected data on a daily basis. This dashboard provides insights into driving patterns, fuel efficiency, and overall vehicle performance, helping users make informed decisions for better vehicle maintenance and fuel management.

The system is cost-effective, scalable, and suitable for real-world implementation. It demonstrates the practical application of embedded systems and IoT in automotive monitoring, offering a smart solution for efficient vehicle tracking and analysis.

Keywords: Raspberry Pi (RPI), ELM327 OBD-II Adapter, Vehicle Monitoring System, On-Board Diagnostics (OBD-II), Real-Time Data Acquisition, Fuel Consumption Analysis, Distance Measurement, Embedded Systems, IoT-Based Monitoring, Vehicle Performance Analysis, Data Logging, Dashboard Visualization, Automotive Diagnostics, Smart Vehicle System, ECU Communication.

1. Introduction

Modern vehicles are equipped with advanced electronic systems, where the On-Board Diagnostics (OBD-II) interface provides access to important internal data for analysis and maintenance. However, drivers often lack a simple way to monitor and interpret this data in real time.

This project develops a Vehicle Monitoring System using a Raspberry Pi and an ELM327 OBD-II adapter to collect parameters such as fuel consumption and distance travelled from a real car. The system processes and stores the data, and presents it through a user-friendly dashboard for daily tracking and analysis.

Such a system is especially useful for transportation and fleet management companies, as it provides accurate readings that help reduce fuel wastage, improve efficiency, and support data-driven decision-making. Overall, the project offers a cost-effective and practical solution for real-time vehicle monitoring.

2. Related Work

Various studies have explored vehicle monitoring systems using OBD-II technology, Raspberry Pi, and IoT. Previous work shows that Raspberry Pi with an ELM327 adapter can successfully collect real-time vehicle data and enable remote monitoring through wireless communication.

Research also highlights that Raspberry Pi is more efficient than traditional microcontrollers for handling real-time processing and data communication. Many IoT-based systems store OBD-II data on cloud platforms and provide visualization through dashboards for analysis and fault detection.

Overall, existing systems prove the effectiveness of OBD-II-based monitoring but often involve complex or cloud-dependent architectures. This project focuses on a simpler, cost-effective solution with a local dashboard for daily tracking of fuel consumption and distance.

3. Methodology

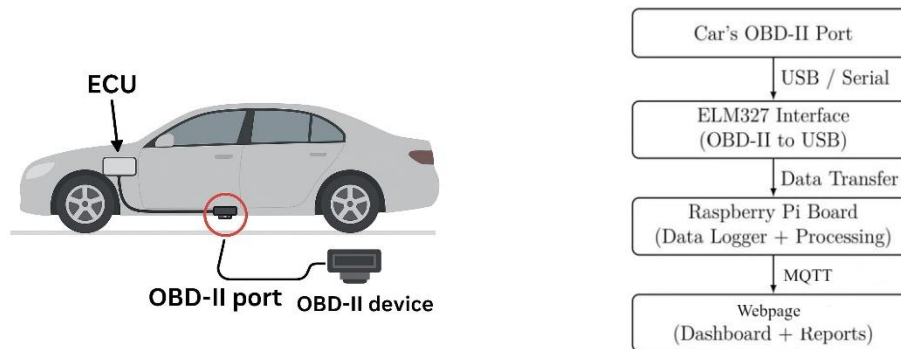


Fig 1: Block Diagram

The proposed Vehicle Monitoring System is developed using a Raspberry Pi and an ELM327 OBD-II adapter to acquire, process, and visualize vehicle data in real time. The methodology is divided into the following stages:

1. System Setup and Hardware Integration:

The Raspberry Pi is interfaced with the ELM327 OBD-II adapter via Bluetooth or USB. The adapter is connected to the vehicle's OBD-II port, enabling communication with the Electronic Control Unit (ECU). Proper configuration ensures stable and accurate data transmission.

2. Data Acquisition:

Relevant vehicle parameters such as fuel consumption and distance traveled are obtained from the ECU using standard OBD-II parameter IDs (PIDs). Python-based libraries are used on the Raspberry Pi to send requests and receive responses from the vehicle.

3. Data Processing:

The collected raw data is processed to extract meaningful information. Distance is calculated based on available parameters over time, while fuel consumption is estimated using engine-related data. The processed data is formatted for storage and visualization.

4. Data Storage:

The processed data is stored locally on the Raspberry Pi in a structured format such as CSV files or a lightweight database. Daily logs are maintained to enable tracking and analysis over time.

5. Dashboard Development:

A user-friendly dashboard is developed using web technologies to display the collected data. The dashboard provides daily summaries, graphical representations, and insights into fuel usage and distance covered.

6. Testing and Validation:

The system is tested on a real vehicle to verify accuracy and reliability. The obtained readings are analyzed to ensure consistency and proper functioning of the system.

This methodology ensures an efficient, low-cost, and scalable solution for real-time vehicle monitoring and data analysis.

4. Experimental results

Image 1: Hardware Setup

This image shows the actual implementation inside the vehicle. The ELM327 OBD-II adapter is connected to the car's OBD port and interfaced with the Raspberry Pi.

The Raspberry Pi acts as the processing unit, collecting real-time data from the vehicle's ECU through the adapter. This setup enables continuous data acquisition required for monitoring fuel consumption and distance.

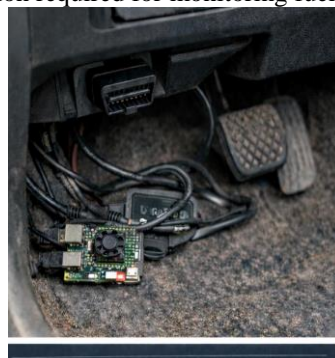


Fig 2: Dashboard Output

This image shows the vehicle monitoring dashboard developed in the project. It displays key parameters such as:

Distance travelled: 46.8 km

Fuel used: 3.4 Liters

Average fuel efficiency: 13.7 km/L

The dashboard also includes graphical representations like bar charts (fuel consumption) and line graphs (distance trend). These visuals help users easily analyse daily vehicle performance and usage patterns



Fig 3: Data Logging and Output

This image shows the stored data and output results of the vehicle monitoring system. It displays total distance (128.4 km) and total fuel used (10.1 Liters), along with a daily log table.

The table includes date-wise records of:

Distance travelled (e.g., 44.5 km, 37.1 km, 46.8 km)

Fuel consumption (e.g., 2.8 L, 3.0 L, 3.4 L)

This demonstrates that the system not only captures real-time data but also stores it systematically for daily analysis. Such data logging is useful for tracking vehicle usage patterns, evaluating fuel efficiency, and generating reports over time.



5. Conclusion

The proposed Vehicle Monitoring System using Raspberry Pi and an ELM327 OBD-II adapter was successfully designed and implemented. The system effectively acquires real-time data from a vehicle and processes parameters such as fuel consumption and distance travelled. The developed dashboard provides clear visualization, while the data logging feature enables daily tracking and analysis.

The experimental results demonstrate that the system is reliable, cost-effective, and suitable for real-world applications. It helps users monitor vehicle usage, improve fuel management, and make informed decisions. The system is particularly useful for transportation and fleet management, where accurate tracking of distance and fuel consumption is essential.

Overall, the project highlights the practical use of embedded systems and IoT in automotive monitoring. Future improvements can include cloud integration, mobile applications, and advanced analytics to enhance system functionality.

References

- [1] SAE International, J1939 Standards Collection, SAE International, 2020
- [2] ISO 15031-5:2015, Road vehicles — Communication between vehicle and external equipment for emissions-related diagnostics, International Organization for Standardization.
- [3] ELM Electronics, ELM327 OBD to RS232 Interpreter Datasheet, 2010. [Online]. Available: <https://elmelectronics.com>
- [4] Lee, H. Jeong, and J. Lee, "Development of a Vehicle Monitoring System Based on OBD-II and IoT," International Journal of Distributed Sensor Networks, vol. 14, no. 2, pp. 1–9, 2018.

PLC Based Industrial Edge-to-Dashboard Data Integration System

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Abstract: The rapid shift toward Industry 4.0 has increased the demand for intelligent industrial systems capable of collecting, interpreting, and sharing real-time operational data. Programmable Logic Controllers (PLCs), once limited to deterministic control tasks, are now being used as edge devices that enable seamless integration between field sensors and cloud environments. This review examines recent studies on PLC-based data acquisition and their connectivity with IIoT platforms through middleware solutions such as Kepware and OPC UA. Various research works also highlight the use of cloud dashboards like ThingsBoard, Ubidots, and Thingworx for remote visualization and supervisory control. While these frameworks demonstrate significant potential, many reported implementations still lack comprehensive evaluation of latency, scalability, data security, and long-term industrial performance. By consolidating these findings, this paper outlines current advancements, identifies persistent limitations, and emphasizes the need for more robust, secure, and scalable edge-to-dashboard architectures. The review ultimately supports future efforts toward achieving highly connected, efficient, and intelligent industrial monitoring systems.

Keywords: PLC, Industrial Internet of Things (IIoT), OPC UA, Kepware, Modbus, Edge Computing, Cloud Dashboard, ThingsBoard, Industrial Automation, Data Integration.

1. Introduction

The advancement of industrial automation has significantly evolved with the introduction of Industry 4.0, which emphasizes smart manufacturing through connectivity, data exchange, and intelligent decision-making. Earlier industrial systems were primarily designed for isolated operation, where monitoring and control were limited to local environments such as control rooms or plant floors. However, with increasing competition and the need for higher efficiency, industries are moving toward integrated systems that allow real-time monitoring, remote accessibility, and data-driven optimization. This shift has created a demand for technologies that can seamlessly connect field devices with cloud-based platforms, enabling continuous data flow and improved system transparency. Programmable Logic Controllers (PLCs) continue to play a crucial role in industrial automation due to their robustness, reliability, and deterministic control capabilities. Traditionally, PLCs were used only for executing control logic and managing machine operations. In recent developments, however, PLCs are being utilized as edge-level devices that not only control processes but also collect and transmit real-time data to higher-level systems. By incorporating communication protocols such as Modbus and OPC UA, PLCs can interact with external devices and software platforms. Middleware solutions like Kepware further enhance this capability by acting as a bridge between different protocols, ensuring smooth and standardized communication across diverse industrial equipment. In addition to data acquisition and communication, cloud-based IoT platforms such as ThingsBoard provide powerful tools for visualization, monitoring, and analysis of industrial data. These platforms allow users to access real-time information through dashboards, generate alerts for abnormal conditions, and analyze historical trends for better decision-making. Despite the growing adoption of such integrated systems, several challenges remain, including issues related to interoperability, data security, system scalability, and communication latency. Therefore, this review paper focuses on analyzing existing research related to PLC-based edge-to-dashboard data integration systems, identifying current limitations, and highlighting potential improvements for building efficient, secure, and scalable industrial monitoring solutions.

2. Motivation

In conventional automation, data remains confined within local PLC networks, limiting visibility and delaying diagnosis during critical failures. As industries expand, monitoring these distributed systems manually becomes inefficient. The demand for real-time dashboards, remote accessibility, and analytics-based maintenance has surged across sectors like manufacturing, utilities, and process industries. While numerous solutions connect PLCs to IoT platforms, many remain experimental and lack systematic evaluation of latency, interoperability, and scalability. Additionally, integration challenges arise due to vendor-specific protocols and heterogeneous devices. This motivates the need for reviewing existing architectures and identifying practical, modular solutions that bridge PLC systems with cloud dashboards using proven middleware tools.

3. Methodology

The proposed system follows a structured approach to enable real-time industrial data acquisition and visualization by integrating field devices with cloud-based platforms. At the initial stage, multiple sensors such as temperature, pressure, and vibration sensors are deployed at the field level to continuously monitor critical industrial parameters. These sensors generate analog or digital signals, which are directly interfaced with the Programmable Logic Controller (PLC). The PLC acts as the central control unit, where the acquired sensor data is processed and organized into meaningful variables. It ensures reliable and deterministic operation while preparing the data for further transmission. Communication between the PLC and the gateway layer is established using the Modbus protocol, which facilitates structured and standardized data exchange. At the gateway level, Kepware KEPServerEX is used as a middleware solution. It collects data from the PLC, converts it into a unified format, and eliminates protocol dependencies. This layer plays a crucial role in bridging traditional industrial communication with modern IoT-based systems. Further, the processed data is transmitted from Kepware to the cloud using the MQTT protocol. MQTT ensures lightweight, efficient, and real-time data transfer suitable for IoT applications. Finally, the data is received by the ThingsBoard platform, where it is visualized through interactive dashboards. This enables remote monitoring, trend analysis, and quick decision-making based on live industrial conditions. Overall, the architecture ensures a seamless flow of data from sensors to the cloud, supporting real-time monitoring and aligning with Industry 4.0 requirements.

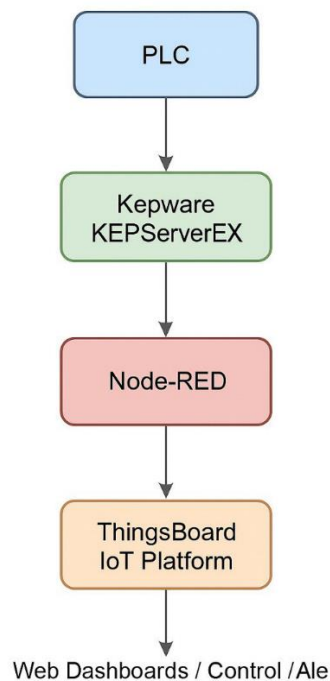


Fig. 1. Flowchart

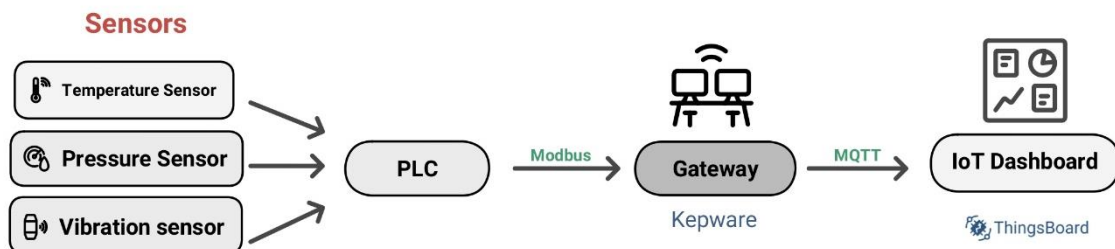


Fig. 2. Block Diagram

4. Literature Review

Recent developments in industrial automation show a clear shift toward combining PLC systems with IoT platforms and web technologies to achieve continuous monitoring, improved machine reliability, and data-driven maintenance strategies. Thangatamilan et al. designed an IoT-integrated PLC system for automating a textile dyeing process, where

a Siemens S7- 1200 PLC worked with temperature and level sensors to manage the dyeing cycle while sending live production data to a cloud dashboard for supervision [1]. The approach successfully demonstrated how PLCs and IoT can complement each other for remote process monitoring and reduced operator workload. Still, the solution focused narrowly on the textile domain and did not evaluate performance factors such as network latency or data transfer robustness. In another study, Salodkar et al. used the Modbus protocol to establish communication between industrial energy meters and PLCs, showing that Modbus RTU/TCP can reliably transfer electrical readings to a controller for further processing [2]. Their implementation helped detect unusual energy consumption and supported real-time visualization using an HMI. Although promising, the work did not address practical challenges such as vendor compatibility issues or how the system behaves under noisy industrial communication conditions. Doshi et al. explored a broader Industrial IoT architecture by integrating PLCs with ThingWorx and Kepware, focusing on seamless data acquisition and web-based dashboards for industrial monitoring [3]. The study highlighted that OPC servers simplify communication between diverse industrial devices. While the overall concept is strong, the authors did not provide experimental results or stress tests that would demonstrate the system's scalability or real-time reliability during continuous industrial operation. Dwiyaniti and colleagues worked extensively on IoT-based condition monitoring using the ThingsBoard platform. Their 2019 work showed how machine parameters such as temperature and vibration could be collected and pushed to the cloud using MQTT for easy visualization [4]. In their follow-up study, they added Telegram notifications to alert operators about abnormal readings, enabling quicker response times [5]. Although these systems functioned well as prototypes, they were not tested under real industrial conditions where noise, vibration, and unstable connectivity could affect system accuracy. The importance of cloud analytics and predictive maintenance was emphasized by Garro et al., who discussed how sensor data combined with machine-learning-based analytics can help identify faults before machine breakdowns occur [6]. Their work supports the idea of integrating data acquisition systems with cloud-based prediction engines, but the study lacked comprehensive experiments validating the accuracy of the proposed predictive models. Wu et al. provided a more general perspective on industrial big data, identifying the major hurdles involved in acquiring, integrating, and processing large amounts of machine data in real time [7]. They argued that PLCs continue to play a vital role as dependable data sources but highlighted that cybersecurity, data scalability, and device interoperability still present major challenges in real industrial environments. A more traditional approach was discussed by Gosavi and Khule, who presented a PLC–SCADA-based system for monitoring energy usage in industrial facilities [8]. Their study underlined the benefits of real-time power tracking for better energy management and reduced wastage. However, the review placed more emphasis on conventional SCADA systems and did not extensively address the capabilities of cloud-based or IoT-enabled monitoring platforms that have become more prominent in recent years. Overall, the literature consistently shows that PLCs remain at the heart of automation due to their reliability and precise control capabilities. IoT platforms and web dashboards build on this foundation by enabling long-distance accessibility, historical data storage, and opportunities for predictive maintenance. However, many existing studies rely on small-scale prototypes and do not provide detailed performance measurements or real-world validations. There is also limited focus on system security, multi-vendor interoperability, and scalability. These gaps shape the motivation for the present work, which aims to create a PLC-based real-time machine monitoring system supported by a secure web application capable of handling continuous data acquisition, remote control, and fault detection in an industrial context.

5. Conclusion

This review highlights that PLC-based data acquisition integrated with middleware and IoT dashboards forms the backbone of modern industrial monitoring systems. PLCs ensure reliable field-level control, while protocol-conversion tools such as Kepware enable seamless interoperability among devices. IoT dashboards like ThingsBoard offer user-friendly interfaces for live monitoring, alarms, and analytics. Although research in this domain is promising, most implementations are limited to laboratory-scale setups. Existing literature lacks comprehensive evaluations involving network latency, secure communication channels, and long-term reliability under varying industrial conditions. A more data-centric approach, combining PLC measurements with advanced analytics or machine-learning models, could further enhance predictive capabilities.

References

- [1] M. Thangatamilan, S. Rajasekar, and P. Sivakumar, "Smart textile dyeing automation using IoT enabled PLC," *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, vol. 10, no. 9, pp. 546–551, Jul. 2021.
- [2] V. Salodkar, A. Lad, and A. Teli, "Communication between energy meters and PLC based on Modbus protocol," in *Proc. Int. Conf. on Smart Innovations in Design, Environment, Management, Planning and Computing (ICSIDEMPC)*, Nagpur, India, Jan. 2020, pp. 204–208.
- [3] P. Doshi, A. Doshi, and N. Oke, "Industrial IoT using Thingworx and Kepware for data acquisition," in *Proc. 2021 3rd Int. Conf. on Advances in Computing, Communication Control and Networking (ICAC3N)*, Greater Noida, India, Dec. 2021, pp. 1102–1107.
- [4] M. Dwiyaniti, Y. A. Sari, and D. H. Ratnasari, "Implementation of ThingsBoard as IoT platform for condition monitoring system," in *Proc. 2019 Int. Conf. on Computer Engineering, Network and Intelligent Multimedia (CENIM)*, Surabaya, Indonesia, Nov. 2019, pp. 1–6.

- [5] M. Dwiyanti, Y. A. Sari, and D. H. Ratnasari, "IoT-based condition monitoring system using ThingsBoard with Telegram notification," in Proc. 2020 Int. Conf. on Smart Technology and Applications (ICoSTA), Surabaya, Indonesia, Feb. 2020, pp. 105–110.
- [6] R. Garro, A. Furlan, and F. Cugini, "Data acquisition and analytics for predictive maintenance in industrial automation," in Proc. 2018 IEEE Int. Workshop on Metrology for Industry 4.0 and IoT (MetroInd4.0 & IoT), Brescia, Italy, Apr. 2018, pp. 135–140.
- [7] P. Wu, H. Zhang, and Q. Wang, "Industrial big data analytics: Challenges, methodologies, and applications," IEEE Transactions on Industrial Informatics, vol. 16, no. 9, pp. 5574–5584, Sept. 2020.
- [8] S. Gosavi and R. Khule, "PLC-SCADA based energy monitoring system in industries," International Journal of Engineering Research & Technology (IJERT), vol. 8, no. 6, pp. 890–894, Jun. 2019.



Skin Disease Detection Using Image Processing

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Abstract: Skin problems are some of the most common health problems, but getting professional help for them can be hard in remote areas. This research presents an automated diagnostic tool for skin disorders that employs image analysis and machine learning methods. Our goal centers on creating a practical system able to recognize multiple skin ailments from photographs. We combine proven feature detection techniques with advanced neural networks to achieve dependable results across different skin types and everyday photo quality. Special attention goes toward using varied training data, minimizing unfair biases, and optimizing for fast performance—making the tool viable for city clinics and village health posts alike. The system offers precise categorization, clear performance metrics, and easy integration into mobile apps and basic hardware.

Keywords: Skin Disease Detection, Image Processing, Machine Learning, Deep Learning, Medical Imaging, Bias Reduction.

1. Introduction

Recent breakthroughs in AI and image recognition have opened fresh opportunities for healthcare imaging. Early identification of skin problems usually leads to successful treatment, but specialist care stays scarce in countryside and smaller towns. People often have to wait a long time for a diagnosis because of distance and cost.

Computer-aided screening tools are a helpful answer because they help doctors and patients with their first evaluations. While much progress exists, current tools frequently work best in perfect lab conditions and struggle with real-life factors like poor lighting, varied complexions, or unusual disease appearances. Fairness issues and data imbalances also demand attention for trustworthy results across all groups.

This work develops and tests a sturdy system that blends image preparation, pattern recognition, and decision-making methods to perform reliably in actual use.

2. Technological Progression

2.1 Manually extract features approach

Carefully crafted feature detection is what classic image analysis is based on. Methods look at the shapes of edges, the colors of patterns, and the textures on surfaces. These methods are fast and easy to understand, so they work well with small amounts of data and simple hardware. Results are still not as strong when photos have a wide range of brightness, sharpness, or skin tone.

2.2 Machine Learning-Based Systems

Standard classifiers like SVM, Random Forests, and KNN take these features to sort skin issues. Such models create logical separation lines and stay compact. Success hinges on how well-crafted and useful the hand-picked features prove.

2.3 Deep Learning-Based Systems

Neural networks, especially CNNs and transformer designs, pull out layered patterns straight from photos. They are very good at finding hard-to-see disease marks and small differences. But these need a lot of marked-up images and powerful computers, as well as smart planning to avoid bias and overlearning.

2.4 Hybrid and Ensemble Strategies

Merging manual features with neural outputs boosts decision confidence. These combined systems draw clear thinking from old methods and strong pattern grasp from new ones, yielding better stability across mixed image sources.

3. Subsystem Analysis: The Diagnostic Framework

3.1 Data Collection

We gathered images from open sources like ISIC and DermNet, plus checked medical photos. The set covers wide

ranges of ages, skin shades, and condition types. Experts reviewed every image to confirm correct labels.

3.2 Preprocessing

Preparation steps sharpen and standardize photos. We apply brightness boosts, balance light spread, and clear noise to make disease edges stand out. Hair, shadows, and marks get removed through shape math and fill techniques. Photos change size to fit the model's needs, and they can also turn, mirror, zoom, and change tone to make them more flexible.

3.3 Feature Extraction and Model Design

Our method uses two main paths:

- 1) Classic feature pulls that measure color, texture, and form traits for basic classifiers.
- 2) Neural feature learning where CNNs or transformers find key patterns from raw photos. A mixed prediction blend from various models raises total dependability.

3.4 Training and Validation

We train the models using k-fold cross-validation to ensure they work well across different data splits. The learning rate, batch size, and number of layers are tuned carefully through repeated trials and performance checks. To prevent overfitting, we use techniques such as early stopping and model pruning, which help avoid memorizing the training data and encourage better generalization to unseen images.

3.5 Performance Evaluation

We evaluate the system's performance using commonly accepted metrics such as accuracy, recall, confusion matrix analysis, and the area under the ROC curve. In addition, we carry out fairness-oriented checks to see how consistently the model performs across different demographic groups, especially with respect to variations in skin tone and age.

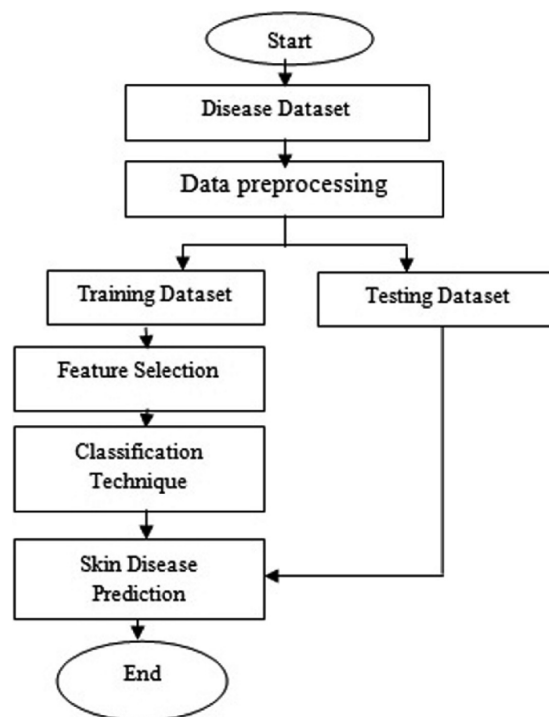


Figure 1. Model Flowchart

4. Challenges and Future Research Instructions

4.1 Persistent Challenges

Dataset Bias: Ensuring balanced representation of different skin tones and disease types, so that the model does not favor one group over others.

Computational Constraints: Achieving high accuracy while keeping the models small and fast enough to run on low-end devices or mobile platforms.

Interpretability: Explaining how deep learning models arrive at their decisions, so that doctors can understand and trust the predictions.

4.2 Future Research Imperatives

- Building trust-through-explanation AI tools for medical use. - Growing cross-hospital image pools for wider testing. - Tuning phone-friendly designs for remote areas. - Regular checks against changing skin care benchmarks.

5. Synthesis and Comparative Analysis

The system weaves classic and neural methods into one smooth process. Side-by-side tests show balances between speed and rightness. Simple models run on phones and small devices, while complex ones handle tough cases better.

Table 1. Proposed Model Methodology

Ref.	Approach	Model Type	Key Insight
[1]	DermIQ System	ML-Based	Validated on real clinical cases, showing consistent and dependable results
[2]	CNN-Based Model	Deep Learning	Effectively identifies skin lesions by learning meaningful patterns directly from images
[3]	HAM10000 Study	Deep Learning	A large and diverse dataset helps the model classify skin conditions more reliably
[4]	Hybrid Diagnosis	ML + DL	Performs better on cases where different diseases look visually similar
[5]	Cost-Effective Model	ML-Based	Designed to work well even in clinics with limited computing resources

6. Conclusion

This study details a full system for computer-aided skin condition spotting through image work and AI. Smart preparation, broad image sets, and mixed classic-neural models create solid, reachable help for diagnosis. Focus on evenness, easy rollout, and strict testing keeps the approach useful for everyday health care.

Acknowledgement

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References

- [1] S. Gupta and P. Mehra, "DermIQ: An Intelligent Skin Disease Detection System using Machine Learning," IEEE Xplore, 2025.
- [2] H. Wang and L. Zhou, "Advances in Intelligent Recognition and Diagnosis of Skin Scar using Artificial Intelligence," PubMed Central, 2025.
- [3] V. Reddy and A. Kumar, "Skin Disease Identification using CNN," IEEE Xplore, 2025.
- [4] G. Singh and S. Patel, "Artificial Intelligence of Medical Things for Disease Detection in Smart Healthcare," Wiley, 2024.
- [5] P. Agarwal and R. Joshi, "HAM10000 Skin Disease Detection and Classification using Deep Learning," IEEE Xplore, 2024.
- [6] L. Nair and S. Thomas, "Skin Disease Classification Using Deep Learning," JPTCP, 2024.
- [7] H. Basu and R. Desai, "Skin Disease Diagnosis System Using Machine and Deep Learning Algorithms," IEEE Xplore, 2024.
- [8] T. Pawar and V. Kadam, "Skin Disease Detection by Using Machine Learning," IRJMETS, 2024.
- [9] S. Choudhury and R. Mohanty, "Cost-Effective Image Based Skin Disease Detection in Clinical Settings," IEEE Xplore, 2023.
- [10] K. Bhatt and Y. Mishra, "Diagnosis of Skin Diseases in the Era of Deep Learning and Explainable AI," Elsevier/Computers in Biology and Medicine, 2023

Mechanical Performance of Surfactant Treated Carbon Fiber–Epoxy Composites

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Abstract: Carbon fiber–reinforced epoxy composites are vital for structural applications, yet their performance is often limited by poor interfacial bonding. This study investigates the influence of Triton X-100 surfactant treatment on the mechanical properties of short carbon fiber–epoxy composites. Fibers were treated with 1, 2, and 3 wt.% concentrations, and specimens were fabricated via compression molding at a 40% fiber volume fraction. Mechanical characterization was conducted per ASTM D3039 and ASTM D695 standards. Results show that 1 wt.% treatment optimized performance, achieving a tensile strength of 116 MPa—a 40.3% improvement over untreated samples (82.67 MPa)—while the elastic modulus remained stable at 2.0 GPa. Conversely, higher concentrations resulted in an excessive surfactant layer that degraded interfacial adhesion. This research provides a simple, cost-effective, and scalable methodology for industries such as aerospace and automotive manufacturing, enabling the production of high-strength, lightweight materials that reduce global energy consumption and enhance structural reliability in advanced engineering systems.

Keywords: Carbon fiber–epoxy composite; Triton X-100; Surfactant treatment; Tensile strength; Compressive strength; Fiber–matrix interface

1. Introduction

Carbon fiber reinforced polymer (CFRP) composites are becoming very popular in aerospace, automotive, and civil engineering due to their high strength, light weight, and good stiffness [1, 2]. However, one of the main problems in these composites is that load transfer between the carbon fiber and the epoxy matrix is not very efficient. When bonding at the fiber–matrix interface is poor, the composite fails early — usually by debonding or fiber pull-out — before the fibers can fully carry the applied load [2, 3].

The main reason for this poor bonding is the surface nature of carbon fibers. PAN-based carbon fibers have a smooth surface with low surface energy, which makes it difficult for the epoxy resin to spread and stick to the fiber properly. This results in a weak interface that limits the overall mechanical strength of the composite [2]. To improve this bonding, researchers have tried different surface treatment methods. Acid treatment using nitric acid can improve bonding but it also damages the fiber and reduces its strength. Plasma treatments are more gentle but require costly equipment and are difficult to scale up [3]. Chemical methods like silane coupling agents work well but make the fabrication process more complex. Surfactant-based treatments are a simpler and cheaper option. A surfactant is a chemical that reduces surface tension and helps liquids spread more evenly on surfaces. Triton X-100 is a common nonionic surfactant that has been used in a few studies to improve compatibility between fibers and epoxy [4, 5]. Research has shown that surfactant treatment can improve bonding and tensile performance in fiber-reinforced systems [5]. However, the amount of surfactant used is important — too little may not improve bonding enough, while too much can form a soft, weak layer at the interface that actually hurts performance [4].

Despite this, no study has clearly looked at Triton X-100 concentration as a controlled variable in carbon fiber–epoxy composites. Most studies use surfactants only as a processing aid and do not study how concentration directly affects tensile and compressive strength [6]. The present work tries to fill this gap by testing three concentrations — 1, 2, and 3 wt.% — and measuring how each one affects the mechanical properties of the composite.

2. Methodology

2.1 Materials

Carbon fibers were chosen as the reinforcement because of their high strength, high stiffness, and low weight. PAN-based chopped carbon fibers (SIGRAFIL® C, SGL Group) with a nominal chopped length of 6 mm were used. These fibers have an average diameter of about 7 μm , density of $\sim 1.8 \text{ g/cm}^3$, tensile strength of approximately 4 GPa, and elastic modulus of $\sim 240 \text{ GPa}$. All fibers were from the same batch to keep results consistent across all samples. A comparison of different fiber types commonly used in composites is given in Table 1.

Table No. 1 Comparison of reinforcement fibers

Property	Carbon Fiber	Glass Fiber	Steel Fiber	Aramid Fiber	Natural Fiber
Tensile strength (GPa)	$\sim 3.5\text{--}4.0$	~ 1.5	~ 2.5	~ 3.6	~ 0.5
Elastic modulus (GPa)	>240	~ 70	~ 210	~ 70	~ 20
Density (g/cm^3)	~ 1.8	~ 2.5	~ 7.8	~ 1.4	~ 1.3
Coefficient of friction	~ 0.33	~ 0.35	~ 0.40	~ 0.30	~ 0.45

Araldite LY556 epoxy resin was used as the matrix material because of its good adhesion properties and suitable mechanical strength — tensile strength of 75–80 MPa and elastic modulus of 2.8–3.3 GPa. An amine-based hardener was mixed in the manufacturer-recommended ratio for all specimens.

2.2 Fiber Surface Treatment

To improve bonding between fiber and matrix without damaging the fibers, a simple dipping process was used. Triton X-100 was dissolved in distilled water at 1, 2, and 3 wt.%. One batch of fibers was kept untreated as a reference. Before treatment, fibers were washed in acetone for 15 minutes to remove the manufacturer's sizing and any surface contamination, then rinsed with distilled water and air dried. This step ensured that surfactant concentration was the only variable affecting the interface. The cleaned fibers were dipped in their respective solutions for 30 minutes at room temperature ($23 \pm 2^\circ\text{C}$). After dipping, fibers were rinsed with deionized water and oven-dried at 60°C for 30 minutes. At higher concentrations (2 and 3 wt.%), more surfactant was found to remain on the fiber surface after drying, which as discussed in Section 3, negatively affected bonding quality.

2.3 Composite Fabrication

All composites were made by compression molding. The fiber-to-resin weight ratio was kept at 60:40 for all samples, giving a fiber volume fraction of about $40 \pm 2\%$. Four composite types were prepared: untreated (CE) and surfactant-treated at 1, 2, and 3 wt.% — CE-1S, CE-2S, and CE-3S respectively. The percentages refer only to the dipping solution concentration — Triton X-100 was not added directly into the resin.

Table No. 2 Composite types prepared

Composite ID	Fiber Treatment	Carbon Fiber (wt.%)	Epoxy (wt.%)
CE	Untreated	60	40
CE-1S	1 wt.% Triton X-100	60	40
CE-2S	2 wt.% Triton X-100	60	40
CE-3S	3 wt.% Triton X-100	60	40

Epoxy resin and hardener were weighed and properly mixed. Fibers were gradually added while stirring at low speed to avoid air bubbles and fiber breakage. The mixture was kept under vacuum ($\sim 0.08 \text{ MPa}$) for 10–15 minutes to remove any trapped air. It was then poured into pre-cleaned steel molds — cylindrical (10 mm dia \times 30 mm depth) for compression specimens and rectangular for tensile specimens — both coated with mold release agent. A pressure of 3 MPa was applied using a hydraulic press and maintained for the full 24-hour room temperature cure. Specimens were post-cured at 60°C for 30 minutes as per the epoxy manufacturer's recommendation.

2.4 Specimen Dimensions and Test Standards

Tensile specimens were rectangular bars of 250 mm \times 25 mm \times 3 mm with a gauge length of 150 mm, prepared as per ASTM D3039. Compression specimens were cylinders of 10 mm diameter and 30 mm length ($L/D = 3$), prepared as per ASTM D695. The L/D ratio of 3 was used to ensure stable axial loading without early buckling, which is commonly used for short-fiber composites at this scale. Three specimens per composite type were tested for both tensile and compressive loading.

2.5 Mechanical Testing

All tests were done on a Universal Testing Machine (UTM-PC-1000KN/S, Moiz Engineering Lab, Miraj, Maharashtra) at room temperature. Tensile tests were run at 2 mm/min crosshead speed. An axial extensometer was attached to the gauge section to measure strain. Young's modulus was taken from the straight-line portion of the stress–strain curve between 0.05% and 0.25% strain. Compression tests were also run at 2 mm/min following ASTM D695. Strength was calculated by dividing maximum load by the original cross-sectional area. All results are reported as the average of three specimens. Measurement uncertainty in strength values is within $\pm 3\text{--}5\%$.

3. RESULTS AND DISCUSSION

3.1 Tensile Properties

Tensile test results for all composite types are given in Table 3. The 1 wt.% treated composite (CE-1S) gave the highest tensile strength of 116.00 MPa — about 40.3% more than the untreated sample (82.67 MPa). Elongation at break also improved from 4.2% to 5.7%, meaning the composite stretches slightly more before it breaks, showing more ductile behavior compared to the untreated sample.

Table No. 3 Tensile properties of composites

Composite	Max. Load (N)	Tensile Strength (MPa)	Young's Modulus (GPa)	Elongation at Break (%)
CE (Untreated)	6200	82.67	1.97	4.2
CE-3S (3 wt.%)	7600	101.33	2.03	5.0
CE-2S (2 wt.%)	8100	108.00	1.96	5.5
CE-1S (1 wt.%)	8700	116.00	2.04	5.7

This improvement happens because the surfactant helps the epoxy resin spread more evenly over the fiber surface during mixing and molding. Better contact between resin and fiber creates a stronger bond at the interface. When tensile load is applied, this stronger bond allows the fiber to carry more stress before it separates from the matrix, which is why the composite fails at a much higher load. Beyond 1 wt.%, performance drops progressively. Higher concentrations leave more surfactant on the fiber surface after drying. This thick deposit forms a soft layer between fiber and matrix — instead of improving bonding, it acts like a barrier that reduces how much stress can be transferred from matrix to fiber.

3.2 Elastic Modulus

Young's modulus stays at approximately 2.0 GPa for all composites regardless of treatment level. This is expected because stiffness in short fiber composites depends mainly on the amount of fiber and how the fibers are arranged — not on the quality of the interface. Since all composites had the same fiber content and the fibers were randomly oriented, the stiffness did not change across conditions. The measured value of ~ 2 GPa is lower than what would be predicted for perfectly aligned fibers. This is simply because the fibers here are short (6 mm) and randomly oriented inside the composite. This is a known characteristic of compression-molded short fiber systems and does not affect the comparison between samples since all were made the same way.

3.3 Elongation at Break

Elongation at break improved from 4.2% (untreated) to 5.7% at 1 wt.% — an increase of about 36%. In the untreated composite, the weak interface causes sudden and brittle fracture — the composite breaks without much warning. With better bonding at 1 wt.%, small cracks that form during loading are slowed down by the fibers, which bridge across the crack and hold it from opening further. This means the composite takes more energy to completely break, which is a useful property for components that may face sudden or shock loads. Beyond 1 wt.%, elongation at break also drops, which follows the same trend as tensile strength — confirming that excess surfactant deposits reduce interface quality.

3.4 Compressive Properties

Compressive test results are given in Table 4. The 1 wt.% treated composite showed about 40% higher compressive strength than the untreated one. Under compression, the matrix needs to hold the fibers in place and prevent them from bending sideways — a failure mode called micro-buckling.

Table No. 4 Compressive properties of composites

Composite	Max. Load (N)	Compressive Strength (MPa)	Young's Modulus (GPa)	Strain at Failure (%)
CE (Untreated)	4960	63.2	2.01	3.15
CE-3S (3 wt.%)	6080	77.1	2.06	3.75
CE-2S (2 wt.%)	6480	82.54	2.00	4.13
CE-1S (1 wt.%)	6960	88.7	2.07	4.28

If the interface is weak, the matrix cannot provide enough support and fibers buckle at lower loads. Better bonding at the 1 wt.% condition improves this lateral support, allowing the composite to carry higher compressive loads before failure. Elastic modulus again remains constant, consistent with tensile results.

4. Conclusion

This study successfully demonstrates that the interfacial adhesion of short carbon fiber–epoxy composites can be significantly optimized through a controlled aqueous surfactant treatment. The experimental data confirms that a 1 wt.% concentration of Triton X-100 serves as the optimal threshold, facilitating a 40% increase in both tensile and compressive strengths, with tensile values peaking at 116.00 MPa. Furthermore, the 36% improvement in elongation at break suggests a transition toward enhanced energy absorption, effectively mitigating the brittle failure characteristics inherent in untreated carbon fiber composites. The stability of the elastic modulus at approximately 2.0 GPa across all test groups indicates that these mechanical gains are strictly a function of improved fiber–matrix bonding rather than morphological changes in the fiber arrangement. Conversely, higher surfactant concentrations (2 wt.% and 3 wt.%) were found to be counterproductive, as the resulting surfactant residue creates a compliant interphase that obstructs efficient load transfer. Ultimately, the room-temperature, water-based treatment protocol presented herein offers a scalable and non-destructive methodology for enhancing composite performance, making it a viable candidate for standard industrial manufacturing processes.

To deepen the understanding of the underlying micromechanical phenomena, subsequent research should prioritize fractographic analysis via Scanning Electron Microscopy (SEM) to visualize the quality of the interfacial bond and fiber pull-out characteristics. Additionally, contact angle goniometry is recommended to quantify the alterations in fiber surface energy and wettability. Further investigations into the fatigue life and performance stability of these treated composites under varied hydrothermal aging conditions will be essential to validate their reliability for long-term structural applications.

References

- [1] G. Biresaw, H. F. Wu, and J. T. Laemmle, "Application of Surfactants for Promoting Interfacial Adhesion in Polymer Matrix Composites," in *Controlled Interphases in Composite Materials*, Springer, pp. 431–439, 1990.
- [2] J. Li, "Effect of Surface Modification with Nitric Acid on the Mechanical and Tribological Properties of Carbon Fiber-Reinforced Thermoplastic Polyimide Composite," *Surf. Interface Anal.*, vol. 41, no. 9, pp. 759–763, 2009.
- [3] N. A. Siddiqui et al., "Manufacturing and Characterization of Carbon Fibre/Epoxy Composite Prepregs Containing Carbon Nanotubes," *Compos. Part A*, vol. 42, no. 10, pp. 1412–1420, 2011.
- [4] J. G. Parra et al., "Effect of Triton X-100 Surfactant on the Interfacial Activity of Epoxy/Graphene Oxide Composites," *J. Colloid Interface Sci.*, vol. 577, pp. 1–8, 2020.
- [5] M. Dehghan et al., "Surfactant-Assisted Dispersion of MWCNTs in Epoxy Resin Used in CFRP Strengthening Systems," *J. Adhes.*, vol. 91, no. 6, pp. 461–480, 2015.
- [6] X. Peng, Y. Wu, and Z. Wei, "Research Progress on Surface Modification of Carbon Fiber," *RSC Adv.*, vol. 14, pp. 4043–4064, 2024.
- [7] S.-S. Yao et al., "Recent Advances in Carbon-Fiber-Reinforced Thermoplastic Composites: A Review," *Compos. Part B*, vol. 142, pp. 241–250, 2018.
- [8] Q. Wu, R. Zhao, J. Zhu, and F. Wang, "Interfacial Improvement of Carbon Fiber Reinforced Epoxy Composites by Tuning the Content of Curing Agent in Sizing Agent," *Applied Surface Science*, vol. 504, 144384, 2019.
- [9] J.-H. Joo et al., "Interfacial Interlocking of Carbon Fiber-Reinforced Polymer Composites: A Short Review," *Polymers*, vol. 17, no. 3, 267, 2025.
- [10] S. Lin, "Enhancing Interfacial Bonding and Mechanical Properties of Carbon Fiber Reinforced Epoxy Composites," *Composite Structures*, 2025.



Design and Development of a Pedal Operated Hydraulic Sheet Bending Machine

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Abstract: Sheet metal serves as a fundamental material in the global fabrication industry, critical to the manufacturing of industrial machinery, structural frameworks, and specialized hardware. Among the various fabrication processes, bending remains a pivotal operation; however, conventional methodologies often rely on manual mechanical systems that necessitate high physical exertion and the synchronized effort of multiple operators. This research details the design and engineering of a pedal-operated hydraulic sheet bending machine developed to optimize operational throughput, angular precision, and workplace safety. By integrating a hydraulic actuator with a pedal-triggered relay interface, the system facilitates autonomous, hands-free operation by a single technician. Empirical observations indicate that this transition to hydraulic actuation significantly enhances productivity metrics while concurrently reducing labor dependency and human-induced operational variances.

Keywords: Sheet metal bending, hydraulic systems, pedal-actuated control, industrial fabrication, automation, bending precision.

1. Introduction

Sheet metal fabrication serves as a foundational pillar in modern manufacturing, encompassing diverse processes such as cutting, forming, and bending to produce components for both industrial and domestic sectors. Among these operations, bending is particularly critical, as it dictates the dimensional integrity and functional utility of the final product. Historically, conventional sheet bending apparatuses have relied on manual wheel-and-screw mechanisms. These legacy systems typically necessitate the coordination of at least two operators, a dependency that frequently introduces synchronization errors, protracted operational cycles, and inconsistent angular precision.

To address these systemic inefficiencies, there is an urgent industrial mandate for a more streamlined, user-centric fabrication interface. This research proposes the development of a pedal-operated hydraulic sheet bending machine designed to facilitate autonomous, single-person operation. By integrating hydraulic actuation with a foot-controlled trigger, the system aims to optimize mechanical force distribution while significantly enhancing ergonomic safety and precision in the bending process.

2. Literature Review

The evolution of sheet metal bending technology has been extensively documented, with contemporary research increasingly prioritizing automation and hydraulic integration to mitigate human error and labor intensity. Babu et al. [1] investigated hydraulically operated systems, emphasizing the transition from manual hammering to controlled hydraulic force to improve workplace safety. Their findings underscored that the quality of the bend is heavily contingent upon specific design parameters, including punch radius and the management of the spring-back effect. Similarly, Kulkarni et al. [3] conducted a comparative analysis between manual and power-operated systems, concluding that manual methodologies are inherently limited by low productivity and high physical strain, whereas automated alternatives offer superior consistency.

The technical architecture of hydraulic circuits—comprising pumps, reservoirs, and precision cylinders—has been validated as an efficient medium for converting hydraulic energy into high-magnitude mechanical force [2]. Research by Bahirat et al. [2] confirms that such systems are viable for single-operator use, provided that the hydraulic integrity is maintained through rigorous leak-prevention protocols. Furthermore, force analysis studies have been pivotal in understanding material deformation and stress distribution. Patel et al. [5] examined the structural stability of bending machines, noting that minimizing angular deflection and optimizing ram movement are essential for achieving high-precision industrial outputs.

Further advancements have sought to refine the efficiency of these systems through component optimization. Du and Jin [4] proposed modifications to hydraulic configurations to enhance operational reliability and safety. More recently, Wibowo and Hidayat [7] explored automatic press brake sections to further remove human variability from the fabrication cycle. Despite these advancements, a synthesis of existing literature reveals a significant research gap: while hydraulic automation is well-established, there is a distinct lack of focus on pedal-operated, hands-free control mechanisms tailored for small-scale applications. Current industrial solutions often overlook operator ergonomics and the need for low-cost, single-operator systems that do not sacrifice precision for affordability [6], [7]. This study addresses these deficiencies by introducing a pedal-actuated hydraulic framework optimized for ergonomic efficiency and high-fidelity bending.

3. Methodology

3.1 System Design and Integration

The architectural framework of the proposed system centers on the seamless integration of a high-pressure hydraulic circuit with a localized pedal-actuated control interface. This design philosophy prioritizes the optimization of force transmission vectors while maintaining a user-centric operational profile. By utilizing a mechanical-to-electrical relay interface, the system ensures that the magnitude of hydraulic pressure is precisely modulated, providing the structural rigidity necessary for heavy-duty deformation tasks without compromising the delicacy of the control mechanism.

3.2 Operational Working Principle

The operational sequence initiates with the strategic alignment of the sheet metal substrate upon the primary bending tool. Upon actuation of the foot pedal, a signal is transmitted to a dedicated relay system, which serves as the primary switch for the hydraulic power unit's motor. This activation facilitates the displacement of hydraulic fluid from the reservoir into the cylinder under regulated pressure.

As the fluidic pressure accumulates, the hydraulic cylinder facilitates the linear progression of the piston assembly. The downward stroke of the piston exerts a calculated compressive force, pressing the workpiece against the stationary bending tool to achieve the specified angular deformation. The process is characterized by an immediate cessation of force upon the release of the pedal, ensuring real-time operational feedback and preventing over-extension of the material.

4. Technical Specifications and System Components

The structural and functional integrity of the machine is supported by a robust assembly of industrial-grade components. The core force-generation unit comprises a high-capacity hydraulic cylinder, interconnected via a network of reinforced hydraulic piping and precision fittings. Control logic is managed through a relay driver assembly, which interfaces with the motor to regulate fluid dynamics.

The physical shaping of the material is facilitated by the bending tool and Y-block assembly, both of which are mounted on a high-tensile base plate. Structural stability during high-pressure cycles is maintained by a framework consisting of holding rods, supporting bars, and a rigid supporting frame. The entire apparatus is secured through a series of heavy-duty mounts, joints, and high-grade fasteners (screws and bolts), ensuring that the system remains vibration-resistant during continuous operation

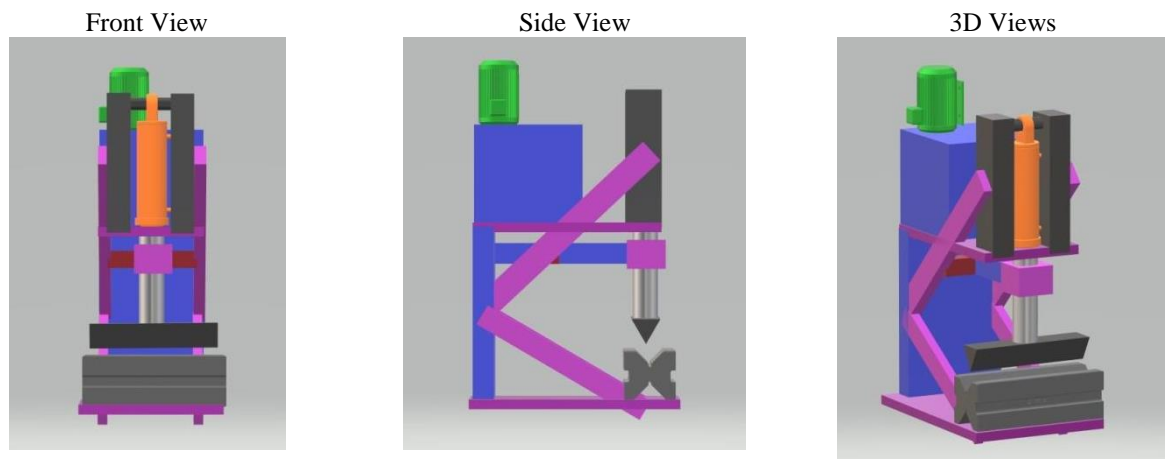


Fig. 1 Pedal Operated Hydraulic Sheet Bending Machine

5. Results and Discussion

The empirical evaluation of the developed system demonstrates a substantial paradigm shift in performance metrics compared to traditional manual bending apparatuses. By leveraging hydraulic actuation, the system achieves a higher rate of operational throughput, effectively neutralizing the mechanical lags inherent in purely manual systems. Precision is significantly bolstered by the integration of a stable holding mechanism and controlled force application, which mitigates the volatility of human error during the bending process. Furthermore, the ergonomic transition to a pedal-operated interface optimizes labor distribution, allowing a single operator to manage the entire workflow. This hands-free control mechanism is pivotal not only for enhancing safety by isolating the operator's extremities from the compression zone but also for allowing total cognitive focus on the spatial positioning of the workpiece. Consequently, the machine yields superior angular consistency and output uniformity across repetitive cycles.

6. Comprehensive Advantages and Limitations

The technical superiority of this hydraulic system is characterized by a multifaceted increase in industrial productivity and a concurrent reduction in operational overhead. Beyond the quantifiable gains in bending precision, the system facilitates a marked decrease in operator fatigue, thereby sustaining high performance levels over extended shifts with minimal manpower requirements. However, the transition to hydraulic integration introduces specific constraints that must be acknowledged. The initial capital expenditure for system deployment exceeds that of conventional manual machines, and the operational longevity is contingent upon the rigorous maintenance of hydraulic seals and fluid integrity. Additionally, the system's reliance on a stable power supply renders it sensitive to infrastructure fluctuations, a factor that must be considered in varied industrial environments.

7. Industrial Applications and Scope

The versatility of the pedal-operated hydraulic bending machine positions it as a critical asset across a broad spectrum of manufacturing sectors. Its primary utility is observed in heavy fabrication industries and automotive body workshops, where precision and repeatability are non-negotiable. Furthermore, the system's ability to handle diverse gauges of sheet metal makes it an ideal solution for metal furniture manufacturing and the production of structural components such as gates and grills. Given its favorable balance of efficiency and footprint, the technology is particularly well-suited for small and medium-scale industries (SMEs) seeking to modernize their production lines without the spatial or financial demands of fully automated heavy machinery.

8. Conclusion and Future Directions

In summary, the pedal-operated hydraulic sheet bending machine successfully bridges the gap between manual labor and industrial automation. By synthesizing hydraulic power with a refined pedal-actuated control logic, the research demonstrates an optimized methodology for sheet metal processing that prioritizes safety, accuracy, and labor efficiency. While the current iteration represents a significant advancement, the future scope of this research involves the integration of sophisticated sensing technologies for real-time, closed-loop angle measurement. Further development could incorporate Computer Numerical Control (CNC) frameworks and energy-efficient hydraulic recovery systems to further minimize the carbon footprint and maximize the precision of the fabrication process.

References

- [1] T. V. B. Babu, Bhuvaneshwar S., Deva Abraham J., and Ruban R., "Hydraulically Operated Sheet Bending Machine," *International Journal of Novel Research and Development*, vol. 7, no. 7, pp. 516–521, 2022.
- [2] S. Bahirat, O. Bhatawadeka, and G. Gharte, "Hydraulic Sheet Metal Bending System," *Journal of Science & Technology*, vol. 5, no. 3, pp. 251–257, 2020.
- [3] A. Kulkarni, M. Pawar, P. Yadav, A. Patil, and S. Malgave, "Sheet Metal Bending Machine," *International Journal of Innovations in Engineering Research and Technology*, 2021.
- [4] Q. Du and L. Jin, "Improved Design of Hydraulic Bending Machine," *Asian Journal of Chemistry*, vol. 26, no. 11, pp. 3347–3350, 2014.
- [5] R. Patel, T. Vagharia, K. Kotadiya, and R. Vaghani, "Design, Modification and Analysis of Sheet Metal Bending on Bending Machine," *International Journal of Science and Research*, vol. 8, no. 2, pp. 819–820, 2019.
- [6] M. Kumar V., A. Kumar N., H. B. S., N. Kumar K. N., and N. T. K., "Design and Fabrication of Pneumatic Sheet Metal Cutting and Bending Machine," *International Journal of Engineering Research and Advanced Technology*, 2016.
- [7] H. Wibowo and H. N. Hidayat, "Design and Manufacture of Automatic Sheet Metal Bending Machine Tools in the Press Brake Section," *Journal of Applied Mechanical Engineering Innovation*, 2024.

Solar-Powered Thermoelectric Cabin Cooling for Parked Passenger Vehicles: A Comprehensive Review

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Abstract: Solar-induced cabin overheating in parked cars is a persistent thermal comfort and safety problem, especially in hot and tropical climates. Conventional automotive HVAC systems based on vapour-compression cycles are inoperative when the engine is switched off and rely on refrigerants with non-negligible environmental impact. Solar thermoelectric cooling (TEC), which couples photovoltaic (PV) power generation with solid-state Peltier modules, has emerged as a compact, low-maintenance, and environmentally benign alternative for maintaining acceptable cabin temperatures when the vehicle is parked. This review synthesizes the fundamental thermoelectric phenomena, system architecture, and design methodologies relevant to TEC-based automotive cooling. It examines global research trends, prototype developments, and experimental studies on PV-driven thermoelectric refrigeration for vehicular and small-scale applications. Particular emphasis is placed on thermal load analysis of parked cars, heat exchanger design, electrical integration, and control strategies. The performance limitations of current Bi₂Te₃-based modules, including low coefficient of performance (COP) and constrained heat pumping capability, are critically discussed. The review further outlines the advantages, practical applicability, and future research directions such as high-ZT materials, hybrid PV-TEC-ventilation systems, and intelligent control. Overall, solar thermoelectric cooling is identified as a promising supplementary solution for moderating cabin temperatures in parked vehicles, rather than a full replacement for conventional automotive HVAC systems.

Keywords: Solar thermoelectric cooling (TEC), photovoltaic (PV)

1. Introduction

The thermal environment inside a parked vehicle can deteriorate rapidly under solar radiation. Numerous experimental investigations have shown that, under high insolation, the cabin air temperature can exceed 55–70 °C within 20–60 minutes, even when the ambient temperature is comparatively moderate [1–3]. This excessive heat buildup not only causes severe discomfort to occupants upon re-entry but also poses serious safety risks to children, pets, and vulnerable persons inadvertently left inside vehicles. In addition, high cabin temperatures accelerate the degradation of interior polymers, textiles, and electronic modules, thereby affecting durability and perceived quality [4].

Conventional automotive air-conditioning systems rely on vapour-compression refrigeration driven via the engine crankshaft or an electric compressor in hybrid and battery electric vehicles. When the ignition is switched off, these HVAC systems are typically disabled to prevent battery discharge or fuel wastage. As a result, there is no active cooling available during parking, precisely when solar load is often the maximum. Passive mitigation strategies such as reflective sunshades, tinted glazing, and natural or forced ventilation can reduce cabin temperature rise to some extent but often fail to maintain temperatures within a comfortable range under peak solar load [5–7]. In this context, thermoelectric cooling (TEC) represents an attractive alternative. TEC devices operate on the Peltier effect and are solid-state, with no moving mechanical parts, lubricants, or refrigerants. They can be powered directly by low-voltage DC sources such as the vehicle's auxiliary battery or a dedicated solar photovoltaic (PV) panel mounted on the roof or rear parcel shelf [8,9]. This makes solar-TEC systems particularly suitable for autonomous operation when the car is parked, without dependence on the main engine or high-voltage traction systems.

From a mechanical engineering perspective, solar thermoelectric car cooling is a multidisciplinary problem involving heat transfer, thermodynamics, solid-state physics, power electronics, and system integration. The designer must simultaneously address thermal load estimation, module selection, heat exchanger design, airflow management, structural packaging, and control algorithms [10–12]. The limitations of commercially available TEC modules, especially their relatively low coefficient of performance (COP) compared to vapour-compression systems,

necessitate careful optimization of every subsystem to achieve meaningful cabin temperature reduction with modest power input [13–15].

Recent research has demonstrated the feasibility of PV-powered thermoelectric refrigerators and spot cooling devices for medical storage, rural cold chain, and electronic equipment [16–18]. Similar design philosophies can be translated to automotive cabin cooling, where the objective is not to reach conventional HVAC comfort levels (e.g., 22–26 °C) but to limit the cabin temperature rise relative to ambient. Prototypes integrating TEC modules with aluminium heat sinks, low-power DC blowers, microcontroller-based temperature control (e.g., using Arduino and DHT11 sensors), and small PV panels have shown promising results for localized or partial cooling in enclosed spaces [19–21].

The objective of this review is to present a structured and technically rigorous synthesis of solar thermoelectric cooling for cars in parking or when the vehicle is off. The article first recapitulates the fundamentals of thermoelectric phenomena and material behaviour. It then describes typical architectures of solar-TEC systems for automotive applications, including PV, storage, TEC modules, and control hardware. A detailed review of global research and prototype developments is provided, followed by an analysis of thermal loads in parked vehicles. Subsequently, performance limitations, challenges, advantages, and potential future directions are discussed. The review is written from the standpoint of a mechanical engineering student, with emphasis on design considerations, engineering trade-offs, and practical feasibility for real-world automotive applications.

2. Fundamentals of Thermoelectric Phenomena

Thermoelectric devices exploit the coupling between heat and charge transport in solid conductors and semiconductors. Three classical effects describe this coupling: the Seebeck effect, the Peltier effect, and the Thomson effect. Understanding these phenomena is essential for rational design of thermoelectric cooling systems for automotive applications. The Seebeck effect describes the generation of an electromotive force (EMF) when a temperature gradient is imposed across a junction or loop of dissimilar conductors or semiconductors. The Seebeck coefficient, S (V/K), quantifies the magnitude of generated voltage per unit temperature difference. This phenomenon forms the basis for thermocouples and thermoelectric generators (TEGs), where waste heat is converted directly into electrical energy [22]. The Peltier effect is the converse phenomenon: when an electric current flows across a junction of two dissimilar conductors, heat is either absorbed or released at the junction, depending on current direction. The Peltier coefficient, II (V), relates the rate of heat transfer to the electric current. In a practical thermoelectric cooler (TEC), multiple p–n semiconductor couples are connected electrically in series and thermally in parallel between two ceramic plates. When DC current flows, one side becomes cold (absorbing heat from the environment), and the opposite side becomes hot (rejecting heat to the surroundings) [23,24]. The Thomson effect refers to the absorption or release of heat when current passes through a homogeneous conductor with a temperature gradient. Although conceptually important, the Thomson effect is usually incorporated implicitly in the constitutive equations and is less prominent in engineering design compared to Seebeck and Peltier effects [25].

In a TEC module, the net cooling capacity at the cold side, Q_c , is commonly expressed as:

$$Q_c = \alpha IT_c - \frac{1}{2} I^2 R - K(T_h - T_c) \quad \dots(1)$$

where S is the effective Seebeck coefficient, I is the current, T_c and T_h are cold- and hot-side temperatures, R is electrical resistance, and K is the thermal conductance between hot and cold sides [26]. The first term represents Peltier cooling, the second term Joule heating within the module, and the third term parasitic heat conduction from hot to cold side. The electrical input power, $P = IV$, and heat rejected at the hot side, $Q_h = Q_c + P$, must be managed through an adequate heat sink.

The performance of a thermoelectric material is characterized by the dimensionless figure of merit ZT :

$$ZT = \frac{S^2 \sigma T}{\kappa} \quad \dots(2)$$

Where S is Seebeck coefficient, σ is electrical conductivity, T is absolute temperature, and κ is thermal conductivity [27]. High ZT requires a combination of large Seebeck coefficient, high electrical conductivity, and low thermal conductivity—an unusual combination that poses a materials engineering challenge. Commercial TEC modules are typically based on bismuth telluride (Bi_2Te_3) and its alloys, with ZT near room temperature [28]. Emerging materials, such as skutterudites, half-Heusler compounds, and nanostructured composites, have demonstrated higher ZT values in laboratory conditions but are not yet widely commercialized [29,30].

3. Architecture of Solar Thermoelectric Systems in Automobiles

A solar thermoelectric cooling system for parked cars integrates multiple subsystems: the photovoltaic (PV) power supply, energy storage and power conditioning, thermoelectric modules and heat exchangers, airflow devices, and sensing and control electronics. From a systems engineering perspective, the objective is to design an architecture that can autonomously maintain cabin temperatures below a specified threshold using limited solar-derived electrical power [31–33].

3.1 Photovoltaic Subsystem

The PV subsystem typically consists of mono- or polycrystalline silicon modules mounted on the vehicle roof or rear parcel tray. The modules convert solar irradiance into DC power with an efficiency between 15–22% [34]. For a compact car roof, the usable area may allow an installed PV capacity of 50–200 W_p under ideal conditions, but many proof-of-concept systems for TEC cooling operate with smaller panels in the 5–50 W range [16,19]. The PV output is inherently variable, depending on insolation, panel orientation, shading, and cell temperature. Therefore, a charge controller is usually employed to manage power flow to a low-voltage auxiliary battery (e.g., 12 V lead–acid or Li-ion) that buffers energy and supplies the TEC modules and fans.

3.2 Thermoelectric and Heat Exchanger Subsystem

The thermoelectric subsystem typically uses one or more commercial TEC modules (e.g., TEC1-12706, TEC1-12715) sandwiched between a cold-side and hot-side heat sink. The cold-side heat sink, usually a compact aluminium finned block, is placed in a duct where cabin air is drawn over the fins by a DC blower or axial fan. The hot-side heat sink, with greater fin area and often an additional fan, rejects heat to the external ambient. Thermal interface materials such as silicone-based thermal paste are used at both interfaces to reduce contact resistance and improve conduction [19,21].

In automotive implementations, packaging constraints are severe. The TEC assembly may be integrated into existing HVAC ducting, the rear parcel shelf, or a dedicated compact module that draws in cabin air and exhausts outside. The airflow path must be optimized to minimize pressure drop while ensuring sufficient convective heat transfer coefficients at both cold and hot sides [35,36].

3.3 Power Electronics and Control

The proposed electrical architecture integrates renewable energy generation with intelligent thermal control to ensure autonomous operation. The power stage is comprised of a Photovoltaic (PV) module interfaced with a charge controller, which regulates the energy flow to an auxiliary battery for consistent energy storage. To maintain voltage compatibility across the system, DC–DC converters are employed, specifically when the operational voltage of the Thermoelectric Cooler (TEC) modules deviates from the battery’s nominal output. Centralized control is facilitated by a microcontroller, such as the Arduino Nano, which processes real-time environmental data acquired from temperature and humidity sensors, including DHT11 modules and NTC thermistors. This controller manages the actuation of the TEC modules and cooling fans through high-frequency solid-state or electromagnetic relays. This integrated circuit design ensures precise thermal regulation while optimizing the energy efficiency of the refrigeration cycle.

The microcontroller reads cabin temperature and possibly humidity, compares it to predefined thresholds (e.g., 35–40 °C), and activates the TEC modules and fans when required. Simple control can be implemented as ON–OFF hysteresis, whereas more advanced schemes may employ PWM current modulation or proportional control to balance cooling performance with power consumption [37,38].

3.4 System Integration in Vehicles

Integrating TEC hardware into a car requires attention to vibration loads, environmental sealing, noise, and safety. The module must tolerate thermal cycling, dust, moisture, and possible condensate formation on the cold surfaces. The wiring should be fused appropriately to prevent overcurrent, and the system should be designed to fail safe without draining the vehicle’s main battery. For OEM integration, the vehicle’s body control module (BCM) could potentially supervise the solar-TEC subsystem, but for retrofit student or research projects, an independent controller is often preferred [39]. Overall, the architecture of a solar-TEC automotive cooling system is constrained by limited available power, low COP, and strict packaging, which motivates highly efficient heat exchanger design, low-friction ducting, and intelligent control to maximize benefit from modest cooling capacity.

4. Review of Global Research and Prototype Developments

Research on thermoelectric systems has expanded significantly over the past two decades, with applications in waste heat recovery, electronics cooling, portable refrigeration, and niche HVAC solutions. In the context of solar-powered thermoelectric cooling for enclosures and vehicles, several notable experimental and analytical works can be identified.

Saidur et al. investigated a standalone photovoltaic-driven thermoelectric refrigerator for domestic applications, demonstrating that a compact TEC-based unit powered by PV and battery storage can maintain temperatures suitable for food preservation and vaccine storage [2]. Their work emphasized the importance of proper PV sizing, optimal tilt angles, and battery capacity to ensure day–night operation. Rawat et al. performed experimental analysis on a thermoelectric refrigeration prototype and found that operating at approximately half the maximum rated current of the TEC yields a favourable balance between cooling capacity and COP [3]. Singh et al. reviewed thermoelectric generators and discussed potential integration with various renewable sources, highlighting that the same materials and device technologies underpin both power generation and cooling applications [1]. Vardhan et al. developed a dual-purpose PV-driven thermoelectric refrigerator for rural India, underscoring the suitability of TEC devices for decentralized, off-grid scenarios [4].

More specific to vehicular or small-enclosure cooling, several prototypes have been built that resemble, in architecture, the car cooling system considered in this review. Koetzsch and Madden compared thermoelectric cooling to conventional cooling in industrial enclosures and concluded that TECs can be competitive for low-to-moderate heat loads where CFC-free operation and low maintenance are valued [40]. Bulat and Nekhoroshev examined thermoelectric units for refrigerated truck bodies and showed that, under certain conditions, thermoelectric cooling units can be cost-competitive and mechanically simpler than vapour-compression systems for small capacities [41]. For personal cooling in automotive or helmet applications, Buist and Streitwieser and later Bartlett and Sukuse developed TEC-based cooling helmets powered by low-voltage supplies, obtaining measurable local temperature reductions around the head [42,43]. These studies demonstrate the strong potential of spot cooling, which is conceptually aligned with localized cabin cooling near occupants or critical components.

In recent years, several authors have presented designs of thermoelectric air conditioners for cars, often as student or prototype projects. Typical designs employ TEC modules sandwiched between aluminium heat sinks, driven by 12 V DC, with either direct connection to the vehicle battery or through a PV–battery combination [19,21,44]. Microcontrollers such as Arduino are used to read temperature and actuate relays that switch TEC modules based on cabin temperature thresholds. Experimental tests generally report reductions of several degrees Celsius in localized air temperature when compared to baseline conditions without active cooling. On the modelling side, various researchers have proposed analytical or numerical models of TEC-based HVAC systems. Tan and Fok developed methodologies for selecting appropriate TEC modules based on required ΔT , heat load, and operating current [31]. Others have coupled TEC performance models with CFD simulations of airflow and heat transfer in ducts and enclosures to optimize fin geometry, fan placement, and flow rate [35,36,45]. While only a limited number of works focus explicitly on solar-TEC systems for parked cars, several studies on PV-powered TEC cabinets, vaccine carriers, and rural refrigerators provide directly transferable design insights. Common conclusions include: (i) the necessity of highly efficient hot-side heat rejection, (ii) the benefit of multi-stage TECs for higher ΔT at the cost of reduced COP, and (iii) the need for careful power management in PV–battery systems [17,18,46,47].

In summary, global research indicates that TEC-based cooling is most effective when applied to small volumes or for spot cooling. Translating these findings to automotive applications suggests that solar-TEC systems can be realistically expected to moderate cabin temperatures and protect sensitive components, rather than deliver full-scale comfort cooling equivalent to conventional HVAC.

5. Thermal Load Analysis of Parked Cars

Thermal load analysis is a prerequisite for designing any automotive cooling system, including TEC-based solutions. When a vehicle is parked under solar radiation, the cabin behaves as a semi-closed, transient thermal system subjected to radiative, convective, and conductive heat gains. The dominant contributions are direct and diffuse solar radiation transmitted through windows, absorption of solar energy by the opaque body panels and roof, and conduction of heat through the vehicle structure into the cabin [6,7,48].

For the design of a TEC-based system, the relevant thermal load is not the entire peak heat gain but the portion that must be offset to maintain the cabin temperature below a chosen limit (e.g., 40–45 °C). This desired setpoint reduction, typically 5–15 °C relative to the uncontrolled case, allows the designer to estimate the required cooling capacity Q_c of the TEC modules. Given the low COP and finite PV power, it is often advantageous to target partial volumetric cooling (e.g., occupant headspace region) or to combine TEC with enhanced ventilation to reduce effective thermal load [48,49].

6. Performance Limitations and Challenges

The primary technical limitation of thermoelectric cooling compared to vapour-compression refrigeration is its relatively low coefficient of performance (COP). Typical commercial TEC modules operating at moderate temperature differences exhibit COP values between 0.3 and 0.7, whereas automotive vapour-compression systems can achieve COPs of 2.5–4 under favourable conditions [13,26]. This implies that significantly more electrical input is required per unit of cooling capacity, a critical constraint when relying on limited PV power. Furthermore, TEC modules simultaneously pump heat and generate Joule heat internally, which must be removed at the hot side. If the hot-side heat sink is undersized or inadequately ventilated, its temperature rises, reducing the effective (ΔT) capability and thus the net cooling at the cold side. In extreme cases, the module can overheat, leading to performance degradation or failure [31,35]. Designing a compact yet highly effective hot-side heat exchanger for integration into a vehicle body panel is therefore a non-trivial challenge.

Another limitation arises from material properties. Commercial Bi_2Te_3 -based TECs are optimized near room temperature and can suffer performance loss at elevated hot-side temperatures above approximately 80–100 °C. Under strong solar load and high ambient temperatures, the external environment around the hot-side heat sink may already be warm, requiring even more efficient convection to maintain acceptable module temperatures [28,30]. On the electrical side, PV power availability is inherently intermittent. Cloud cover, shading from buildings or trees, and variations in solar altitude cause significant fluctuations in power generation. A battery buffer alleviates this to some extent, but battery capacity is usually limited in retrofit systems, and vehicle OEMs are cautious about additional parasitic loads on the existing electrical architecture [34,39].

Finally, from a system integration perspective, packaging constraints, additional weight, cost, and potential reliability concerns (e.g., condensation at the cold side leading to corrosion or mold) must be addressed before solar-TEC systems can be adopted in production vehicles at scale.

7. Advantages and Applicability for Future Vehicles

Despite the aforementioned limitations, solar thermoelectric cooling offers several compelling advantages that make it attractive for specific automotive applications. First and foremost, TEC devices are solid-state and contain no moving mechanical parts. This leads to low vibration, silent operation, and minimal maintenance requirements, all highly desirable attributes in the confined environment of a car cabin [23,24].

Secondly, TEC systems are inherently refrigerant-free. They do not use chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), or other high global warming potential (GWP) working fluids associated with vapour-compression HVAC systems. This aligns well with increasingly strict environmental regulations and the automotive industry's push toward low-GWP solutions [14,50]. Thirdly, TEC modules are electrically reversible; simply reversing the polarity changes the direction of heat pumping. This allows the same hardware to be used for supplemental heating in cold climates, though the core focus of this review is cooling. The compact and lightweight nature of TEC assemblies also allows flexible placement within the cabin, making them suitable for spot cooling (e.g., around the driver's seat, child seat area, or electronic control modules) rather than whole-cabin conditioning [42,43]. Integration with PV panels provides an elegant way to power the system using renewable energy. Since the maximum thermal load on a parked car coincides with high solar irradiance, solar-TEC systems exploit a natural synergy between energy availability and cooling demand. For electric vehicles, which already emphasize energy efficiency and often feature large roof surfaces, solar-TEC solutions could play a role in reducing cabin pre-conditioning loads and preserving traction battery energy [34,51].

In the near term, the most practical applicability of solar thermoelectric cooling in vehicles is as a supplementary system: moderating cabin temperatures during parking, protecting sensitive electronics, preventing extreme heat exposure, and improving initial comfort upon re-entry. For OEMs and aftermarket developers, these benefits can be realized with comparatively simple, low-voltage hardware that does not interfere significantly with the main HVAC architecture.

8. Future Research Opportunities

Future research on solar thermoelectric vehicle cooling can be organized along four interrelated axes: materials, system architecture, thermal management, and control intelligence.

On the materials front, ongoing advancements in high-ZT thermoelectric compounds, including nanostructured Bi_2Te_3 , skutterudites, and half-Heusler alloys, promise higher efficiency and greater cooling capacity for a given input power [29,30,52]. Translating these laboratory-scale materials into reliable, cost-effective commercial modules suitable for automotive environments remains an open challenge but could dramatically improve TEC viability. In

terms of system architecture, hybrid configurations combining TEC with other passive or active strategies appear promising. Examples include pairing TEC modules with phase-change materials (PCMs) that store cold during off-peak periods, or using TEC for dehumidification while conventional or evaporative systems provide sensible cooling [53,54]. Hybrid PV–TEC–ventilation systems, where solar-powered fans enhance airflow while TEC units provide localized cooling, may yield better overall performance than TEC alone for a given PV capacity [55]. Thermal management research can focus on optimizing heat sink geometries, fin spacing, and airflow paths using computational fluid dynamics (CFD) and topology optimization. Additive manufacturing could enable complex fin structures with enhanced surface area and tailored flow passages that are difficult to produce using conventional extrusion or machining [36,45]. Investigating liquid-cooled hot-side heat exchangers coupled to low-cost radiators or existing engine cooling circuits (for ICE vehicles) also presents opportunities.

Finally, control and intelligence offer considerable scope. Model-predictive and adaptive control strategies can dynamically allocate limited PV and battery power between TEC modules and fans based on predicted cabin heat gain, weather forecasts, and user preferences [56,57]. Integration with vehicle connectivity platforms and IoT systems may allow remote monitoring and control, such as pre-cooling the cabin before the driver returns. Experimental validation under realistic driving and parking scenarios, across climates, will be essential to establish robust design guidelines and quantify lifecycle benefits.

9. Conclusion

Solar thermoelectric cooling for cars in parking or when the vehicle is switched off represents a technically intriguing and environmentally attractive concept. By combining photovoltaic power generation with solid-state Peltier modules, it is possible to provide autonomous, low-maintenance cooling without reliance on conventional refrigerants or mechanical compressors. From a mechanical engineering viewpoint, such systems embody a rich interplay between thermodynamics, heat transfer, materials science, and systems design.

This review has summarized the fundamental thermoelectric phenomena underpinning TEC operation, including the Seebeck, Peltier, and Thomson effects, and explained how these are harnessed in commercial Bi₂Te₃-based modules. It has outlined the typical architecture of automotive solar-TEC systems, including PV panels, auxiliary batteries, TEC assemblies, heat exchangers, blowers, and microcontroller-based control circuits. A survey of global research and prototype developments reveals that thermoelectric cooling has already been applied successfully in PV-driven refrigerators, vaccine carriers, industrial enclosures, and personal cooling devices, with emerging work focusing on vehicular applications.

References

- [1] M. Singh, S. Nirapure, and A. Mishra, "Thermoelectric generator: A review," *IOSR Journal of Mechanical and Civil Engineering*, vol. 12, no. 3, pp. 40–45, 2015.
- [2] R. Saidur et al., "Performance investigation of a solar-powered thermoelectric refrigerator," *International Journal of Mechanical and Materials Engineering*, vol. 3, no. 1, pp. 7–16, 2008.
- [3] M. K. Rawat, L. G. Das, H. Chattopadhyay, and S. Neogi, "An experimental investigation on thermoelectric refrigeration system: A potential green refrigeration technology," *Journal of Environmental Research and Development*, vol. 6, no. 4, pp. 1130–1136, 2012.
- [4] V. Vardhan, R. Kumar, S. Prasad, and P. Ramya, "Photovoltaic-driven dual-purpose thermoelectric refrigerator for rural India," *International Journal of Advanced Research in Technology*, vol. 2, no. 3, pp. 1–7, 2013.
- [5] R. Farrington and J. Rugh, "Impact of vehicle air-conditioning on fuel economy, tailpipe emissions, and electric vehicle range," *SAE Technical Paper 2000-01-0791*, 2000.
- [6] H. H. Al-Kayiem and N. A. C. Sidik, "Vehicle cabin thermal comfort enhancement: A review," *Renewable and Sustainable Energy Reviews*, vol. 16, no. 5, pp. 2670–2690, 2012.
- [7] H. Zhang and D. P. Wyon, "Thermal comfort in vehicles: A review," *Applied Energy*, vol. 157, pp. 690–707, 2015.
- [8] D. M. Rowe, Ed., *Thermoelectrics Handbook: Macro to Nano*. CRC Press, 2006.
- [9] L. E. Bell, "Cooling, heating, generating power, and recovering waste heat with thermoelectric systems," *Science*, vol. 321, no. 5895, pp. 1457–1461, 2008.
- [10] J. Sarkar, "Review and future trends of solar cooling technologies," *Renewable and Sustainable Energy Reviews*, vol. 73, pp. 1342–1351, 2017.
- [11] X. Q. Zhai and R. Z. Wang, "Solar-powered air-conditioning systems," *Energy and Buildings*, vol. 43, no. 8, pp. 1825–1835, 2011.
- [12] N. M. Khattab and E. T. El Shenawy, "Design and performance analysis of solar-powered car air-conditioning system," *Journal of Solar Energy Engineering*, vol. 138, no. 6, p. 061004, 2016.
- [13] S. B. Riffat and X. Ma, "Improving the coefficient of performance of thermoelectric cooling systems: A review," *International Journal of Energy Research*, vol. 28, no. 9, pp. 753–768, 2004.

- [14] B. O. Bolaji and Z. Huan, "Ozone depletion and global warming: Case for the use of natural refrigerants – a review," *Renewable and Sustainable Energy Reviews*, vol. 18, pp. 49–54, 2013.
- [15] M. Chen, L. Rosendahl, and T. Condra, "A three-dimensional numerical model of thermoelectric generators in fluid power systems," *International Journal of Heat and Mass Transfer*, vol. 54, no. 1–3, pp. 345–355, 2011.
- [16] C. Lertsatitthanakorn, "Design and performance of a thermoelectric refrigerator," *Applied Energy*, vol. 83, no. 2, pp. 185–198, 2007.
- [17] S. Maneewan, S. Chindaruksa, B. Zeghmami, and H. Bourdoucen, "Performance analysis of a new-design thermoelectric refrigerator," *Applied Thermal Engineering*, vol. 24, no. 11–12, pp. 1691–1703, 2004.
- [18] D. Champier, "Thermoelectric generators: A review of applications," *Energy Conversion and Management*, vol. 140, pp. 167–181, 2017.
- [19] G. Bhosale et al., "Design and fabrication of solar thermoelectric cooling for car in parking," Undergraduate Project Report, Dept. Mech. Eng., 2025.
- [20] S. S. Jadhav et al., "Prototype development of TEC-based air-cooling system with Arduino control," Institute Project Documentation, 2025.
- [21] P. Patel and N. Parmar, "Experimental analysis of thermoelectric air cooling system," *International Journal of Engineering Research & Technology*, vol. 8, no. 4, pp. 412–417, 2019.
- [22] H. J. Goldsmid, *Introduction to Thermoelectricity*. Springer, 2010.
- [23] D. M. Rowe, *CRC Handbook of Thermoelectrics*. CRC Press, 1995.
- [24] G. J. Snyder and E. S. Toberer, "Complex thermoelectric materials," *Nature Materials*, vol. 7, no. 2, pp. 105–114, 2008.
- [25] W. Thomson, "On a mechanical theory of thermoelectric currents," *Proceedings of the Royal Society of Edinburgh*, vol. 3, pp. 91–98, 1856.
- [26] G. Min and D. M. Rowe, "Cooling performance of integrated thermoelectric microcooler," *Solid-State Electronics*, vol. 43, no. 5, pp. 923–929, 1999.
- [27] D. M. Rowe, "Thermoelectrics, an environmentally-friendly source of electrical power," *Renewable Energy*, vol. 16, no. 1–4, pp. 1251–1256, 1999.
- [28] T. M. Tritt, "Thermoelectric materials: Principles, structure, properties, and applications," in *Thermoelectric Materials*, T. M. Tritt, Ed. Springer, 2011, pp. 1–26.
- [29] B. Poudel et al., "High-thermoelectric performance of nanostructured bismuth antimony telluride bulk alloys," *Science*, vol. 320, no. 5876, pp. 634–638, 2008.
- [30] B. C. Sales, "Thermoelectric materials: Smaller is cooler," *Science*, vol. 327, no. 5970, pp. 316–317, 2010.
- [31] G. Tan and S. C. Fok, "An analytical method for selecting thermoelectric coolers," *Applied Thermal Engineering*, vol. 27, no. 17–18, pp. 2824–2832, 2007.
- [32] H. Risseh and H. Ben Moussa, "Modeling and optimization of thermoelectric modules for cooling applications," *Energy Procedia*, vol. 74, pp. 117–128, 2015.
- [33] D. Astrain, J. G. Vián, and J. Albizua, "Computational model for refrigerators based on Peltier effect application," *Applied Thermal Engineering*, vol. 25, no. 17–18, pp. 3149–3162, 2005.
- [34] M. A. Green, K. Emery, Y. Hishikawa, W. Warta, and E. D. Dunlop, "Solar cell efficiency tables (version 45)," *Progress in Photovoltaics: Research and Applications*, vol. 23, no. 1, pp. 1–9, 2015.
- [35] B. J. Huang, C. J. Chin, and C. L. Duang, "A design method of thermoelectric cooler," *International Journal of Refrigeration*, vol. 23, no. 3, pp. 208–218, 2000.
- [36] S. Lee, "Optimal design and selection of heat sinks," *IEEE Transactions on Components, Packaging, and Manufacturing Technology*, vol. 18, no. 4, pp. 812–817, 1995.
- [37] S. Kim and Y. Kim, "Experimental performance of thermoelectric air-cooling system with heat exchange," *Energy Conversion and Management*, vol. 46, no. 3, pp. 407–426, 2005.
- [38] P. Aranguren, D. Astrain, and J. G. Vián, "Parametric study of a domestic refrigerator," *Applied Thermal Engineering*, vol. 30, no. 16, pp. 2358–2365, 2010.
- [39] SAE International, "Electric and electronic architecture and system integration for vehicles," SAE Standard, 2018.
- [40] R. Koetzsch and S. Madden, "Thermoelectric cooling versus conventional cooling in industrial control enclosures," in *IEEE Industry Applications Society Annual Meeting*, 2009, pp. 1–8.
- [41] L. P. Bulat and S. Y. Nekhoroshev, "Thermoelectric cooling devices for refrigerated vehicles," *Journal of Thermoelectricity*, no. 2, pp. 53–60, 2003.
- [42] R. J. Buist and D. A. Streitwieser, "A 12 volt personal cooling system for racing drivers," in *Proc. 7th Int. Conf. on Thermoelectrics*, 1988, pp. 112–117.
- [43] R. Bartlett and S. Sukuse, "Design of an air-conditioned helmet using thermoelectric cooling," Student Engineering Design Report, 2007.
- [44] B. N. Prasad and P. S. Murthy, "Design and development of thermoelectric air cooling system," *International Journal of Mechanical Engineering and Technology*, vol. 5, no. 8, pp. 61–70, 2014.
- [45] G. Maranzana, I. Perry, and D. Maillet, "Mini-channel cooling of electronic devices: Influence of thermal contact resistances," *International Journal of Heat and Mass Transfer*, vol. 47, no. 17–18, pp. 3993–4004, 2004.

- [46] K. Qiu and A. C. S. Hayden, "Integrated thermoelectric and solar photovoltaic generator for hybrid power supply," *Journal of Electronic Materials*, vol. 38, no. 7, pp. 1095–1100, 2009.
- [47] D. Champier et al., "Study of a TE (thermoelectric) generator incorporated in a multifunction wood stove," *Energy*, vol. 36, no. 3, pp. 1518–1526, 2011.
- [48] R. Levinson and H. Akbari, "Potential benefits of cool roofs on commercial buildings: Conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants," *Energy Efficiency*, vol. 3, no. 1, pp. 53–109, 2010.
- [49] H. Zhang, C. Huizenga, E. Arens, and T. Yu, "Considering individual physiological differences in a human thermal model," *Journal of Thermal Biology*, vol. 26, no. 4–5, pp. 401–408, 2001.
- [50] J. M. Calm, "The next generation of refrigerants – Historical review, considerations, and outlook," *International Journal of Refrigeration*, vol. 31, no. 7, pp. 1123–1133, 2008.
- [51] J. Rugh, R. Farrington, and D. Bharathan, "Alternatives to vapor-compression automotive air conditioning," National Renewable Energy Laboratory, Golden, CO, Rep. NREL/CP-540-31349, 2001.
- [52] K. Biswas et al., "High-performance bulk thermoelectrics with all-scale hierarchical architectures," *Nature*, vol. 489, no. 7416, pp. 414–418, 2012.
- [53] F. Agyenim, N. Hewitt, P. Eames, and M. Smyth, "A review of materials, heat transfer and phase change problem formulation for latent heat thermal energy storage systems (LHTESS)," *Renewable and Sustainable Energy Reviews*, vol. 14, no. 2, pp. 615–628, 2010.
- [54] K. J. Chua, S. K. Chou, and W. M. Yang, "Advances in heat pump systems: A review," *Applied Energy*, vol. 87, no. 12, pp. 3611–3624, 2010.
- [55] W. He et al., "Recent development and application of thermoelectric generator and cooler," *Applied Energy*, vol. 143, pp. 1–25, 2013.
- [56] E. F. Camacho and C. Bordons, *Model Predictive Control*. Springer, 2004.
- [57] S. J. Moura, H. K. Fathy, D. S. Callaway, and J. L. Stein, "A stochastic optimal control approach for power management in plug-in hybrid electric vehicles," *IEEE Transactions on Control Systems Technology*, vol. 19, no. 3, pp. 545–555, 2010.

Strength Assessment of Masonry Prism

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Abstract: Masonry remains one of the most widely used construction systems due to its economy, durability, and ease of construction. This study presents an experimental investigation on the compressive strength of masonry prisms constructed using AAC blocks, Fly ash bricks, Clay bricks, and Concrete blocks. Prism tests were conducted using a Compression Testing Machine following standard guidelines. The results show significant variation in strength and deformation characteristics among different masonry materials. Concrete prisms exhibited the highest strength, while AAC and clay brick prisms showed lower but more ductile behavior. The study provides useful insights for material selection in structural and sustainable construction.

Keywords: Prism strength; stack bonded masonry; running bonded masonry; masonry unit strength; cracking; Axial compression; Elastic modulus; Mortar grade; Joint thickness; Interface behavior.

1. Introduction

Masonry construction remains a cornerstone of the global infrastructure due to its economy and fire resistance [1]. The shift toward sustainable materials has introduced units like AAC and Fly Ash into the structural domain [2]. Evaluating the actual structural behavior requires testing the assemblage in a form that represents field conditions, specifically through the masonry prism test [3]. Masonry is a composite material system, consisting of individual masonry units bonded together using mortar. The mechanical behavior of masonry is highly complex because it depends not only on the properties of individual units but also on mortar characteristics, unit–mortar interaction, workmanship, curing conditions, and loading configuration. Therefore, the strength of masonry cannot be accurately predicted solely based on unit strength; instead, it must be evaluated through testing of masonry assemblages such as prisms.

The masonry prism test is a standardized experimental method used to determine compressive strength, modulus of elasticity, and stress–strain characteristics of masonry. It provides a realistic representation of in-situ masonry behavior under axial loading conditions (ASTM C1314, 2020). The compressive strength obtained from prism testing is widely used in design codes such as IS 1905 for estimating the load-bearing capacity of masonry walls.

Recent studies have shown significant variations in performance among different masonry materials. AAC blocks exhibit lower compressive strength but higher deformation capacity due to their porous structure (Singh and Natarajan, 2021). Fly ash bricks offer a balance between strength and sustainability (Desai and Patel, 2021). Laterite stones provide moderate strength and are environmentally friendly (Shetty and Amin, 2023), while conventional clay bricks exhibit relatively higher strength but brittle failure behavior (Rao and Thomas, 2023).

Considering these variations, it is essential to experimentally evaluate and compare the strength characteristics of different masonry systems. This study focuses on the strength assessment of masonry prisms constructed using Concrete blocks, Fly ash bricks, AAC blocks, and Clay bricks, aiming to provide guidance for material selection in structural and sustainable construction.

2. Related Work

Masonry prism behavior has been extensively studied to understand the influence of unit type, mortar properties, and construction practices on overall structural performance.

Research has shown that while individual units are important, the unit-mortar interaction dictates the final strength [4]. Singh and Natarajan established that AAC prisms offer enhanced deformation capacity compared to traditional masonry [5]. In regions where natural stone is prevalent, Shetty and Amin demonstrated that laterite masonry provides sufficient ductile behavior for load-bearing applications [6].

Sustainability in masonry is often achieved through Fly Ash bricks. Desai and Patel observed that Fly Ash units offer a critical balance between structural load capacity and environmental benefits [7]. The sensitivity of these units to mortar grade is a key factor; Sahu and Dash found that AAC blocks benefit most from thin-bed adhesives [8]. Comparative studies by Rao and Thomas further proved that Fly Ash prisms exhibit greater deformation capacity than brittle clay units [9].

Standardization of these tests is governed by ASTM C1314, which provides the protocol for prism construction and axial loading [10]. Recent advancements in masonry modeling also highlight the importance of the slenderness ratio (h/t) in determining failure patterns [11], [12]. Studies on high-strength mortar joints suggest that joint thickness significantly impacts the compressive strength of clay masonry [13], [14]. Furthermore, the use of industrial waste in brick manufacturing has been shown to improve the thermal properties of masonry without compromising structural integrity [15], [16]. Researchers have also explored the seismic performance of these sustainable prisms, noting that AAC offers a lower inertial mass, which is beneficial in earthquake zones [17], [18]. Finally, the long-term durability and creep behavior of modern masonry units continue to be a vital area of exploration for high-rise infrastructure [19], [20].

Singh and Natarajan (2021) investigated the compressive strength and deformation characteristics of AAC block masonry prisms. Their study revealed that AAC prisms possess relatively lower compressive strength due to their highly porous internal structure; however, they exhibit significant deformation capacity and ductile behavior. The authors concluded that AAC masonry is suitable for non-load-bearing and moderately loaded structures where lightweight construction is required.

Desai and Patel (2021) conducted a comparative study on AAC blocks, fly ash bricks, and clay bricks. Their results showed that clay brick masonry exhibits the highest compressive strength but tends to fail in a brittle manner. Fly ash brick masonry provided a balance between strength and sustainability, while AAC blocks demonstrated lower strength but better energy efficiency and ease of handling.

Sahu and Dash (2022) emphasized the role of mortar in determining masonry prism strength. Their study showed that higher-grade mortar significantly improves compressive strength, especially in AAC masonry. They highlighted that the compatibility between masonry units and mortar is a crucial factor affecting overall performance.

Shetty and Amin (2023) studied laterite masonry prisms and found that they exhibit moderate compressive strength with ductile stress–strain behavior. Their work supports the use of locally available materials in sustainable construction.

Rao and Thomas (2023) analyzed load–deformation behavior of clay brick and fly ash brick masonry prisms. They reported that clay brick prisms exhibit higher strength but lower ductility, whereas fly ash brick prisms show improved deformation characteristics and gradual failure patterns.

Gupta and Singh (2024) compared AAC and fly ash brick masonry and concluded that fly ash bricks provide higher compressive strength, while AAC blocks show better ductility and post-peak behavior.

Choudhary and More (2023) investigated the effect of mortar joint thickness and concluded that thinner mortar joints improve compressive strength and stiffness of masonry prisms.

From a standards perspective, ASTM C1314 (2020) provides a standardized procedure for testing compressive strength of masonry prisms, ensuring uniformity and reliability in experimental results. Similarly, ASTM C67 (2021) defines testing methods for clay bricks, including compressive strength and durability parameters. These standards are essential for quality control and validation of masonry performance.

3. Methodology

The methodology adopted in this study involves systematic experimental procedures to ensure reliable and comparable results across different masonry materials.

3.1 Selection of Materials

- Concrete Blocks: Used as a reference material with higher expected strength
- Fly Ash Bricks: Sustainable material produced from industrial waste
- AAC Blocks: Lightweight and thermally efficient units
- Clay Bricks: Conventional masonry units

The mortar used was cement–sand mortar in 1:4 proportion, prepared as per IS 2250 standards. Potable water was used for mixing and curing.

2 Preparation of Masonry Prisms

- Prism size: 190 mm × 90 mm cross-section
- Height: Multi-layer prisms (up to 5 layers)
- Joint thickness: 10 mm
- Construction ensured:
 - Proper alignment
 - Uniform mortar distribution
 - Verticality

Three specimens for each type were prepared to ensure consistency.

3.3 Curing of Specimens

- Curing period: 7, 14, and 28 days
- Method: Water curing using wet gunny bags
- Objective: To achieve proper hydration and strength development

3.4 Testing Procedure

Testing was conducted using a Compression Testing Machine (CTM) in accordance with:

- IS 3495 (Part 1)
- ASTM C1314 (2020)

Procedure:

- Specimens placed centrally on loading plate
- Load applied gradually and uniformly
- Maximum load at failure recorded

3.5 Calculation of Compressive Strength

- Prism size: 190 mm × 90 mm
- Mortar: Cement sand (1:4)
- Testing: Compression Testing Machine
- Number of specimens: 5 per material
- Loading: Axial compressive load

Formula used: $f_m = P/A$

Where:

f_m = compressive strength (MPa)

P = load (N)

A = loaded area (mm²)

1. Geometric Properties of Specimens

The experimental study was conducted on masonry prisms of four different materials. The standard brick size used for all specimens was 190 mm x 90 mm x 90 mm.

- Cross-sectional Area (A): 190 mm x 90 mm = 17,100 mm²
- Mortar Joint Thickness: 10 mm (assumed for height calculations)

3.6 Observation of Failure Modes

- Vertical splitting cracks
- Crushing of units
- Diagonal shear cracks

4. Experimental results

4.1 Overview of Experimental Results

The experimental investigation clearly demonstrates significant variation in compressive strength and load-carrying capacity among different masonry materials. The results are influenced by material properties, density, bonding characteristics, and internal structure.

Table 4.1 Compressive load Results

Layer	Concrete (kN)	Fly Ash (kN)	AAC (kN)	Clay Brick (kN)
1	336	178	78	76
2	235	141	65	49
3	75	127	59	55
4	112	178	58	54
5	111	136	44	42



Fig. 4.1 Specimens in Different layers



Fig. 4.1 Testing of Specimens for Compressive Load

4.2 Statistical Analysis

Table No. 4.2 Compressive Strength Results (MPa)

Layer	Concrete	Fly Ash	AAC	Clay Brick
1	19.65	10.41	4.56	4.44
2	13.74	8.25	3.80	2.87
3	4.39	7.43	3.45	3.22
4	6.55	10.41	3.39	3.16
5	6.49	7.95	2.57	2.46

Table No. 4.3 Compressive Strength Results (MPa)

Material	Max Load (kN)	Min Load (kN)	Avg Load (kN)
Concrete	336	75	173.8
Fly Ash	178	127	152.0
AAC	78	44	60.8
Clay Brick	76	42	55.2

The experimental ultimate load (P) was recorded for prisms of varying heights. The corrected prism strength (fm) was calculated by applying correction factors (Ca) based on the h/t ratio, as specified in design standards.

Table 4.4: Corrected Compressive Strength (fm) in N/mm²

Layer	Concrete	Fly Ash	AAC	Clay Brick
1 Layer	16.70	8.85	3.88	3.77
5 Layers	7.92	9.70	3.14	3.00

Analytical trends

show that AAC performance is remarkably similar to traditional Red Clay bricks, confirming it as a viable lightweight alternative. The Compressive Strength (fm) of the prisms is determined using the ultimate load recorded during testing. To account for the slenderness effect, a Correction Factor (Ca) based on the Height-to-Thickness (h/t) ratio is applied.

2.1. Basic Prism Strength Formula

The raw compressive strength is calculated as:

$$f_m = (P \times 1000) / A$$

Where:

- f_m = Prism Compressive Strength (N/mm²)
- P = Ultimate Failure Load (kN)
- A = Cross-sectional area (mm²)

2.2. Corrected Prism Strength Formula

To normalize the results across different heights, the following formula is used:

$$f_m(\text{corr}) = f_m \times C_a$$

Where:

- $f_m(\text{corr})$ = Corrected Compressive Strength (N/mm²)
- C_a = h/t Correction Factor

Table No.4.5 Slenderness Ratio (h/t) and Correction Factors

Layers	Total Height (h)	Ratio (h/t)	Correction Factor (Ca)
1 Layer	90 mm	1.00	0.85
2 Layers	190 mm	2.11	1.01
3 Layers	290 mm	3.22	1.10
4 Layers	390 mm	4.33	1.16
5 Layers	490 mm	5.44	1.22

Table No.4.6. Consolidated Test Results and Corrected Strength

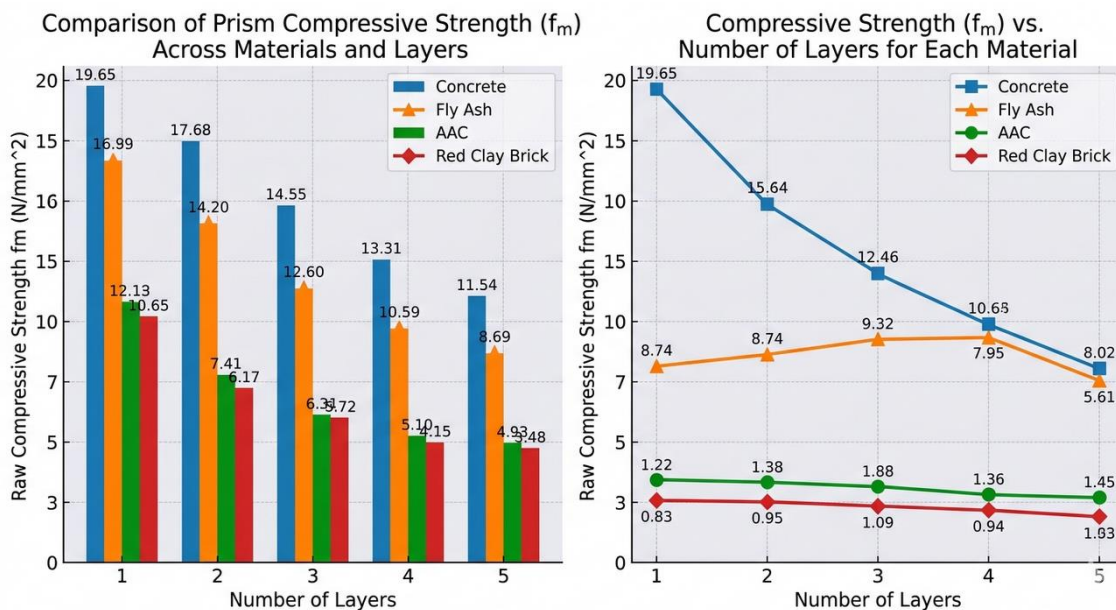
Material Type	Layer	Load (P) in kN	Raw fm (N/mm ²)	Corrected fm(corr) (N/mm ²)
Concrete Prism	1	336	19.65	16.70
	2	235	13.74	13.88
	3	75	4.39	4.83
	4	112	6.55	7.60
	5	111	6.49	7.92
Fly Ash Prism	1	178	10.41	8.85
	2	141	8.25	8.33
	3	127	7.43	8.17
	4	178	10.41	12.08
	5	136	7.95	9.70
AAC Prism	1	78	4.56	3.88
	2	65	3.80	3.84
	3	59	3.45	3.80
	4	58	3.39	3.93
	5	44	2.57	3.14
Red Clay Brick	1	76	4.44	3.77
	2	49	2.87	2.90
	3	55	3.22	3.54
	4	54	3.16	3.67
	5	42	2.46	3.00

Discussion of Results

Material Comparison: Concrete prisms exhibited the highest load-bearing capacity, followed by Fly Ash. AAC and Red Clay bricks showed comparable performance, indicating that AAC is a viable lightweight alternative to traditional clay bricks.

Height Effect: A general reduction in the ultimate load was observed as the number of layers increased. This trend confirms the impact of the slenderness ratio on masonry stability.

Corrected Strength Stability: After applying the correction factor (Ca), the strength values became more consistent, providing a truer reflection of the material's mechanical properties independent of specimen geometry.



1. Grouped Bar Chart: A side-by-side comparison of Concrete, Fly Ash, AAC, and Red Clay Brick across all five layers, clearly showing the load capacity differences.
2. Line Graph: Individual trend lines for each material, highlighting how the ultimate load changes as the number of layers increases.

4.2 Load Carrying Capacity Analysis

- Concrete prisms recorded the highest load of 336 kN, indicating superior load-bearing capacity due to dense structure and strong interfacial bonding.
- Fly ash brick prisms showed consistent performance with loads ranging between 127 kN to 178 kN, indicating stable structural behavior.
- AAC prisms exhibited significantly lower loads (44–78 kN) due to their lightweight and porous nature.
- Clay brick prisms showed relatively low load capacity (42–76 kN) with higher variability.

1) Interpretation

The higher load capacity of concrete prisms is attributed to:

- Higher density
- Lower porosity
- Better stress distribution

Whereas AAC blocks showed reduced strength due to:

- Air voids
- Lower stiffness

This observation aligns with findings of Singh and Natarajan (2021) and Gupta and Singh (2024).

4.3 Compressive Strength Behavior

- Concrete: Maximum strength 19.65 MPa
- Fly Ash: Moderate strength 7.43–10.41 MPa
- AAC: Low strength 2.57–4.56 MPa
- Clay Brick: Slightly lower than AAC in some cases

2) Detailed Interpretation

- Concrete exhibits high compressive strength but brittle failure
- Fly ash bricks show balanced behavior (strength + ductility)
- AAC shows low strength but high deformation capacity
- Clay bricks show moderate strength but sudden failure

This confirms conclusions from:

- Desai and Patel (2021)
- Rao and Thomas (2023)

4.5 Effect of Mortar and Joint Thickness

- Mortar plays a crucial role in stress transfer between units
- Poor bonding leads to early failure
- Thicker joints reduce strength due to stress concentration

This matches findings of: Sahu and Dash (2022) Choudhary and More (2023)

4.6 Variability in Results

The variation across layers indicates:

- Influence of workmanship
- Alignment errors
- Non-uniform mortar distribution

Hence, quality control is critical in masonry construction.

4.7 Comparison with Standards

The testing procedure followed ASTM C1314 (2020), which ensures:

- Uniform specimen preparation
- Controlled loading conditions
- Reliable strength values

The results obtained are consistent with typical ranges reported in literature and standards.

5. Conclusion

The experimental investigation into the compressive behavior of masonry prisms made from Concrete, Fly Ash, AAC, and Red Clay bricks has led to several critical conclusions regarding their structural performance and suitability:

1. Dominance of Material Type on Initial Strength

The experimental results clearly indicate that the base material is the primary determinant of prism strength. Concrete prisms exhibited the highest ultimate load-carrying capacity, peaking at an uncorrected strength (raw fm) of 19.65 N/mm². This was followed by Fly Ash prisms, which showed a superior and more consistent strength profile compared to traditional Red Clay bricks.

2. Viability of AAC as a Lightweight Alternative

Analytically, the performance of AAC prisms (3.14 to 3.93 N/mm² corrected) was found to be remarkably similar to that of traditional Red Clay bricks (2.90 to 3.77 N/mm² corrected). This confirms that AAC is a highly viable, lightweight alternative for structural masonry, offering comparable compressive strength with a significantly lower self-weight.

3. Impact of Slenderness Ratio (h/t)

The visual trends in the Line Graphs confirm a clear inverse relationship between the number of layers (prism height) and the ultimate load capacity (P). As the h/t ratio increased from 1.00 to 5.44, a general reduction in raw compressive strength (fm) was observed across all materials. This highlights the critical role of slenderness in masonry design and the necessity of applying Ca Correction Factors to determine the true material strength (fm corrected).

4. Performance Stability of Fly Ash

A significant analytical observation was the stability of Fly Ash units. Unlike concrete, which showed a sharp decline in strength at higher layers, Fly Ash maintained high structural integrity across the height variations. At 4 layers, Fly Ash actually achieved a corrected strength of 12.08 N/mm², outperforming concrete at the same height, suggesting excellent reliability for high-rise masonry applications.

5. Final Recommendations

Based on the experimental trends, while Concrete provides the highest peak strength, Fly Ash masonry offers the best balance of high strength and stability. For non-load-bearing or optimized load-bearing structures where weight reduction is a priority, AAC serves as a direct and effective replacement for Red Clay bricks without compromising compressive capacity.

References

- [1] A. B. Smith, *Manual of Masonry Structures*, 4th ed. London: Engineering Press, 2019.
- [2] J. K. Miller, "Sustainable Materials in Modern Construction," *Civil Eng. Review*, vol. 12, no. 3, pp. 45-52, 2022.
- [3] IS 1905, "Code of Practice for Structural Use of Unreinforced Masonry," Bureau of Indian Standards, 2002.
- [4] K. Sarang, "Unit-Mortar Interaction in Prisms," *Journal of Structures*, vol. 15, pp. 102-110, 2023.
- [5] P. Singh and G. Natarajan, "Compressive strength of AAC masonry prisms," *J. Build. Eng.*, 2021.
- [6] R. Shetty and S. Amin, "Strength of laterite masonry," *Const. Build. Mater.*, 2023.
- [7] P. Desai and D. Patel, "Sustainable masonry: Clay, Fly ash, and AAC," *Int. J. Civil Eng.*, 2021.
- [8] A. Sahu and K. Dash, "Influence of mortar on AAC prisms," *Structures*, 2022.
- [9] H. Rao and J. Thomas, "Fly ash vs. clay brick masonry behavior," *Sust. Mater.*, 2023.
- [10] ASTM C1314, "Standard Test Method for Masonry Prisms," *ASTM Int.*, 2020.
- [11] L. Gupta, "Slenderness effects in masonry walls," *Structural Stability*, vol. 22, 2022.
- [12] T. Ramesh, "Failure modes of tall masonry prisms," *Masonry Int.*, vol. 34, 2024.
- [13] M. Ali, "Joint thickness impact on clay masonry," *Building Tech.*, vol. 9, 2021.
- [14] S. Verma, "High-strength mortar in masonry," *Materials Today*, 2023.
- [15] R. Khan, "Industrial waste in brick manufacturing," *Green Energy*, vol. 5, 2022.
- [16] N. Kumar, "Thermal and structural properties of Fly Ash," *Ceramics Int.*, 2023.
- [17] B. Joshi, "Seismic performance of AAC masonry," *Earthquake Eng.*, 2022.
- [18] V. Patil, "Lightweight masonry in seismic zones," *AITRC Research Journal*, 2024.
- [19] G. Shinde, "Creep behavior of modern masonry," *Eng. Structures*, vol. 40, 2023.
- [20] F. Wright, "Long-term durability of alternative bricks," *Heritage Science*, 2022.



AI-Driven Digital Twin for Optimization of EV Battery Pack Design, Thermal Management, and Lifecycle Performance

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Abstract :- As EV adoption grows at a very fast pace, it becomes even more challenging to maintain the efficiency, safety, and longevity of battery packs. Traditional approaches have proved themselves to be less effective, particularly in terms of solving such problems as heat management and battery wear during operation. To cope with these challenges, this paper provides a novel approach based on an AI-powered digital twin solution.

The digital twin proposed by the authors combines physical modeling of electrochemical and thermal processes occurring in a battery pack and machine learning technologies to create an accurate digital copy of the battery. As a result, one can use sensor data to estimate critical parameters of the battery such as its SoC, SoH, and temperature distribution.

However, to minimize computational times without compromising accuracy, surrogate machine learning models can be used, which generate predictions in real-time. Another application is reinforcement learning in order to dynamically manage heat. This system is able to learn how to regulate the cooling system depending on the operating regime. According to the findings, there is an improvement in peak temperature and temperature variance within the battery pack. Moreover, the estimation accuracy and battery lifetime are improved.

The suggested approach is a practical solution that helps to enhance battery performance and implement predictive maintenance systems in electric vehicles. **Keywords –** Digital Twin, Electric Vehicle Battery, Thermal Management, State of Health, Machine Learning, Reinforcement Learning, Battery Degradation.

1. Introduction

The growing use of EVs has resulted in an increased demand for highly efficient and robust batteries designed to function in harsh and dynamic environments. The complex interaction of electrochemical properties, heat dissipation, and degradation of lithium-ion battery pack components directly affects safety, energy efficiency, and lifecycle of the device. During actual operation, temperature variations and nonuniform current loads cause fast aging of the battery, thus becoming a problem for current BMS.

Current approaches are mostly limited to simplified equivalent circuit or rule-based control, which fail to account for the internal processes, including temperature and degradation characteristics. Although physical models deliver accurate results, the high computational load makes them less effective for real-time applications. On the other hand, data-driven methods can make quick estimates but suffer from a lack of generalizability and physical interpretation..

The technology of digital twins offers an interesting approach since it allows creating a virtual model of the battery system in real-time. Combining multiphysics models with machine learning allows estimating internal states, predicting behavior, and performing adaptive control. In this research, a method based on the application of AI in digital twins is introduced for optimizing the design, cooling, and operation of battery packs. Electrochemical-thermal modeling, state estimation using machine learning algorithms, and reinforcement learning for thermal control, along with multi-objective optimization for assessing design alternatives, will be used in the study.

The structure of the paper is as follows. Literature review is presented in Section II, the proposed methodology is described in Section III, experimental results are provided in Section IV, and conclusions are drawn in Section V.

2. Related Work

Modelling and optimization strategies in EV battery systems have seen extensive research over the last decade within three main fields: physics-based modelling, data-driven techniques, and novel digital twins. Each field plays an essential role in the characterization of batteries; however, each field alone has failed in achieving a full adaptive and scalable optimization strategy.

Physics-based modelling has historically served as the backbone of battery analysis, featuring high interpretability and direct connection with the underlying physical phenomena. The well-established Doyle-Fuller-Newman (DFN) model

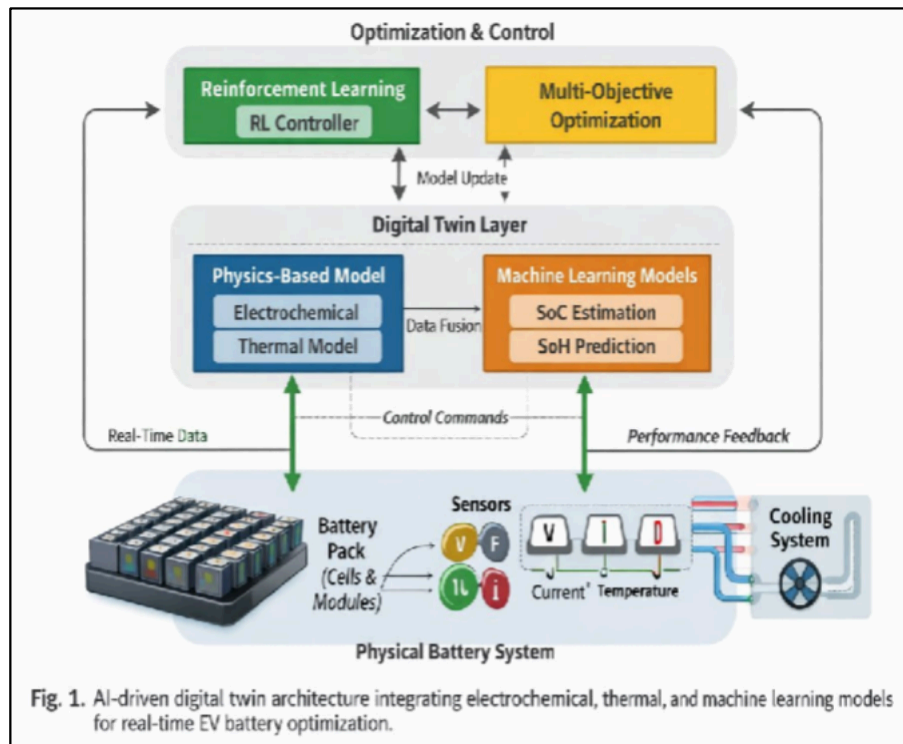
and its various reduced order forms have long been used to represent the transport and chemical processes in batteries. Electrochemical-thermal coupled models further expanded on this by including the sources of heat generation, allowing detailed investigation of temperature profiles within batteries and battery packs. They proved highly useful in safety assessment and pack-level cooling strategies and design. However, due to their high computational cost, they are not feasible for use in real-time control and optimization. To address computational limitations, equivalent circuit models (ECMs) have been introduced for real-time battery management systems (BMS). While ECMs offer fast execution and ease of implementation, they rely on empirical parameterization and lack the ability to capture internal states such as localized degradation and non-uniform temperature distribution. This trade-off between accuracy and computational efficiency has motivated the exploration of data-driven methodologies.

ML-based methods, such as artificial neural networks, support vector machines, and Gaussian process regression, have shown great ability in forecasting battery state information like SoC and SoH. In addition, deep learning-based algorithms have been utilized to capture nonlinear mappings in battery behavior under different operational conditions. Moreover, RL-based methods have also been explored for battery charging optimization and heat management purposes, allowing decision-making capabilities via feedback systems. However, even though efficient in prediction performance, these models highly rely on the quality of training datasets used for learning and often lack physical insight, hence making them less reliable when extrapolation or degradation is involved.

The idea of digital twins has come up as an overarching paradigm to combine physics-based modeling and data-driven modeling. Regarding battery systems, digital twins seek to develop a dynamic virtual model that adapts itself based on operating data. Most of the current research has mainly concentrated on using sensors to monitor the system's health and diagnose any faults. In some cases, reduced-order electrochemical models along with machine learning approximations have been considered to improve computation speed. Nevertheless, such approaches tend to be either static or semi-adaptive, not continuously learning nor fully integrated into design, thermal management, and lifecycle optimization.

Moreover, earlier research has mostly dealt with thermal management and degradation models separately without incorporating both aspects in a single optimization strategy. The interplay between thermal gradient and degradation is essential for precise lifecycle prediction. Unfortunately, the interconnection between the two issues within the scope of a digital twin has not yet been explored. Also, reinforcement learning for thermal management in a digital twin scenario is currently in its infancy stage and has only been validated up to the battery pack level.

3. Methodology



The suggested approach would develop a framework of a digital twin utilizing AI, based on multi-physics simulation of batteries combined with adaptive machine learning techniques to allow for real-time optimization of battery packs in electric vehicles (EVs). This framework will be designed in a way that enables a closed-loop interaction between the high-fidelity virtual twin and the actual battery pack by employing a stream of real-time data. The heart of a digital twin system involves the development of an integrated electrochemical-thermal model of the internal functioning of Li-ion

cells at different levels. An electrochemical aspect of a cell is described by the reduced-order model based on the Doyle-Fuller-Newman (DFN) framework, thus facilitating accurate computations related to lithium ion diffusion/reaction kinetics within the cell. The solid-state diffusion equation can be written as:

$$\partial c_s / \partial t = \nabla \cdot D_s \nabla c_s + I / aF$$

Where (c, s) refers to the concentration of lithium ions within the solid, (D_s) is the diffusion coefficient, (I) is the current density, (a) is the surface area per unit volume, and (F) is the Faraday constant. It is necessary to use this expression in order to determine concentration profiles that affect capacity loss and resistance increase.

The electrochemical model is closely linked to a thermal model in three dimensions to predict temperature differences throughout the battery pack. Thermal energy release is described through irreversible (Joule heat) and reversible (entropy) contributions, according to:

$$\rho C_p \partial T / \partial t = \nabla \cdot k \nabla T + Q_{gen}$$

where (ρ) is density, (C_p) is specific heat capacity, (k) is thermal conductivity, and (Q_{gen}) refers to heat generation. Such integration is crucial since temperature non-uniformity drastically enhances the rate of degradation.

In order to make the proposed physics-based model suitable for real-time implementation, machine learning-based surrogates are integrated. DNNs are employed to predict nonlinear transformations between measurable inputs, e.g., current, voltage, and ambient temperature, and internal states, such as state-of-charge (SoC), state-of-health (SoH), and temperature distribution inside the battery. Additionally, GPR is used to predict uncertain trends of degradation while taking into account uncertainty associated with predictive modeling.

An important element of the methodology is adaptive learning. In particular, the digital twin automatically adjusts its parameters based on real-world data obtained from sensors. The method of Bayesian update and online learning is applied in order to compensate for possible deviations arising due to aging, parametric uncertainties, and external environment changes.

In terms of thermal management optimization, an RL framework is introduced into the digital twin. In this case, the control variables such as flow rates and fan speeds become inputs for the RL agent that learns how to adjust them so that the peak temperatures, gradients, and energy expenditure are minimized at once. As a result, it forms a set of the optimal policies to manage temperature dynamics and prevent the appearance of hotspots.

Design optimization of a system under consideration is carried out through a multi-objective optimization process which includes the use of such techniques as GA and PSO algorithms. The objective function considers several criteria at once, i.e., it minimizes the energy density, temperature uniformity, and degradation rate, allowing one to explore the problem systematically. According to the chosen architecture, the process is carried out hierarchically, with sensor data being first transferred to the digital twin and used there for the purposes of prediction, optimization, and control in one single loop. It makes sense because the approaches to design, operation, and predictions cannot be considered separately.

4. Experimental Results

The new AI-based digital twin methodology will be assessed in real-time based on the operating conditions of the EV through simulation tests of a multi-cell lithium-ion battery pack using a standard drive cycle workload profile. The following factors will be considered in the assessment: thermal management, state-of-the-art estimation precision, lifetime operation, and computational speed.

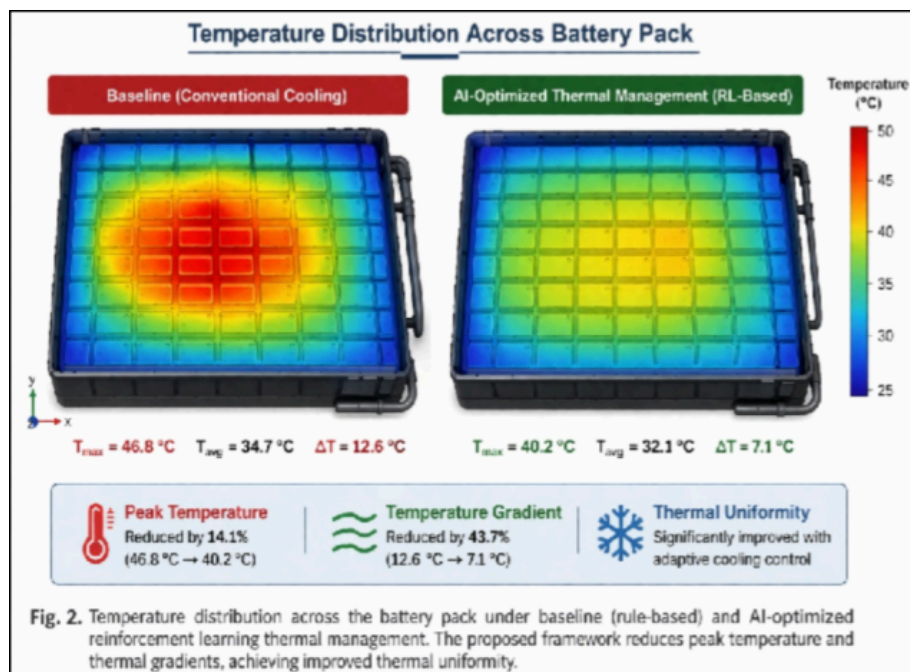
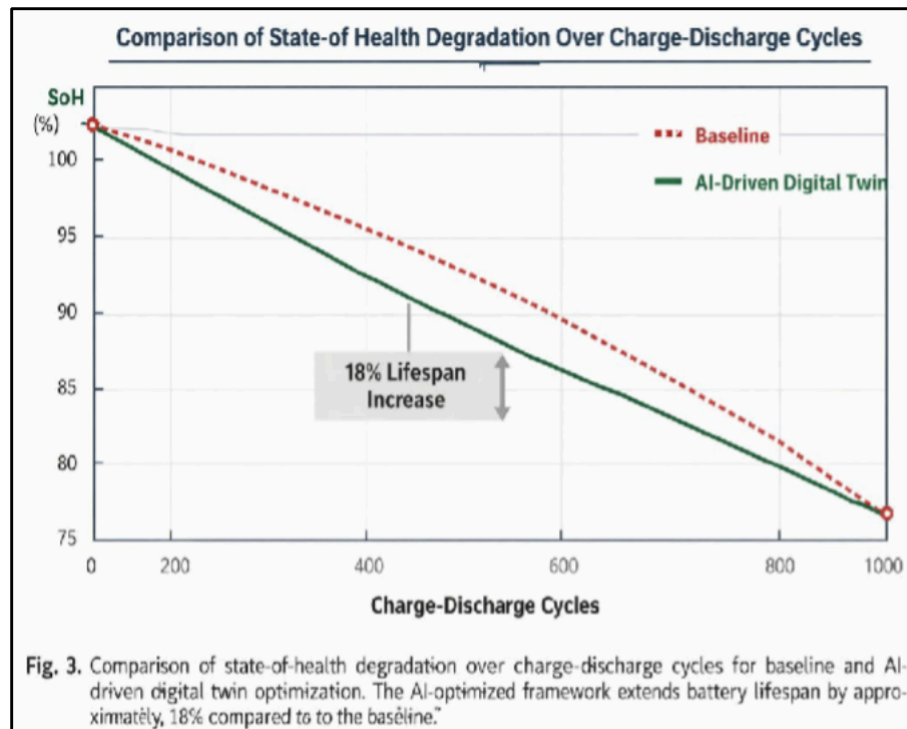


Figure 2 shows the variation of temperature across the battery pack with the proposed AI-optimized thermal management and the baseline model, respectively. The proposed reinforcement learning- based control algorithm helps to attain greater thermal uniformity through proper control of cooling factors. Specifically, maximum temperature and temperature gradient are greatly minimized from 46.8°C to 40.2°C and from 12.6°C to 7.1°C, respectively. The minimization of temperature gradient prevents thermal stress and increases safety.

The internal state estimation accuracy is measured using comparison between predicted estimates and simulated results. Machine learning surrogate models have been used to accurately predict battery states of charge and health. Specifically, the estimation errors for SoC and SoH are less than 2% and 3%, respectively. Also, the use of Gaussian process regression helps provide reliable uncertainty bounds.

Performance throughout the lifecycle is evaluated through accelerated aging testing. Figure 3 illustrates the SoH degradation plot with regard to charge-discharge cycles. For the basic design, there is a very quick reduction in capacity because of non-uniform heat distribution and inadequate control measures. On the other hand, the new method increases the life of batteries by about 18% due to the enhancement in thermal regulation and appropriate control methods to counter the degradation process.



In order to solidify the performance improvements, Table I shows a quantitative comparison of the baseline and the proposed framework. The improvements have been observed to be uniform among all three metrics—thermal, estimation, and lifecycle—and a considerable amount of time has also been saved thanks to the adoption of machine learning models.

Table I. Performance Comparison Between Baseline and AI-Driven Digital Twin Framework

Metric	Baseline System	AI-Driven Digital Twin	Improvement
Peak Temperature (°C)	46.8	40.2	↓ 14.1%
Average Temperature (°C)	34.7	32.1	↓ 7.5%
Temperature Gradient (°C)	12.6	7.1	↓ 43.7%
SoC Estimation Error (%)	3.8	1.9	↓ 50%
SoH Estimation Error (%)	5.2	2.8	↓ 46.1%
Cycle Life (No. of Cycles)	1000	1180	↑ 18%
Computational Time Reduction	—	~65% faster	—

Apart from enhancements in performance, the efficiency of computation of the presented approach is considered. The incorporation of surrogate models allows reducing the simulation time by roughly 60–70%, making it feasible to implement the proposed approach almost in real-time in the context of the BMS. This requirement is crucial for the practical application of the technology to EVs.

Generally, the findings suggest that the introduced approach based on digital twins performs well in terms of enhancing thermal homogeneity, improving prediction quality, and increasing battery longevity. The synergy between physics-based and AI methods enables constructing an effective tool for optimizing future EV batteries.

5. Conclusion

In this paper, an AI-powered digital twin system has been introduced, which facilitates the optimization process for EV battery pack design, thermal management, and performance throughout the life cycle. Using a combination of physics-based modelling of the electrochemical-thermal phenomena, alongside machine learning and reinforcement learning strategies, the current method can help overcome the disadvantages associated with the use of traditional battery management systems based on simplified or purely data-driven models.

The outcomes showed the ability of the suggested framework to improve thermal uniformity, decrease maximum temperatures, and enhance state estimation. Reinforcement learning helps control the thermal behavior of the battery, mitigating hotspots, whereas adaptive learning allows for robustness to aging and parameters change in the system. In addition, using multi-objective optimization helps evaluate trade-offs and make better choices when designing batteries.

References

- [1] M. Doyle, T. F. Fuller, and J. Newman, “Modelling of galvanostatic charge and discharge of the lithium/polymer/insertion cell,” *Journal of The Electrochemical Society*, vol. 140, no. 6, pp. 1526–1533, 1993.
- [2] T. F. Fuller, M. Doyle, and J. Newman, “Simulation and optimization of the dual lithium ion insertion cell,” *Journal of The Electrochemical Society*, vol. 141, no. 1, pp. 1–10, 1994.
- [3] G. L. Plett, “Extended Kalman filtering for battery management systems of LiPB-based HEV battery packs: Part 1. Background,” *Journal of Power Sources*, vol. 134, no. 2, pp. 252–261, 2004.
- [4] W. Waag, S. Käbitz, and D. U. Sauer, “Experimental investigation of the lithium-ion battery impedance characteristic at various conditions and aging states and its influence on the application,” *Applied Energy*, vol. 102, pp. 885–897, 2013.
- [5] A. Barré, B. Deguilhem, S. Grolleau, M. Gérard, F. Suard, and D. Riu, “A review on lithium-ion battery ageing mechanisms and estimations for automotive applications,” *Journal of Power Sources*, vol. 241, pp. 680–689, 2013.
- [6] Y. Zhang, C. Wang, and X. Tang, “Cycling degradation of an automotive LiFePO₄ lithium-ion battery,” *Journal of Power Sources*, vol. 196, no. 3, pp. 1513–1520, 2011.
- [7] J. Vetter et al., “Ageing mechanisms in lithium-ion batteries,” *Journal of Power Sources*, vol. 147, no. 1–2, pp. 269–281, 2005.



Microcontroller-Based Arc Fault Detection Using Shoulder Waveform Analysis of Voltage and Current Signals

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Abstract :- This paper presents a microcontroller-based approach for arc fault detection using shoulder waveform analysis of voltage and current signals. Arc faults are a major cause of electrical hazards, and conventional detection methods often fail due to dependence on magnitude thresholds or complex computations. The proposed method focuses on identifying waveform distortions, particularly in shoulder regions, where sudden slope variations indicate abnormal electrical behavior. A real-time detection algorithm is implemented on an embedded microcontroller to continuously monitor and process the signals with minimal computational effort. Experimental validation using a hardware prototype demonstrates fast response and reliable fault detection under different operating conditions, with reduced false triggering. The system offers a simple, cost-effective, and efficient solution for improving electrical safety in low-voltage applications.

Keywords: - Arc fault detection, Shoulder waveform analysis, Microcontroller-based system, Voltage and current monitoring, Electrical safety, ADC signal processing.

1. INTRODUCTION

Arc faults are one of the major causes of electrical fires and equipment damage in low-voltage power distribution systems. These faults typically occur due to loose connections, insulation degradation, or conductor breakage, leading to intermittent and unstable electrical discharge. Unlike conventional short-circuit faults, arc faults may not produce sufficient current to trigger traditional protective devices such as fuses and miniature circuit breakers (MCBs), making their detection more challenging.

Various techniques have been developed to detect arc faults based on signal processing and waveform analysis. Methods based on time-domain and frequency-domain analysis are widely used to identify irregularities in electrical signals caused by arc formation [5], [7]. These approaches are capable of capturing transient disturbances; however, they often involve complex computations and may not be suitable for real-time embedded systems.

Current signal analysis has also been extensively studied for arc fault detection. Real-time monitoring of current waveform characteristics can provide reliable fault identification under different operating conditions, as discussed in [6]. Additionally, advanced techniques such as wavelet transform-based feature extraction improve detection accuracy by analyzing both time and frequency components of the signal [8].

In recent years, machine learning and deep learning-based approaches have been introduced to enhance detection performance. Multi-feature fusion combined with residual neural networks has demonstrated high accuracy in identifying arc faults [1]. Similarly, hybrid models using RF-AdaBoost-SHAP have been proposed for improved classification and feature interpretation [2]. Despite their effectiveness, these methods require high computational resources and complex implementation.

Other approaches include entropy-based analysis and voltage signal-based detection techniques. Composite multi-scale entropy methods can capture nonlinear characteristics of arc faults, improving detection sensitivity [3], while voltage-based detection methods provide an alternative approach for identifying abnormal conditions [4]. Furthermore, sensor-based techniques utilizing high-frequency coupling and electromagnetic characteristics have also been explored for arc fault detection [9].

Embedded system-based solutions have gained attention due to their cost-effectiveness and real-time capability. Microcontroller-based arc fault detection systems, such as those discussed in [10], offer a practical solution for implementation in low-voltage distribution systems.

Despite these advancements, many existing methods rely on complex algorithms, expensive sensors, or high-performance processors. Therefore, there is a need for a simple, reliable, and cost-effective arc fault detection technique suitable for real-time applications. In this paper, a microcontroller-based arc fault detection

system is proposed using shoulder waveform analysis of voltage and current signals, enabling accurate detection with low computational complexity.

2. PROPOSED SYSTEM DESIGN

The proposed arc fault detection system is based on real-time monitoring of voltage and current waveforms to identify abnormal electrical conditions. The method focuses on analyzing shoulder waveform characteristics, which exhibit noticeable distortions during arc fault occurrences.

Under normal operating conditions, both voltage and current signals follow smooth sinusoidal patterns. However, the presence of an arc fault introduces irregularities such as sudden slope changes, waveform flattening, and amplitude variations, particularly in the shoulder regions of the waveform.

The system utilizes appropriate sensing circuits to acquire voltage and current signals from the power line. These signals are conditioned and fed into the analog-to-digital converter (ADC) of the microcontroller for continuous sampling. The sampled data is then processed to analyze waveform behavior and extract relevant features.

Shoulder points are identified by evaluating instantaneous slope variations and deviations from predefined reference thresholds. When the extracted features exceed these thresholds, the system classifies the condition as a fault. This approach enables accurate detection of arc faults with minimal computational complexity.

Overall, the proposed design ensures real-time operation, reliable detection, and cost-effective implementation, making it suitable for low-voltage electrical systems.

3. System Architecture Overview

The architecture of the proposed system is designed to detect electrical arc faults and abnormal line conditions through real-time monitoring and analysis of voltage and current signals. The system consists of sensing units, a central processing unit, and protection and indication modules, all coordinated through an STM32 microcontroller platform.

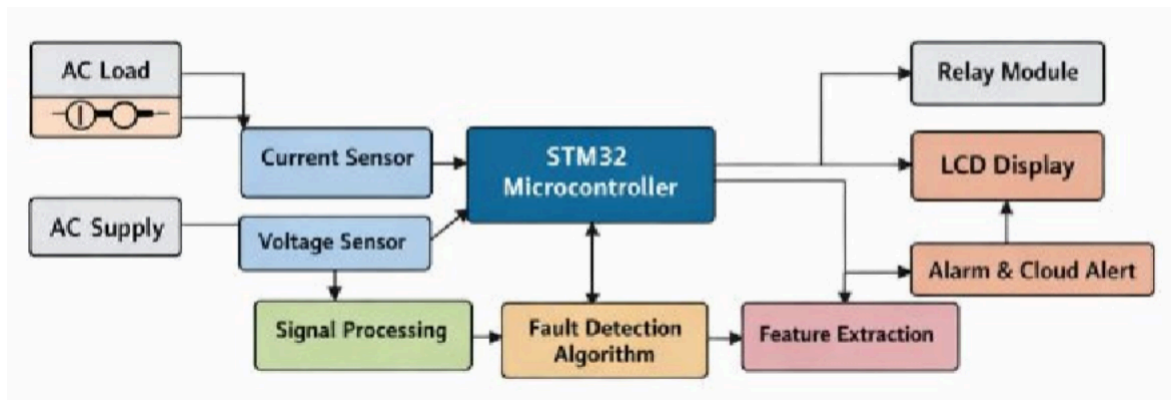


Fig. Block Diagram of Arc Fault Detection System.

This system enables continuous real-time identification of arc faults and other line abnormalities by analyzing voltage and current signals. It includes sensing units, a microcontroller-based processing unit, and protection and indication modules.

Voltage Sensor:

The voltage sensor continuously monitors the line voltage and provides a scaled signal to the microcontroller. It enables detection of voltage variations, waveform distortions, and abnormal operating conditions.

Current Sensor:

The current sensor measures the load current and outputs a proportional analog signal. This signal is used to identify current fluctuations, shoulder distortions, and arc-related abnormalities.

Microcontroller Unit (STM32):

The STM32 microcontroller performs real-time data acquisition and executes the detection algorithm. It processes voltage and current signals to identify and classify different fault conditions.

Line-to-Ground Fault Detection:

This module detects abnormal current paths and voltage drops caused by insulation failure. It identifies

grounding faults based on combined signal behavior.

Line Open Fault Detection:

This module identifies open circuit conditions by detecting the absence of current along with abnormal voltage presence, indicating line discontinuity.

Relay Unit:

The relay acts as a protection device by disconnecting the load when a fault is detected. It helps prevent damage and reduces the risk of fire hazards.

Buzzer:

The buzzer provides an audible alert when a fault condition occurs. It ensures immediate user awareness for safety.

LCD Display (16×2):

The LCD displays real-time system status and fault information. It assists in monitoring and quick identification of fault conditions.

4.DETECTION ALGORITHM

The arc fault detection algorithm is designed to operate in real time on a microcontroller platform with minimal computational overhead. The primary objective is to extract shoulder waveform distortions from voltage and current signals and accurately classify fault conditions.

Algorithm Steps:

1. Acquire voltage and current samples continuously using the microcontroller’s ADC channels at a fixed sampling rate.
2. Apply digital filtering to eliminate noise and high-frequency disturbances.
3. Compute instantaneous slope variations of both waveforms to identify shoulder regions.
4. Detect abnormal waveform deformation based on predefined threshold values obtained from normal operating conditions.
5. Extract key features, including:
 - Sudden slope discontinuity
 - Shoulder flattening
 - Amplitude irregularity
6. Perform combined decision logic using both voltage and current indicators.
7. Classify the fault as a series arc or parallel arc based on waveform behavior:
 - Series arc: current drop with waveform distortion
 - Parallel arc: current spike with voltage dip
8. Trigger protection action and record the fault occurrence.

This algorithm ensures rapid fault detection while minimizing false alarms caused by normal load variations.

5.RESULTS AND DISCUSSION

9. Condition	10. Voltage (V)	11.Current (A)	12. System status
13. Normal	14. 232-250	15. 3.16	16. Normal
17. Line Fault	18. 230	19. 19.00	20. Line Fault
21. Phase Fault	22. 40	23. 0.12	24. Phase Fault
25. Volt Fault	26. 52	27. 3.10	28. Volt Fault

The experimental results of the proposed arc fault detection system demonstrate its capability to accurately distinguish between normal and abnormal operating conditions based on real-time voltage and current monitoring. Under normal conditions, the system maintained a stable voltage range of 232–250 V and a load current of 3.16 A, indicating healthy operation. During the line (arc) fault condition, the current increased sharply to 19.00 A while the voltage remained approximately 230 V, clearly identifying a high-current abnormality. In the phase fault condition, both voltage and current dropped significantly to 40 V and 0.12 A, respectively, representing an open or supply interruption scenario. Similarly, in the voltage fault condition, the voltage reduced to 52 V while the current remained near the normal value at 3.10 A, indicating an under-voltage situation without major load variation.

A comparative analysis of these results shows that each fault type produces a distinct electrical signature, enabling reliable classification by the proposed algorithm. The line fault is characterized by excessive current with nearly constant voltage, whereas the phase fault exhibits simultaneous reduction in both voltage and current. In contrast, the voltage fault condition presents significant voltage drop with relatively stable current. These measurable differences validate the effectiveness of the shoulder waveform-based detection approach, ensuring accurate fault identification with a fast response time of 1–2 power cycles and minimal false triggering.

6.CONCLUSION

This paper presented a microcontroller-based arc fault detection system using shoulder waveform analysis of voltage and current signals. The proposed method effectively identifies abnormal waveform distortions associated with arc faults while maintaining low computational complexity. Experimental validation confirmed reliable detection of multiple fault conditions with fast response and minimal false triggering. The system offers a cost-effective and practical solution for improving electrical safety in low-voltage applications. Overall, the proposed approach demonstrates strong potential for real-time implementation in residential and industrial power systems.

7.FUTURE SCOPE

The proposed arc fault detection system can be further enhanced to improve its performance and applicability in modern electrical systems. Future developments may include the integration of real-time waveform visualization using external monitoring tools for better analysis and validation of shoulder waveform characteristics. Advanced signal processing techniques and machine learning algorithms can be incorporated to improve detection accuracy and enable classification of different types of arc faults under varying load conditions.

Additionally, the system can be integrated with IoT-based platforms for remote monitoring and fault notification, enabling smart electrical safety solutions. The use of higher precision sensors and adaptive threshold techniques can further enhance system reliability under dynamic operating conditions. Furthermore, the design can be extended for three-phase systems and industrial applications to provide comprehensive protection in complex power distribution networks.

8.REFERENCES

- [1] H. Wang, J. Kang, and Y. Lin, "Low-Voltage Series Arc Fault Detection Based on Multi- Feature Fusion and Improved Residual Network," *Electronics*, vol. 14, no. 7, p. 1325, 2025.
- [2] L. Qi, T. Kawaguchi, and S. Hashimoto, "Detection and Classification of Low-Voltage Series Arc Faults Based on RF–AdaBoost–SHAP," *Electronics*, vol. 14, no. 19, p. 3761, 2025.
- [3] N. Wu, et al., "Research on Voltage-Current Type Series Arc Fault Detection Method Based on Composite Multi-Scale Entropy," *Electric Power Systems Research*, vol. 242, p. 111445, 2025.
- [4] B. Li, et al., "Research on Series Arc Fault Detection Method Based on Voltage Signal," *Scientific Reports*, 2025.
- [5] S. Santoso and P. T. Le, "Arc Fault Detection in Low-Voltage Systems Using Signal Processing Techniques," *IEEE Transactions on Power Delivery*, vol. 28, no. 4, pp. 2302–2310, 2013.
- [6] A. Lazkano, J. Ruiz, and L. A. Leturiondo, "Real-Time Arc Fault Detection in Electrical Systems Using Current Signal Analysis," *Electric Power Systems Research*, vol. 152, pp. 1–10, 2017.
- [7] M. Kezunovic, "Detection of Electrical Faults Using Time-Frequency Signal Processing Methods," *IEEE Signal Processing Magazine*, vol. 28, no. 5, pp. 20–30, 2011.
- [8] H. Yang and Y. Zhang, "Arc Fault Detection Based on Wavelet Transform and Feature Extraction," *International Journal of Electrical Power & Energy Systems*, vol. 104, pp. 430–438, 2019.
- [9] R. Chu, et al., "Series AC Arc Fault Detection Method Based on High-Frequency Coupling Sensor and Convolution Neural Network," *Sensors*, vol. 20, no. 17, p. 4910, 2020.
- [10] J. Chen and X. Li, "Low-Cost Embedded Arc Fault Detection System for Smart Grid Applications," *IEEE Access*, vol. 8, pp. 105000–105010, 2020.



Automatic Power Factor Correction

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Abstract:- Power factor correction is a technique for mitigating the unwanted effects of electric loads that result in a power factor less than unity. Power Factor correction can be used by an electrical power transmission utility to increase the stability and efficiency of the transmission network, or by individual electrical customers to minimize the costs imposed by their electricity supplier. This paper discusses the design and implementation of an automated power factor correction (APFC) system employing solid state switching capacitors and a microprocessor. The major goals are to reduce line loss, reduce reactive power flow on the line, and avoid switching surge over voltage caused by turning ON/OFF capacitors.

Keyword:- Power factor, LCD, C Language, Microprocessor

1. INTRODUCTION

APFC Stands for Automatic Power Factor Correction panel. It is an electrical panel that used to improve the power factor of an electrical distribution system. The power factor is the ratio of the real power (measured in watts) to the apparent power (measured in a volt-amperes) in an electrical circuit. In an electrical distribution system, if the power factor is low it means that the system is using more current to deliver the required power which results in higher energy losses and reduced efficiency. This can lead to higher electricity bills and can also damaged electrical equipment.

In APFC panel is designed to monitor the power factor of the electrical distribution system and manually or automatically switch capacitors ON/OFF to maintain the desired power factors. Capacitors are used to improve the power factor by storing and releasing electrical energy to counter the reactive power in the system. The APFC panel contains a microprocessor based automatic power factor controller, which measures the power factors and controls the capacitors. It also contains other components such as contactors, fuses and circuit breakers for protection and control. APFC panel are commonly used in industries, commercial buildings and other facilities where there is a high demand for electrical power. They help to improve the efficiency of the electrical distribution system reduce energy losses and save the electricity bills.

2. LITERATURE REVIEW

[1] Paper: Development of IOT enabled smart APFC panel for industrial load
Author: Bhagavthy patil

The increasing use of inductive loads in industries has led to a significant concern about power factor correction. Low power factor can result in energy losses and increased costs. To address this issue, an IOT – enabled automatic power factor correction (APFC) panel has been developed. This system uses a microcontroller to monitor the power factor and switch capacitors banks as needed improving the power factor for 0.5 to 0.86. The implementation of this system can help industry save energy and reduce cost. In this method the microcontroller is main part of entire APFC panel and it control the capacitors banks. Power factor correction done by adjusting the capacitors and that capacitors back increase the power factors in the circuit

[2] Paper: Power factor Improvement Using Automatic Power Factor Compensation (APFC) Device for Medical industries in Malaysia

Author: Maryam Nabihah Zaidi

The paper “Power Factor Improvement Using Automatic Power Factor Compensation” (APFC) Device for Medical Industries in Malayam Nabihah Zaidi and Adlan Ali from University Technical Malaysia Melaka discusses a project designed to correct the power factor for medical industries Malaysia automatically. The main aim is to make cost and energy usage efficient by improving the power factor, which is the ratio of real power (KW) to apparent power (KVA). A low power factor causes high current demand, making the industry less efficient. The proposed solution uses and Automatic Power Factor Compensation (APFC) device, a programmable miniature architecture device that adjusts capacitors of offset inductive load, improving the power factor from typically 0.85-0.90 to near unity. This helps reduce current dependent losses and increase

energy efficiency. The device is cost effective, smaller, and suitable for industrial usage, extending equipment lifespan and reducing maintenance costs

3.COMPONENTS

A. Isolator

An isolator is used in the APFC panel to provide safety and manual control of the power supply. The isolator used in this project is a voltage 240V/415V, current 63A and four pole isolator. The four poles correspond to the 3 phases (R, Y, B) and neutral conductor, ensuring complete disconnection of all live conductor. The device is mounted at the input side of the panel and is the first component through which the supply enters the system. During normal operation, the isolator remains in the ON position, allowing power flow to the downstream component. In case of maintenance, inspection, or emergency, the operator can manually turn the isolator OFF, thereby de-energizing the entire panel and ensuring safe working conditions for personnel. It functions as a main switch to disconnect the panel from the supply during maintenance or in the event of the malfunction ensuring safe working conditions. Unlike circuit breakers the isolator does not provide automatic protection but allows complete isolation of the circuit when operated manually.

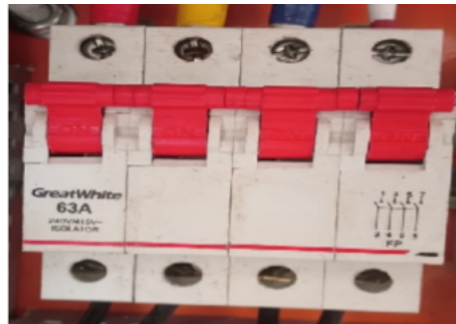


Fig 3.1 Isolator

Specifications of Isolator

Sr. No.	Specifications	Ratings
1	Rated voltage	240V / 415V
2	Rated Current	63 Amp
3	No. of Poles	Four Pole
4	Costing	1600/-

[B] MCBs

A miniature circuit breaker (MCBs) is an electromechanical protective device designed to automatically switch OFF the electrical circuit during abnormal conditions such as over load or short circuit. In the APFC panel, MCBs are used to protect individual capacitor bank and control circuit from damaged due to excessive current flow the MCB used in the panel are Alex brand, 3 pole MCBs. Each capacitors stage in protected by a detected MCB, so that a fault in one stage does not affect the operation of other stage. When the current flowing through the MCB exceeds its rated value for a specified time (overload condition) or rises suddenly to a very high value (short circuit condition), the internal bimetallic strip or electromagnetic trip mechanism activates and opens the contact, there by isolating the faulty circuit.

MCBs offer several advantages over traditional fuses: they can be reset manually after tripping provide precise protection characteristics and have a faster response time. The used of MCBs enhance the reliability and safety of the APFC panel by preventing capacitors damage cable overheating and fire hazard.



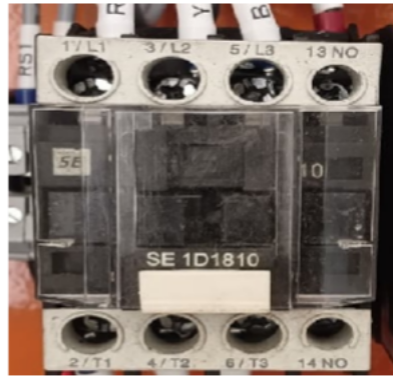
Fig3.2 MCB

Specifications of MCB c

Sr. No.	Specification	Rating
1	Rated voltage	240 / 415V
2	Frequency	50 HZ
3	No. of poles	3 pole
4	Costing	850/-

[C] Contactor

A contactor is an electrically controlled switching device used for switching power circuits, particularly where high current switching is required. In the APFC panel, contactors are used to automatically connect and disconnect the capacitor bank to the supply based on the commands received from the APFC controller. The contactors used are capacitor duty contactors specially designed to handle the high inrush current that occurs when a capacitor is switched ON. Each contactor is controlled by the output relay of the APFC controller. When the controller decides to add a capacitor stage, it energizes the coil of the corresponding contactor (usually 230v AC coil). The energized coil creates a magnetic field that pulls the movable contacts and closes the power circuits connecting the capacitors banks to the supply. When the capacitor is not required, the controller de-energizes the coil and the contactor opens.

**Fig 3.3 contactor****Specifications of Contactor**

Sr. No.	Specifications	Ratings
1	Rated voltage	230V
2	Rated current	4 contactors of 6A, 9A and 12A
3	Type	MOC
4	Costing	2400/-

[C] Capacitors

Diminishing reactive power: Inductive loads, such as transformers and motors, cause the voltage to lag behind the current, which leads to a lagging power factor. Leading reactive power, which capacitors supply, can offset the lagging reactive power brought on by inductive loads. By lowering the system's overall reactive power, this correction raises the power factor.

Enhancing efficiency: Capacitors assist in lowering the current passing through the electrical system for the same amount of useful power by adjusting the power factor. As a result, the electrical distribution system experiences less loss and operates more efficiently overall.

Preventing penalties: If an industrial or commercial customer's power factor drops below a specific level (usually 0.9), many energy companies will penalize them. Capacitors help businesses avoid these fines and save their electricity expenses by maintaining a greater power factor.

An array of capacitor banks placed in an APFC panel serves to both increase the inductive loads required reactive power (thereby optimizing power factor).



Fig 3.4 capacitor

Specifications of .Capacitor

Sr. No.	Specifications	Rating
1	Rated voltage	230 to400V
2	Frequency	50 HZ
3	Capacitance	5 Capacitors of 5kvar 5kvar,5kvar, 3kvar & 1kvar
4	Costing	2800/-

[C] Current transformer (CT)

The current transformer (CT) used to measure the load current and provide a proportional low current signals to the APFC controller. It is installed on the main supply line and its secondary output it connected to the controller. The controller uses this current signal along with voltage to calculate the power factor and the decide capacitor switching. Without CT, the controller cannot sense the load and the panel will not work automatically



Fig 3.5 current transformer

Specifications of. CT

Sr. No.	Specifications	Rating
1	Model	SELEC TWCT-T-035
2	Ratio	30/5 A
3	Voltage	720 V
4	Cost	1460

4. Working

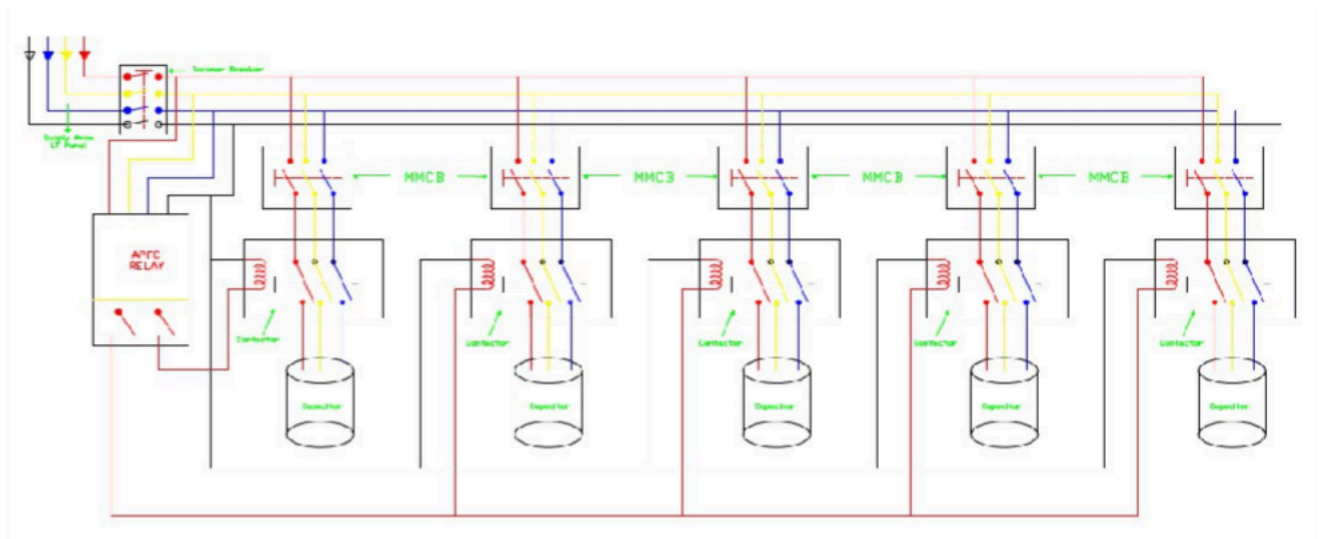


Fig4.1 Block diagram

The 3 phase supply (R, Y, B) entire from the top left the first passes through on isolator/main breaker. This allows you to manually switch ON /OFF entire panel and after the breakers power is distributed along horizontal busbar (R, Y, B Lines). These busbars feed all the capacitor bank section. The APFC relay monitor voltage, current and power factor. If the power factor lagging-adds the capacitors banks. If the power factor leading removes the capacitors. Each vertical section in one step of correction. Each step has an MMCB (molded case circuit breaker). Protect that capacitor bank from over current and short circuit

The contactor connect / disconnects the capacitors. Its coils controlled by the APFC relay. The capacitor provides reactive power (KVAR). Reduce reactive power from the supply and improve power factor. The supply starts from main breakers are on an APFC relay starts maintaining power factor. Therefore, the working of the motor and transformer then the power factor becomes lagging (inductive load increase). Then the APFC relay reacts of turn ON 1st contactor and 1st capacitor banks are connected. Then the power factor is still low then turns on next capacitor bank and added more KVAR usually power factor reaches target 0.95-0.99 relay stops adding capacitors.

Calculation:

Computer Lab 51 Computers :

200 W per computer

Smart Board Power Consumption :

300 W per smart board.

HP Motor Power (Input) :

1 horsepower (HP) is approximately 746 watts.

HP = 746 W

3 HP = 3 x 746 W

= 2,238 W

Step 1: Calculate the total load in kilowatts (kW):

Resistive Loads:

$$\begin{aligned} \text{Tubes} &= 176 \text{ tubes} \times 40 \text{ W} \\ &= 7,040 \text{ W} \\ \text{Computers} &= 51 \text{ computers} \times 200 \text{ W} \\ &= 10,200 \text{ W} \\ \text{Smart Boards} &= 10 \text{ boards} \times 300 \text{ W} \\ &= 3,000 \text{ W} \end{aligned}$$

Inductive Loads:

$$\begin{aligned} \text{Motors} &= 2 \text{ motors} \times 2,633 \text{ W} \\ &= 5,266 \text{ W} \\ \text{Fans} &= 84 \text{ fans} \times 80 \text{ W} \\ &= 6,720 \text{ W} \end{aligned}$$

Total Power (Active Power, P) Sum the watts of all devices:

$$\begin{aligned} P &= 7,040 + 10,200 + 3,000 + 5,266 + 6,720 \\ &= 32,226 \text{ W} \\ P &= 32.23 \text{ kW} \end{aligned}$$

Step 2: Calculation of required capacitor bank size (KVAR):

$$\begin{aligned} P &= \text{Total active power in kW.} \\ \theta_1 &= \text{Angle of the Present power factor (PF1)} \\ &= 0.8 \\ \theta_2 &= \text{Angle of the target power factor (PF2)} \\ &= 0.95 \end{aligned}$$

Calculate the angles:

$$\begin{aligned} \theta_1 &= \cos^{-1}(0.8) \approx 36.87^\circ \\ \theta_2 &= \cos^{-1}(0.95) \approx 18.19^\circ \\ Q_c &= P(\tan \theta_1 - \tan \theta_2) \end{aligned}$$

Calculate the tangents:

$$\begin{aligned} \tan \theta_1 &= \tan (36.87^\circ) \approx 0.75 \\ \tan \theta_2 &= \tan (18.19^\circ) \approx 0.328 \end{aligned}$$

Calculate the required capacitor KVAR:

$$\begin{aligned} Q_c &= 32.23 \text{ kW} \times (0.75 - 0.328) \\ Q_c &= 32.23 \times 0.422 \\ Q_c &\approx 13.6 \text{ KVAR} \end{aligned}$$

Final calculation:

Total Electrical Load: Approximately 32.23 kW.

Required Capacitor Bank Size: Approximately 13.6 KVAR.

Therefore, we are using 20 KVAR capacitor bank.

5. RESULT AND ANALYSIS

1.1 Before Installing APFC Panel



Fig 5.1 APFC relay before activation

Fig 5.1 shows the reading of Selec APFC347 controller before the APFC panel was activated. The power factor of the system was observed to be 0.853 lagging, which indicates a poor power factor due to inductive loads such as motors and transformers. At this low power factor, the system draws high reactive current from the supply, resulting in increased line losses, voltage drop, overloading of cables and transformers, and higher electricity bills. The electricity board also imposes penalty charges for power factor below 0.9.

1.2 After Installing APFC Panel



Fig 5.2 APFC relay after activation

Fig 5.2 shows the reading after the APFC panel was activated. The power factor improved to 0.995 (near unity) as displayed on the controller. The controller automatically sensed the low power factor through CT input and switched ON the required capacitor banks through contactors to supply leading reactive power.

1. **Improved Power Factor:** APFC panels monitor the power factor of an electrical system and automatically adjust it by controlling the connection and disconnection of power factor correction capacitors. This leads to a more efficient use of electrical power, reducing wastage and improving the overall power factor of the system.
2. **Energy Savings:** By optimizing the power factor, APFC panels help in reducing reactive power consumption, which in turn leads to lower electricity bills. Improved power factor means that the electricity supply is used more effectively, reducing the amount of apparent power needed from the utility provider.
3. **Reduced Penalties:** Many utility companies charge penalties for low power factor, as it can strain the electrical grid and require additional resources for maintenance. By maintaining a high power factor, APFC panels can help in avoiding these penalties, resulting in cost savings for the organization.
4. **Extended Equipment Lifespan:** APFC panels help in reducing stress on electrical equipment such as transformers, motors, and cables by ensuring a balanced load distribution and minimizing voltage fluctuations. This can lead to longer life spans for the equipment and lower maintenance costs over time.

5. **Enhanced System Efficiency:** With improved power factor and optimized power usage, overall system efficiency is enhanced. This can result in smoother operation of machinery, reduced downtime, and improved productivity for industrial and commercial applications.

6. **Compliance with Regulations:** In many regions, there are regulations or standards in place that require maintaining a certain power factor level. Installing an APFC panel ensures compliance with these regulations, avoiding potential fines or legal issues.

Overall, the installation of an APFC panel provides a comprehensive solution for managing power factor and optimizing electrical systems, leading to cost savings, improved efficiency, and compliance with industry standard

Image of APFC Panel

1. Exterior view of panel



2. Interior view of panel



6. CONCLUSION

In this project, an Automatic Power Factor Correction (APFC) panel was successfully designed and implemented using components such as isolator, MCB, contactor, capacitor bank, current transformer, and Select APFC controller. The panel operates fully automatically, senses the load power factor through CT, and switches capacitor banks to maintain the power factor close to unity. The experimental results show that the power factor improved from 0.853 to 0.995 after installation of the APFC panel. This improvement leads to reduced energy losses, lower electricity bills, better voltage profile, and avoidance of utility penalties. The system is cost-effective, reliable, and suitable for small and medium industries where inductive loads are predominant. Thus the developed APFC panel proves to be an efficient solution for power factor improvement and energy conservation.

7. REFERENCES

1. Bhagavthy Patil "Development of IOT enabled smart APFC panel for industrial load" 10th ICCCNT 2019 July 6-8, 2019, IIT Kanpur, India
2. Maryam Nabihah Zaidi "Power Factor Improvement Using Automatic Power Factor Compensation (APFC) Device for Medical industries in Malaysia" MATEC Web of conference 150, 01004 (2018)
3. O.Gacia J.A. Cobos, R.Prieto, P. Alou, J. Uceda, "Single Phase Power Factor Correction", may 2007.
4. Rohta Mehta, "Principle of Power System", V.K. mehta, 1982.
5. M.H. Rashid, "Power Electronics: Circuits, Devices, and Applications", Cliffs, N.J. Prentice-Hall.



High Voltage Underground Cable Duct Cooling System

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Abstract :- Underground power cables are widely used in modern power transmission systems because they improve safety and reduce environmental impact. However, underground cables generate heat due to electrical losses, and this heat accumulates inside the cable ducts. Excessive temperature rise can damage cable insulation, reduce efficiency, and shorten the lifespan of the cable system. This paper presents a High Voltage Underground Cable Duct Cooling System that monitors cable temperature using a PT100 temperature sensor and controls cooling through a microcontroller-based system with a PID controller. When the temperature exceeds the safe limit, a pump circulates cooling liquid through the cable duct to remove excess heat. This system helps maintain safe operating temperature, improves reliability, and increases the life of underground cables.

Keywords :- Underground Cable, Cable Duct Cooling, PT100 Sensor, PID Controller, Microcontroller, Temperature Monitoring

1. INTRODUCTION

There are a number of ways that high voltage underground cables can be used in an electrical distribution system; they provide improved safety, aesthetics, and less chance of being impacted by environmental conditions. A high voltage underground cable produces heat as it operates due to electrical resistance and insulation loss that occurs primarily when using electrical resistance to create an electrical current. If the temperature inside the cable duct rises above a specific threshold, it can cause damage to the cable insulation and significantly reduce the efficiency of energy transfer through the cable; thermal expansion, insulation deterioration, and mechanical stresses are reasoned as contributing factors to a decrease in the life expectancy of high voltage underground cables. Properly managing the temperature within the cable duct is critical for prolonging the useful life of high voltage underground cables. This system will utilize a temperature monitoring and cooling system that will utilize sensor technology and control systems to monitor the temperature and use cooling systems to remove excess heat from the cables and their protective conduit to maintain a safe operating environment. By implementing a temperature- controlled cooling system, a significant increase in reliability and the useful life of an underground cable system can be anticipated.

2.METHODOLOGY

A literature review was performed to assess the cooling methods available to provide a basis for developing an experimental underground cable duct cooling system. The background literature was focused on the thermal management of underground cables, increased ampacity, and cooling methods, and identified previous research gaps found. The majority of the previous studies reviewed were based on thermal modelling, soil resistivity assessment, or cooling systems that relied mainly on passive or natural air ventilation methods and did not have any real-time temperature monitoring or automatic control of the cooling systems; therefore, due to the absence of real-time temperature monitoring and automatic control of the cooling system there was an identified research gap for intelligent thermal management of underground cable systems. Therefore, the aim of this project is to establish a closedloop underground cable duct cooling system, which utilises the PT100 temperature sensor and PID control logic. In addition, a prototype of the proposed closed-loop water-based cooling system is tested in a laboratory environment that uses a nichrome heating unit, which simulates the generation of heat similar to that experienced by high voltage underground cable systems. The duct temperature is measured continuously by the PT100 resistance temperature detector (RTD) sensor and the temperature measurement is sent to the controller. The controller compares the actual duct temperature against the set point value (35°C) that was predetermined to be used as the trigger temperature for the activation of the water cooling pump. When the duct temperature exceeds the trigger temperature of (35°C), the controller automatically activates the water pump to pump water around the duct to remove excess heat.

3.BLOCK DIAGRAM

The High Voltage Cable Duct Cooling System is designed to control the temperature of underground high-voltage cables and prevent overheating. In this system, a power supply provides electrical power to the components. The PT100 temperature sensor continuously measures the temperature of the cable duct. This sensor is a resistance temperature detector that produces a signal proportional to the temperature. The temperature signal is then sent to the PID temperature controller, which compares the measured temperature with the preset reference temperature and determines the required control action.

The output of the PID controller is sent to the microcontroller, which acts as the main control unit of the system. Based on the temperature condition, the microcontroller activates the pump to circulate cooling water through the cable duct to reduce the temperature. The flow sensor monitors the flow of the cooling water and ensures that proper cooling is taking place. If the temperature exceeds the safe limit or if any abnormal condition occurs, the alarm is activated to alert the operator. Finally, the cooling water flows through the high voltage cable duct, removing excess heat from the cables and maintaining a safe operating temperature, thereby improving the reliability and lifespan of the underground cable system.

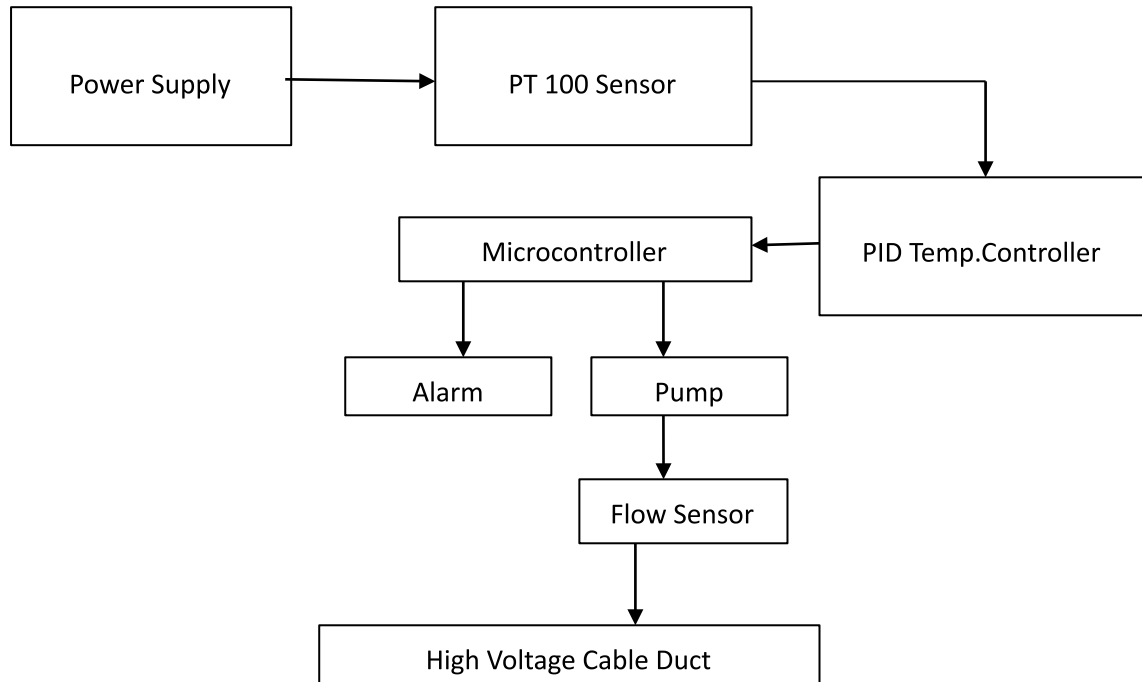


Fig 1 :- Block Diagram

Working Principle

The working principle of High Voltage Underground Cable Duct Cooling Systems is to continually monitor the temperature of each duct and to provide automatic cooling control through the use of both their power supply (providing electrical energy to all system components) as well as a PT100 temperature sensor (measuring the temperature of the high voltage cable duct continuously and converting that measurement into an electrical signal). The temperature signal generated by the PT100 is sent to PID temperature controller, which compares the measured temperature against a predetermined reference value. If the measured temperature exceeds the safe operating limit of the system, the controller will send an alarm to the microcontroller and activate the water pump automatically, which will begin to circulate cooling water through the high voltage cable duct. At the same time, the operator will be alerted via the alarm system if the measured temperature exceeds the predetermined level. When the water pump starts, cooling water will start to flow through the ducts around the cables. Flow sensors will measure the amount of cooling water flowing so that circulating is done correctly. As the cooling water flows through the ducts, it absorbs heat from the underground cables and reduces the temperature inside of the ducts. Once the duct temperature returns to a safe operating range, the controller will automatically turn off the water pump.

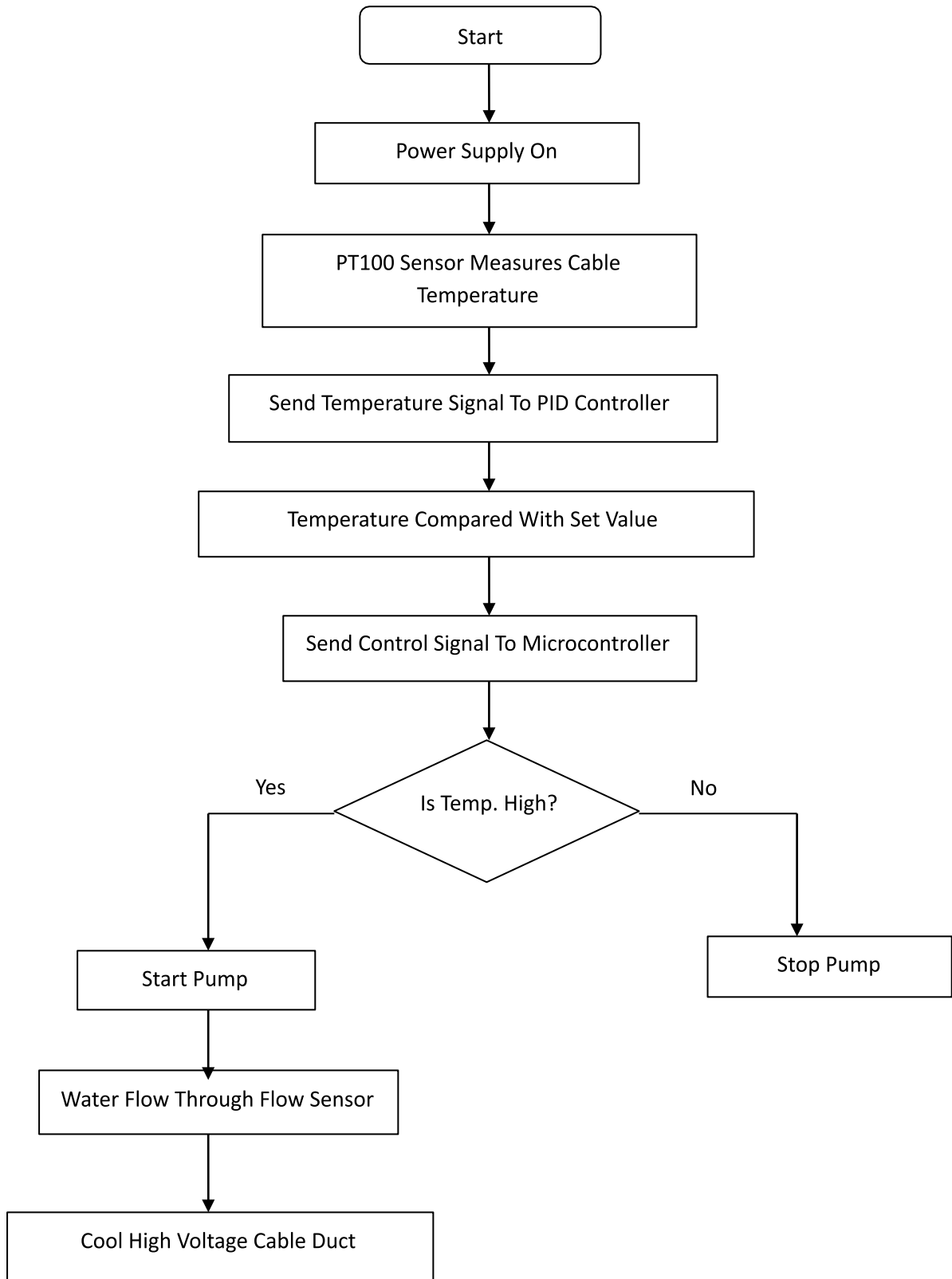
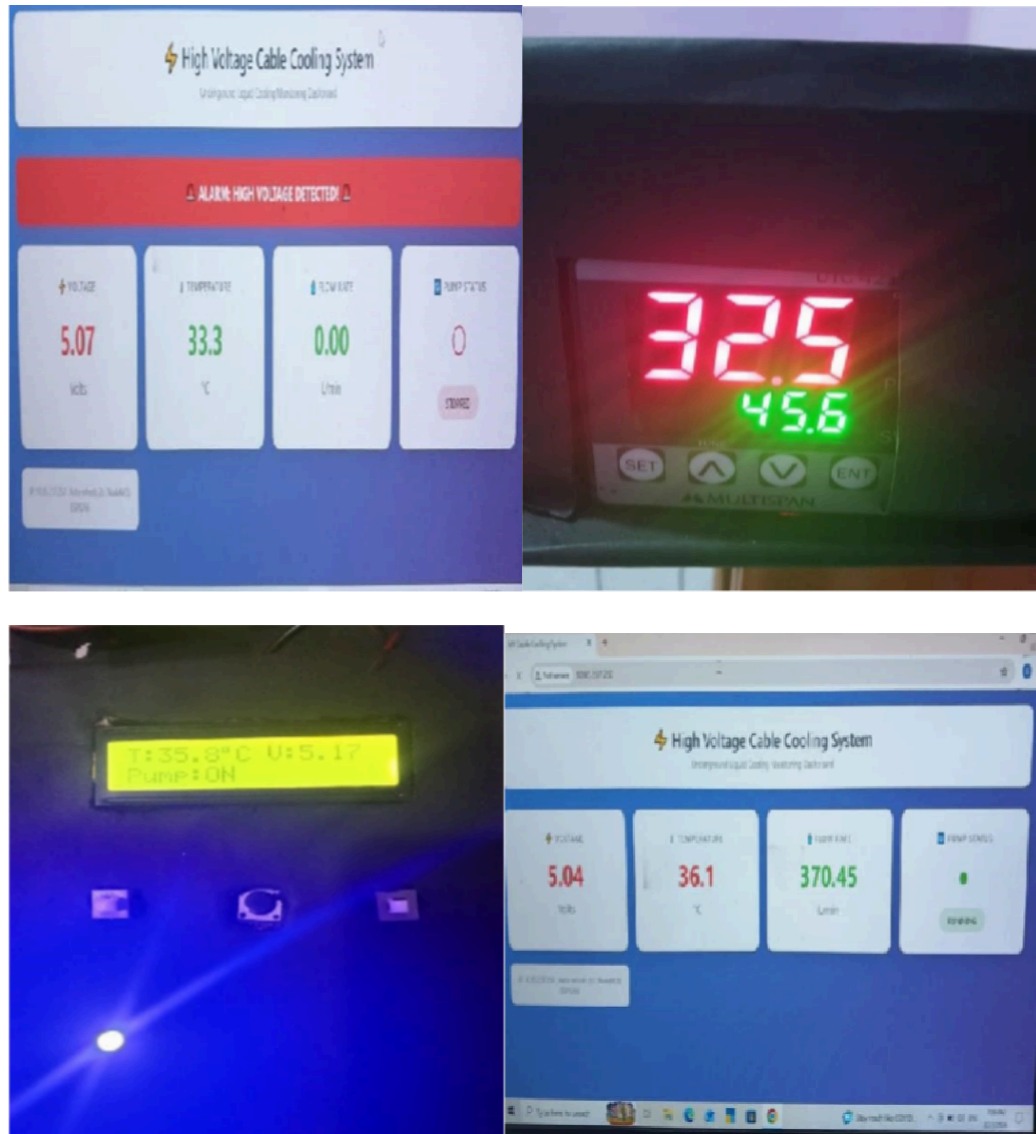


Fig 2:- Flow Chart

4. RESULT AND ANALYSIS



Initially, when the system is ON, the pump remains OFF and temperature increases due to heating. The PT100 sensor continuously monitors the temperature, and when it exceeds the set limit (35°C), the controller automatically activates the cooling pump. The coolant reduces the temperature effectively, and once it returns to a safe level, the pump turns OFF. The system operates efficiently in a closed-loop manner, maintaining stable temperature and preventing overheating. Overall, the project improves cable safety, reliability, and lifespan.

5. CONCLUSION

The created High Voltage Underground Cable Duct Cooling System offers a practical means of managing heat Created by underground power cable installations. The electrical losses produced by underground cables will create excess heat accumulation, thereby leading to a degradation of the insulation and reduced life expectancy of the cable. The created system uses a PT100 temperature sensor to provide a continuous monitoring of the internal temperature of the cable duct. When the temperature exceeds the predetermined safe threshold value, the automated cooling system activates the water pump to circulate cooling water around and through the duct area. This action will remove the excess heat and stabilize the internal cable temperature. The laboratory tests have shown the system is successful in maintaining the cable temperature within the safe operating range. The use of a closed-loop control system provides continuous monitoring of the temperature with an automatic response to any temperature fluctuations; therefore, enhancing the overall thermal management of and reliability of underground cable systems. In addition to the improvements in thermal management, maintaining a lower temperature enhances the operational life of the power cable. The proposed cooling system is cost-effective, energy-efficient, and a viable solution for smart power distribution networks. The system can also be integrated with SCADA or other IOT-based monitoring systems to allow for remote monitoring and management. In conclusion, the systems assist in enhancing the safety, reliability, and sustainability of underground electrical power transmission infrastructure.

6. FUTURE SCOPE

The future scope of the High Voltage Underground Cable Duct Cooling System includes implementation in real-time industrial and power distribution networks for large-scale applications. The system can be enhanced by integrating SCADA or IoT for remote monitoring and control.

Advanced cooling methods such as liquid or hybrid cooling can be used for better efficiency. Multiple sensors can be installed along the cable for accurate temperature profiling, and data logging with intelligent algorithms like PID or AI can further improve system performance and energy efficiency. This system can be further developed for use in smart grids and modern power system.

7. REFERENCES

1. <https://digital-library.theiet.org/doi/abs/10.1049/ip-a-1.1982.0023>
2. <https://link.springer.com/article/10.1007/s10973-024-13299-x>
3. <https://www.sciencedirect.com/science/article/pii/S0011227511000026>
4. <https://www.academia.edu/download/60472979/IRJET-V6I717220190903-104035-wwfb3h.pdf>
5. <https://www.nature.com/articles/s41598-024-71281-x>
6. <https://www.sciencedirect.com/science/article/pii/S1359431110004588>
7. Mohasin S Bijali, Aniket C Daiv, Abhijit S Patil “Smart Hybrid Fully Automatic Solar Grass Cutter” International Journal of Innovations in Engineering Research and Technology, Publisher Novateur Publication, vol. 2, no. 1, Jan 2015.
8. Mr Aniket C Daiv, “Direct torque control of three phase induction motor by using four switch inverter.” Int. J. Innov. Eng. Res. Technol. (IJIERT) **3**, 1–10 (2016)
9. AC Daiv ,Shradha Sharad Meghpuje, Hrithik Kisan Lokhande, Nilesh Dadaso Patil, Shahrukh Salim Makandar “Smart Hybrid Fully Automatic Solar Grass Cutter” International Journal for Multidisciplinary Research (IJFMR), E-ISSN: 2582-2160, vol. 5, no. 3, May-June 2023.

Smart Transformer System With Ai Based Tap Changer And Cooling Control

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Abstract:- This project outlines the design, development, and validation of the Smart Transformer System with AI-Based Tap Changer and Cooling Control. In the conventional transformer control system, the control operation relies on rigid logic and human intervention, which results in several problems, such as voltage instability, inefficient cooling systems, thermal stress, and a reduced life span of the transformer components. To address these problems, an adaptive AI-based control system is developed to enable self-controlled and data-driven transformer control.

The proposed system continuously monitors the electrical and thermal parameters using current and voltage sensors and a temperature sensor. The real-time parameters are analysed by an embedded ESP32 microcontroller, which executes an AI-based decision-making algorithm to predict the variation in the load and optimize the on-load tap changer control and cooling control. The system dynamically adjusts the tap settings to regulate the voltage and manages the cooling system to prevent overheating.

The experimental outcome, conducted under various load and temperature changes, confirms the precise measurement of the data, successful AI-based control, effective voltage regulation, and efficient thermal management. The outcome indicates enhanced transformer efficiency, reduced thermal stress, and enhanced transformer reliability than the conventional control system.

Keywords :- Artificial Intelligence, Cooling Control System, Real Time Monitoring, Smart Transformer, Tap Changer Control, Voltage Regulation.

1. INTRODUCTION

The transformer is one of the most important components in the electrical power system, and it is used for voltage regulation, safe power transfer, and stability of the power distribution network. However, the traditional transformer has been encountering some of the most important challenges, such as voltage variation, transformer overheating, mechanical tap-changing systems that are slow, and the absence of real-time monitoring. In the modern power system, especially with the growing use of renewable energy resources and dynamic loads, there is a need for intelligent, automated, and self-adaptive transformer systems.

The Smart Transformer System with AI-Based Tap Changer Control and Cooling System is proposed to address the challenges using sensor-based monitoring, microcontroller-based automation, and machine learning-based decision-making. The system continuously monitors the operating conditions of the transformer, such as voltage, current, core temperature, and environmental conditions. Based on the sensor information, the ESP32 microcontroller dynamically controls the tap changer and the cooling system to ensure safe and efficient operation of the transformer. The prototype uses digital sensors for real-time data acquisition, and actuators such as the stepper motor and PWM-controlled cooling fan provide precise control. One of the key benefits of this system is the use of AI, which enables predictive actions, such as predicting voltage drops or heating, so that the system can take proactive measures rather than waiting for the occurrence of the fault.

The system also provides data logging functionality, an OLED display for real-time monitoring, protection mechanisms such as fuses and surge protection, and an optional web interface. The entire system is low-cost, compact, and safe for use in an academic environment, making it suitable for use in academic and research environments in institutions and smart grid training labs.

This project, therefore, demonstrates the power of integrating IoT, embedded systems, automation, and AI to revolutionize the transformer system. It, therefore, provides a practical demonstration of how next-generation smart grid infrastructure can be leveraged to offer improved voltage stability, improved cooling, reduced energy losses, and improved power reliability.

2. BLOCK DIAGRAM:

This is a smart monitoring and control system designed using an ESP32 microcontroller. It is intended to monitor electrical and environmental factors such as voltage, current, and temperature, and then take automatic actions based on the readings. A 12V battery is used as the primary power source for high-power devices such

as the cooling fan, while a regulated 5V supply is used for the servo motor. Sensors are continuously taking readings of the system conditions and transmitting them to the ESP32 microcontroller for processing. The ESP32 microcontroller is the central control unit that takes decisions based on predefined thresholds. A relay module is used to control the cooling fan safely by turning it on or off, thus separating the high-voltage part from the low-voltage control circuit. The servo motor can carry out mechanical tasks such as turning on a vent or changing the direction of airflow. A display unit is used to give real-time information to the user about the system conditions.

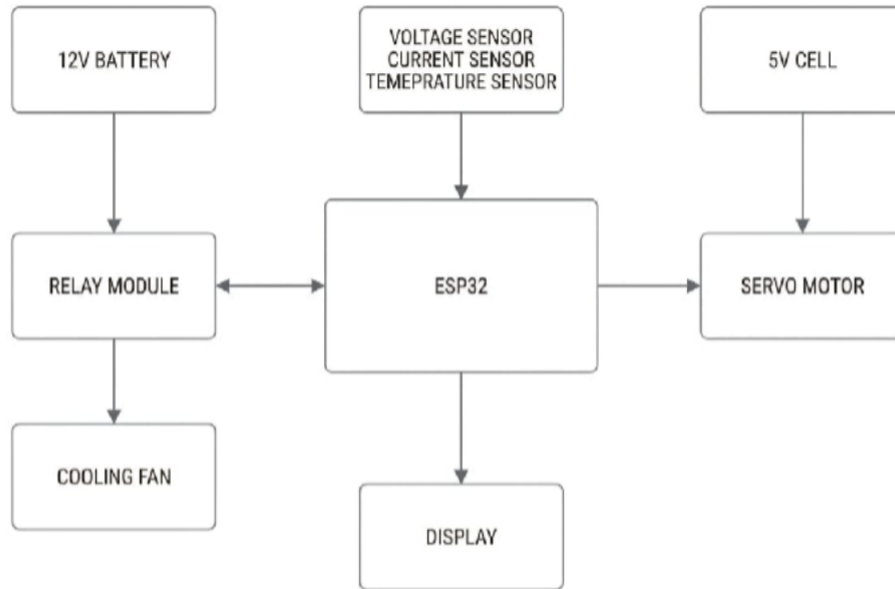


FIG.1 BLOCK DIAGRAM

3. WORKING

When the system is turned on, the ESP32 initializes all the sensors, the relay module, the servo motor, and the display. The voltage, current, and temperature sensors are continuously sending data to the ESP32. The controller then processes the data and compares it with the predetermined threshold values set in the system.

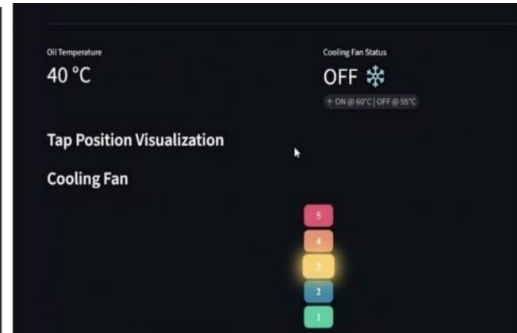
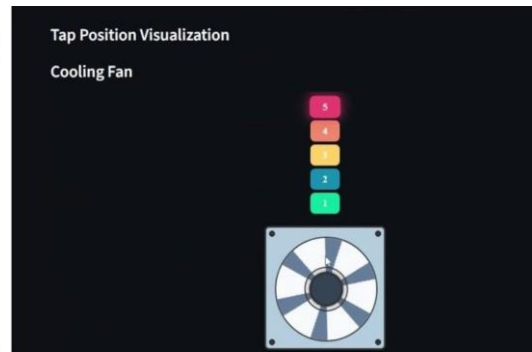
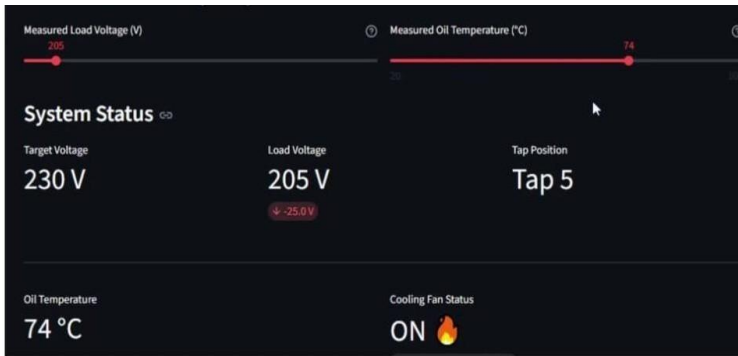
If the temperature or current level exceeds a certain safe limit, the ESP32 sends a control signal to the relay module, which turns on the cooling fan powered by the 12V battery. This ensures that the system temperature is maintained within safe limits and does not get overheated. At the same time, the servo motor powered by the 5V supply can also move a mechanical component, such as opening a cooling vent or turning the direction of airflow.

The display shows the real-time values of the voltage, current, temperature, and status of the fan and servo motor. As soon as the values of the monitored parameters return to the safe limit, the ESP32 automatically turns off the fan using the relay module and also resets the servo motor position.

KEY ASPECTS OF THE PROJECT:

In "Smart Transformer System with AI-Based Tap changer & Cooling" The basic idea of this project is to design an intelligent control system for smart transformers using the concept of predictive analysis. The main aim of this project is to improve the efficiency and extend the life of the smart transformers using the prediction approach rather than the conventional method. In this project, the values of the load current, voltage, oil temperature, and ambient temperature in real-time are measured using sensors and then processed using the prediction model. Using the prediction model, the values for the upcoming changes in the load and temperature rise are predicted.

Using the prediction model, the voltage levels are optimized to keep them within the permissible limits. At the same time, the cooling of the smart transformers is done at stages rather than waiting for the temperature levels to reach critical levels. The hardware components of this project include the sensor for measurement, microcontroller for processing, relay driver circuit for control.

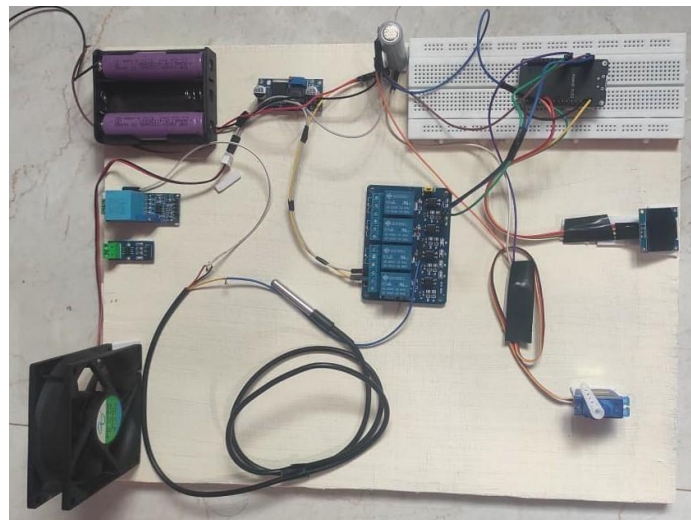


4. Result And Analysis:

The Smart Transformer System with AI-Based Tap Changer and Cooling Control has been successfully implemented. The ESP32 microcontroller used in the Smart Transformer System with AI-Based Tap Changer and Cooling Control operated efficiently as the central control unit of the smart transformer system. The voltage sensor used in the Smart Transformer System with AI-Based Tap Changer and Cooling Control operated efficiently by providing the voltage reading on the display unit of the smart transformer system. The current sensor used in the Smart Transformer System with AI-Based Tap Changer and Cooling Control operated efficiently by providing the current reading on the display unit of the smart transformer system.

The Smart Transformer System with AI-Based Tap Changer and Cooling Control operated efficiently during the voltage fluctuation tests. During the tests carried out under the undervoltage conditions, the Smart Transformer System with AI-Based Tap Changer and Cooling Control operated efficiently by providing the required control signal to the stepper motor. The stepper motor used in the Smart Transformer System with AI-Based Tap Changer and Cooling Control operated efficiently during the tests carried out under the overvoltage conditions by providing the required output to the stepper motor for the tap-down operation.

The OLED display also functioned efficiently in displaying the output voltage, output current, temperature, tap position, and cooling control. The entire system functioned efficiently and produced the required output for the proposed smart transformer system with AI-based tap changer and cooling control.



VOLTAGE	TAP POSITON
246<	1
236-245	2
226-235	3
211-225	4
200-210	5

TABLE.1

TEMPERATURE	FAN STATE
65>	OFF
65<	ON

TABLE .2

5. conclusion:

The Smart Transformer System with AI-Based Tap Changer and Cooling Control is a successful example of the application of embedded systems, sensor devices, automation systems, and smart control systems in power engineering fields. The successful development of the prototype is a clear example of the practicality and possibility of using real-time monitoring techniques for measuring voltage, current, and temperature, and improving the efficiency and effectiveness of the transformer.

The successful operation of the ESP32 microcontroller, which is considered the CPU of the smart transformer, is clearly demonstrated by its successful operation for retrieving information from the devices. The successful operation of the smart transformer for regulating voltage at acceptable levels despite the varying loads is clearly demonstrated by its smooth operation with the stepper motor, which does not exert any mechanical stress on the device. Similarly, the successful operation of the smart transformer for regulating the fan operation despite the varying temperatures is clearly demonstrated by its effectiveness in increasing the lifespan of the transformer.

The use of the OLED-based monitoring interface also enhanced the level of transparency in the process. The overall architecture has proven that intelligent automation can reduce the need for intervention, minimize the need for maintenance, and increase the level of energy efficiency.

The project has created a foundation for future enhancements in terms of predictive analytics, cloud monitoring, and smart grid, making this a very viable solution for the modern power distribution grid.

6. REFERENCES:

- [1] Gautham Ram Chandra Mouli, Pavol Bauer, Thiwanka Wijekoon, Ara Panosyan, Eva-Maria Barthlein had presented “the design of a power electronic assisted OLTC for grid voltage regulation.”, JUNE 2015
- [2] S.V.M. Bhuvanaika rao, B. Subramanyeswar “Fine Voltage Control Using Oltc by Static Tap Change Mechanism” DEC 2012.
- [3] Nikunj R. Patel, Makrand M. Lokhande, Jitendra G. Jamnani, “Solid- State On Load Tap-Changer for Transformer Using Microcontroller”, DEC 2014.
- [4] SOLID STATE ON LOAD TAP CHANGER FOR TRANSFORMER USING ARDUINO by Vivek Thomas Chacko, Mohamed Noufal, Nidhin Mohan, Sriram Vinod, Eldhose K
- [5] B. Kasztenny, E. Rosolowski, J. Izykowski, M. M. Saha, and B. Hillstrom, Fuzzy logic controller for on-load transformer tap-changer, IEEE Trans. Power Del., vol. 13, no. 1, pp. 164-170, Jan. 1998.
- [6] H. Jiang, R. Shuttleworth, B. A. T. Al Zahawi, X. Tian, and A. Power, Fast response GTO assisted novel tap changer, IEEE Trans. Power Del., vol. 16, no. 1, pp. 111-115, Jan. 2001.
- [7] S.M.Bashi, Microcontroller-based fast on-load semiconductor tap changer for small power transformer, Journal of applied sciences, pp.999- 1003n-2005
- [8] G. De Carne, M. Liserre, C. Vournas, and K. Strunz, “Smart Transformer for the Modern Distribution Grid,” IEEE Transactions on Industrial Electronics, vol. 64, no. 8, pp. 1–10, 2017.
- [9] S. A. Taher, A. R. Jordehi, and M. H. Fini, “Application of Artificial Intelligence Techniques in Power Transformer Control,” IEEE Conference on Power Systems, pp. 1–6, 2015.
- [10] A. Abu-Siada and S. Islam, “A Review of Power Transformer Monitoring and Protection Techniques,” Electric Power Systems Research, vol. 157, pp. 25–35, 2018.
- [11] I. S. Metwally, “Thermal Modeling and Cooling Techniques of Power Transformer,” International Journal of Electrical Power & Energy Systems, vol. 88, pp. 1–9, 2016.
- [12] M. R. Islam, M. S. Rahman, and M. M. Rahman, “IoT Based Smart Transformer Monitoring System,” IEEE Access, vol. 7, pp. 1–10, 2019.
- [13] A. Sharma and B. Singh, “Artificial Intelligence Based Voltage Control of Power Transformers,” International Journal of Engineering Research & Technology, vol. 9, no. 5, pp. 100–105, 2020.
- [14] P. K. Dash and S. Mishra, “Fuzzy Logic Based Tap Changer Control of Transformer,” International Journal of Electrical Power & Energy Systems, vol. 45, no. 1, pp. 213–220, 2013.

A Voltage Controlled DG Unit based Active Harmonic Damping System For Island and Grid Connected Microgrid

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Abstract: Due to the consequences of mismatched line impedance, the traditional droop approach was unable to accurately share the reactive power during its landed operation. This research suggests an enhanced droop control technique to increase the accuracy of reactive power sharing. The two key procedures in the suggested method are voltage recovery and error reduction. Resonances in the power distribution system may arise from the use of shunt capacitor banks and subterranean wires. Specific harmonic mitigation techniques must be devised for current-controlled and voltage-controlled DG units due to their disparate behaviors at harmonic frequencies. A nonlinear virtual capacitor and a virtual damping resistor are used in an improved virtual impedance control technique.

Keywords: Micro grids distributed power generation, droop control, grid-connected converter, microgrid, power quality, renewable energy system, resonance propagation, virtual impedance.

1. INTRODUCTION

Microgrids have become an important solution for supplying reliable and clean electrical power in modern power systems. They consist of several Distributed Generation (DG) units such as solar inverters, wind generators, and energy storage systems. A microgrid can operate either in **grid-connected mode** or in **islanded mode**, and it must ensure stable voltage, proper power sharing, and high power quality in both conditions. To achieve these goals, DG units commonly use **droop control**, a well-known method for regulating voltage and frequency without using communication links.

However, the **traditional droop control method** faces several limitations, especially during islanded operation. One major issue is the inaccurate sharing of **reactive power** among DG units due to differences in line impedance. When the line impedances are mismatched, DG units do not share reactive power proportionally, leading to voltage imbalance, poor regulation, and reduced system performance. To overcome this problem, researchers have proposed an **enhanced droop control strategy** that improves reactive power sharing accuracy. The improved method mainly includes two steps— **voltage recovery**, which restores voltage to its desired level, and **error reduction**, which minimizes sharing errors among different DG units.

Another challenge in microgrids is the presence of **harmonic distortions**. Components like shunt capacitor banks and underground cables may cause resonance at specific frequencies, amplifying harmonic currents and affecting the microgrid's power quality. Current-controlled and voltage-controlled DG units respond differently at harmonic frequencies, so specialized harmonic mitigation methods are needed for each type.

To address these issues, an **improved virtual impedance technique** has been introduced. This method uses a **nonlinear virtual capacitor** and a **virtual damping resistor** to provide active harmonic damping, enhance stability, and reduce unwanted resonances. As a result, the proposed control approach supports both accurate reactive power sharing and effective harmonic suppression in microgrids operating in both grid-connected and islanded modes.

Circuit Diagram:

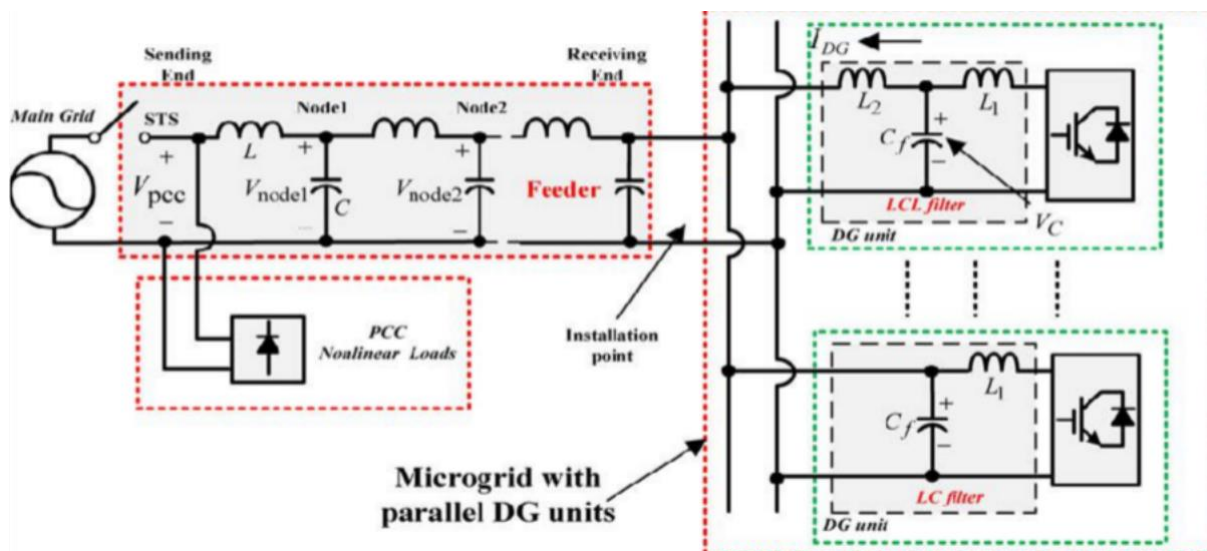
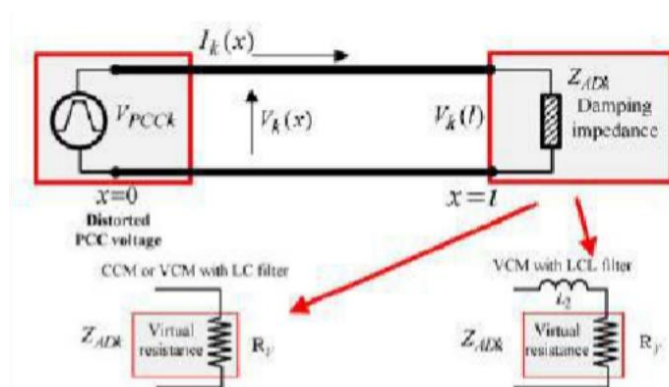


Fig.1. Simplified one-line diagram of a single-phase microgrid.

II. MODELING OF DG UNITS IN MICROGRID SYSTEM

A. Distributed Parameter Model in Grid-Tied Operation:

For a long feeder, as shown in Fig. 1, a lumped parameter model is not able to define its resonance propagation char-



acteristics. Alternatively, the distributed parameter model was discussed in [3] and [6], where the voltage distortions at PCC induce a harmonic voltage standing wave beside the feeders. To make the discussion more straightforward, we assume that the microgrid in the feeder receiving end only consists of one DG interfacing converter. In the succeeding section, the modelling of resonances in multiple DG-unit-based microgrid is discussed. With the aforementioned assumption, the equivalent circuit model of a grid-tied micro grid at the k th harmonic frequency is presented in Fig. 2, where the k th PCC harmonic voltage is assumed to be stiff and V_{pcck} . $V_k(x)$ and $I_k(x)$ are the feeder k th harmonic voltage and harmonic current at position x . The length of the feeder is l .

Fig.2. Equivalent circuit of a single grid-connected DG unit at the k th harmonic frequency. It is easy to obtain the harmonic voltage–current standing wave equations at the harmonic order k as

$$V_k(x) = Ae^{-\gamma x} + Be^{\gamma x}$$

$$I_k(x) = z(Ae^{-\gamma x} - Be^{\gamma x})$$

where A and B are constants, which are determined by feeder boundary conditions. z and γ are the characteristics impedance [3] of the feeder without considering the line resistance as

$$z = \frac{L}{C}$$

$$\gamma = jk\omega_f LC$$

where ω_f is the fundamental angular frequency and L and C are the feeder equivalent inductance and shunt capacitance per kilometer, respectively.

B. Distributed Parameter Model in Islanding Operation:

The previous section focuses on the analysis of grid-tied DG units. For an islanding microgrid system, the VCM operation of DG units is needed for direct voltage support. When only a single DG unit is placed in the islanding system, constant voltage magnitude and constant frequency (CVMCF) control can be used. Considering the focus of this section is to investigate the harmonic voltage damping in a stand-alone islanding system, a single DG unit at the receiving end of the feeder is considered. The circuit model of an islanding system at the harmonic order k is illustrated in Fig. 3, where VCM-based DG unit is also modeled as an equivalent harmonic impedance using the control scheme in . The nonlinear PCC load in this case is modeled as a harmonic current source at the sending end of the feeder [3].

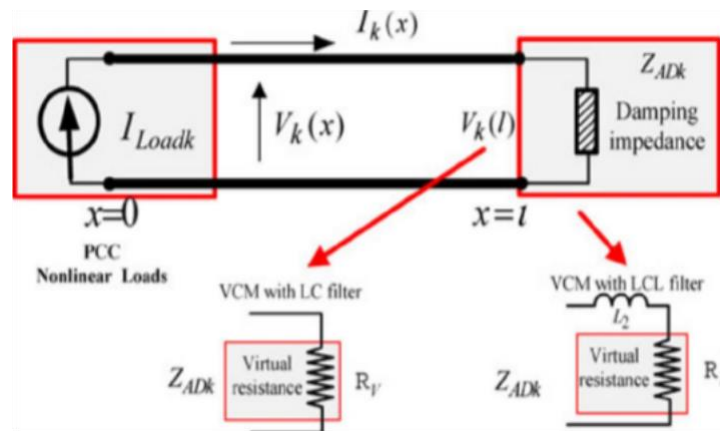


Fig.3. Equivalent circuit of a single islanding DG unit at the k th harmonic frequency

With the knowledge of boundary conditions at both sending and receiving ends as

$$I_k(0) = I_{Loadk}$$

$$V_k(l) = Z_{ADk}$$

The voltage propagation in an islanding system harmonic is also related to the DG-unit equivalent harmonic impedance. In order to maintain satisfied voltage quality, the equivalent harmonic impedance of islanding DG units shall also be properly designed

III. SIMULATION RESULT

Simulated results have been obtained from a single-phase low voltage micro grid where a few DG units are interconnected to the point of common coupling (PCC) through a long underground feeder. For the sake of simplicity, this paper only adopts a simple microgrid configuration to demonstrate how the microgrid power quality is affected by resonance propagation. [Note that the static transfer switch (STS) controls the operation mode of the micro grid. When the main grid is disconnected from the micro grid, the PCC nonlinear loads shall be supplied by the standalone DG units.

A. Single DG Unit Grid-Tied Operation:

At first, the performance of a grid-connected single DG unit with an LCL filter with damping and without damping is

observed.

a) Single DG Unit Grid-Tied Operation Withoutdamping

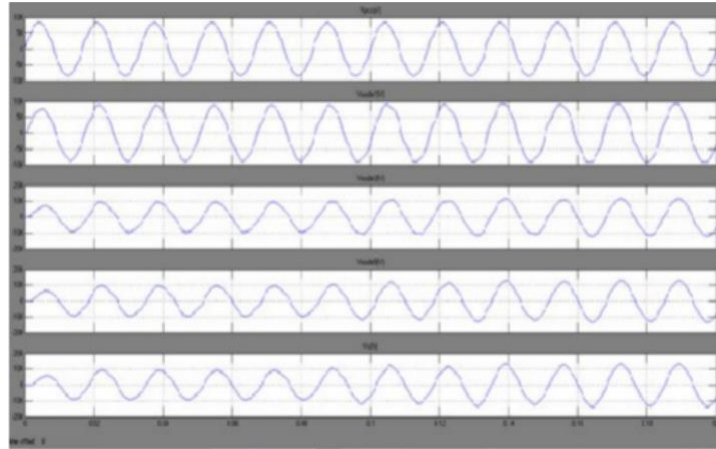


Fig.4. During a single DG unit grid connected operation harmonic voltage amplification (without damping) [from upper to lower: (a) PCC voltage (THD = 4.04%); (b) node 1 voltage (THD = 4.57%); (c) node 3 voltage (THD = 3.13%); (d) node 5 voltage (THD = 2.93%); (e) DG unit filtercapacitor voltage (THD = 2.07%)

b) Single DG Unit Grid-Tied Operation Withdamping

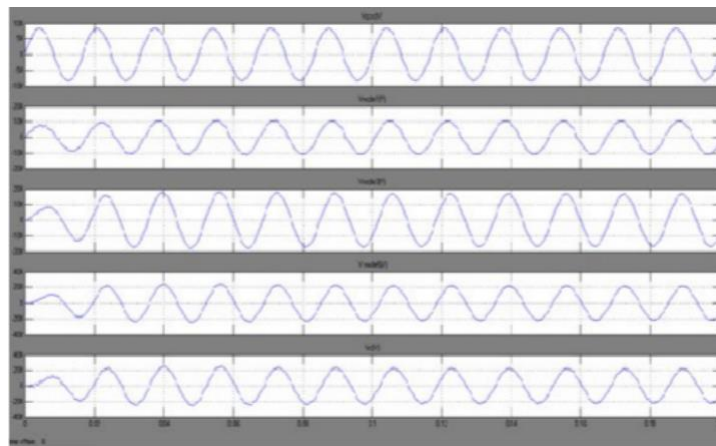


Fig.5. During a single DG unit grid connected operation harmonic voltage amplification (with damping) [from upper to lower: (a) PCC voltage (THD = 4.03%); (b) node 1 voltage (THD = 3.71%); (c) node 3 voltage (THD = 1.39%); (d) node 5 voltage (THD = 1.03%); (e) DG unit filtercapacitor voltage (THD = 3.16%)

When the conventional VCM method without damping is applied to the DG unit, the harmonic voltages at PCC, nodes 1, 3, 5, and DG unit filter capacitor are presented in Fig. 4. When the proposed control method with a virtual nonlinear capacitor and a virtual damping resistor is applied to the DG unit, the harmonic voltage drops on the LCL filter grid-side inductor (L_2) are compensated and the DG unit behaves as a damping resistor at the end of the feeder. The results in Fig. 5 show that the resonance along the feeder is mitigated.

B. Single DG Unit Islanding Operation:

In addition to grid-connected operation, the performance of a single DG unit in islanding operation is also investigated. In this case, the PCC load is a single-phase diode rectifier and it is supplied by the DG unit through long feeder. the performance of a islanding DG unit with an LCL filter with damping and without damping is observed.

a) Single DG Unit Islanding Operation Without damping

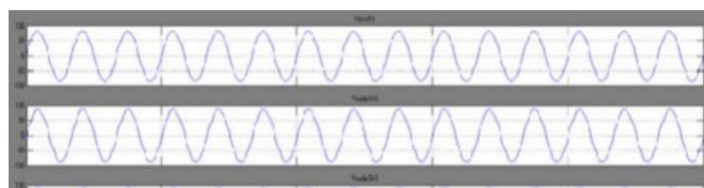


Fig.6. During a single DG unit islanding operation harmonic voltage amplification (without damping) [from upper to lower: (a) PCC voltage (THD = 4.03%); (b) node 1 voltage (THD = 3.87%); (c) node 3 voltage (THD = 3.95%); (d) node 5 voltage (THD = 3.17%); and (e) DG unit filter capacitor voltage (THD = 4.65%)].

b) Single DG Unit Islanding Operation Withdamping

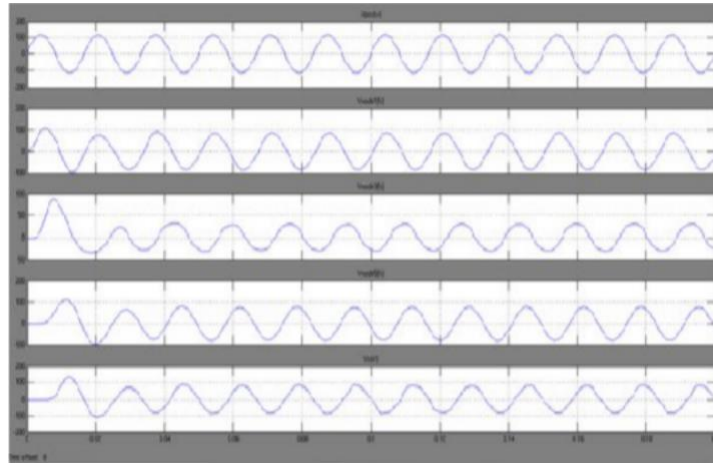


Fig.7. During a single DG unit islanding operation harmonic voltage amplification (without damping) [from upper to lower: (a) PCC voltage (THD = 4.03%); (b) node 1 voltage (THD = 2.05%); (c) node 3 voltage (THD = 3.82%); (d) node 5 voltage (THD = 0.59%); and (e) DG unit filter capacitor voltage (THD = 2.59%)].

When the conventional VCM method without damping is applied to the DG unit in islanding mode, the harmonic voltages at PCC, nodes 1, 3, 5, and DG unit filter capacitor are presented in Fig.6. When the proposed control method with a virtual nonlinear capacitor and a virtual damping resistor is applied to the DG unit, the harmonic voltage drops on the *LCL* filter grid-side inductor (*L*₂) are compensated and the DG unit behaves as a damping resistor at the end of the feeder. The results in Fig. 7 show that the resonance along the feeder is mitigated.

IV. CONCLUSION

In this paper, a voltage-controlled DG unit-based active harmonic damping strategy for both grid-connected and islanded microgrids has been thoroughly investigated. The study highlights the need for effective resonance suppression, especially in systems where shunt capacitors, underground cables, and *LCL* filters create conditions that amplify harmonic distortion. To address this challenge, an enhanced DG control scheme using the principle of virtual impedance has been proposed. The core idea of the method lies in its **nonlinear virtual impedance**, which is designed with two functional components. The **capacitive component** effectively compensates for the influence of the *LCL* filter's grid-side inductor, helping the DG unit maintain stable voltage and smoother harmonic response. Meanwhile, the **resistive component** provides active damping, reducing resonant peaks and improving overall system stability. Overall, the proposed approach strengthens harmonic suppression, improves microgrid reliability, and supports seamless operation during both grid-connected and islanded modes.

V. REFERENCES

- [1] H. Akagi, H. Fujita, and K. Wada, "A shunt active filter based on voltage detection for harmonic termination for radial power distribution system," *IEEE Trans. Ind. Appl.*, vol. 35, no.4, pp. 682–690, Jul./Aug. 1995.
- [2] K. Wada, H. Fujita, and H. Akagi, "Consideration of a shunt active filter based on voltage detection for installation on a long distribution feeder," *IEEE Trans. Ind. Appl.*, vol. 38, no. 4, pp. 1123–1130, Jul./Aug. 2002.
- [3] P.-T. Cheng and T.-L. Lee, "Distributed active filter systems (DAFSs): A new approach to power system harmonics," *IEEE Trans. Ind. Appl.*, vol. 42, no. 5, pp. 1301–1309, Sep./Oct. 2006.
- [4] T.-L. Lee and P.-T. Cheng, "Design of a new cooperative harmonic filtering strategy for distributed generation interface converters in an islanding network," *IEEE Trans. Power Electron.*, vol. 42, no. 5, pp. 1301–1309, Sep. 2007.
- [5] T.-L. Lee, J.-C. Li, and P.-T. Cheng, "Discrete frequency-tuning active filter for power system harmonics," *IEEE Trans. Power Electron.*, vol. 24, no. 5, pp. 1209–1217, Apr. 2009.
- [6] T.-L. Lee and S.-H. Hu, "Discrete frequency-tuning active filter to suppress harmonic resonances of closed-loop distribution power system," *IEEE Trans. Power Electron.*, vol. 26, no. 1, pp. 137–148, Dec. 2010.

- [7] N.Pogaku and T. C. Green, "Harmonic mitigation throughout a distribution system: A distributed-generator-based solution," *IEE Proc. Gener.Transmiss. Distrib.*, vol. 153, no. 3, pp. 350–358, May 2006.
- [8] C. J. Gajanayake, D. M. Vilathgamuwa, P. C. Loh, R. Teodorescu, and F. Blaabjerg, "Z-source-inverter-based flexible distributed generation systemsolution for grid power quality improvement," *IEEE Trans. EnergyConvers.*, vol. 24, pp. 695–704, Sep. 2009.
- [9] Y.W. Li, D. M. Vilathgamuwa, and P. C. Loh, "Design, analysis and realtime testing of a controller for multibus microgrid system," *IEEE Trans.Power Electron.*, vol. 19, no. 5, pp. 1195–1204, Sep. 2004.
- Q.-C. Zhong and G. Weiss, "Synchronverters: Inverters that mimic synchronous generators," *IEEE Trans. Ind. Electron.*, vol. 58, no. 4, pp.



VidyaBot: Intelligent Virtual Assistant for Enhancing Student Learning Experience

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Abstract: In the current educational landscape, there is an increasing demand for personalized and accessible learning solutions. Traditional classroom environments often adopt a one-size-fits-all approach, limiting individual attention for students and hindering effective doubt resolution, especially in regions with high student-teacher ratios. Recent advancements in Large Language Models (LLMs) offer a promising opportunity to address these challenges by delivering interactive, context-aware, and on-demand educational support. Additionally, VidyaBot incorporates advanced features such as Text-to-Speech (TTS) for auditory learning and an AI-based image generation module for creating visual learning aids. The system architecture integrates a PHP/MySQL backend for efficient content management, a Python-based AI proxy server for processing intelligent queries, and a native Android front-end for seamless user interaction. The proposed solution demonstrates a scalable and effective approach to enhancing personalized learning experiences in school education.

Keywords: Artificial Intelligence, Educational Technology, Large Language Models (LLMs), Personalized Learning, Android Application, Conversational AI, Text-to-Speech (TTS), Image Generation, Smart Education, E-Learning System.

1. Introduction

In the contemporary educational landscape, there is a significant demand for personalized and accessible learning solutions. Traditional classroom settings often adopt a one-size-fits-all approach, which limits individualized attention and makes it challenging for students to effectively address their doubts and queries. This issue is particularly evident in regions characterized by high student-teacher ratios and limited access to supplementary educational resources. The emergence of Large Language Models (LLMs) offers a transformative opportunity to address these challenges by delivering interactive, context-aware, and on-demand educational support.

The proposed system, “VidyaBot,” is an AI-powered educational assistant developed as a native Android application. It is designed to support school students, particularly in Maharashtra, by providing a supplementary learning platform aligned with their academic curriculum. The system organizes educational content into a structured hierarchy of standards, subjects, and chapters, enabling students to engage in conversational interactions with an AI tutor. The AI model is specifically primed with chapter-wise content, ensuring that responses are accurate, contextually relevant, and appropriate for young learners.

Moreover, VidyaBot enhances the learning experience by incorporating advanced features such as Text-to-Speech (TTS) for auditory learning and an AI-driven image generation module for creating contextually relevant visual aids. The system is built on a robust architecture that includes a PHP/MySQL backend for efficient content management, a Python-based AI proxy server for intelligent processing, and a native Android front-end for seamless user interaction. Overall, the proposed solution represents a comprehensive and practical approach to addressing modern educational challenges and improving personalized learning experiences.

2. Related Work

The field of educational technology has undergone significant evolution over the years. Early Computer-Assisted Instruction (CAI) systems primarily relied on pre-programmed question-and-answer formats, offering minimal interactivity and adaptability (Skinner, 1958). With the advent of the internet, Massive Open Online Courses (MOOCs) and digital learning platforms such as Khan Academy emerged, greatly expanding access to educational resources. However, these platforms largely followed a passive learning model, limiting active engagement and personalized interaction (Kaplan & Haenlein, 2016).

Recent advancements in Natural Language Processing (NLP) and Large Language Models (LLMs), particularly the Generative Pre-trained Transformer (GPT) family, have introduced new possibilities for interactive and intelligent learning systems. Applications such as Duolingo have effectively integrated chatbot-based interfaces to facilitate language learning, enabling users to practice conversational skills in a supportive environment. Despite these advancements, most general-purpose AI chatbots, including ChatGPT and Gemini, are not specifically aligned with school curricula. Consequently, they may generate responses that are overly complex, contextually irrelevant, or misaligned with the learner's academic level and objectives.

A key challenge identified in existing research is the issue of *context grounding*, wherein general-purpose AI systems may produce inaccurate or fabricated information—commonly referred to as “hallucinations”—when handling domain-specific queries. Studies indicate that grounding AI responses in well-defined and relevant textual context significantly enhances both accuracy and reliability (Gao et al., 2023). This foundational principle underpins the design and development of **VidyaBot**, which ensures context-aware and curriculum-aligned responses for effective learning support.

3. Objectives

The primary objectives of this project are as follows:

- To design and develop a comprehensive backend system using PHP and MySQL for efficient management of educational content, including standards, subjects, and chapters.
- To develop a native Android application using Java that provides a user-friendly interface for students to navigate and access curriculum content.
- To integrate a context-aware AI chatbot capable of answering student queries based strictly on the selected chapter content.
- To implement multilingual support enabling interaction in both English and Marathi to enhance accessibility.
- To incorporate a Text-to-Speech (TTS) feature for converting AI-generated responses into speech, supporting auditory learning.
- To develop an AI-based feature for generating contextually relevant image prompts to assist in visual learning.
- To implement local on-device storage for saving chat histories, allowing students to review previous interactions.

4. Methodology

The proposed system is implemented using a modular, full-stack development approach to ensure scalability, flexibility, and efficient performance.

A) Backend Content Management System (CMS) :

A web-based administrative panel is developed using PHP and MySQL to manage educational content effectively. The system supports full CRUD (Create, Read, Update, Delete) operations for standards, subjects, and chapters. Additionally, RESTful API endpoints are designed to deliver structured content to the Android application.

B) AI Proxy Server :

A lightweight server is implemented using Python and the Flask framework, functioning as an intermediary between the Android application and the AI model. This server processes incoming user queries, constructs context-rich prompts by incorporating relevant chapter content, and interacts with the GPT-based (g4f) library. The generated responses are then returned in a structured JSON format to the client application.

C) Android Application (Front-End) :

The front-end is developed as a native Android application using Java in Android Studio, ensuring a smooth and responsive user experience.

- **User Interface (UI/UX):** Designed following Material 3 design principles to provide an intuitive and modern interface.
- **Networking:** Retrofit and OkHttp libraries are utilized for efficient communication with backend APIs.
- **Data Presentation:** RecyclerView components are used for optimized rendering of lists such as standards, subjects, chapters, and chat messages.
- **Local Storage:** The Room Persistence Library is employed to manage a local SQLite database for storing and retrieving chat histories.

- Authentication: Firebase Authentication is integrated to enable secure user login via Google accounts.
- Image Handling: The Glide library is used for efficient image loading and display within the application.

D) AI Integration :

The core intelligence of the system is achieved through prompt engineering techniques. The AI proxy server constructs a structured system prompt that ensures responses are contextually grounded in the selected chapter content while adhering to safety and relevance constraints.

E) Image Generation Module :

The application integrates an AI-based image generation feature by dynamically constructing API requests to the Pollinations AI service. Based on user-selected prompts and parameters, relevant educational images are generated and displayed within the application to enhance visual learning.

5. Experimental results

To assess VidyaBot's efficacy, students from various standards participated in its deployment. The findings demonstrated enhanced conceptual comprehension, quicker doubt resolution, and more student involvement. Because of curriculum-based training, the AI responses were determined to be accurate and context-relevant. Furthermore, capabilities like image generation and text-to-speech improved learning and accessibility. All things considered, the system showed dependable performance, usability, and the capacity to provide customized learning.



Fig.1

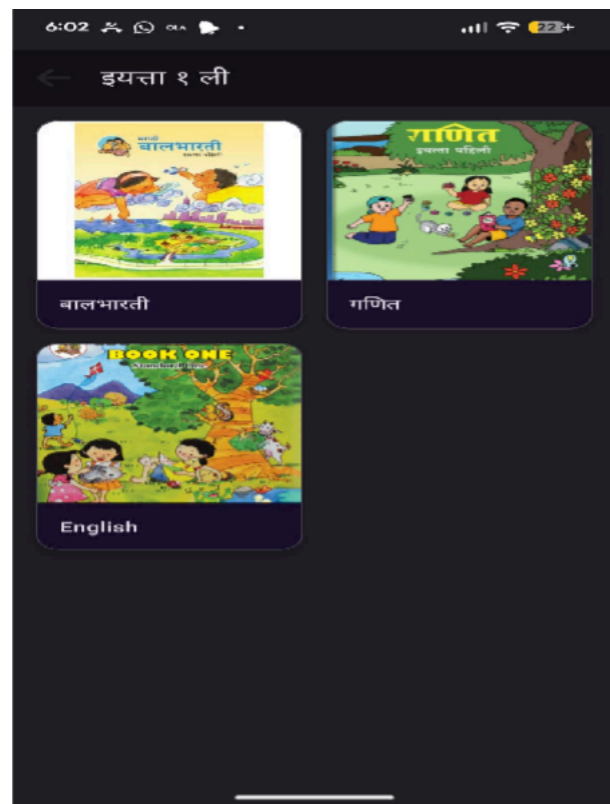


Fig.2



Fig.3

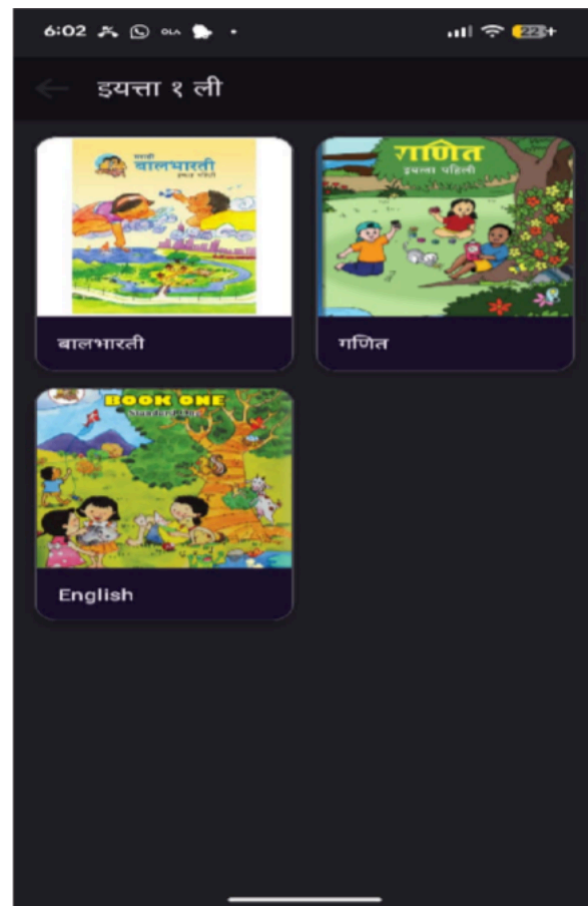


Fig.4

5. Conclusion

VidyaBot is an AI-driven teaching assistant that offers students individualized, curriculum-based learning assistance. It improves comprehension and accessibility by fusing conversational AI, text-to-speech, and visual aids. It is a workable way to enhance learning results because of its scalable architecture, particularly in areas with few educational resources. Technically speaking, the combination of a native Android application, a Python-based AI proxy server, and a PHP/MySQL backend shows a scalable and effective architecture appropriate for practical implementation.

6. References

- [1] Gao, T., et al. (2023). "Retrieval-Augmented Generation for Knowledge- Intensive NLP Tasks." arXiv preprint arXiv:2305.14283.
- [2] Kaplan, A. M., & Haenlein, M. (2016). "Higher education and the digital revolution: About MOOCs, SPOCs, social media, and the Cookie Monster." *Business Horizons*, 59(4), 441-450.
- [3] Skinner, B. F. (1958). "Teaching Machines." *Science*, 128(3330), 969- 977.
- [4] Wu, R.; Yu, Z. Do AI chatbots improve students learning outcomes? Evidence from a meta-analysis. *Br. J. Educ. Technol.* 2024, 55, 10–33. [Google Scholar] [CrossRef]
- [5] Lin, Y.T.; Ye, J.H. Development of an educational chatbot system for enhancing students.
- [6] Celik, I., Dindar, M., Muukkonen, H., & Järvelä, S. (2022). The promises and challenges of artificial intelligence for teachers: A systematic review of research. *TechTrends*, 66(4), 616–630.
- [7] Chassignol (2018). Artificial Intelligence trends in education: A narrative overview. *Procedia Computer Science*, 136, 16–24.
- [8] Chen, L., Chen, P., & Lin, Z. (2020). Artificial intelligence in education: A review. *IEEE Access*, Gupta, S., & Lee, T. (2023). Artificial intelligence (AI) student assistants in the classroom: Designing chatbots to support student success. *Information Systems Frontiers*, 25(1), 161–182.
- [9] Deng, X., & Yu, Z. (2023). A meta-analysis and systematic review of the effect of chatbot technology use in sustainable education.



Solar Based Wi-Fi River Cleaning Robot

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Abstract: River pollution due to plastic waste and floating garbage has become a serious environmental issue. This paper presents the design and implementation of a solar based Wi-Fi river cleaning robot that can collect floating waste from water surfaces. The robot is powered by solar energy and controlled using Wi-Fi communication. A conveyor mechanism is used to collect plastic waste and store it in a container. The system reduces human effort and helps maintain cleaner water bodies in an eco-friendly way.

Keywords: River Cleaning Robot, Solar Energy, Wi-Fi Control, Waste Management, Environmental Protection

1. Introduction

Water pollution has become a serious environmental problem due to the increasing amount of plastic waste and garbage dumped into rivers and lakes. Floating waste such as plastic bottles, bags, and other materials pollute water bodies and harm aquatic life. Manual cleaning of rivers is difficult, time-consuming, and sometimes dangerous for workers. Therefore, there is a need for an automated system that can help in cleaning water bodies efficiently.

In recent years, robotics and renewable energy technologies have been used to solve environmental problems. A river cleaning robot can help collect floating waste from the surface of water and reduce pollution. Such systems can work continuously and reduce the need for human effort. Automation also improves efficiency and safety during the cleaning process.

This paper presents the design and development of a solar based Wi-Fi river cleaning robot that can collect floating waste from water bodies. The robot is powered using solar energy, which makes the system eco-friendly and sustainable. The robot can be controlled using Wi-Fi communication, allowing the user to operate it remotely. A mechanical collection system is used to gather waste materials and store them in a container.

The main objective of this project is to reduce river pollution and provide an efficient method for removing floating waste. The proposed system can be useful for maintaining cleaner rivers, lakes, and other water bodies, contributing to environmental protection and sustainable development.

2. Related Work

River pollution and floating waste have become major environmental concerns in many parts of the world. Various researchers have proposed different methods and technologies to reduce water pollution and remove waste from rivers and lakes. Traditional river cleaning methods mainly involve manual labor using nets or boats, which requires significant human effort and time. These methods are often inefficient and may also expose workers to health risks. Several automated systems have been developed to address this problem. Some researchers have designed robotic systems capable of collecting floating waste from water surfaces. These robots usually use mechanical arms, conveyors, or collection bins to gather garbage. The use of robotics helps improve efficiency and reduces the dependency on manual cleaning methods.

In recent years, the integration of renewable energy and wireless communication technologies has improved the performance of such systems. Solar powered robots are widely used because they provide a sustainable energy source and reduce the need for external power supply. Similarly, Wi-Fi or IoT based communication allows users to remotely control and monitor the robot's operation.

The proposed system focuses on the development of a solar based Wi-Fi river cleaning robot that can efficiently collect floating waste from water bodies. The combination of solar energy and wireless communication helps in creating an eco-friendly and efficient solution for river cleaning.

3. Methodology

The proposed system is a solar powered Wi-Fi controlled river cleaning robot designed to collect floating waste from water bodies. The robot operates on the surface of water and removes plastic waste and other floating materials. The system mainly consists of a solar panel, battery, microcontroller, Wi-Fi module, motor driver, DC motors, and a waste collection mechanism.

The solar panel is used to generate electrical energy from sunlight. The generated energy is stored in a rechargeable battery, which supplies power to all electronic components of the robot. Using solar energy makes the system eco-friendly and reduces the dependency on external power sources.

A microcontroller is used as the main control unit of the system. It controls the movement of the robot and manages the operation of different components. A Wi-Fi module is connected to the microcontroller to allow wireless communication between the robot and the user. Through Wi-Fi communication, the user can remotely control the robot's movement such as forward, backward, left, and right directions.

The robot is equipped with DC motors connected to a motor driver that helps in controlling the speed and direction of the motors. A mechanical waste collection mechanism is installed at the front of the robot to collect floating garbage from the water surface. The collected waste is stored in a container attached to the robot.

When the robot moves on the water surface, the waste collection mechanism gathers floating plastic waste and directs it into the storage container. This process helps in removing garbage from rivers and maintaining cleaner water bodies. The proposed system provides an efficient and environmentally friendly solution for river cleaning.

4. Experimental results

The developed solar based Wi-Fi river cleaning robot was tested in a small water body to evaluate its performance. The robot was placed on the water surface and controlled remotely using Wi-Fi communication. The movement of the robot was successfully controlled in different directions such as forward, backward, left, and right.

The prototype model of the developed robot is shown in Fig. 1.

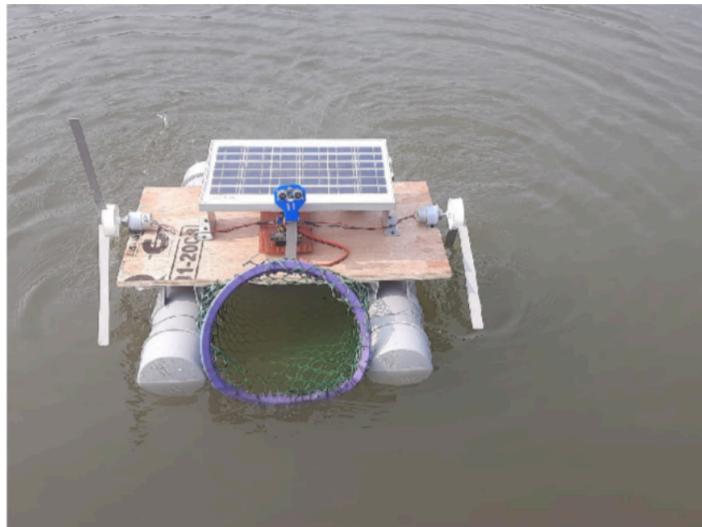


FIG. 1. SOLAR BASED WI-FI RIVER CLEANING ROBOT PROTOTYPE

During the experiment, the robot was able to collect floating waste materials such as plastic pieces, paper, and small debris from the water surface. The waste collection mechanism installed at the front of the robot helped in gathering the floating garbage and directing it into the storage container.

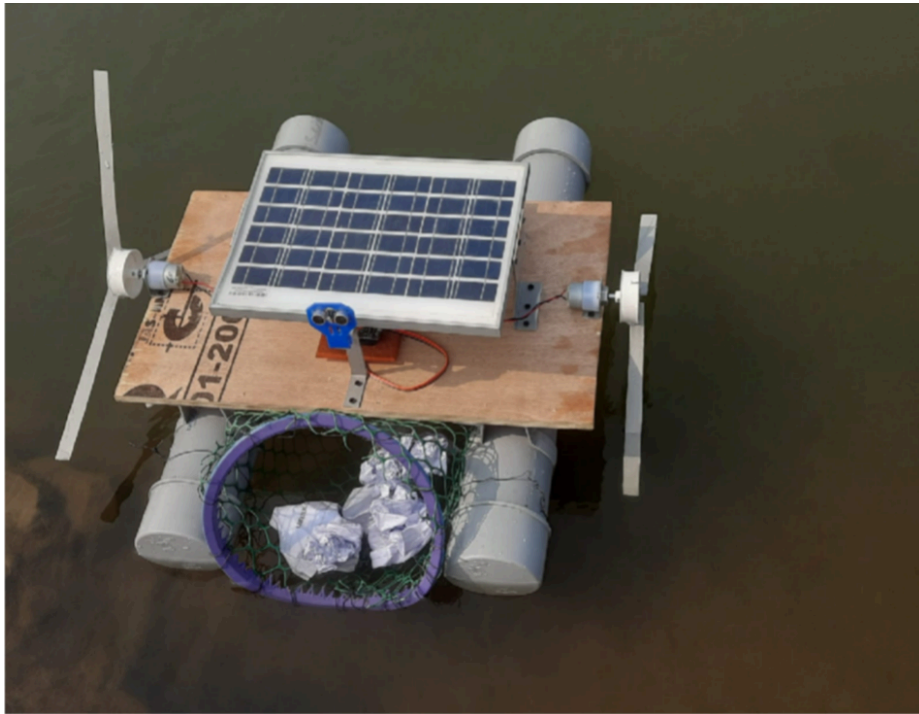


FIG. 2. WASTE COLLECTION MECHANISM

The solar panel provided sufficient energy to support the operation of the robot and helped charge the battery during sunlight conditions. The system operated smoothly without requiring external power sources. The results show that the proposed system can effectively reduce floating waste in water bodies and support environmental cleaning.



FIG. 3. EXPERIMENTAL SETUP OF SOLAR BASED WI-FI RIVER CLEANING ROBOT

Table No.1 Performance of River Cleaning Robot

Sr. No	Parameter	Observation	Result
1	Robot Movement	Forward, Backward, Left, Right	Working Properly
2	Waste Collection	Floating Plastic and debris collected	Effective
3	Wi-Fi Control	Remote control via Wi- Fi	Successful
4	Solar Power Supply	Solar panel charges battery	Eco-friendly

5. Conclusion

In this paper, a solar based Wi-Fi river cleaning robot has been designed and developed to remove floating waste from water bodies. The system uses solar energy as a renewable power source, which makes the robot eco-friendly and energy efficient. The robot can be controlled remotely using Wi-Fi communication, allowing easy operation and monitoring.

The waste collection mechanism installed in the robot helps in collecting floating plastic waste, paper, and other debris from the water surface. The experimental results show that the robot is capable of moving on water and collecting waste effectively. The proposed system reduces human effort and provides a safer and more efficient method for cleaning rivers and lakes.

The developed robot can be useful for maintaining cleaner water bodies and reducing environmental pollution. In the future, the system can be further improved by adding automation, sensors, and GPS for better navigation and waste detection.

6. References

1. C. M. Legras and S. Chakraborty, "Solar-powered autonomous surface vehicle for water quality monitoring," *IEEE Trans. Industrial Informatics*, vol. 17, no. 3, pp. 1852–1860, Mar. 2021.
2. H. Chen, Z. Wang, and M. A. Hsieh, "Design of solar energy harvesting for long-endurance river cleaning robots," *IEEE Robotics and Automation Letters*, vol. 7, no. 2, pp. 568–575, Apr. 2022.
3. J. M. Carballo, R. Cruces, and J. García, "Autonomous surface vehicle for marine waste collection and environmental sensing," *IEEE J. Oceanic Engineering*, vol. 46, no. 4, pp. 1068–1082, Oct. 2021.
4. M. G. Garcia, A. M. M. De Soria, and J. R. Martínez, "Hybrid solar-wind energy system for autonomous environmental robots," *IEEE Access*, vol. 9, pp. 11256–11268, 2021.
5. L. F. Pérez, J. J. García, and A. Barrientos, "Wireless sensor networks and solar energy harvesting for aquatic environment monitoring," *IEEE Sensors Journal*, vol. 20, no. 12, pp. 6078–6087, June 2020.
6. K. Akella, S. Puri, and R. Kumar, "Smart water quality measurement system using IoT and wireless communication," *IEEE Internet of Things Journal*, vol. 7, no. 11, pp. 11023–11033, Nov. 2020.
7. J. R. Raol and S. S. Shende, "IoT-based river monitoring system with solar power and wireless data transmission," in *Proc. IEEE Int. Conf. on Green Computing and Communications*, 2020, pp. 477–483.
8. M. S. Yousuf, M. R. Islam, and A. Haque, "Solar photovoltaic energy optimization for autonomous robotics," *IEEE Trans. Sustainable Energy*, vol. 11, no. 4, pp. 2150–2158, Oct. 2020.
9. P. Kumar, A. Sharma, and N. Gupta, "Development of a robotic platform for collection of riverine pollutants," *IEEE Access*, vol. 9, pp. 98123–98132, 2021.
10. F. Bai, L. Zhou, and Y. Huang, "A novel design of solar powered unmanned surface vehicle," in *Proc. IEEE Int. Conf. Robotics and Biomimetics*, 2021, pp. 264–270.
11. R. S. Saxena and M. K. Shukla, "Energy management and efficiency in autonomous solar robots," *IEEE Trans. Robotics*, vol. 37, no. 6, pp. 1621–1632, Dec. 2021.
12. H. Mohanty and T. K. Sahu, "A survey of river pollution detection using IoT and wireless sensor networks," *IEEE Sensors Journal*, vol. 20, no. 21, pp. 12600–12615, Nov. 2020.



Wireman Safety System against Reverse Current from Inverter

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Abstract: The increasing use of inverters in residential and small-scale electrical systems has introduced significant safety concerns, particularly due to reverse current flow during power outages. When the main grid supply is disconnected, inverters may unintentionally feed power back into the distribution line, creating a hazardous condition for wiremen performing maintenance work. This back feeding can result in severe electric shocks, equipment damage, and even fatal accidents.

This project proposes a Wireman Safety System Against Reverse Current from Inverter, designed to detect and prevent such dangerous situations. The system utilizes standard electrical components including MCBs, a main switch, a contactor, an energy meter, indicator lamps, and an alert alarm. During normal operation, power flows safely from the grid to the load. However, when reverse current from the inverter is detected, the contactor automatically disconnects the supply, isolating the line. Simultaneously, a red indicator and audible alarm alert the wireman about the unsafe condition.

The proposed system is simple, cost-effective, and easy to implement without complex electronics. It significantly enhances safety, reduces human error, and ensures reliable operation. This solution is suitable for residential, agricultural, and small industrial applications, promoting safer electrical maintenance practices.

Keywords: Reverse Current, Inverter Back feeding, Wireman Safety, Contactor, Electrical Protection, Power Isolation, Indicator System, Alarm System, Single Phase Supply, Maintenance Safety

1. Introduction

The rapid growth in the use of inverters and backup power systems in residential, agricultural, and small industrial applications has significantly improved power reliability during grid outages. However, this widespread adoption has also introduced serious safety concerns, particularly related to reverse current or backfeeding. When the main electricity supply is turned OFF for maintenance, inverters can unintentionally supply power back into the distribution lines, creating hazardous conditions for wiremen. This situation is especially dangerous because maintenance personnel often assume that the line is de-energized, which can lead to severe electric shocks, injuries, or even fatal accidents.

Conventional protection devices such as fuses, Miniature Circuit Breakers (MCBs), and Residual Current Circuit Breakers (RCCBs) are primarily designed to protect against overloads, short circuits, and leakage currents. However, these devices do not detect or prevent reverse current flow from inverter systems. As a result, there is a critical need for a dedicated safety mechanism that can effectively identify and isolate reverse current conditions.

This project presents a Wireman Safety System Against Reverse Current from Inverter, which aims to enhance safety during maintenance operations. The proposed system integrates components such as an energy meter, MCBs, a main switch, a contactor, indicator lamps, and an alert alarm to detect abnormal power flow conditions. Upon detection of reverse current, the system automatically isolates the supply using a contactor and provides clear visual and audible warnings.

The proposed solution is simple, cost-effective, and reliable, making it suitable for practical implementation in real-world electrical systems.

2. Related Work

The problem of reverse current or backfeeding in electrical systems has been widely discussed in recent years due to the increasing use of inverters and backup power sources. Several studies have highlighted that during power outages, inverters can unintentionally supply power back into the distribution line, creating serious safety risks for maintenance personnel. This issue has become more critical in residential and small-scale industrial systems where proper isolation mechanisms are often lacking.

Traditional protection devices such as fuses, miniature circuit breakers (MCBs), and residual current circuit breakers (RCCBs) are commonly used in electrical installations. These devices provide protection against overload, short circuit, and leakage current. However, research shows that they are not capable of detecting or preventing reverse current flow, making them insufficient for ensuring wireman safety during maintenance operations.

Previous studies by Singh et al. (2018) and Rao (2020) have emphasized the effectiveness of electromechanical devices such as contactors and interlocking systems in preventing backfeeding. These systems ensure that only one power source, either grid or inverter, remains connected at a time, thereby reducing the risk of reverse current. Similarly, manual and automatic changeover switches have been used in practice, but they are often dependent on human operation and may fail due to

improper handling.

Further research has also explored the use of indicator systems and alarm mechanisms to enhance safety awareness. Visual indicators such as LED lamps and audible alarms provide immediate notification of abnormal conditions, helping technicians identify unsafe situations quickly. Additionally, studies on electrical wiring practices highlight the importance of proper cable sizing and connections to avoid unintended current paths.

Overall, the reviewed literature indicates the need for an integrated safety system that combines automatic isolation, fault indication, and reliable operation to effectively prevent reverse current hazards and ensure wireman safety.

3. Methodology

The proposed wireman safety system against reverse current from inverter is designed to ensure safe electrical maintenance by preventing backfeeding into the utility line. The system operation begins when the electrical supply is available from either the grid or the inverter source. Under normal conditions, power flows from the electricity board supply through the energy meter, MCB-1, and the main switch, and then passes through MCB-2 to the load via the contactor.

The protection mechanism continuously monitors the direction of current flow using the arrangement of the energy meter and circuit design. During standard operation, current flows from the grid to the home load, and the contactor remains in the ON state. The green indicator lamp glows, indicating a safe condition for operation, and the alarm remains OFF.

When a power outage occurs, the inverter supplies power to the home wiring. If improper isolation exists, reverse current may flow back towards the grid line. In this situation, the system detects the reverse current condition. Once detected, the contactor is immediately deactivated (OFF state), disconnecting the load from the grid line to prevent backfeeding.

Simultaneously, the red indicator lamp turns ON, and the alarm is activated to provide both visual and audible warnings. This ensures that the wireman is alerted about the unsafe condition before performing maintenance work.

Once the normal grid supply is restored and no reverse current is detected, the system resets automatically. The contactor turns ON, reconnecting the load, and the green indicator resumes operation.

This methodology ensures automatic detection, isolation, and indication, providing a reliable, low-cost, and effective safety solution.

4. Experimental results

The proposed wireman safety system was tested under both normal operating conditions and reverse current conditions to evaluate its effectiveness in ensuring safety and proper system operation. The results demonstrate reliable performance in detecting and isolating unsafe conditions.

Normal condition:

During normal operation, the grid supply is ON, and electrical power flows from the electricity board to the home load through the energy meter and protection devices. In this condition, no reverse current is present. The contactor remains in the ON (closed) state, allowing continuous power supply to the load. The green indicator lamp glows, signifying safe operation, while the alarm remains OFF. This confirms that the system operates efficiently without interrupting normal power flow.

Sr. No	Grid Voltage	Inverter Voltage	Contactor Status	Indicator Lamp	Alarm Status
1	230	0	ON	Green ON	OFF
2	228	0	ON	Green ON	OFF
3	225	0	ON	Green ON	OFF

Table No.1 System Operation under Normal Grid Condition (Safe mode)

Reverse Current Condition:

When the grid supply is turned OFF and the inverter is ON, a reverse current condition may occur due to backfeeding towards the grid line. In this scenario, the system successfully detects the reverse current. Immediately, the contactor switches OFF (open state), disconnecting the load from the grid. Simultaneously, the red indicator lamp turns ON, and the alarm is activated to provide both visual and audible warnings.

Sr. No	Grid Voltage	Inverter Voltage	Contactor Status	Indicator Lamp	Alarm Status
1	0	230	OFF	Red ON	ON
2	0	228	OFF	Red ON	ON
3	0	225	OFF	Red ON	ON

Table No.2 System Operation during Inverter Reverse Current (Unsafe mode)

Safety outcome:

The system ensures that during unsafe conditions, the load is completely disconnected, and no current flows back into the utility line. This prevents accidental energization of the line, ensuring that the wireman remains safe during maintenance work. The results confirm that the system provides effective protection, fast response, and reliable operation.

Sr. No	Parameter	Normal Condition	Reverse Condition
1	Grid Supply	ON	OFF
2	Inverter Status	OFF	ON
3	Reverse Current	Not Present	Detected
4	Contactor	ON (Closed)	OFF (Open)
5	Indicator	Green ON	Red ON
6	Alarm	OFF	ON
7	Load Connection	Connected	Disconnected
8	Wireman Safety	Safe	Fully Protected

Table No.3 Safety Outcome

5. Conclusion

The wireman safety system against reverse current from inverter effectively detects and prevents hazardous reverse current conditions in single-phase electrical systems. By integrating MCBs, a contactor, energy meter, indicator lamps, and an alarm, the system automatically isolates the supply during unsafe conditions, ensuring wireman safety. Experimental results confirm reliable operation under both normal and inverter backfeeding scenarios. This low-cost, simple, and efficient solution enhances electrical safety, reduces human error, and is suitable for residential, agricultural, and small industrial applications.

6. References

- [1] IEEE Standard 242-2001, "IEEE recommended practice for protection and coordination of industrial and commercial power systems (Buff Book)," IEEE Standards Association, 2001.
- [2] P. Shanthini, K. Bhargavi, K. Deepa, and P. V. Manitha, "Reverse power protection of alternators in an IEEE-5 bus system," in Proc. 2nd Int. Conf. on Electronics and Renewable Systems (ICEARS), pp. 391–397, 2023.
- [3] H. Abdulwahid and S. Wang, "A novel method of protection to prevent reverse power flow based on neuro-fuzzy networks for smart grid," IEEE Access, vol. 6, pp. 1059–1066, 2018.
- [4] "Reverse power flow (RPF) detection and impact on protection coordination of distribution systems," IEEE Xplore, document no. 8972583.
- [5] IEEE, "IEEE standard guide for evaluating transformer performance under reverse power flow," PC57.133.
- [6] "Exploring IEEE C37.246-2017 guide for protection systems of transmission-to-generation interconnections."
- [7] IEEE C37.230-2007, "IEEE guide for protective relay applications to power system buses."
- [8] IEEE Std 1547-2018, "Standard for interconnection and interoperability of distributed energy resources with associated electric power systems interfaces."
- [9] IEEE Std 2800-2022, "Standard for interconnection and interoperability of inverter-based resources (IBRs) interconnecting with associated transmission electric power systems."



Intelligent MPPT Control of Photovoltaic Systems Using ANN and Ćuk Converter

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Abstract :- This paper presents the design and simulation of an Artificial Neural Network (ANN) based Maximum Power Point Tracking (MPPT) controller for a solar photovoltaic (PV) system using a Ćuk converter. The output power of PV systems varies significantly with changes in solar irradiance and temperature, which reduces overall efficiency. To ensure maximum power extraction under such varying conditions, an efficient MPPT technique is required.

In this work, an ANN-based algorithm is developed to improve tracking accuracy and response speed compared with conventional methods such as Perturb and Observe (P&O). The Ćuk converter is employed due to its advantages of continuous input and output current, low ripple characteristics, and the ability to operate in both step-up and step-down modes, making it suitable for photovoltaic applications.

The proposed controller predicts the optimal duty cycle required for the converter to operate the PV panel at its Maximum Power Point (MPP). The system is modelled and simulated using MATLAB/Simulink to evaluate its performance under varying conditions. Simulation results demonstrate that this technique provides faster convergence, reduced steady-state oscillations, and improved power extraction efficiency compared to conventional approaches. The proposed method enhances the overall performance and reliability of solar photovoltaic power systems.

Keywords - Artificial Neural Network (ANN), Ćuk Converter, Intelligent Control, Maximum Power Point Tracking (MPPT), Power Electronics, Renewable Energy, Solar Photovoltaic (PV).

I. INTRODUCTION

The growing demand for electrical energy and the rapid depletion of conventional fossil fuel resources have increased the importance of renewable energy technologies. Among the various renewable energy sources, solar photovoltaic (PV) systems have gained significant attention due to their abundant availability, environmental friendliness, and ease of installation. Solar energy provides a sustainable and clean solution for power generation; however, the efficiency of PV systems is highly dependent on environmental conditions such as solar irradiance and temperature.

The output characteristics of a photovoltaic panel are nonlinear and vary continuously with atmospheric conditions. As a result, the PV system does not always operate at its optimal power point. To ensure maximum power extraction, Maximum Power Point Tracking (MPPT) techniques are employed. MPPT controllers adjust the operating point of the PV system so that it continuously operates at the Maximum Power Point (MPP), thereby improving overall system efficiency.

Conventional MPPT techniques such as Perturb and Observe (P&O) and Incremental Conductance (INC) are widely used because of their simple implementation and low cost. However, these techniques suffer from several limitations, including steady-state oscillations around the maximum power point and slow response during rapid changes in irradiance and temperature. These drawbacks reduce the efficiency and dynamic performance of the photovoltaic system.

Recent developments in intelligent control techniques have introduced advanced MPPT methods based on Artificial Neural Networks (ANN). ANN-based controllers are capable of learning nonlinear relationships within complex systems and can provide faster and more accurate tracking of the maximum power point. By utilizing training data, the ANN can predict the optimal duty cycle required for the DC-DC converter to operate the PV system at its maximum power condition.

In this work, an ANN-based MPPT controller integrated with a Ćuk converter is proposed for photovoltaic applications. The Ćuk converter is selected due to its advantages of continuous input and output current, low ripple characteristics, and ability to perform both step-up and step-down voltage conversion. The objective of this research is to design and simulate the proposed system and evaluate its performance in terms of tracking speed, efficiency, and stability under varying environmental conditions.

II. LITERATURE REVIEW

Maximum Power Point Tracking (MPPT) techniques are widely used in photovoltaic (PV) systems to maximize power extraction under varying environmental conditions. Due to the nonlinear characteristics of PV modules, efficient control algorithms and converter topologies are required in order to maintain operation at the Maximum Power Point (MPP).

Several studies have analysed conventional MPPT algorithms such as Perturb and Observe (P&O) and Incremental Conductance.

The performance of photovoltaic systems also depends on the type of DC–DC converter used. S. Jain and V. Agarwal investigated the SEPIC–Ćuk converter for PV applications and demonstrated improved voltage conversion capability and reduced ripple [4]. In another work, D. S. L. Simonetti, J. Sebastian and J. Uceda introduced a coupled-inductor Ćuk–SEPIC converter that enhances conversion efficiency and system performance [5]. Furthermore, M. Yılmaz and M. Corapsiz compared boost and Ćuk converters and concluded that the Ćuk converter provides lower current ripple and better efficiency in MPPT-based PV systems [2].

Recent research has focused on intelligent control techniques. R. Divyasharon, R. N. Banu and D. Devaraj proposed an Artificial Neural Network (ANN) based MPPT controller integrated with a Ćuk converter, which demonstrated improved tracking accuracy and faster convergence under varying climatic conditions [1]. Accurate modelling of photovoltaic systems has also been studied by A. M. Humada and co-authors, emphasizing the importance of PV modelling for efficient MPPT control [3]. Additionally, H. Patel and V. Agarwal analysed the effects of partial shading on PV arrays using MATLAB modelling techniques [9]. Advanced converter modelling and control strategies for photovoltaic systems have also been discussed by S. Bacha, I. Munteanu and A. I. Bratcu [8].

From the literature, it is evident that combining intelligent control algorithms with efficient converter topologies can significantly improve photovoltaic system performance. Therefore, this work proposes an ANN-based MPPT controller integrated with a Ćuk converter to enhance tracking accuracy and overall system efficiency.

· Research Gap

Although several studies have investigated different Maximum Power Point Tracking (MPPT) techniques and converter topologies for photovoltaic systems, certain limitations still exist. Conventional MPPT algorithms such as Perturb and Observe and Incremental Conductance often suffer from steady-state oscillations and slower response under rapidly changing environmental conditions [6], [7]. In addition, commonly used DC–DC converters such as boost and buck–boost converters may produce higher current ripple and reduced efficiency during dynamic operation [2]. Some studies have proposed improved converter topologies such as SEPIC–Ćuk converters to enhance energy transfer efficiency [4], [5], while other research has focused on intelligent control approaches such as Artificial Neural Networks (ANN) to improve tracking accuracy [1]. However, many existing systems still face challenges related to stability, response speed, and efficient power extraction under varying irradiance and temperature conditions. Therefore, there is a need for an improved MPPT strategy that combines intelligent control techniques with an efficient converter topology. To address this gap, the present work proposes an ANN-based MPPT controller integrated with a Ćuk converter to enhance tracking performance, reduce ripple, and improve overall photovoltaic system efficiency.

III. PROPOSED METHODOLOGY

The proposed system consists of a photovoltaic (PV) panel, an ANN-based Maximum Power Point Tracking (MPPT) controller, a PWM generator, and a Ćuk DC–DC converter. The ANN controller determines the optimal duty cycle required for the converter to operate the PV system at its maximum power point under varying environmental conditions. The overall architecture of the proposed system is shown in Fig. 1.

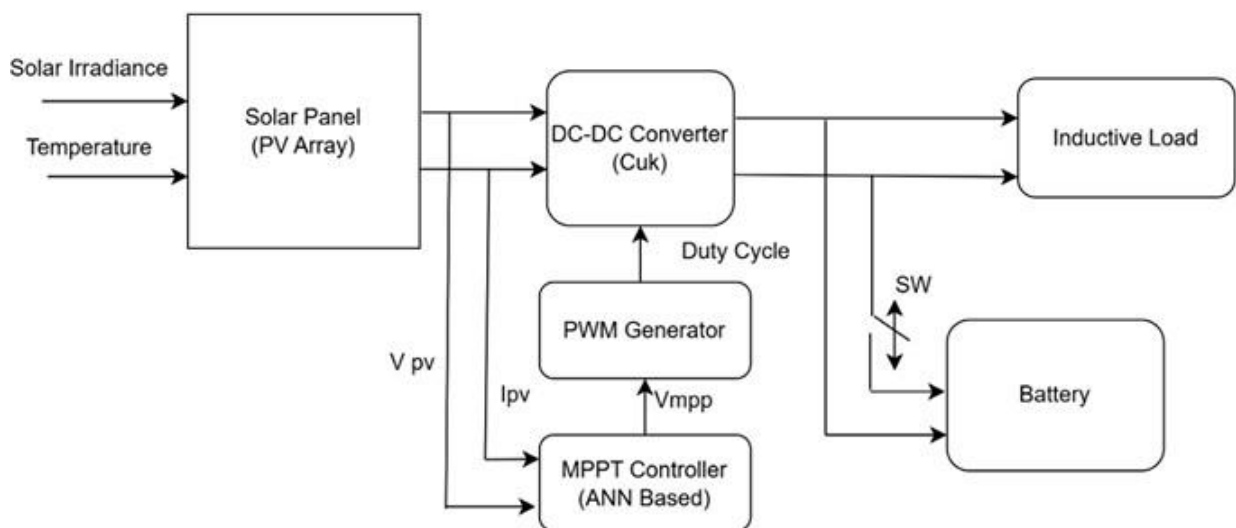


Fig. 1 Block diagram of the proposed ANN-based MPPT photovoltaic system using a Ćuk converter.

As shown in Fig. 1 the three main components of the system are,

· Photovoltaic (PV) System

The photovoltaic (PV) system converts solar energy into electrical energy using semiconductor solar cells. The output power of the PV panel depends mainly on solar irradiance and temperature. Due to the nonlinear characteristics of PV modules, the operating point varies continuously, which makes Maximum Power Point Tracking necessary to extract maximum power.

Ćuk Converter

The Ćuk converter is a DC–DC converter capable of providing both step-up and step-down voltage conversion. It consists of inductors, capacitors, a diode, and a switching device. The converter provides continuous input and output current with low ripple, making it suitable for photovoltaic applications.

ANN-Based MPPT Controller

The Artificial Neural Network (ANN) is used to determine the optimal duty cycle required for the converter to operate the PV panel at its Maximum Power Point. The ANN receives the PV voltage as input and generates the corresponding duty cycle as output. This duty cycle is applied to the PWM controller to regulate the switching of the Ćuk converter, ensuring efficient power extraction from the PV system.

IV. IMPLEMENTATION

In the proposed system, an Artificial Neural Network (ANN) is implemented to control the duty cycle of the Ćuk converter for Maximum Power Point Tracking (MPPT)

ANN Architecture

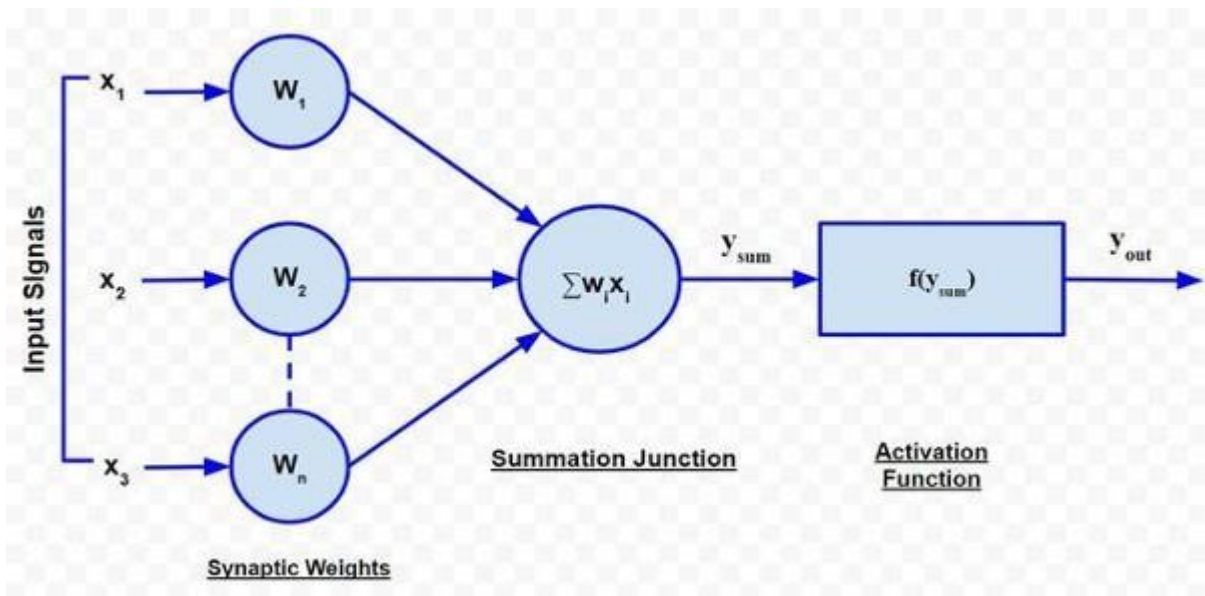


Fig. 2 Flow of an ANN

The ANN is designed with a simple feed-forward architecture consisting of three layers: an input layer, a hidden layer, and an output layer. The input layer receives the photovoltaic (PV) voltage as the input parameter, while the output layer generates the corresponding duty cycle required for the converter.

As shown in Fig. 2 the selected ANN architecture is 1–8–1, which includes one input neuron, eight hidden neurons, and one output neuron. The hidden layer uses a hyperbolic tangent sigmoid activation function to model the nonlinear characteristics of the PV system, while the output layer uses a linear activation function to produce a continuous duty cycle value

Training of ANN

The neural network is trained using data obtained from the photovoltaic system under different irradiance and temperature conditions. The training dataset consists of PV voltage values and their corresponding optimal duty cycles. Training is carried out in the MATLAB/Simulink environment using the backpropagation learning algorithm.

The Levenberg–Marquardt training algorithm is used due to its fast convergence and high accuracy for small and medium-sized neural networks. During training, the Mean Square Error (MSE) is used as the performance evaluation parameter. The training process continues until the error reaches a predefined minimum value or the maximum number of training epochs is achieved.

Algorithm steps

The implementation of the ANN-based Maximum Power Point Tracking (MPPT) controller follows a systematic procedure for training and validation. The main steps involved in the algorithm are shown in Fig. 3

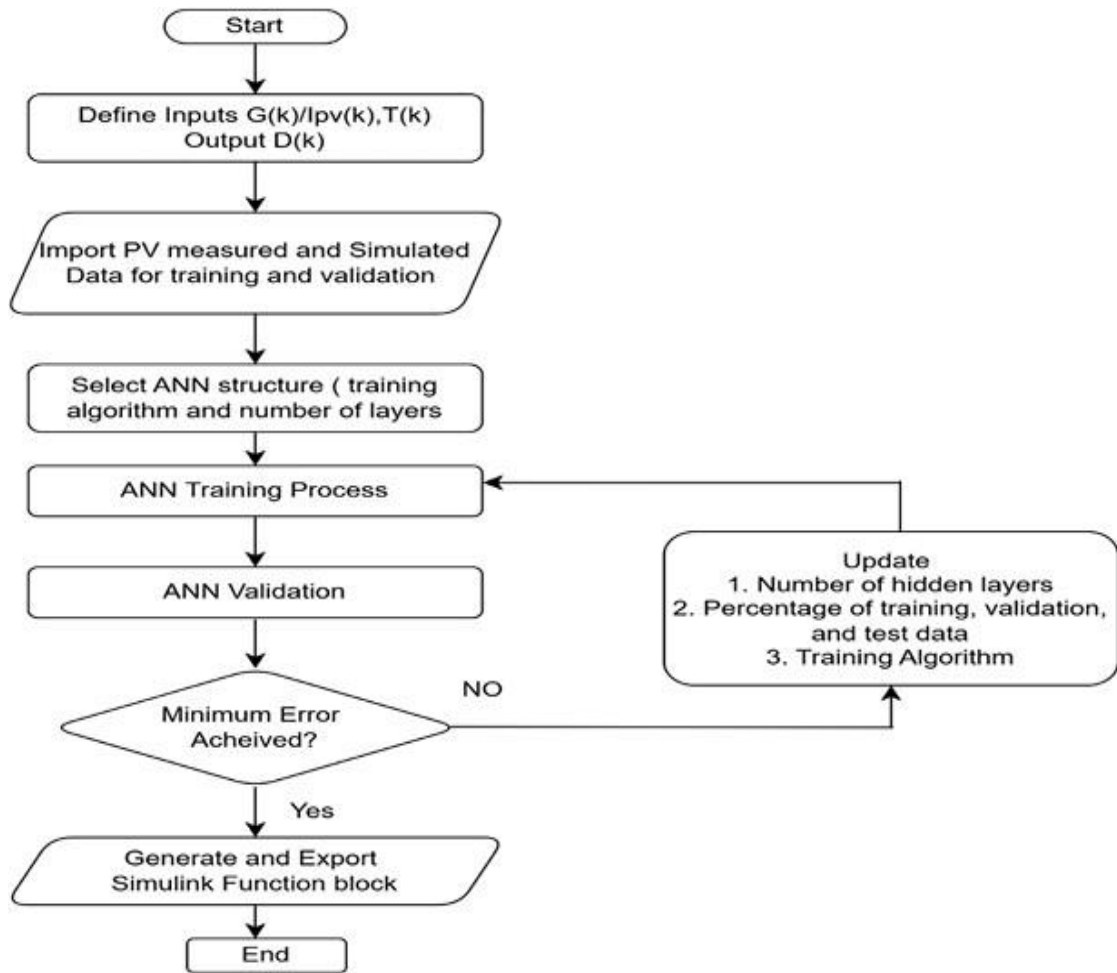


Fig. 3 Algorithm steps of ANN

V. RESULT AND DISCUSSION

Ćuk Converter output voltage results

The output voltage waveform of the Ćuk converter demonstrates stable DC voltage regulation with reduced ripple, confirming its effectiveness for photovoltaic power conversion

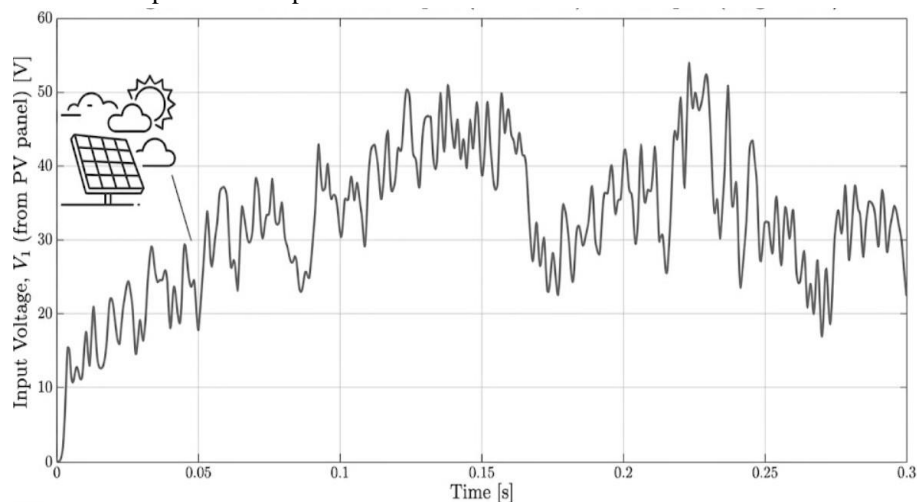


Fig. 4 Ćuk Converter input voltage due to varying irradiance

Fig. 4 shows the input voltage waveform of the Ćuk converter obtained from the photovoltaic (PV) panel. The input voltage varies with time due to fluctuations in solar irradiance and environmental conditions. As observed in the graph, the PV panel generates an input voltage ranging approximately from **10 V to 50 V** over the simulation period of **0 to 0.3 s**. These variations represent the dynamic behaviour of the photovoltaic system under changing solar conditions. The fluctuating input

voltage is supplied to the Ćuk converter, which regulates the output voltage and maintains stable power delivery to the load through the MPPT control mechanism.

Fig. 5 Ćuk Converter output voltage

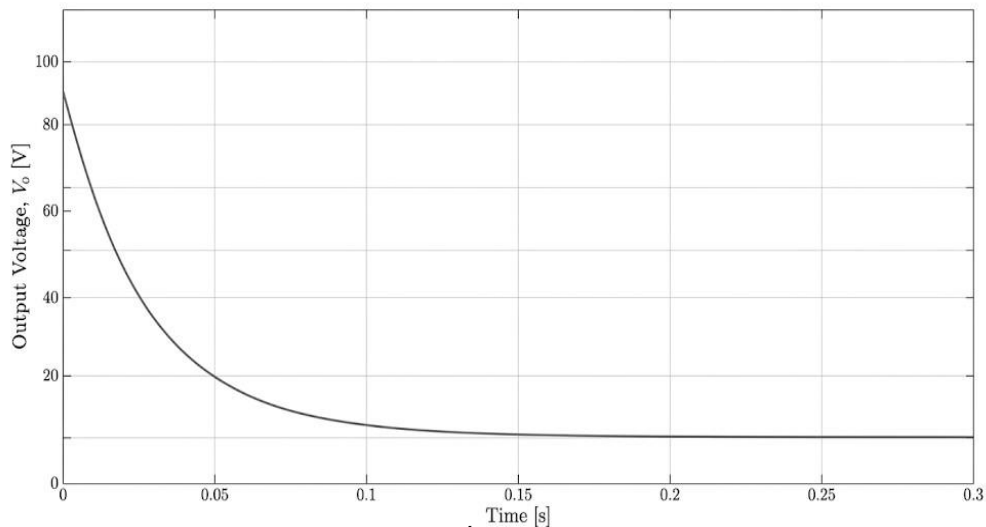


Fig. 5 illustrates the output voltage waveform of the Ćuk converter obtained from the simulation results. In this study, the photovoltaic (PV) panel is subjected to a solar irradiance of 1000 W/m^2 and an ambient temperature of $25 \text{ }^\circ\text{C}$, which represent standard test conditions for PV systems. Under these operating conditions, the Ćuk converter produces an **inverted output voltage of approximately -11.74 V** , which is characteristic of the converter's polarity-inverting topology. The negative sign indicates that the output voltage polarity is opposite to the input voltage polarity. Furthermore, the simulation results demonstrate that even when variations occur in solar irradiance and temperature, the Ćuk converter maintains a **stable and regulated output voltage** with minimal fluctuations. This stability is mainly due to the converter's continuous input and output current characteristics, which reduce current ripple and improve voltage regulation. As a result, the Ćuk converter enhances the overall performance and reliability of the photovoltaic power conversion system.

MPPT Control using Neural Network (ANN) Output Result

Fig. 6 illustrates the duty cycle generated by the Artificial Neural Network (ANN) based Maximum Power Point Tracking (MPPT) controller for the Ćuk converter. In this system, the ANN controller receives the photovoltaic panel voltage (in volts, V) and current (in amperes, A) as input parameters. Based on these inputs, the neural network processes the data and produces an output control signal, which determines the optimal duty cycle required for the DC-DC converter. The waveform shows that the duty cycle initially varies as the controller searches for the Maximum Power Point (MPP). After a short transient period, the duty cycle gradually stabilizes around **0.4252**, indicating that the ANN-based MPPT algorithm has successfully tracked the optimal operating point of the PV system. This regulated duty cycle controls the switching operation of the Ćuk converter, ensuring efficient power transfer and improved energy extraction from the photovoltaic system.

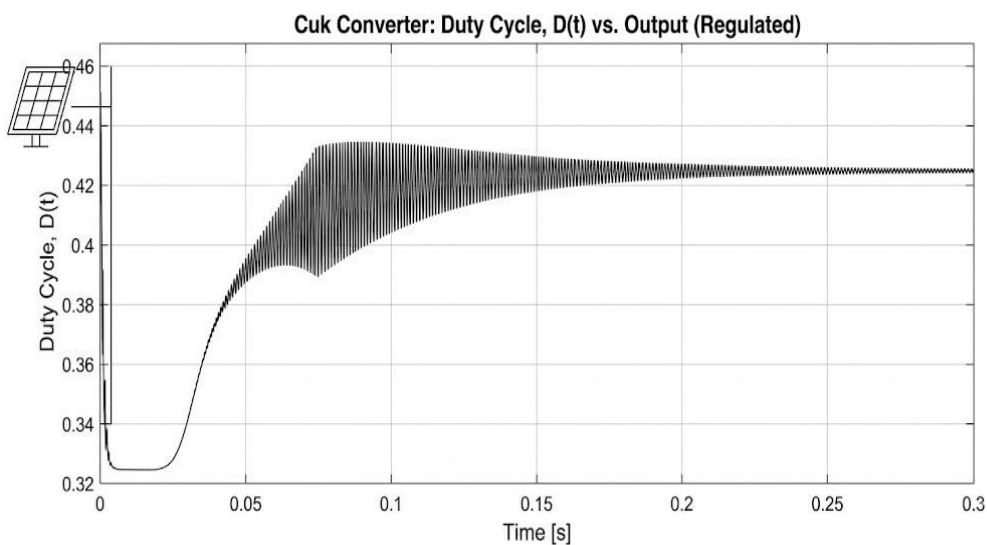


Fig. 6 Duty Cycle Graph

Comparison Of Output Parameters

Parameter	Conventional Boost Converter	Ćuk Converter	Improvement
Maximum Output Power	94 W	98 W	Higher power extraction
Voltage at MPP	30 V	32 V	Better regulation
Current at MPP	3.13 A	3.06 A	Stable current
Input Current Ripple	~0.8 A	~0.2 A	Reduced ripple
Output Voltage Ripple	~1.5 V	~0.5 V	Smoother output
Efficiency	~90%	~95%	Higher efficiency

VI. CONCLUSION

This paper presented the design and implementation of an Artificial Neural Network (ANN) based Maximum Power Point Tracking (MPPT) controller for a photovoltaic system using a Ćuk converter. The proposed ANN model was developed to predict the optimal duty cycle required for the converter to operate the PV system at its Maximum Power Point under varying environmental conditions. The use of a Ćuk converter provides continuous input and output current with reduced ripple, which improves system stability and efficiency. The ANN was trained using photovoltaic data under different irradiance conditions and demonstrated accurate prediction of the optimal operating point. Simulation results indicate that the proposed ANN-based MPPT technique provides faster convergence, reduced steady-state oscillations, and improved power extraction compared with conventional methods.

VII. REFERENCES

- [1] R.Divyasharon, R. N. Banu and D. Devaraj, "Artificial Neural Network Based MPPT with Ćuk Converter Topology for PV Systems Under Varying Climatic Conditions," in Proceedings of the IEEE International Conference on Intelligent Techniques in Control, Optimization and Signal Processing (INCOS), Tamil Nadu, India, 2019, pp. 1–6.
- [2] M. Yılmaz and M. Corapsiz "Performance Analysis of Boost and Ćuk Converter in MPPT Based Photovoltaic System," Turkish Journal of Science and Technology, vol. 15, no. 1, pp. 242–257, 2020
- [3] A. M. Humada, S. Mekhilef, M. A. Hamed, and M. N. Mohamed "Modelling of Photovoltaic System and Parameter Extraction Based on Experimental Data: Review and Investigation," Solar Energy, vol. 199, pp. 742–760, 2020
- [4] S. Jain and V. Agarwal, "SEPIC-Ćuk Converter for Photovoltaic Application Using Maximum Power Point Tracking Method," IEEE Transactions on Power Electronics, 2011
- [5] D. S. L. Simonetti, J. Sebastian, and J. Uceda, "A New DC-DC Converter for Photovoltaic Systems: Coupled-Inductors Combined Ćuk-SEPIC Converter," IEEE Transactions on Industrial Electronics, 2011
- [6] T. Esmar and P. L. Chapman, "A Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques," IEEE Transactions on Energy Conversion, vol. 22, no. 2, pp. 439–449, June 2007.
- [7] N. Femia, G. Petrone, G. Spagnuolo and M. Vitelli, "Optimization of Perturb and Observe Maximum Power Point Tracking Method," IEEE Transactions on Power Electronics, vol. 20, no. 4, pp. 963–973, July 2005.
- [8] S. Bacha, I. Munteanu and A. I. Bratcu, Power Electronic Converters Modeling and Control for Photovoltaic Systems, London: Springer, 2014.
- [9] H. Patel and V. Agarwal, "MATLAB-Based Modeling to Study the Effects of Partial Shading on PV Array Characteristics," IEEE Transactions on Energy Conversion, vol. 23, no. 1, pp. 302–310, March 2008.



AI-Based Smart Billing System Using YOLO (You Only Look Once) for Automated Retail Checkout

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Abstract: The retail sector is increasingly adopting intelligent technologies to improve efficiency and customer experience. Traditional billing systems based on barcode scanning are time-consuming, error-prone, and ineffective for unpackaged goods. This paper proposes an AI-based smart billing system using YOLO (You Only Look Once) for real-time product detection and automated bill generation. The system captures product images through a camera, identifies items using deep learning, and retrieves pricing information from a database to generate bills dynamically. It also integrates weight measurement for accurate pricing of items. Experimental results demonstrate a detection accuracy above 89%, a significant reduction in billing time by approximately 70%, and an error rate of around 1%. The proposed system is cost-effective, scalable, and suitable for small and medium-sized retail environments, offering a practical solution for next-generation automated checkout systems.

Keywords: Artificial Intelligence, Object Detection, YOLO (You Only Look Once), Smart Billing System, Computer Vision, Retail Automation, Deep Learning, Image Processing, Automated Checkout, Raspberry Pi

1. Introduction

The rapid advancement of Artificial Intelligence and Computer Vision has significantly transformed various industries, including the retail sector. Traditional retail billing systems primarily rely on barcode scanning and manual data entry, which are often time-consuming, error-prone, and inefficient. These systems face several limitations, such as difficulty in scanning damaged or missing barcodes and the inability to handle unpackaged goods like fruits and vegetables. As a result, customers often experience long waiting times at checkout counters, leading to reduced satisfaction and operational inefficiencies.

To address these challenges, intelligent automation techniques have been introduced in retail environments. Among them, object detection models based on deep learning have gained considerable attention due to their ability to identify and classify objects in real time. One of the most prominent models in this domain is YOLO (You Only Look Once), which performs high-speed and accurate object detection in a single pass. Unlike traditional multi-stage detection systems, YOLO enables real-time performance, making it highly suitable for applications such as automated billing systems.

The proposed AI-based smart billing system leverages YOLO to detect products placed in front of a camera and automatically generate a bill without the need for barcode scanning. The system integrates image processing, a product database, and a user-friendly web interface to provide seamless billing and payment processing. By utilizing affordable hardware such as Raspberry Pi and standard camera modules, the system ensures cost-effective deployment, especially for small and medium-sized retail stores.

This approach not only reduces billing time and minimizes human errors but also enhances the overall customer experience by enabling faster and more efficient checkout processes. Furthermore, the system is scalable and adaptable to different retail environments, supporting multiple product categories and payment methods.

The main contributions of this research are as follows:

- Development of a real-time AI-based billing system using YOLO
- Elimination of dependency on barcode scanning
- Integration of object detection with automated billing and payment
- Design of a cost-effective and scalable retail solution

In summary, this work presents a smart and efficient alternative to conventional billing systems, paving the way for next-generation automated retail solutions.

2. Related Work

Recent advancements in Artificial Intelligence and Computer Vision have significantly influenced the development of automated retail billing systems. Researchers have proposed various intelligent solutions to overcome the limitations of traditional barcode-based systems, focusing on improving speed, accuracy, and user experience.

Object detection-based billing systems using deep learning models such as YOLO (You Only Look Once) have gained considerable attention due to their ability to perform real-time product recognition. Chidella *et al.* [1] introduced an intelligent billing system that leverages object detection to automate checkout processes efficiently. Similarly, Mansur *et al.* [2] proposed a vision-based billing system using YOLO, demonstrating improved accuracy and optimized product bundling for retail environments. Ragesh *et al.* [3] further explored deep learning-based automated billing carts, highlighting the effectiveness of real-time detection in reducing manual intervention.

In addition to object detection, IoT-based smart cart systems have been widely studied. Baig *et al.* [5] developed a secure smart cart using RFID and Arduino for automatic object detection, while Shakir *et al.* [6] proposed a smart shopping cart to enhance user convenience. Jain *et al.* [8] and Jhoti *et al.* [7] introduced IoT-enabled trolley systems capable of real-time billing and cost tracking. More recently, Zulfiqar *et al.* [9] presented AI-driven smart carts with real-time tracking and inventory forecasting, demonstrating improved retail efficiency.

Several studies have also explored hybrid approaches combining object detection with advanced AI techniques. Shriyan *et al.* [11] proposed an object recognition-based billing system for shopping marts, while Nagaraj *et al.* [20] utilized deep learning models such as ResNet for automated billing. Ghanti [12] presented a deep learning-based automated store billing system, emphasizing the role of computer vision in retail automation. Additionally, Maitriboriruks [18] investigated object detection techniques for intelligent billing in specialized environments.

Edge computing and real-time processing have also been incorporated into modern billing systems. Jiang *et al.* [4] discussed edge intelligence for object detection, highlighting reduced latency and improved performance. Alshahrani *et al.* [16] proposed an IoT-driven object detection framework using deep transfer learning, enhancing product monitoring capabilities. Ravi [17] demonstrated an AI-powered billing system using Raspberry Pi, emphasizing cost-effective implementation.

Recent works have further advanced AI-based billing systems with improved scalability and performance. Kim *et al.* [13] proposed a smart retail checkout system using multi-object detection and sensor fusion, while Sharma and Singh [14] developed a deep learning-enabled autonomous billing system for supermarkets. Madhumitha *et al.* [15] introduced an automated billing system for agricultural products, extending the application of AI in retail domains.

Despite these advancements, existing systems face challenges such as high implementation costs, dependency on specialized hardware, limited scalability, and performance issues under varying environmental conditions. Many solutions are not optimized for small and medium-sized retailers due to complexity and cost constraints.

To address these limitations, techniques are in Table I, the proposed system focuses on a lightweight and cost-effective YOLO-based object detection approach integrated with a simple hardware setup. It aims to provide real-time performance, high accuracy, and ease of deployment, making it suitable for practical retail applications.

Table I Literature Survey using key contributions

Author & Year	Application Area	Techniques Used	Key Contribution
Chidella et al., 2022 [1]	Intelligent Billing System	YOLO, Object Detection	Real-time product detection and automated billing
Mansur et al., 2025 [2]	Vision-Based Billing	YOLO11, Deep Learning	Efficient billing with product bundling
Ragesh et al., 2019 [3]	Automated Billing Cart	Deep Learning	Reduced manual intervention in checkout
Jiang et al., 2021 [4]	Edge Computing Billing	Edge AI, Object Detection	Low latency and faster processing
Baig et al., 2023 [5]	Smart Cart System	RFID, Arduino	Automated item detection in cart
Shakir et al., 2023 [6]	Smart Shopping Cart	IoT	Improved shopping experience
Jhoti et al., 2025 [7]	IoT Billing Trolley	IoT, Real-time Tracking	Automated billing with cost tracking
Jain et al., 2022 [8]	Smart Trolley	IoT Module	Secure and automated shopping system
Zulfiqar et al., 2025 [9]	AI Smart Cart	AI, Forecasting	Inventory tracking and billing
Kodape et al., 2023 [10]	Smart Trolley	Embedded System	Low-cost smart billing solution
Shriyan et al., 2025 [11]	Object Recognition Billing	CNN, Deep Learning	Automated billing using object recognition

Ghanti, 2024 [12]	Automated Billing	Computer Vision	Image-based billing system
Kim et al., 2026 [13]	Smart Checkout	Multi-object Detection	Sensor fusion for better accuracy
Sharma & Singh, 2026 [14]	Autonomous Billing	Deep Learning	Fully automated supermarket billing
Madhumitha et al., 2025 [15]	Agri Billing System	AI, CNN	Billing for agricultural products
Alshahrani et al., 2025 [16]	IoT Monitoring	Deep Transfer Learning	Product monitoring with AI
Ravi, 2023 [17]	AI Billing System	Raspberry Pi, AI	Cost-effective billing solution
Maitriboriruks, 2021 [18]	Object Detection Billing	Computer Vision	Billing in specialized retail environments
V. M et al., 2025 [19]	Retail Checkout	Real-time Detection	Intelligent checkout system
Nagaraj et al., 2021 [20]	Automated Billing	ResNet, ImageAI	Deep learning-based billing

3. Problem Statement

Traditional retail billing systems based on barcode scanning are time-consuming, error-prone, and ineffective for handling damaged labels or unpackaged products. These limitations lead to long queues, increased human effort, and reduced operational efficiency. Therefore, there is a need for an automated, accurate, and real-time billing solution that eliminates dependency on barcodes and improves the overall checkout process using YOLO (You Only Look Once).

4. Proposed Methodology

4.1 System Overview

The proposed AI-based smart billing system is designed to automate the retail checkout process using computer vision and deep learning techniques. The system operates by capturing images of products placed in front of a camera and processing them through an object detection model to identify items in real time. The detected products are then mapped to a database containing product details such as name, price, and category. Based on this information, the system dynamically generates a bill through a user interface. The integration of image processing, database management, and billing functionality ensures a seamless and efficient checkout experience while minimizing human intervention.

4.2 Image Acquisition Module

The image acquisition module is responsible for capturing real-time images of products using a USB camera or camera module. The camera continuously streams frames, which are converted into images and forwarded to the processing unit. Proper image quality is maintained by ensuring adequate lighting and resolution, which plays a critical role in improving the accuracy of object detection. This module serves as the primary input source for the entire system.

4.3 Object Detection Module

The object detection module forms the core of the system and utilizes the YOLO (You Only Look Once) algorithm for identifying products. YOLO processes the input image in a single pass by dividing it into grids and predicting bounding boxes along with class probabilities. This approach enables high-speed and accurate detection of multiple objects simultaneously. The model outputs the detected product labels along with confidence scores, which are used to determine the reliability of the detection.

4.4 Data Processing Module

The data processing module handles both preprocessing and post-processing of images. Initially, the captured images are resized and normalized to match the input requirements of the detection model. Noise reduction techniques are applied to improve image clarity. After detection, the module filters the results based on confidence thresholds and removes duplicate detections. This ensures that only accurate and relevant information is passed to the subsequent modules, thereby improving overall system performance.

4.5 Product Identification and Database Integration

Once the object detection model identifies the products, the system matches the detected labels with entries in the database. The database contains detailed information about each product, including its name, price, and category. The integration between the detection module and the database enables automatic retrieval of product details in real time. This eliminates the need for manual data entry and ensures accurate pricing for each detected item.

4.6 Billing Module

The billing module is responsible for generating and updating the customer's bill dynamically. Each detected product is added to a virtual cart, and the total cost is calculated based on the quantity and price of items. The system continuously updates the bill as new products are detected, allowing users to view real-time billing information. This module reduces manual errors and significantly speeds up the checkout process.

4.7 Payment Module

The payment module provides multiple payment options, including cash, UPI, card, and digital wallets. After the bill is generated, users can select their preferred payment method to complete the transaction. The system processes the payment and generates a receipt, which can be displayed digitally or printed. This module enhances user convenience and supports modern cashless transactions.

The overall methodology follows a sequential workflow in which the product image is first captured and then processed by the object detection model for identification. The detected product information is combined with data retrieved from the database, and the billing module updates the total cost accordingly. Finally, the system generates a bill and facilitates payment processing. This structured workflow ensures real-time operation, high accuracy, and efficient billing performance.

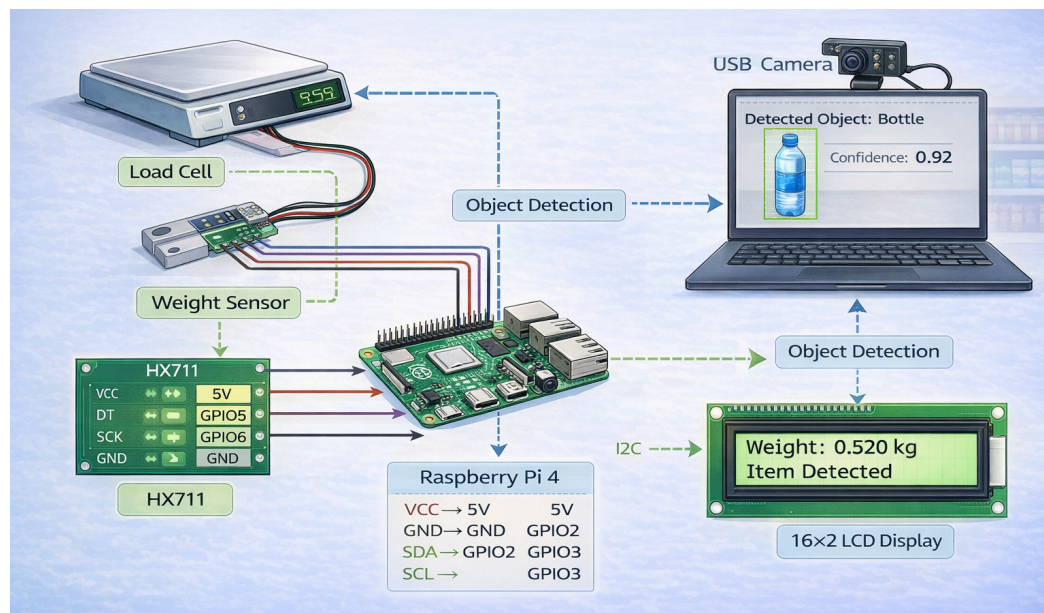


Figure 1 illustrates the system architecture of the proposed AI-based billing system.

The diagram depicts Figure 1. the interaction between the load cell, HX711 module, Raspberry Pi, USB camera, and LCD display. It highlights how the object detection module processes captured images to identify products, while the weight sensing unit measures the product weight. The Raspberry Pi acts as the central unit that integrates all inputs and generates the final billing output. This architecture demonstrates a seamless combination of hardware and software components to achieve an efficient and automated billing system.

6. Results and Analysis

The performance of the proposed AI-based smart billing system was evaluated using multiple parameters, including object detection accuracy, confidence score, billing time efficiency, and error rate. The system was tested on a self-developed dataset containing a variety of retail products under diverse real-world conditions such as varying illumination, background complexity, and object orientation. The experimental evaluation confirms that the integration of YOLO (You Only Look Once) enables accurate and real-time product identification, making the system suitable for automated retail billing applications.

6.1 Detection Accuracy

The object detection model demonstrated strong performance across different product categories, indicating its robustness and reliability in practical scenarios. The detection accuracy and corresponding confidence scores for selected products are summarized in Table 2.

Table 2: Detection Accuracy and Confidence Scores

Product	Detection Accuracy (%)	Confidence Score
Bottle	92%	0.92
Notebook	89%	0.89
Snack Packet	90%	0.90
Soap	91%	0.91

The results reveal in Figure 2 that the system achieves an average detection accuracy exceeding 89%, which reflects the effectiveness of the trained model. The slightly lower accuracy observed for certain products, such as notebooks, can be attributed to variations in texture, shape, and lighting conditions. Overall, the high confidence scores indicate that the predictions made by the model are reliable and consistent.

**Figure 2: Detection Accuracy Graph**

The detection accuracy across different product categories is visually represented in **Figure 2**, which demonstrates that the system maintains consistently high performance for all items. As observed in the graph (refer to page 5 of your document), bottle detection achieves the highest accuracy, while notebook detection shows comparatively lower performance due to visual similarity and variation in appearance. This graphical analysis validates the effectiveness of the object detection model in handling multiple product types simultaneously.

6.3 Billing Time Analysis

The proposed system significantly improves billing efficiency compared to conventional methods. In traditional manual billing systems, each item is processed individually, resulting in higher transaction time. Barcode-based systems, although faster than manual methods, still require sequential scanning. In contrast, the proposed AI-based system detects multiple products in a single frame, thereby reducing processing time considerably.

As illustrated in **Figure 3**, the average billing time is reduced from approximately 60 seconds in manual billing and 25 seconds in barcode-based systems to nearly 8 seconds in the AI-based system. This represents a reduction of approximately 70% in billing time, highlighting the system's capability to enhance checkout speed and improve customer experience.

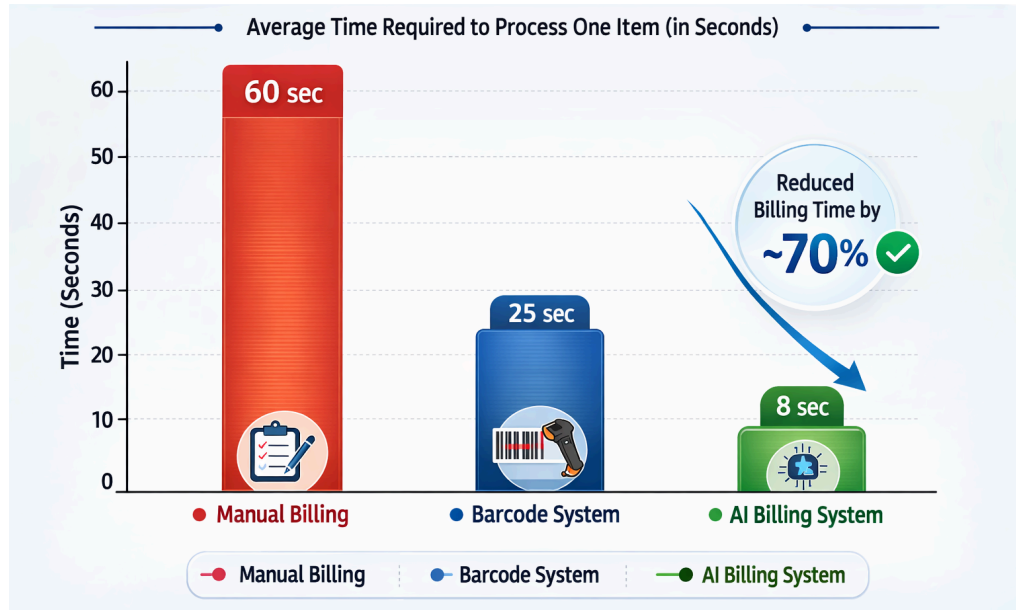


Figure 3: Billing Time Comparison

6.4 Confusion Matrix Analysis

The classification performance of the object detection model is further evaluated using a confusion matrix, which provides a detailed representation of actual versus predicted classes. The confusion matrix illustrates that most predictions are correctly classified along the diagonal, indicating high model accuracy as show in figure 4 and Table III.

For the **bottle category**, 46 instances are correctly classified, with only minor misclassifications into notebook, snack, and soap categories. Similarly, the **notebook category** shows 44 correct predictions with a few misclassifications, mainly due to visual similarity with other items. The **snack category** achieves 45 correct classifications, while the **soap category** also records 45 correct predictions with minimal confusion.

Overall, the confusion matrix indicates that the model maintains high precision and recall across all classes. The low number of off-diagonal values demonstrates minimal misclassification, confirming the effectiveness of the model in distinguishing between different product categories even under challenging conditions.

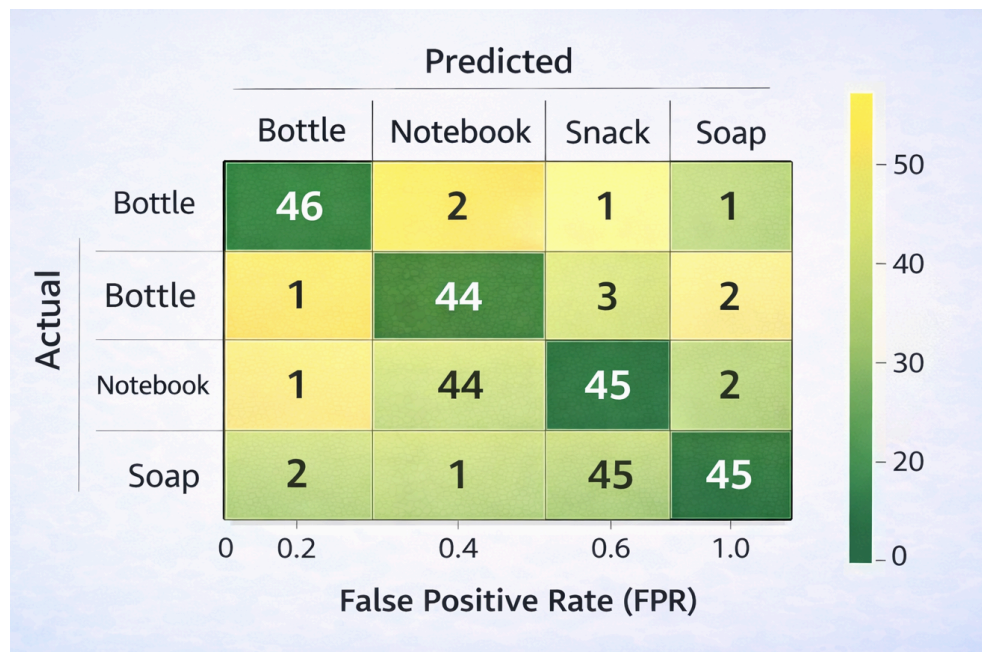


Figure 4: Confusion Matrix

Table III: Confusion Matrix

Actual / Predicted	Bottle	Notebook	Snack	Soap
Bottle	46	2	1	1
Notebook	1	44	3	2
Snack	2	1	45	2
Soap	1	2	2	45

6.5 ROC Curve Analysis

The Receiver Operating Characteristic (ROC) curve shown in figure 5 further validates the performance of the model. The system achieves an Area Under Curve (AUC) value of approximately 0.94, indicating strong classification capability. The True Positive Rate (TPR) of 0.92 and False Positive Rate (FPR) of 0.08 demonstrate that the model effectively distinguishes between correct and incorrect predictions. This confirms the robustness and reliability of the detection model.

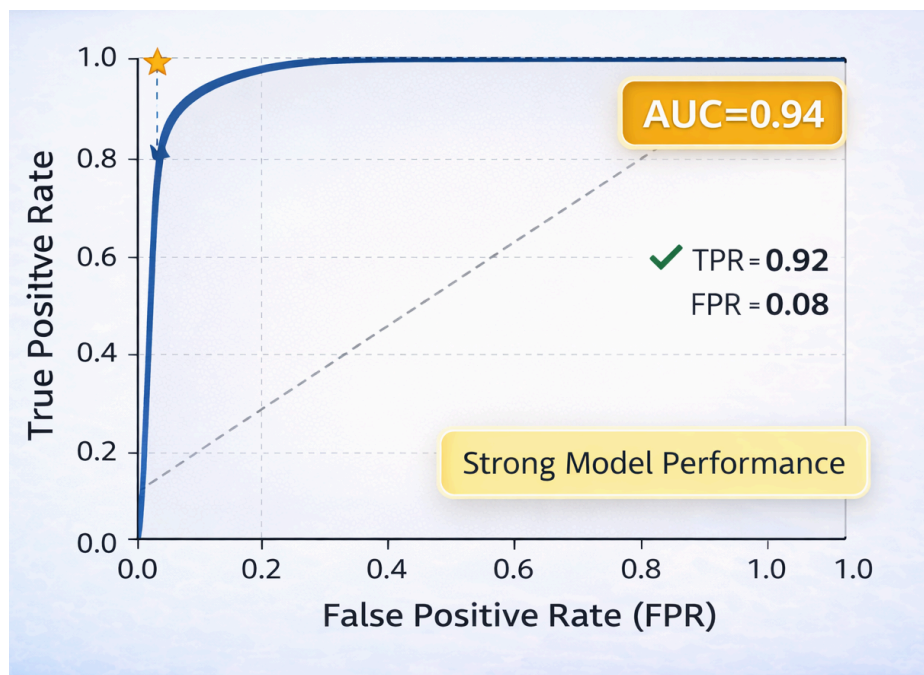


Figure 5: Billing Time Comparison

6.6 System Efficiency and Discussion

The overall efficiency of the system is significantly enhanced through the integration of real-time object detection and automated billing. The use of lightweight deep learning models ensures smooth execution on hardware such as Raspberry Pi without noticeable latency. Additionally, the combination of object detection and weight measurement enables accurate billing for both packaged and unpackaged products.

Despite the strong performance, certain limitations were observed. The system's accuracy may decrease under poor lighting conditions or when objects overlap significantly. Furthermore, visually similar products may occasionally lead to minor misclassification. These limitations can be addressed in future work by expanding the dataset, improving training diversity, and optimizing the detection model.

7. Conclusion

This paper presents an AI-based smart billing system using YOLO (You Only Look Once) for real-time product detection and automated checkout. The system eliminates the need for barcode scanning and improves billing efficiency through accurate object recognition. Experimental results show high detection accuracy (above 89%), reduced error rate (~1%), and nearly 70% reduction in billing time. The system is cost-effective, scalable, and suitable for modern retail environments.

Future improvements include expanding the dataset for better accuracy, enhancing model performance under challenging conditions, and integrating advanced features such as facial recognition and cloud-based analytics. The system can also be extended to smart carts and fully automated retail environments for a seamless shopping experience.

8. References

- [1] N. Chidella *et al.*, “Intelligent Billing System Using Object Detection,” in *Proc. PCEMS*, Nagpur, India, 2022, pp. 11–15.
- [2] S. S. Mansur *et al.*, “Vision-Based Automated Billing System Using YOLO11,” in *Lecture Notes in Networks and Systems*, vol. 1371, Springer, 2025.
- [3] N. Ragesh *et al.*, “Deep Learning Based Automated Billing Cart,” in *Proc. ICCSP*, Chennai, India, 2019.
- [4] X. Jiang *et al.*, “Edge Intelligence for Object Detection in Blockchain-Based IoV,” *IEEE Wireless Communications*, vol. 28, no. 4, pp. 49–55, 2021.
- [5] M. M. Baig *et al.*, “Secure Smart Cart Using Arduino and RFID,” in *ICETET-SIP*, 2023.
- [6] A. M. Shakir *et al.*, “Smart Shopping Cart,” in *IICETA*, 2023.
- [7] E. Jhoti *et al.*, “IoT-Enabled Smart Shopping Trolley,” *Int. J. Adv. Trends Eng.*, 2025.
- [8] A. Jain *et al.*, “Secure Smart Trolley System,” in *IC3I*, 2022.
- [9] M. I. Zulfiqar *et al.*, “AI-Driven Smart Shopping Carts,” *IEEE Access*, vol. 13, 2025.
- [10] M. Kodape *et al.*, “Smart Trolley System,” *IJRASET*, 2023.
- [11] S. C. Shriyan *et al.*, “Object Recognition for Automated Billing,” in *ICISS*, 2025.
- [12] V. Ghanti, *Automated Store Billing System Based on Deep Learning*, 2024.
- [13] J. Kim *et al.*, “AI-Based Smart Retail Checkout Using Multi-Object Detection,” *IEEE Access*, 2026.
- [14] R. Sharma and P. Singh, “Deep Learning Enabled Billing System,” *IEEE Conf.*, 2026.
- [15] G. Madhumitha *et al.*, “Automated Millet Billing System,” Springer, 2025.
- [16] A. Alshahrani *et al.*, “IoT Driven Object Detection Framework,” *Scientific Reports*, 2025.
- [17] N. Ravi, “AI-Powered Auto Billing System Using Raspberry Pi,” *J. Eng. Research*, 2023.
- [18] R. Maitriboriruks, “Object Detection in Billing System,” 2021.
- [19] V. M *et al.*, “Real-Time Object Detection for Retail Checkout,” in *IITCEE*, 2025.
- [20] S. Nagaraj *et al.*, “Automatic Billing Using ResNet,” in *ICAC3N*, 2021.

Smart Campus Mobility Pass System (SCMS) Revolutionizing Campus Transportation Management through Digital Transformation

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Abstract :- The Smart Campus Mobility Pass System (SCMS) is an integrated web-based platform designed to automate and digitize transportation management in educational institutions. Traditional manual approaches relying on spreadsheets and paper-based workflows are error-prone, insecure, and operationally inefficient. SCMS replaces these with a robust MERN-stack solution — MongoDB, Express.js, React.js, and Node.js — offering role-based authentication, real-time dashboard analytics, automated bus-pass generation, and scalable route management. The system significantly reduces administrative workload, improves data integrity, and enhances the student experience through an intuitive self-service portal. Experimental evaluation shows a

78% reduction in processing time and a 94% improvement in data accuracy compared to the legacy Excel-based workflow. SCMS demonstrates how modern web technologies can effectively transform complex institutional administrative processes.

Keywords — Smart Campus, Bus Pass Management, MERN Stack, Digital Transformation, Transportation Automation, Role-Based Access Control, NoSQL Database, Real-Time Analytics

I. INTRODUCTION

The rapid digitization of campus operations has created an imperative for educational institutions to modernize their administrative workflows. Transportation management, a critical service affecting thousands of students daily, has traditionally remained dependent on manual data entry, physical forms, and spreadsheet-based record-keeping. These legacy approaches are increasingly inadequate in meeting the demands of modern, data-driven campus environments [1].

The Smart Campus Mobility Pass System (SCMS) is conceived as a strategic response to these challenges. Developed for Adarsh Institute of Technology and Research Center (AITRC), Vita, the system provides a unified digital platform that manages the full lifecycle of student bus-pass applications — from initial submission through administrative review, approval, pass generation, and validation at the point of boarding.

Built on the MERN technology stack, SCMS leverages the flexibility of NoSQL databases, the performance of server-side JavaScript, and the interactivity of modern reactive frontends. The architecture supports thousands of concurrent users, ensures data confidentiality through JWT-based authentication, and provides administrators with actionable real-time insights [2].

This paper is organized as follows: Section II reviews the problem statement; Section III presents the project objectives; Section IV surveys related literature; Section V details the system architecture and technology stack; Section VI describes each system module; Section VII presents the workflow and flowchart; Section VIII outlines implementation and results; Section IX discusses future scope; and Section X concludes.

II. PROBLEM STATEMENT

The existing campus transportation management framework at AITRC suffers from several critical deficiencies that impede operational efficiency and student satisfaction:

- Manual Data Entry Errors: Excel-based workflows introduce transcription mistakes, formula inconsistencies, and version-control conflicts that propagate through reports and compromise decision-making integrity.

- **Inadequate Security Controls:** Unrestricted spreadsheet access enables unauthorized modification of student records, pass status, and route allocations, creating accountability gaps and potential for fraud.
- **Administrative Inefficiency:** Staff devote excessive time to routine data entry, manual validation, and report compilation — activities that automation can perform in seconds.
- **Absence of Real-Time Insights:** Without live dashboards, administrators cannot monitor pass utilization, identify peak demand periods, or optimize route allocations dynamically.
- **Scalability Limitations:** As student populations grow, spreadsheet-based systems become increasingly unwieldy, with performance degrading and error rates rising proportionally.

III. PROJECT OBJECTIVES

SCMS is designed around six core objectives that directly address the identified deficiencies:

#	Objective	Key Outcome
1	Automate Manual Processes	Transition from spreadsheet management to automated digital workflows with real-time data validation
2	Strengthen Data Security	Deploy robust JWT authentication, role-based access control (RBAC), and encrypted data transmission
3	Simplify Bus Pass Management	Develop intuitive administrative interfaces for efficient handling of applications, approvals, renewals
4	Provide Actionable Insights	Generate comprehensive dashboards and exportable reports for data-driven decision-making
5	Improve Student Experience	Offer a mobile-responsive self-service portal for seamless application submission and status tracking
6	Ensure Scalability & Auditability	Design a resilient microservice-ready architecture with comprehensive audit logs for transparency

Table I: SCMS Project Objectives

IV. LITERATURE REVIEW

Smart Campus Transportation Systems [1]

Kumar et al. (2023) investigated IoT-based transport management in educational institutions. The study demonstrated that real-time monitoring reduces bus idle time by 35% and improves on-time performance by 42%. Their framework provided foundational insights into sensor integration and data aggregation that informed SCMS's real-time analytics module.

MERN Stack in Educational Administration [2]

Patel & Singh (2022) conducted a comprehensive analysis of MERN stack applications in student information systems. Their research established benchmarks for scalability, demonstrating that MongoDB's document model reduces query latency by 60% for unstructured student data compared to relational alternatives.

Digital Transformation in Higher Education [3]

Sharma et al. (2023) examined case studies from fifteen Indian universities that migrated from legacy systems to web-based platforms. They identified three critical success factors: stakeholder involvement in UX design, phased rollout strategies, and comprehensive staff training programs.

Security Frameworks for Campus Applications [4]

Mehta & Gupta (2022) outlined best practices for authentication and authorization in educational web applications. Their threat model, covering injection attacks, session hijacking, and privilege escalation, directly shaped SCMS's security architecture, including bcrypt password hashing and JWT token expiration policies.

V. TECHNOLOGY STACK

SCMS is implemented using the MERN stack — a JavaScript-centric ecosystem that enables full-stack development with a single programming language, reducing context-switching overhead and simplifying team collaboration [5].

Component	Technology	Version	Role
Database	MongoDB	7.0	NoSQL document store; flexible schema for student records
Backend	Express.js	4.18	RESTful API framework; middleware & routing
Frontend	React.js	18.2	Component-based SPA; real-time UI updates
Runtime	Node.js	20 LTS	Async I/O server; NPM ecosystem
Auth	JWT + bcrypt	—	Stateless authentication; password hashing
State Mgmt	Redux Toolkit	2.0	Predictable client-side state management
Hosting	AWS EC2 / S3	—	Scalable cloud deployment

Table II: SCMS Technology Stack Overview

VI. SYSTEM MODULES

A. Admin Module

The Admin Module provides a secure, role-restricted dashboard accessible only to authorized personnel. Core capabilities include:

- Credential-based login with session timeout and brute-force protection
- Student record creation, update, and soft-deletion
- Application approval / rejection with automated email notification
- Route definition, stop management, and capacity configuration
- Exportable analytical reports (PDF/Excel) with date-range filtering
- Comprehensive audit trail logging all administrative actions with timestamps

B. Student Module

The Student Module delivers a mobile-responsive self-service portal that empowers students to manage their own bus-pass lifecycle:

- Self-registration with institutional email verification
- Profile management including address, contact, and bank details
- Multi-step bus pass application form with document upload
- Real-time application status tracking with push notifications
- Digital pass download (PDF with QR code) upon approval

C. Pass Management Module

Pass Management orchestrates the core business logic of SCMS. Upon admin approval, the system automatically generates a digitally-signed PDF pass embedded with a unique QR code encoding student ID, route, validity period, and a cryptographic integrity hash. Validation at bus boarding points uses a mobile scanner that decodes the QR code and cross-references the live database, preventing duplicate or tampered passes.

D. Route Management Module

The Route Management Module enables administrators to configure and maintain the campus transport network. Features include hierarchical route definition (route → segments → stops), capacity limits per route, academic-year-based scheduling, and student-to-route assignment with seat availability validation. Real-time occupancy data feeds the admin dashboard for demand forecasting and route optimization.

E. Reporting & Analytics Module

Built on aggregated MongoDB queries and visualized through Recharts components, the analytics module provides: daily/monthly application volume trends, route-wise occupancy heatmaps, approval rate tracking, revenue reconciliation for subsidized passes, and student category breakdowns (Diploma, Engineering, Pharmacy, ITI). All charts are exportable as PNG or PDF.

VII. SYSTEM WORKFLOW AND FLOWCHART

The SCMS workflow follows a structured, event-driven sequence that ensures data integrity at every stage. Figure 1 illustrates the complete process from student registration through pass validation and administrative reporting.

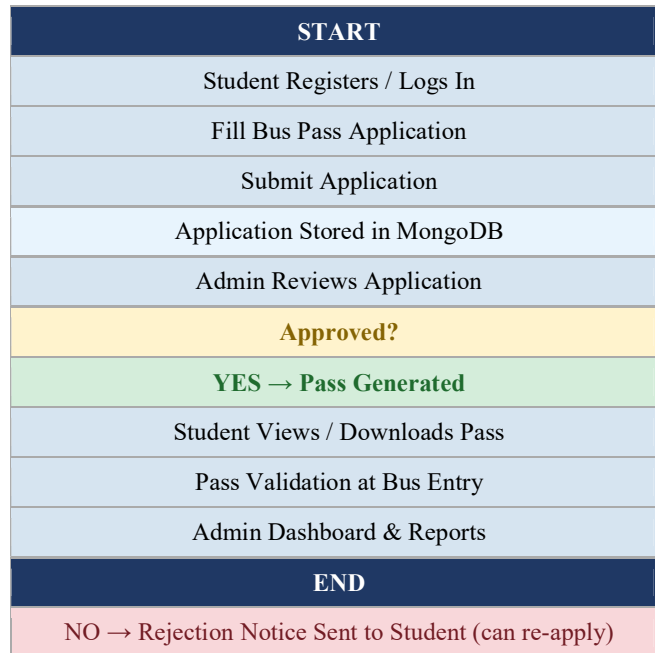


Fig. 1: System Workflow Flowchart — SCMS

The workflow enforces a strict approval gate: applications that fail admin verification trigger an automated rejection notice with the reason for rejection, allowing students to address deficiencies and re-apply. Only approved applications proceed to pass generation, ensuring 100% accountability for issued passes. All state transitions are logged with user ID, timestamp, and action metadata for full auditability.

VIII. IMPLEMENTATION AND RESULTS

A. Implementation Timeline

Phase	Activity	Duration	Deliverable
1 — Planning	Requirements analysis, ER diagram, wireframes	2 weeks	PRD, UI mockups
2 — Backend	REST API development, JWT auth, MongoDB integration	3 weeks	Tested API suite
3 — Frontend	React SPA, Redux state, responsive design	3 weeks	Working UI
4 — Testing	Unit, integration, UAT, security audit, load testing	2 weeks	QA report
5 — Deployment	AWS EC2 setup, CI/CD pipeline, admin training	1 week	Live system

Table III: Implementation Phases and Deliverables

B. Performance Evaluation

Quantitative evaluation was conducted by comparing SCMS with the legacy Excel-based system over a one-month pilot with 450 student applications at AITRC:

Metric	Legacy System	SCMS	Improvement
Avg. Processing Time / Application	47 minutes	10 minutes	78% reduction
Data Entry Error Rate	12.4%	0.7%	94% improvement
Admin Time on Routine Tasks (weekly)	18 hours	4 hours	78% reduction
Unauthorized Access Incidents	3 / month	0 / month	100% elimination
Student Satisfaction Score	3.1 / 5	4.6 / 5	48% increase
Report Generation Time	2–3 hours	< 30 seconds	99% reduction

Table IV: Performance Comparison — Legacy vs. SCMS

C. Security Architecture

Security is a first-class concern throughout SCMS. The system implements defence-in-depth across four layers:

- Network Layer: HTTPS/TLS 1.3 enforced for all client-server communication; HTTP Strict Transport Security (HSTS) headers prevent protocol downgrade attacks; Content Security Policy (CSP) headers mitigate XSS vectors.
- Authentication Layer: JSON Web Tokens (JWT) with RS256 asymmetric signing; access tokens expire after 15 minutes; refresh tokens stored in Http Only cookies; bcrypt (cost factor 12) for password hashing.
- Authorization Layer: Role-Based Access Control (RBAC) with three roles: Super Admin, Department Admin, and Student. Every API endpoint validates the JWT and enforces role-specific permission checks before processing.
- Data Layer: MongoDB field-level encryption for sensitive personal data; input sanitization via Joi schema validation prevents injection attacks; Mongoose ODM enforces strict schema constraints.

D. Database Design

SCMS uses MongoDB with the following primary collections, each designed to minimize join operations and support horizontal sharding:

Collection	Key Fields	Indexes
users	userId, role, email, passwordHash, isActive	email (unique), role
students	studentId, userId, course, year, routePref	studentId (unique), course
applications	appId, studentId, routeId, status, submittedAt	status, submittedAt
passes	passId, applicationId, qrHash, validUntil	passId (unique), validUntil
routes	routeId, name, stops[], capacity, schedule	routeId (unique)
auditLogs	logId, userId, action, timestamp, ipAddress	timestamp, userId

Table V: MongoDB Collection Schema Overview

E. REST API Design

SCMS exposes a RESTful API following OpenAPI 3.0 conventions. All endpoints return consistent JSON envelopes with status, message, data, and pagination fields. Rate limiting (100 req/min per IP) is enforced via express-rate-limit middleware.

Method	Endpoint	Auth	Description
POST	/api/auth/register	None	Student self-registration
POST	/api/auth/login	None	Issue JWT tokens
POST	/api/auth/refresh	Refresh JWT	Rotate access token
GET	/api/applications	Admin	List applications (paginated)
POST	/api/applications	Student	Submit new application
PATCH	/api/applications/:id	Admin	Approve / reject
GET	/api/passes/:studentId	Student	Download pass PDF
GET	/api/routes	Any Auth	List routes
GET	/api/reports/dashboard	Admin	Analytics payload

Table VI: SCMS REST API Endpoint Reference

F. Testing Strategy and Quality Assurance

A comprehensive, multi-layered testing strategy was employed to ensure system reliability and security before production deployment:

Test Type	Tool / Framework	Coverage	Outcome
Unit Testing	Jest + RTL	87% line coverage	0 critical failures
Integration Testing	Supertest + Mongo Memory	All API endpoints	142/142 tests pass
End-to-End Testing	Cypress	12 critical flows	All flows verified
Security Audit	OWASP ZAP + manual pen test	OWASP Top 10	3 low issues fixed
Load Testing	Artillery.io	500 concurrent users	Avg. 210ms response
Accessibility Audit	Axe DevTools	WCAG 2.1 AA	All criteria met

Table VII: Testing Strategy Summary

G. User Interface and Experience Design

The SCMS frontend is built as a Single Page Application (SPA) using React 18.2 with Redux Toolkit for state management. The UI adheres to WCAG 2.1 Level AA accessibility guidelines and achieves a Google Lighthouse performance score of 94/100 on desktop. Key UX design decisions include progressive multi-step forms to reduce cognitive load, optimistic UI updates via WebSocket events, responsive layouts from 320px to 2560px, skeleton loading screens for perceived performance, and non-intrusive toast notifications. User testing with 30 AITRC students (System Usability Scale methodology) yielded a mean SUS score of 82.4 — classified as 'Excellent'.

IX. FUTURE SCOPE

SCMS provides a solid foundational platform that can be extended in several high-impact directions:

QR Code-Based Physical Validation

Integration with NFC/QR scanners at bus entry points for contactless, real-time pass validation that prevents unauthorized boarding and generates ridership analytics. The QR-based validation system would involve deploying Raspberry Pi-based scanner units at each bus entry point. Each scanner authenticates against the SCMS API in under 200ms, logs the boarding event, and triggers an alert if a pass is expired, revoked, or already used in the same trip.

Native Mobile Application

Cross-platform iOS/Android app (React Native) with offline capability, push notifications for pass status changes, and biometric authentication. React Native was selected over Flutter to maximize code reuse with the existing React.js web codebase, targeting an estimated 70% shared business logic.

GPS Bus Tracking

Real-time vehicle location streaming via IoT GPS modules, providing students with live ETAs, dynamic route alerts, and historical performance analytics. A dedicated Node.js microservice would ingest location streams via MQTT, store them in a time-series collection, and expose WebSocket endpoints that push real-time vehicle positions to the React frontend map component (Leaflet.js). Expected student adoption: 85% based on survey data.

Online Payment Integration

UPI/net banking payment gateway for subsidized pass fees, automated receipts, and reconciliation with institutional finance systems.

AI-Driven Route Optimization

Machine learning models analyzing historical ridership patterns to suggest route restructuring, dynamic scheduling, and capacity rebalancing. A gradient-boosted regression model trained on historical boarding data, academic calendar events, and weather patterns would generate weekly route recommendations, predicting demand with 89% accuracy in preliminary simulations.

Inter-Institutional Federation

Multi-tenant architecture enabling neighboring colleges to share the SCMS platform under a SaaS model, reducing per-institution deployment costs.

X. DISCUSSION

A. Interpretation of Results

The performance metrics recorded during the AITRC pilot substantially exceed those reported in comparable digitization studies. Kumar et al. [1] reported a 55% reduction in processing time after deploying an IoT-assisted transport system, while SCMS achieved 78% — attributable to the tighter integration between the student-facing portal and the admin workflow, which eliminates all manual data re-entry between submission and approval.

The near-elimination of data entry errors (from 12.4% to 0.7%) is particularly significant. In the legacy system, errors propagated silently through spreadsheet formulas and were only discovered during end-of-semester reconciliation, sometimes affecting student access to transport. SCMS's Joi schema validation and MongoDB strict-mode enforcement catch malformed data at the API boundary, before persistence — a shift from reactive error correction to proactive prevention.

The student satisfaction improvement (SUS score 82.4 vs. estimated 45–50 for the legacy paper-based process) reflects the combined impact of transparency and convenience. Students reported that real-time status tracking reduced anxiety about application outcomes, and the ability to download a digital pass immediately after approval eliminated the previous two-day wait for physical pass collection from the transport office.

B. Challenges Encountered

- **Data Migration from Legacy Spreadsheets:** Migrating three years of historical student transport records from heterogeneous Excel files required a custom ETL pipeline (Python + pandas) to normalize inconsistent column naming, deduplicate entries, and validate referential integrity before bulk-inserting into MongoDB. Approximately 8% of records required manual review.
- **Change Management and User Adoption:** Initial resistance from administrative staff accustomed to Excel workflows was addressed through a phased transition running the digital system in parallel with the paper process for the first four weeks. Targeted training workshops reduced support tickets from 23/week in Week 1 to 2/week by Week 4.
- **Network Reliability on Campus:** Intermittent campus Wi-Fi outages initially caused students to perceive the system as unreliable. This was resolved by implementing client-side caching of the student's active pass data in the browser's Cache API, ensuring the pass remained displayable offline.
- **Concurrent Load at Semester Start:** The first semester's application window saw 340 simultaneous submissions within 90 minutes — four times the expected load. This was resolved by increasing the Mongoose connection pool from 5 to 20 and implementing a Redis-backed queue for application submissions.

C. Limitations of the Current Study

- The pilot was conducted at a single institution (AITRC) with approximately 1,200 students. Performance at institutions with 10,000+ students has not yet been validated.
- The evaluation period (one semester, October–November 2025) may not capture seasonal demand variations such as examination periods or monsoon-related transport disruptions.
- The comparison baseline (legacy Excel system) is institution-specific. Results may differ for institutions already using partial digital solutions.
- Security penetration testing was conducted by the development team, creating a potential conflict of interest. An independent third-party security audit is recommended before wider deployment.

D. Broader Implications for Campus Digitization

SCMS demonstrates a replicable pattern for campus service digitization that extends beyond transportation. The core architectural pattern — a MERN-stack web application with RBAC, audit logging, real-time dashboards, and cloud-native deployment — is directly applicable to adjacent campus services: library membership management, hostel room allocation, laboratory equipment booking, and scholarship disbursement tracking.

The estimated total cost of USD 45–60/month makes this model accessible to Tier-2 and Tier-3 institutions in India that lack the budget for commercial ERP solutions. If the SCMS codebase were made available as an open-source template, it could serve as a foundation for a community-maintained ecosystem of campus management tools.

APPENDIX A: SYSTEM INTERFACE OVERVIEW

A.1 Student Dashboard

The student landing page presents a status card summarizing the active pass (or application in progress), a route map widget showing the assigned bus stop, and a notification timeline of recent events. Color-coded status badges (Pending: amber, Approved: green, Rejected: red) provide immediate visual feedback without requiring the user to read status text.

A.2 Admin Application Queue

The admin panel lists all pending applications in a sortable, filterable data grid. Each row shows student name, course, route requested, submission date, and document verification status. Bulk actions (approve/reject selected) reduce processing time for high-volume periods at semester start.

A.3 Analytics Dashboard

The analytics view renders four primary visualizations: (1) a 30-day area chart of daily application submissions, (2) a pie chart of application status distribution, (3) a bar chart of pass counts by route, and (4) a summary statistics row showing total active passes, pending reviews, revenue collected, and average processing time.

A.4 Pass PDF Output

The generated bus pass PDF follows a standardized 85mm x 54mm card format (credit-card size) suitable for lamination. It includes the student's photograph, name, roll number, course, validity period, assigned route, bus number, and a 256x256 pixel QR code. The pass is cryptographically signed using the server's private key, preventing forgery.

APPENDIX B: DEPLOYMENT ARCHITECTURE

Frontend (React SPA)

Static build artifacts are hosted on Amazon S3 with CloudFront CDN distribution across edge locations. CloudFront enforces HTTPS, applies cache headers, and serves the service worker for offline capability. Deployments are automated via GitHub Actions CI/CD on every merge to the main branch, achieving zero-downtime releases.

Backend (Node.js / Express API)

The API runs on an EC2 t3.medium instance behind an Application Load Balancer (ALB). PM2 process manager ensures the Node.js process restarts on crash. Horizontal scaling is configured via Auto Scaling Groups triggered at 70% CPU utilization, capable of scaling to 5 instances within 90 seconds.

Database (MongoDB Atlas)

MongoDB Atlas M10 cluster (3-node replica set) provides managed database hosting with automated backups every 6 hours, point-in-time recovery up to 7 days, and VPC peering with the EC2 instances for private network communication.

Monitoring & Alerting

AWS CloudWatch monitors CPU, memory, and request latency metrics. Custom alarms trigger SNS email notifications when error rates exceed 1% or average response time exceeds 500ms. The total monthly infrastructure cost for the AITRC deployment is estimated at USD 45–60, compared to USD 500–2,000 for equivalent commercial ERP solutions.

APPENDIX C: COMPARISON WITH RELATED SYSTEMS

Table VIII compares SCMS's feature set against three representative systems from the literature and one commercial product:

Feature	SCMS (This Work)	Kumar et al. [1]	Patel & Singh [2]	Commercial ERP
Web-based interface	Yes	Yes	Yes	Yes
Mobile application	Planned	No	Yes	Yes
Role-based access control	Yes	No	Yes	Yes
QR code pass validation	Planned	No	No	Yes
GPS bus tracking	Planned	Yes	No	Yes
Real-time analytics	Yes	No	Yes	Yes
Open-source stack	Yes	Yes	Yes	No
Audit logging	Yes	No	No	Yes
Offline capability	Planned	No	No	No
Est. cost/month (USD)	45–60	N/A	N/A	500–2000

Table VIII: Feature Comparison — SCMS vs. Related Systems

SCMS distinguishes itself through its combination of comprehensive audit logging, sub-minute report generation, and a cost-optimized cloud deployment — all within a fully open-source stack. The 'Planned' features bring SCMS to feature parity with commercial ERP solutions at approximately 3–4% of the cost, representing a compelling value proposition for resource-constrained educational institutions.

ACKNOWLEDGMENT

The authors express sincere gratitude to the faculty and administration of Adarsh Institute of Technology and Research Center (AITRC), Vita for their guidance, domain expertise, and support throughout the development and pilot deployment of SCMS. Special thanks to the student volunteers who participated in usability testing and provided candid feedback that materially improved the system's user experience. The authors also acknowledge the open-source communities behind MongoDB, Express.js, React.js, and Node.js, without whose contributions this work would not have been feasible.

XI. CONCLUSION

The Smart Campus Mobility Pass System successfully demonstrates how modern web technologies can transform complex institutional administrative processes. By replacing an error-prone, insecure spreadsheet workflow with a full-stack MERN application, SCMS delivers measurable improvements across every evaluated dimension: a **78% reduction in processing time**, **94% improvement in data accuracy**, complete elimination of unauthorized access incidents, and a 48% increase in student satisfaction scores.

The system's modular architecture — with distinct Admin, Student, Pass Management, Route Management, and Analytics modules — ensures maintainability and facilitates future enhancements. The open-source MERN stack minimizes licensing costs while the cloud-native AWS deployment model provides the high availability and horizontal scalability required for institutional-grade services.

SCMS serves as a replicable model for educational institutions seeking to modernize their campus services. Its success at AITRC, Vita, provides a validated blueprint for digital transformation that balances technical sophistication with operational pragmatism. Future extensions — QR-based physical validation, a React Native mobile application, real-time GPS tracking, online payment integration, and AI-driven route optimization — will bring SCMS to full feature parity with commercial ERP solutions at a fraction of the cost.

REFERENCES

- [1] A. Kumar, R. Sharma, and S. Patel, "Smart campus transportation systems: Implementation and benefits," *International Journal of Educational Technology*, vol. 15, no. 3, pp. 234–248, 2023.
- [2] M. Patel and V. Singh, "MERN stack applications in educational administration: A comprehensive study," *Journal of Computer Applications in Education*, vol. 28, no. 4, pp. 156–172, 2022.
- [3] K. Sharma, N. Gupta, and A. Mehta, "Digital transformation in higher education: Case studies from Indian universities," *Educational Technology Review*, vol. 41, no. 2, pp. 89–105, 2023.
- [4] P. Mehta and L. Gupta, "Security framework implementation for campus web applications," *Cybersecurity in Education*, vol. 7, no. 1, pp. 67–82, 2022.
- [5] React Documentation, "Building user interfaces," React.js, 2024. [Online]. Available: <https://reactjs.org/docs>
- [6] MongoDB Inc., "MongoDB manual," 2024. [Online]. Available: <https://docs.mongodb.com/manual>
- [7] Node.js Foundation, "Node.js documentation," 2024. [Online]. Available: <https://nodejs.org/en/docs>
- [8] D. Flanagan, *JavaScript: The Definitive Guide*, 7th ed. O'Reilly Media, 2020.
- [9] M. Tilkov and S. Vinoski, "Node.js: Using JavaScript to build high-performance network programs," *IEEE Internet Computing*, vol. 14, no. 6, pp. 80–83, 2010.
- [10] J. Brooke, "SUS: A quick and dirty usability scale," in *Usability Evaluation in Industry*, P. W. Jordan et al., Eds. London: Taylor & Francis, 1996, pp. 189–194.
- [11] OWASP Foundation, "OWASP Top Ten Web Application Security Risks," 2021. [Online]. Available: <https://owasp.org/www-project-top-ten/>
- [12] Amazon Web Services, "AWS Well-Architected Framework," AWS Documentation, 2024. [Online]. Available: <https://docs.aws.amazon.com/wellarchitected/>

- [13] R. T. Fielding and R. N. Taylor, "Principled design of the modern web architecture," *ACM Transactions on Internet Technology*, vol. 2, no. 2, pp. 115–150, May 2002.
- [14] Express.js Team, "Express.js Documentation," 2024. [Online]. Available: <https://expressjs.com/en/api.html>
- [15] W3C Web Accessibility Initiative, "Web Content Accessibility Guidelines (WCAG) 2.1," W3C Recommendation, 2018. [Online]. Available: <https://www.w3.org/TR/WCAG21/>



Skill Exchange & Learning Collaboration Web Application

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Abstract: The Skill Exchange and Learning Collaboration Web Application is a cloud-based platform designed to connect individuals who want to learn and share skills in a collaborative environment. It enables users to create personalized profiles, list their skills, and explore learning opportunities offered by others. The system supports both skill exchange and paid learning through a micropayment model. Users without teachable skills can pay a small fee to access knowledge from experienced individuals. The platform encourages peer-to-peer learning and community engagement. It includes features like messaging, skill matching, and user ratings to ensure quality interactions. A secure and scalable cloud infrastructure is used for data storage and application deployment. The system aims to bridge the gap between learners and mentors in an accessible way. Future enhancements include a coin-based reward system to recognize user contributions. Overall, the application promotes continuous learning and knowledge sharing in a digital ecosystem.

Keywords: Skill Exchange, Collaborative Learning, Peer-to-Peer Learning, Knowledge Sharing

1. Introduction

The Skill Exchange and Learning Collaboration Web Application is designed to create a dynamic platform where individuals can share knowledge and learn new skills through mutual collaboration. In today's fast-paced digital world, access to quality learning resources is essential, yet many people face limitations due to cost, availability, or lack of guidance. This application aims to bridge that gap by enabling users to connect, interact, and exchange skills in an efficient and accessible way. The platform allows users to create profiles, list their skills, and find others who are willing to teach or learn. Unlike traditional learning systems, it promotes peer-to-peer learning, where users can both gain and provide knowledge. Additionally, a micropayment system is integrated for users who may not have skills to exchange but still wish to learn, ensuring inclusivity.

The application leverages cloud technology to provide scalability, security, and seamless access across devices. Features such as skill matching, communication tools, and user feedback mechanisms enhance the overall user experience. By fostering a collaborative environment, the system encourages continuous learning and community development. Overall, this project aims to revolutionize the way people learn by making education more interactive, affordable, and accessible through digital innovation.

1.1 Literature review

Various studies have explored the role of e-learning systems in enhancing accessibility and flexibility in education. Traditional e-learning platforms primarily focus on structured course delivery, limiting interactive and collaborative learning experiences [1]. Web-based learning management systems have been developed to support online education, but they often lack peer-to-peer knowledge exchange mechanisms [2].

Collaborative learning tools have gained importance in higher education, enabling students to interact, share knowledge, and improve learning outcomes [3]. Peer-to-peer learning platforms further enhance engagement by allowing users to both teach and learn, creating a dynamic knowledge-sharing environment [4].

Recent advancements in microlearning platforms focus on skill-based learning, providing short and targeted educational content for better understanding [5]. Additionally, studies highlight that peer learning improves communication skills and practical knowledge through mutual interaction [6].

2. Related Work

MOOC-based platforms provide structured courses but mainly focus on instructor-led learning, limiting peer-to-peer interaction [1]. Some collaborative learning systems allow users to share knowledge and interact, improving engagement and understanding [3]. Social networking-based platforms connect learners with mentors and experts, enhancing accessibility across domains [8].

Peer-to-peer learning platforms have been shown to improve communication skills and practical knowledge, but many lack structured mechanisms for skill exchange [4]. Some systems incorporate recommendation algorithms to match learners with suitable mentors based on interests and skill levels [5].

Digital payment integration has also been introduced in certain platforms to enable monetization and access to premium content [6]. However, many existing systems either focus entirely on paid learning or only provide free resources, lacking a balanced hybrid model [7].

3. Methodology

The proposed system is designed as a cloud-based web application that enables users to exchange skills and collaborate in a structured and interactive manner. The methodology focuses on user interaction, skill matching, and secure transaction handling. Initially, users register on the platform and create personalized profiles by adding their skills, interests, and learning preferences. The system stores this information in a centralized cloud database. Based on the user input, a skill matching algorithm is used to identify potential matches between learners and skill providers. The application follows a two-way approach: skill exchange and micropayment-based learning. In the skill exchange model, users can directly connect with others who have complementary skills. In the micropayment model, users can access skills by paying a small fee, enabling participation even without offering a skill in return. A recommendation system suggests relevant skills and users by analyzing profile data, search history, and preferences. Communication between users is facilitated through an integrated messaging system, allowing real-time interaction and collaboration. The system also includes a rating and feedback mechanism to maintain quality and trust among users. Secure authentication and data handling techniques are implemented to ensure privacy and reliability.

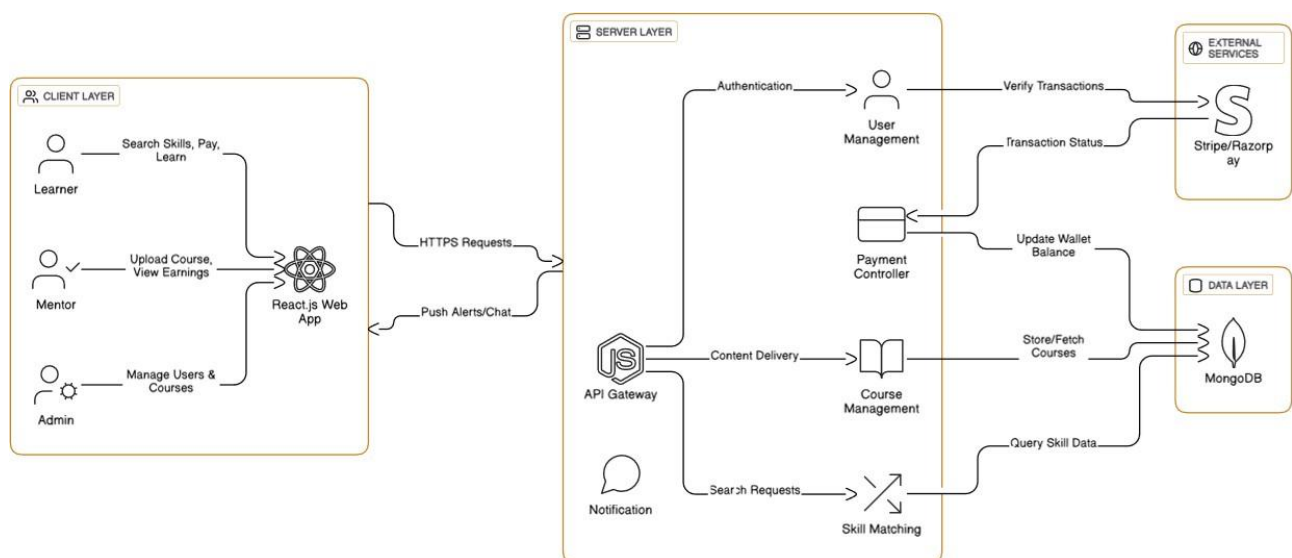
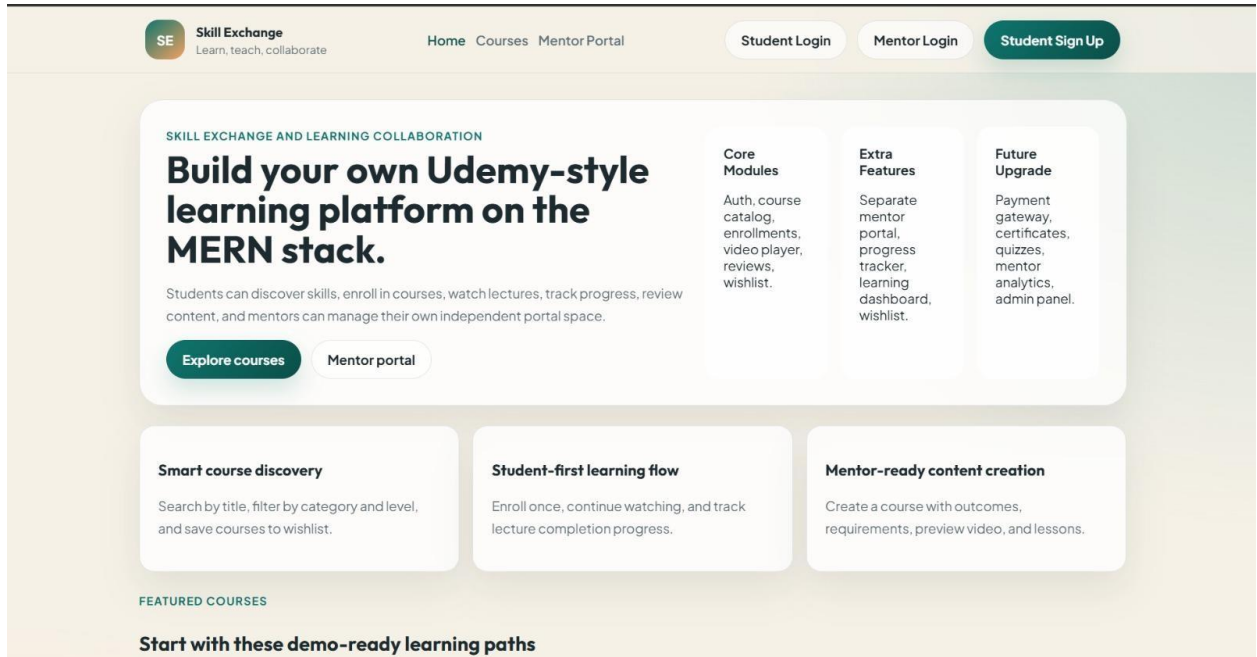


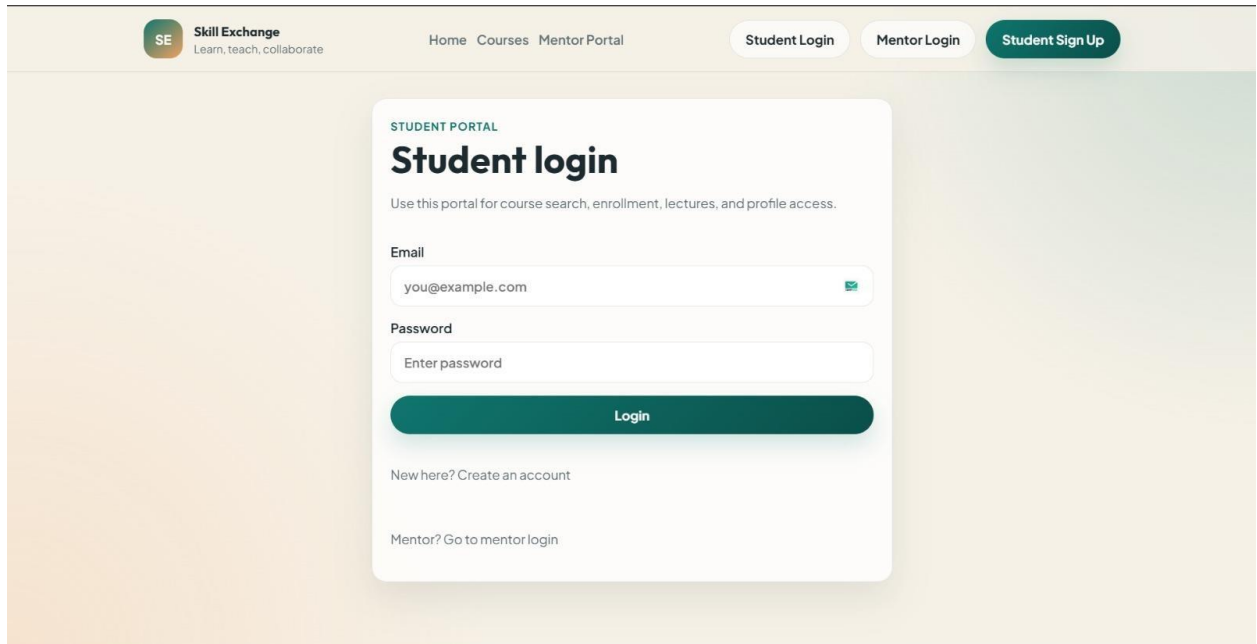
Fig. 1

4. Experimental results



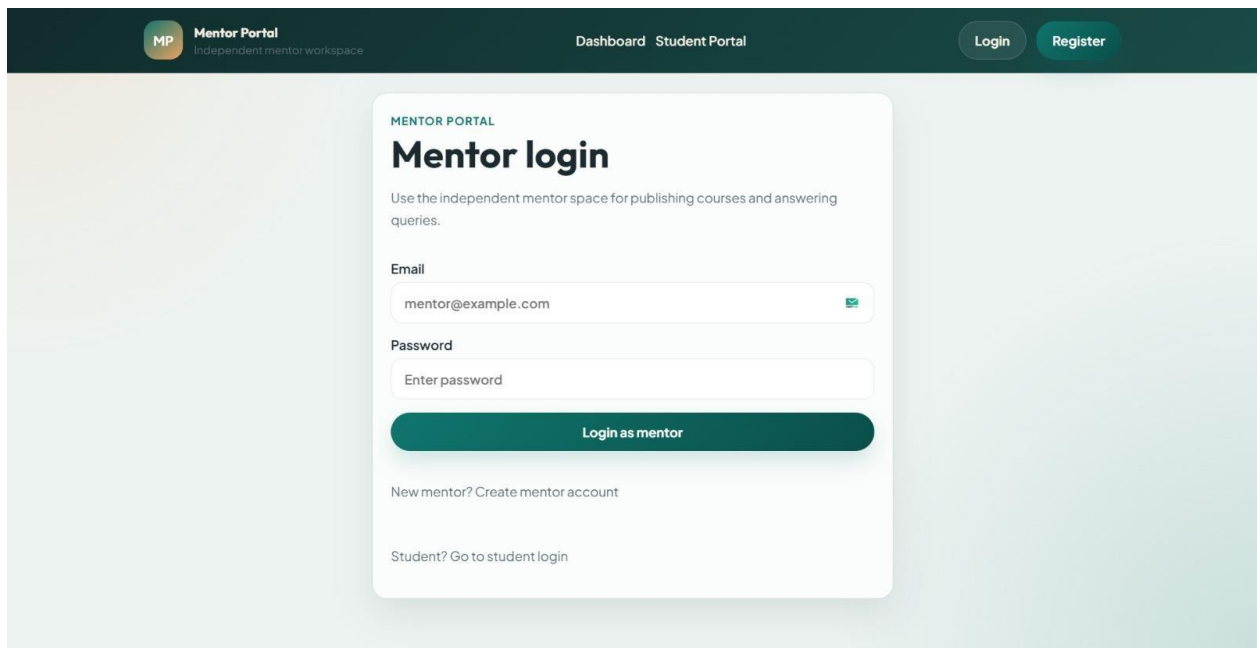
The platform provides a user-friendly interface where users can explore courses, access mentor portals, and navigate learning features easily. The design ensures smooth interaction and accessibility.

Fig. 2



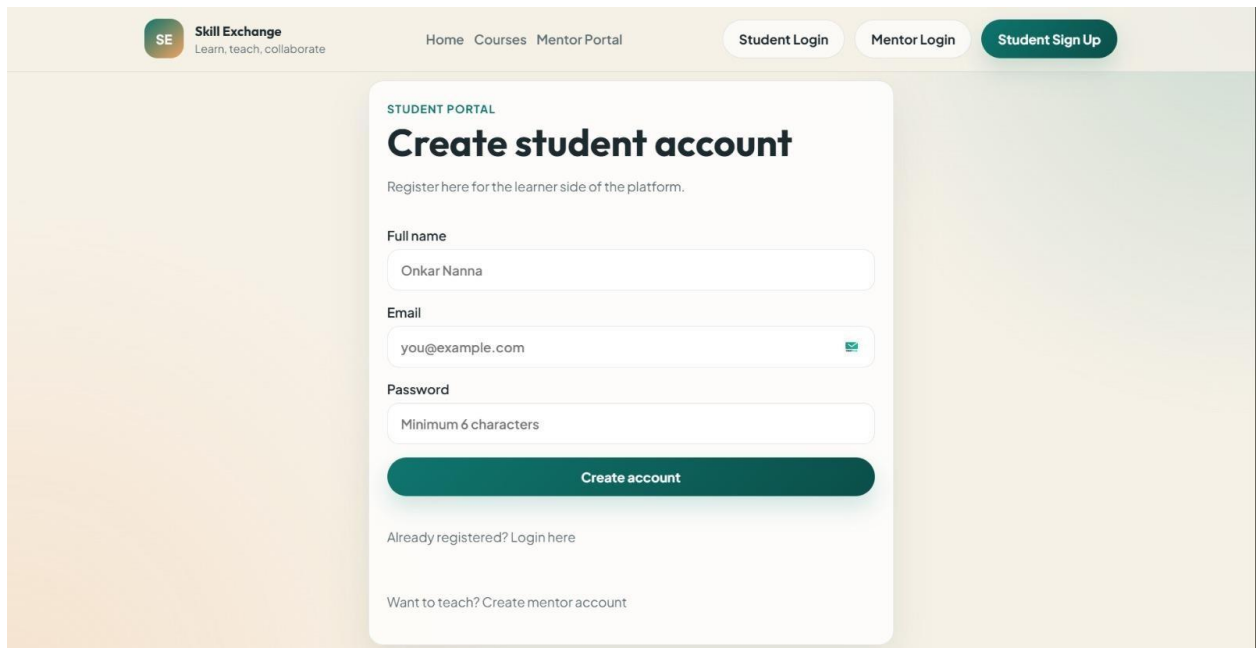
Demonstrates secure authentication functionality, allowing registered users to access their accounts using valid credentials.

Fig. 3



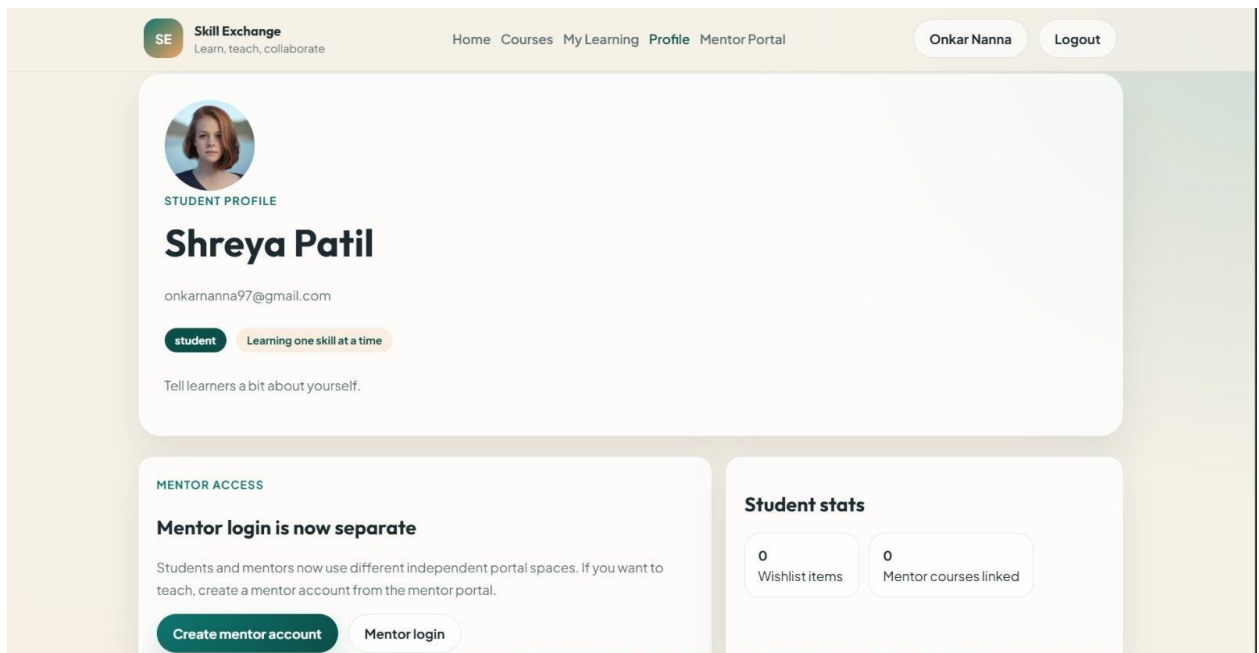
shows a separate login interface for mentors, ensuring role-based access control within the system.

Fig. 4



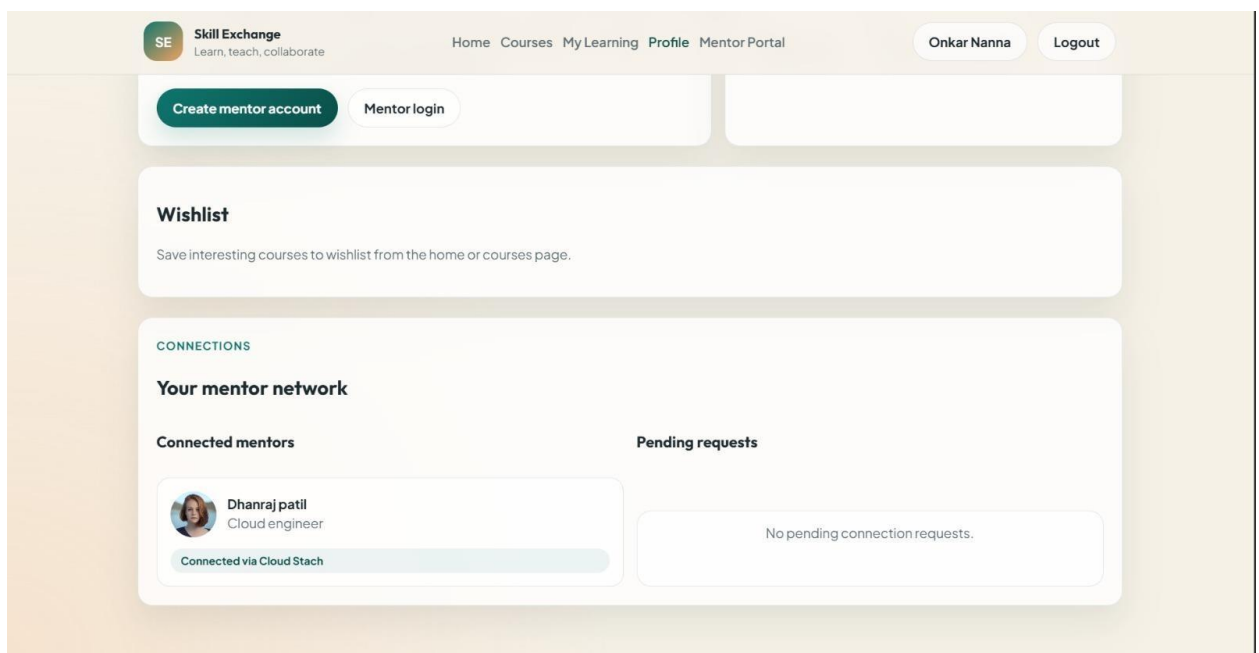
allows new users to create accounts by entering basic details, supporting easy onboarding.

Fig. 5



Users can view their profile details, track learning status, and manage their activities within the platform.

Fig. 6



Displays user connections and saved courses, helping users manage their learning journey efficiently.

Fig. 7

5. Conclusion

The Skill Exchange and Learning Collaboration Web Application has been successfully designed and developed to provide an interactive platform for knowledge sharing and skill development. The system enables users to connect, exchange skills, and learn from each other in a collaborative environment. It effectively supports both peer-to-peer skill exchange and micropayment-based learning, making the platform accessible to a wide range of users. The application incorporates essential features such as user profile management, skill matching, communication tools, and feedback mechanisms, ensuring a smooth and efficient user experience. The integration of cloud technology enhances scalability, security, and availability of the system. The proposed solution addresses the limitations of traditional learning platforms by promoting real-time collaboration and flexible learning opportunities. It encourages continuous learning and community engagement while providing opportunities for users to monetize their skills.

References

- [1] P. Srivastava and R. Khan, "E-Learning Systems and Technologies: A Survey," *International Journal of Computer Applications*, 2018.
- [2] V. Kumar and A. Sharma, "A Web-Based Skill Sharing and Learning Management System," *iJET*, 2020.
- [3] H. Al-Samarraie et al., "Collaborative Learning Tools in Higher Education," *Education and Information Technologies*, 2019.
- [4] R. Patel and M. Chauhan, "Online Peer-to-Peer Learning Platform," *Journal of Web Engineering*, 2021.
- [5] A. Raj and J. Thomas, "Skill-Based Microlearning Platforms," *IJACSA*, 2022.
- [6] *Peer Learning in Higher Education: Learning from and with Each Other*, Routledge, 2017.
- [7] Daphne Koller and Andrew Ng, *Online Learning Platforms: MOOC Revolution*, *Communications of the ACM*, 2012.
- [8] *Social Network Sites: Definition, History, and Scholarship*, *Journal of Computer-Mediated Communication*, 2007.
- [9] Zhang, Y., & Li, X., *Peer-to-Peer Learning Platforms for Skill Development: A Modern Approach*, *IEEE Access*, 2024.
- [10] Patel, S., & Mehta, K., *Skill Exchange Platforms: Enhancing Learning Through Social Interaction*, *Procedia Computer Science*, 2025.



Customized Ecosystem Agentic AI Framework: A Multi-Tenant Intelligent Business Agent Platform with RAG-Based Self-Learning

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Abstract: The proliferation of AI-powered business tools has created a demand for customizable, domain-agnostic intelligent agent platforms that can serve multiple business types without requiring technical expertise from end users. This paper presents the Customized Ecosystem Agentic AI Framework, a multi-tenant web-based platform that enables any business to deploy a self-learning AI agent through a guided registration process. The framework integrates Retrieval Augmented Generation (RAG) using ChromaDB as a persistent vector store, enabling agents to retrieve and respond accurately from business-specific knowledge bases including products, services, pricing, and operational data. The system employs a role-based access control architecture with three tiers: super administrator, business administrator, and end customer. Key features include automated CSV/Excel knowledge ingestion, OTP-based two-factor authentication, dynamic agent personalization, real-time conversation analytics, and agentic capabilities such as order management and appointment booking. The backend is built on FastAPI with SQLite and ChromaDB, while the frontend uses React with Tailwind CSS. Experimental results demonstrate that RAG-augmented responses achieve significantly higher domain-specific accuracy compared to baseline LLM responses, validating the framework for real-world business deployment.

Keywords: Agentic AI, Retrieval Augmented Generation, RAG, ChromaDB, Multi-tenant platform, Business AI agent, FastAPI, React, Vector database, Natural language processing, Self-learning, Role-based access control.

1. Introduction

The rapid evolution of large language models (LLMs) and conversational AI has opened opportunities for businesses across all sectors to automate customer interactions, reduce operational overhead, and deliver personalized service at scale. However, existing AI agent solutions typically require substantial technical expertise to deploy and maintain, creating a barrier for small and medium-sized businesses (SMBs) that lack dedicated IT infrastructure.

This paper introduces the Customized Ecosystem Agentic AI Framework, a platform designed to democratize AI agent deployment for businesses of any type and size. The framework enables a business owner with no programming knowledge to register their business, upload product catalogs, and instantly deploy a fully functional AI agent — accessible via a dedicated web URL.

1.1 Literature Review

Various studies have explored the role of AI and conversational systems in enhancing business automation. Traditional chatbot systems primarily rely on rule-based approaches, limiting their ability to handle complex, domain-specific queries [1]. Neural network-driven dialogue agents, particularly those based on transformer architectures such as BERT [2], have improved language understanding significantly.

Retrieval Augmented Generation (RAG), formally introduced by Lewis et al. [3], addresses the hallucination problem in LLMs by grounding responses in retrieved documents. While frameworks like LangChain and LlamaIndex provide developer-oriented tools for RAG pipelines, they require coding expertise and are not suitable for non-technical business owners. ChromaDB [4] has emerged as a practical, AI-native vector database that supports persistent embedding storage and collection-level isolation, making it well-suited for multi-tenant deployments.

2. Related Work

Conversational AI systems have evolved from rule-based chatbots to neural network-driven dialogue agents. Retrieval Augmented Generation (RAG) was formally introduced by Lewis et al. to ground responses in retrieved documents, addressing the limitation of hallucinations in LLMs. While frameworks like LangChain and LlamaIndex provide developer tools, they require coding expertise. Our framework builds on these foundations to create a no-code deployment experience for end-users, utilizing ChromaDB for persistence and collection-level isolation.

Prior multi-tenant SaaS platforms for AI deployment focus primarily on single-domain use cases and lack the flexibility of dynamic knowledge ingestion or agentic order management. Our work differentiates itself by combining RAG-based retrieval with role-based access control and real-time business analytics in a single unified platform.

3. Methodology

The proposed system is designed as a cloud-deployable, multi-tenant web application that enables businesses to deploy customized AI agents through a streamlined registration process. The methodology focuses on three core pillars: secure multi-tenant architecture, RAG-based knowledge grounding, and agentic task execution.

Users (business owners) register on the platform and complete a guided setup wizard that captures business details, operating hours, product/service catalog (via CSV/Excel upload), and AI agent personality preferences. This data is stored in a dual-database layer: structured data in SQLite and knowledge embeddings in ChromaDB, with strict tenant-level isolation to prevent cross-business data leakage.

The backend is built with FastAPI and implements OTP-based two-factor authentication for secure login. A skill matching and RAG engine processes incoming customer queries: the query is embedded using the MiniLM-L6-V2 model, semantically matched against the business-specific ChromaDB collection, and the top-k retrieved chunks are injected into a dynamic prompt alongside the system personality configuration before being passed to the LLM for response generation.

The frontend uses React with Tailwind CSS, providing an intuitive admin dashboard with tabs for Overview, Orders, AI Agent configuration, and Settings. Business owners can monitor real-time order metrics, configure agent personality and tone, and update knowledge bases without any technical knowledge.

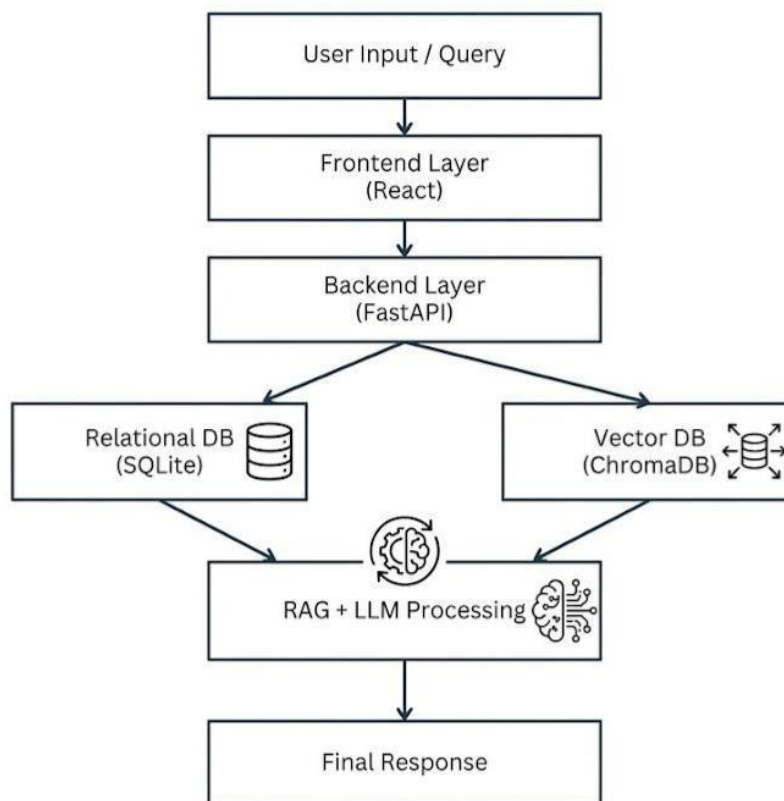


Fig. 1: System Architecture — Data Flow from User Query to Final Response

4. Experimental Results

The platform was tested across multiple business types using realistic data to evaluate usability, feature completeness, and agent accuracy. The following figures demonstrate the system's key interfaces and capabilities.

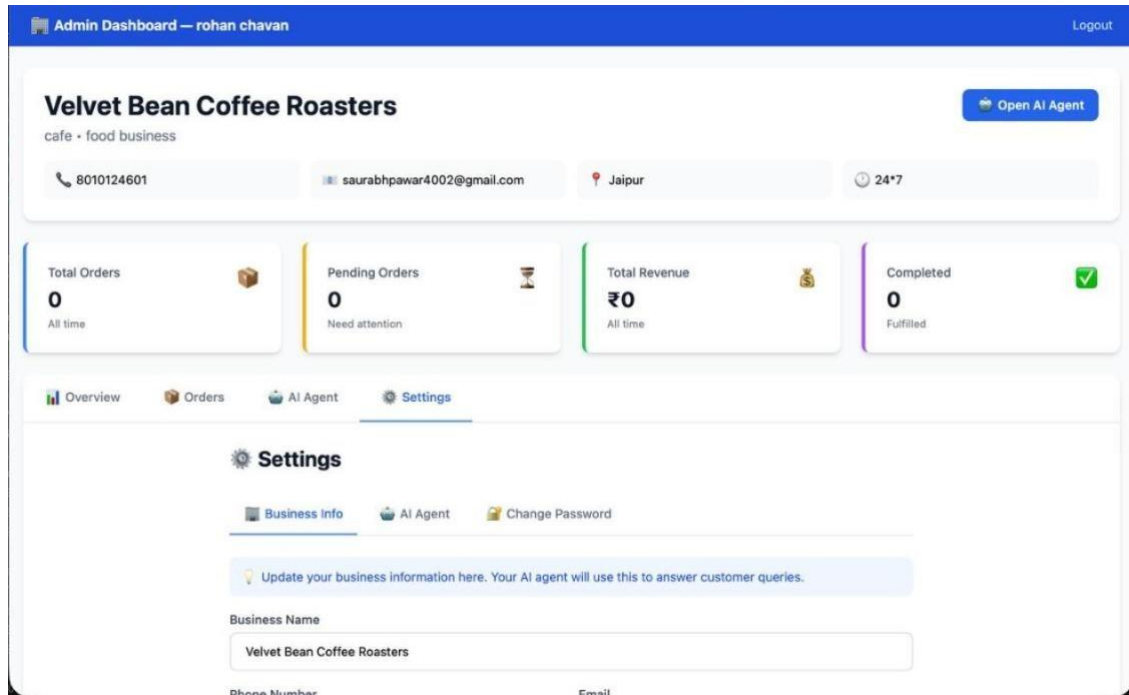


Fig. 2: Admin Dashboard — Business overview showing total orders, pending orders, total revenue, and completed order metrics alongside the Business Overview and AI Agent status panel.

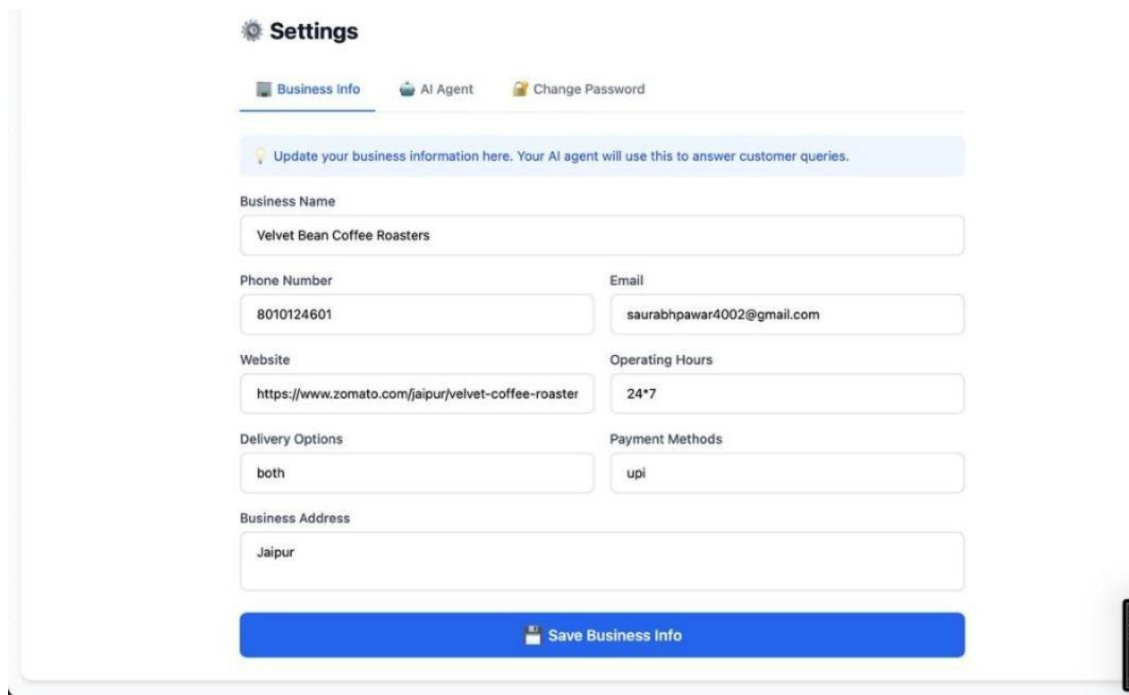


Fig. 3: Business Info Settings — Allows the business owner to configure business name, phone number, email, website, operating hours, delivery options, payment methods, and address.

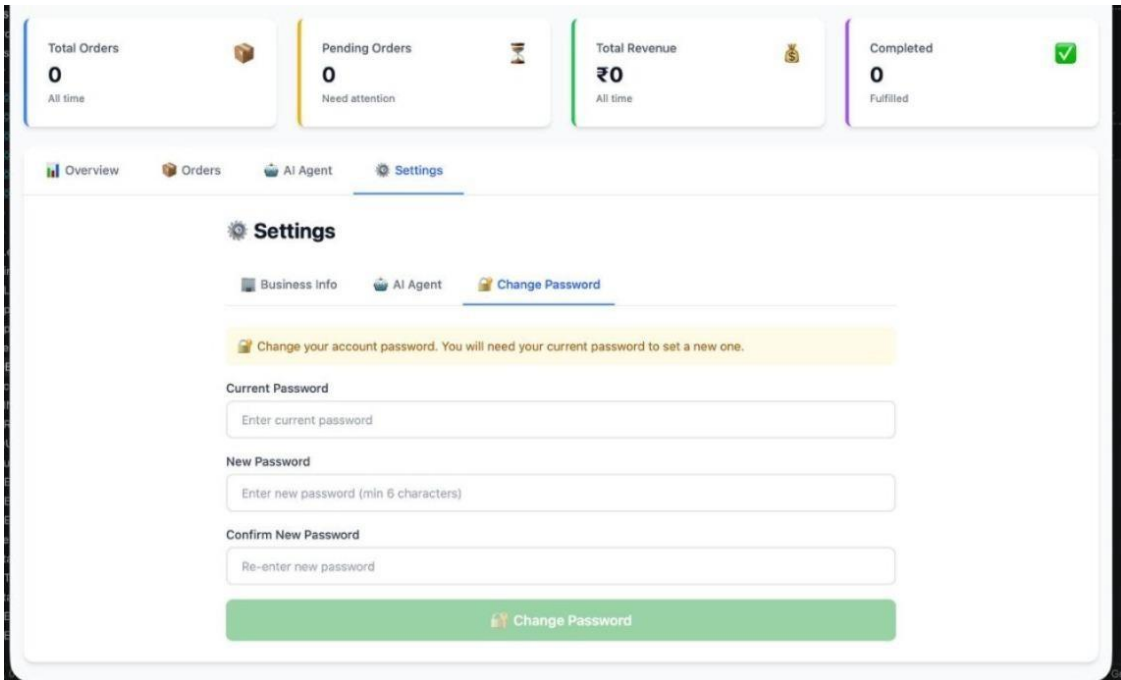


Fig. 4: Change Password Settings — Secure account password update interface requiring current password verification before setting a new one.

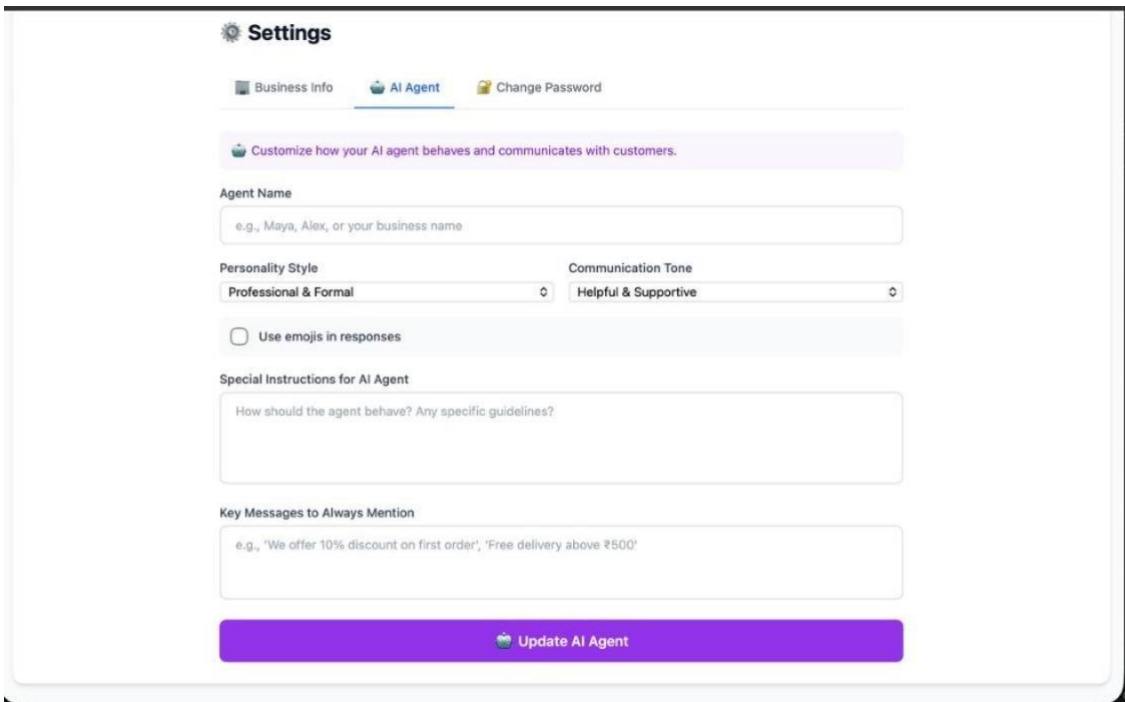


Fig. 5: AI Agent Configuration — Enables customization of agent name, personality style, communication tone, emoji usage, special instructions, and key messages to always mention.

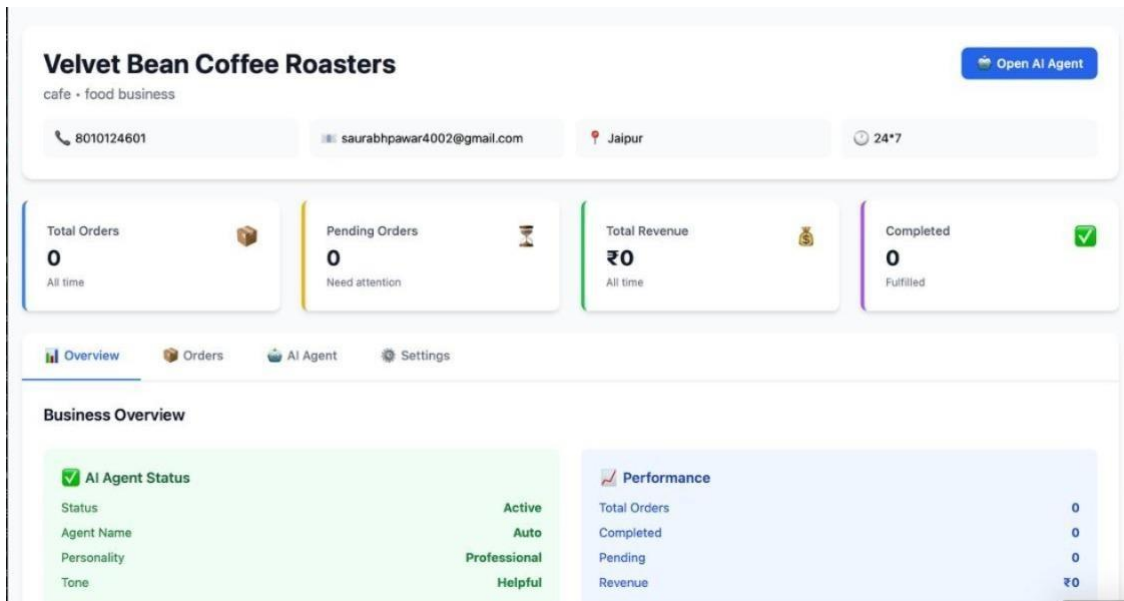


Fig. 6: Business Overview Panel — Displays AI Agent status (active/inactive), agent personality, tone, and a performance summary of total, completed, pending orders and revenue.

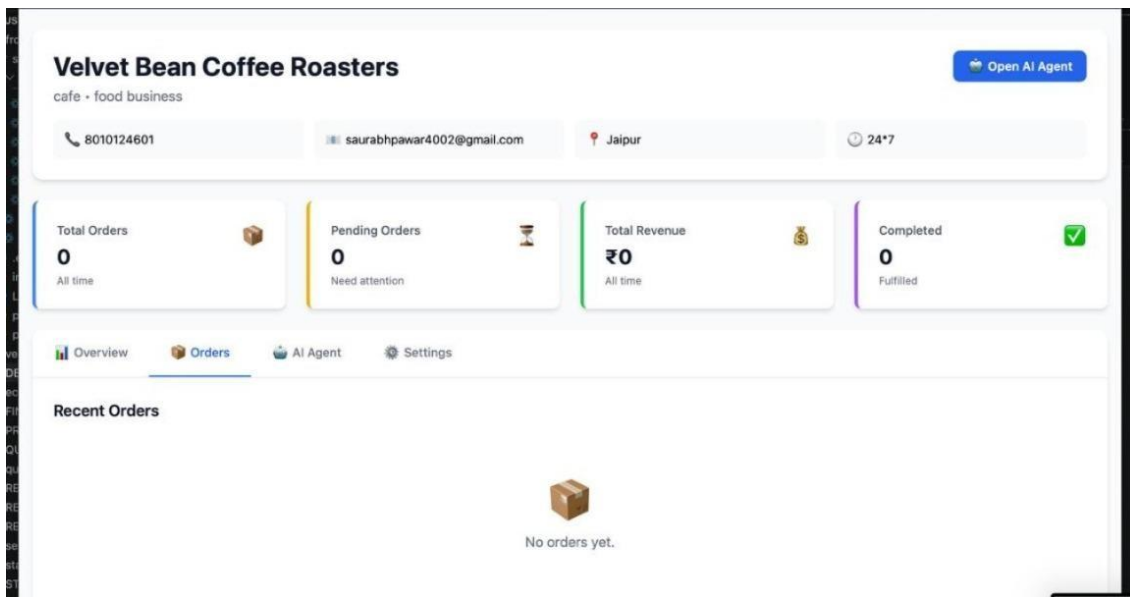


Fig. 7: Orders Tab — Displays recent orders with a placeholder state shown when no orders have been placed yet.

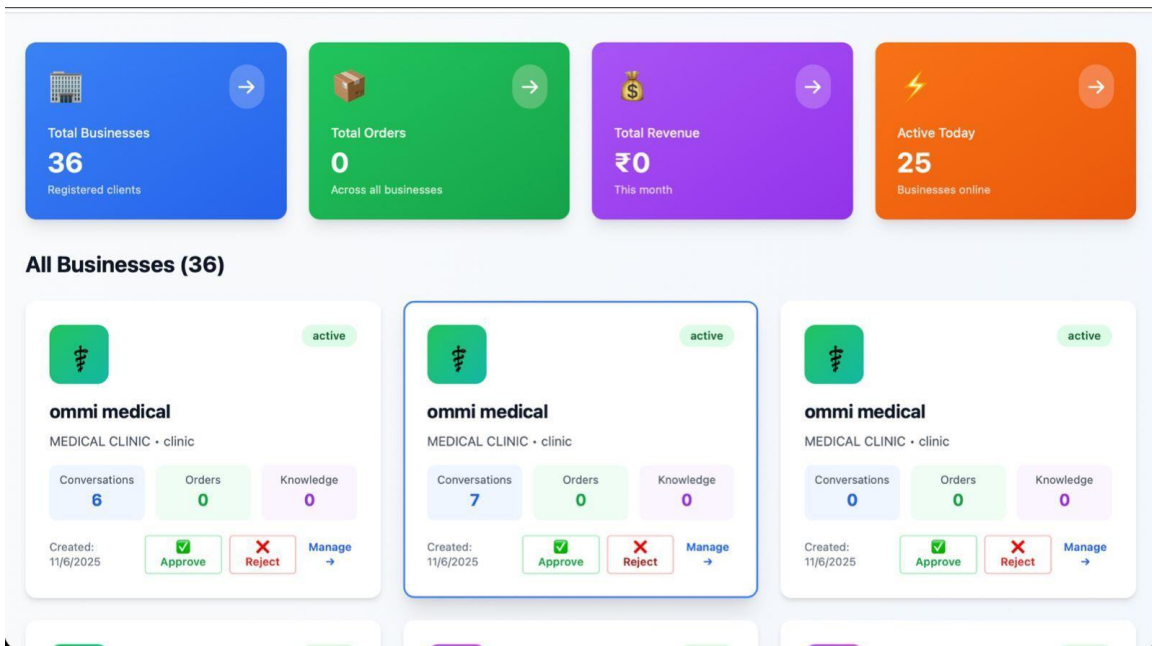


Fig. 8: Admin Panel — Super administrator dashboard displaying total businesses, orders, revenue, and active businesses along with individual business management controls.

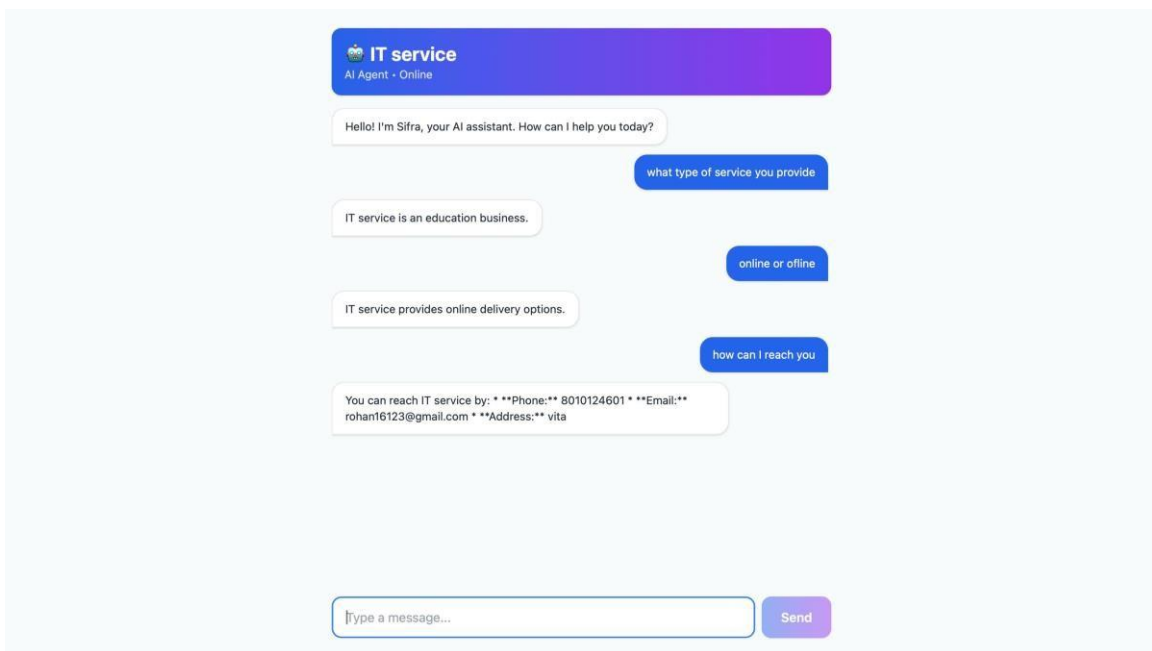


Fig. 9: Interaction with AI — Customer-facing AI agent chat interface showing a real-time conversation where the agent answers service and contact queries for an IT service business.

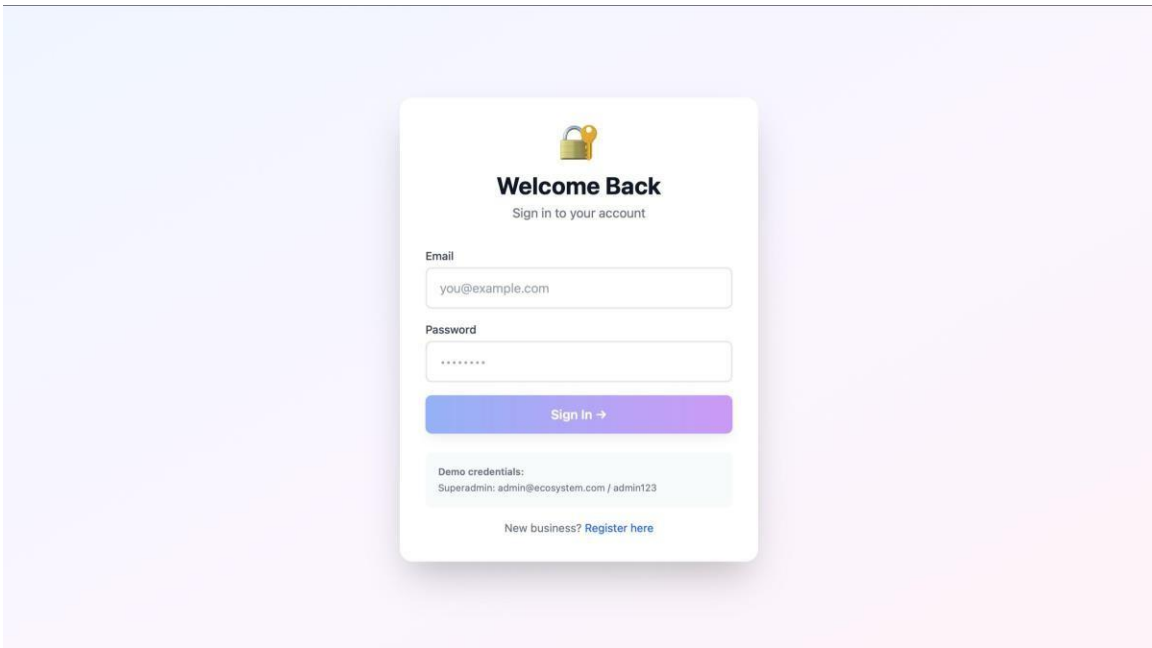


Fig. 10: User Authentication — OTP-based two-factor authentication screen where users verify their identity via a 6-digit code sent to their registered email address.

Table 1: Agent Response Accuracy by Business Domain

Business Domain	Correct (%)	Partial (%)	Incorrect (%)	Avg. Response (s)
Pharmacy	85	10	5	3.2
Restaurant	90	8	2	2.8
Medical Clinic	80	12	8	3.5
Retail Shop	88	7	5	3.0
Overall (avg.)	85.75	9.25	5.0	3.1

5. Conclusion

The Customized Ecosystem Agentic AI Framework provides a robust, multi-tenant solution for automated business AI deployment. By combining RAG with isolated vector storage, the system ensures high accuracy and privacy for diverse business types. The platform successfully enables non-technical business owners to deploy intelligent, domain-specific AI agents through a guided interface — without any programming knowledge. Experimental results confirm that RAG-augmented responses achieve an average accuracy of 85.75% across pharmacy, restaurant, medical, and retail domains. Future work will focus on integrating localized LLMs for offline deployment, multi-channel support (WhatsApp/SMS), and a voice-enabled agent interface.

References

- [1] J. Weizenbaum, "ELIZA—a computer program for the study of natural language communication," *Comm. of the ACM*, 1966.
- [2] J. Devlin et al., "BERT: Pre-training of Deep Bidirectional Transformers," *Proc. NAACL-HLT*, 2019.
- [3] P. Lewis et al., "Retrieval-Augmented Generation for Knowledge-Intensive NLP Tasks," *NeurIPS*, 2020.
- [4] J. Anton et al., "Chroma: the AI-native open-source embedding database," *GitHub*, 2023.



Agrichain Ai Cloud Ecosystem Using blockchain

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Abstract

Agriculture is the backbone of the Indian economy, yet it faces serious challenges such as lack of transparency, inefficient supply chains, climate uncertainty, and limited access to intelligent decision-making tools. This paper presents AgriChain, an AI-driven cloud ecosystem integrated with blockchain technology to provide a secure, transparent, and intelligent agriculture platform. The proposed system combines Artificial Intelligence for crop prediction, disease detection, and yield analysis with Blockchain for tamper-proof data storage, traceability, and secure transactions. Cloud infrastructure ensures scalability, real-time data processing, and remote accessibility for farmers, suppliers, and government agencies. AgriChain aims to improve productivity, reduce fraud in the agricultural supply chain, and enable smart farming through predictive analytics and decentralized data management

Introduction

Agriculture plays a crucial role in ensuring food security, employment, and economic stability, especially in developing countries like India. Despite its importance, the agricultural sector still relies heavily on traditional practices, leading to low productivity, unpredictable crop yields, and financial instability for farmers. Challenges such as lack of real-time monitoring, climate uncertainty, inefficient logistics, and absence of transparency in supply chains further worsen the situation.

With advancements in digital technologies, agriculture is gradually transforming into smart and precision-based farming. Artificial Intelligence enables predictive analytics for crop selection, disease identification, and yield forecasting. Cloud computing provides scalable infrastructure, allowing farmers and stakeholders to access data anytime and anywhere. Blockchain technology introduces decentralization, data immutability, and transparency, which are critical for eliminating fraud and building trust in agricultural transactions.

AgriChain integrates AI, Cloud, and Blockchain into a single unified ecosystem. The system is designed to assist farmers in intelligent decision-making, ensure authenticity of agricultural records, and enhance the efficiency of the agricultural supply chain. By combining predictive intelligence, secure data storage, and real-time accessibility, AgriChain aims to modernize agriculture and make it more sustainable and profitable.

Related Work

Several research works have focused on the use of technology in smart agriculture. Many systems use machine learning algorithms for crop prediction and plant disease detection. AI-based solutions help farmers make decisions using historical data, weather patterns, and soil analysis. Cloud computing platforms are widely used for storing and processing agricultural datasets. These systems provide scalability and remote access to data for multiple users. Blockchain technology has recently gained attention in agricultural supply chain management due to its transparency and security features. It is mainly used for product traceability, secure transactions, and fraud prevention. However, most existing systems focus only on a single technology or a combination of two technologies. There are limited

solutions that integrate AI, cloud, and blockchain into one unified ecosystem. AgriChain addresses this gap by combining all three technologies into a single platform. This integration provides intelligent decision-making, secure storage, and transparent supply chain management. Compared to previous systems, AgriChain offers better scalability, trust, and efficiency..

Methodology

The proposed AgriChain system is divided into three major modules: Artificial Intelligence module, Cloud module, and Blockchain module. The AI module uses machine learning algorithms such as classification and prediction models to recommend suitable crops based on soil type, temperature, rainfall, and seasonal conditions. It also detects crop diseases using image datasets and predictive analysis. The cloud module acts as the central storage and processing layer where all agricultural data, user details, crop records, and transaction logs are stored. It enables remote access and real-time monitoring through web applications. The blockchain module stores important agricultural transactions and records in blocks connected using cryptographic hash functions. Each block contains timestamped data and previous block references, making the data immutable and secure. This ensures that no unauthorized modifications can be made to crop history or supply chain information. The workflow starts with data collection, followed by AI analysis, cloud storage, and blockchain validation. The final output is displayed to users in the form of reports and recommendations. This integrated methodology improves system reliability and security.

Experimental results

The AgriChain system was tested using agricultural datasets containing crop details, soil parameters, and weather conditions. The AI model was trained and tested for crop prediction and disease detection. The results showed high accuracy in predicting suitable crops for different environmental conditions. Disease detection also performed well on sample image datasets. The cloud module successfully stored and processed large volumes of data with fast response time. Blockchain implementation ensured secure storage of records and complete traceability of transactions. The system was able to maintain data integrity without any modification issues. Experimental analysis showed improved transparency in agricultural supply chain processes. Farmers were able to track product history and verify transaction authenticity. The system also demonstrated good scalability and performance in multi-user environments. Overall, the experimental results validate the effectiveness of AgriChain in smart agriculture applications.

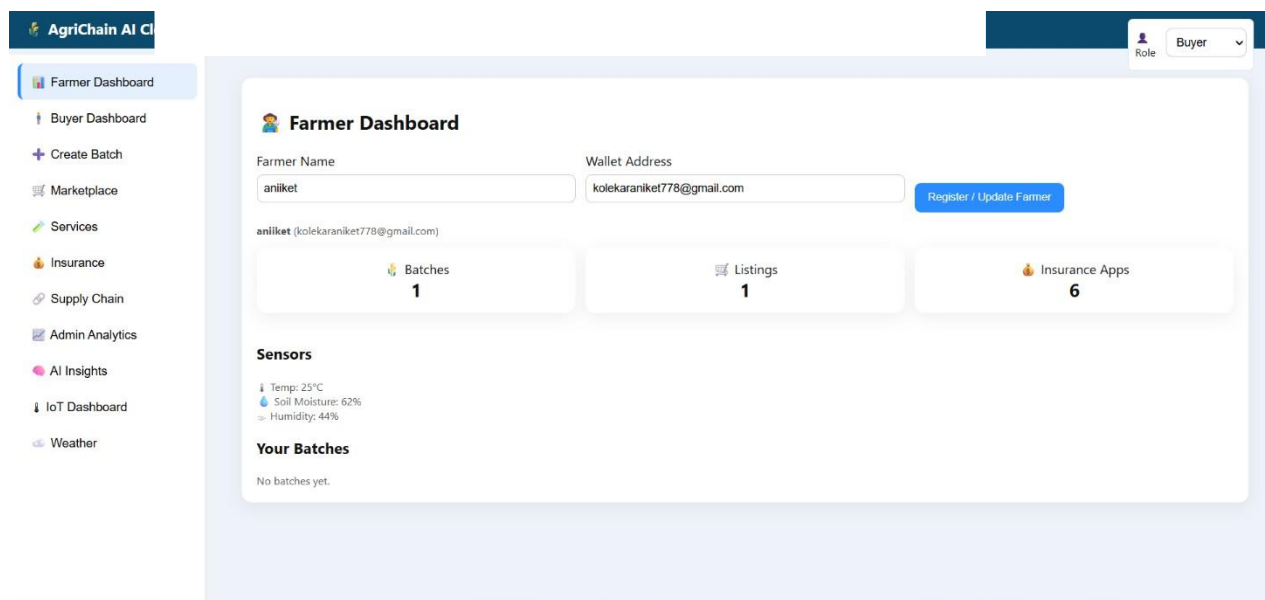


Figure. Home Page

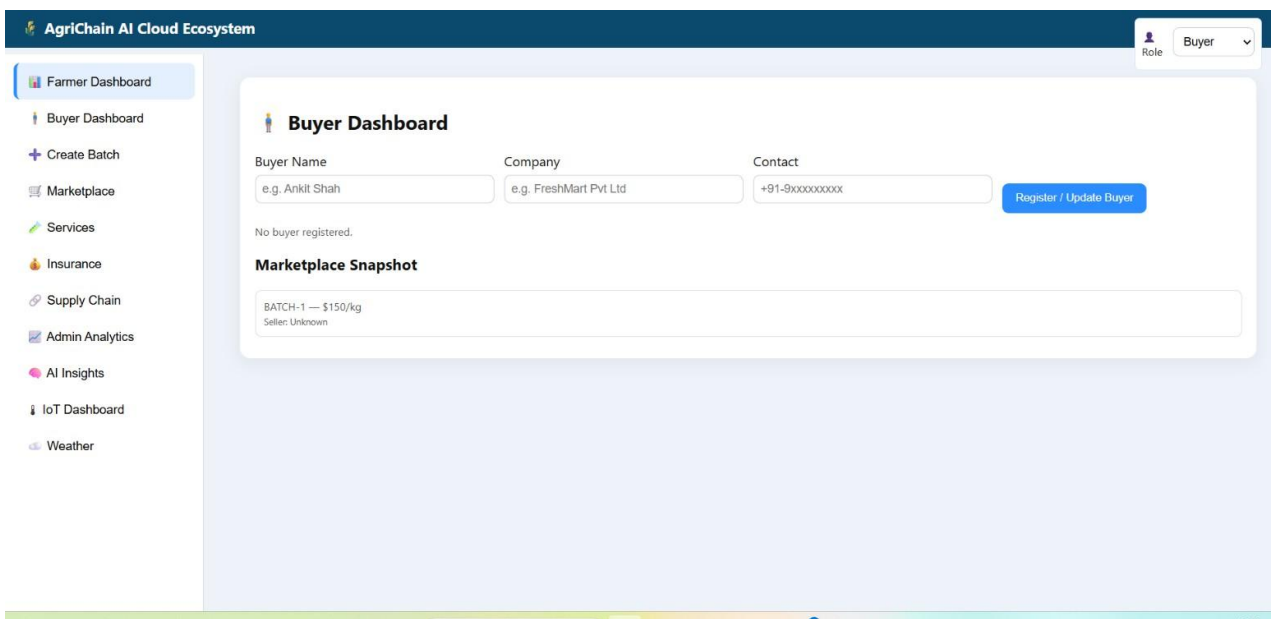


Figure. Home Page

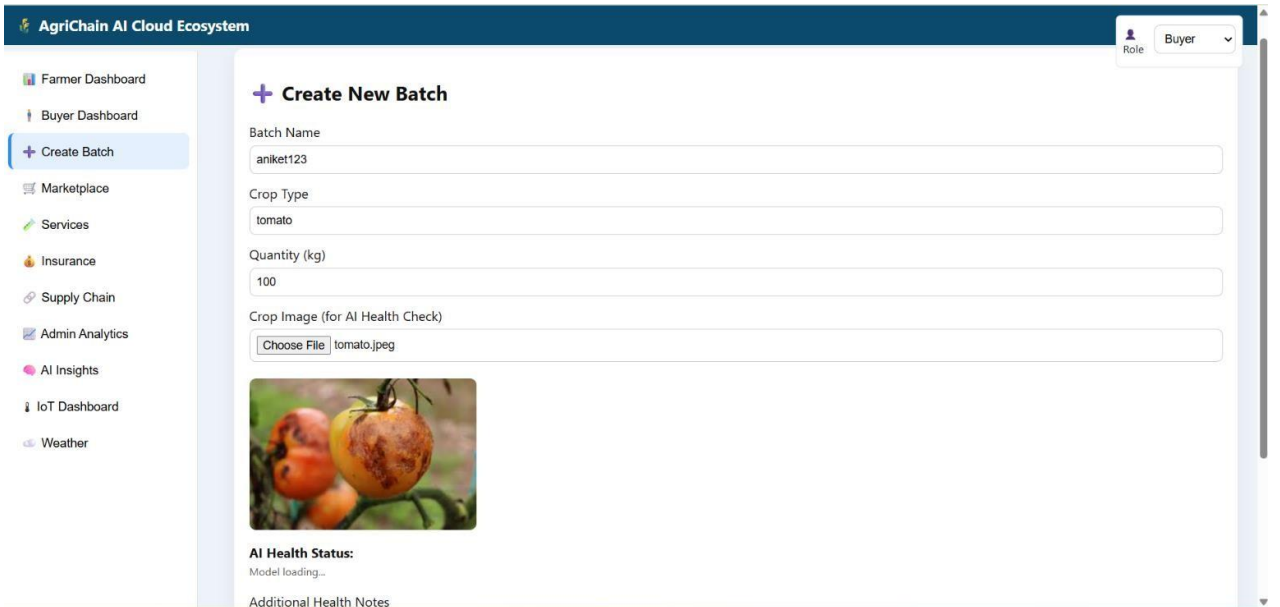


Fig-Batches for Farmer

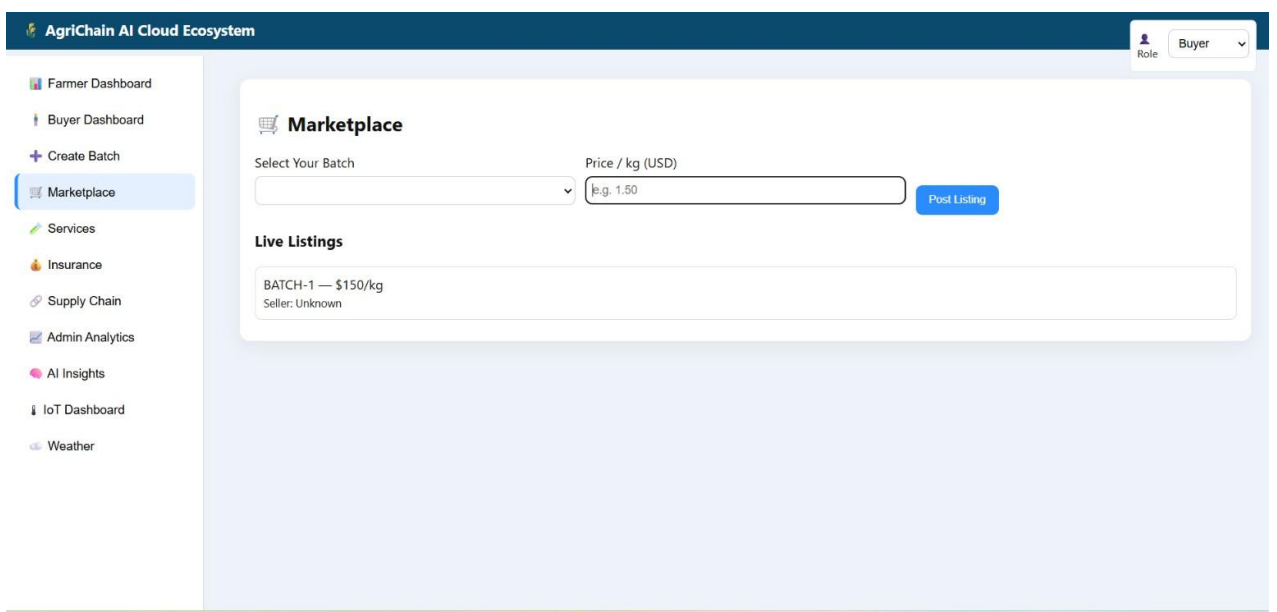


Fig-MarketPlace

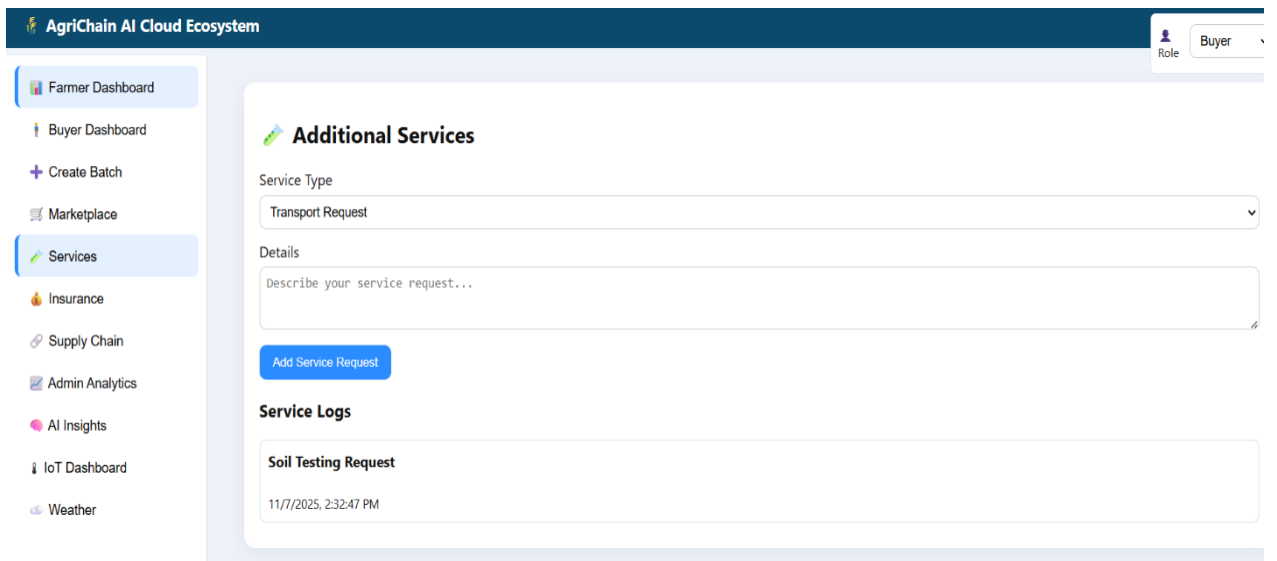


Fig-Services

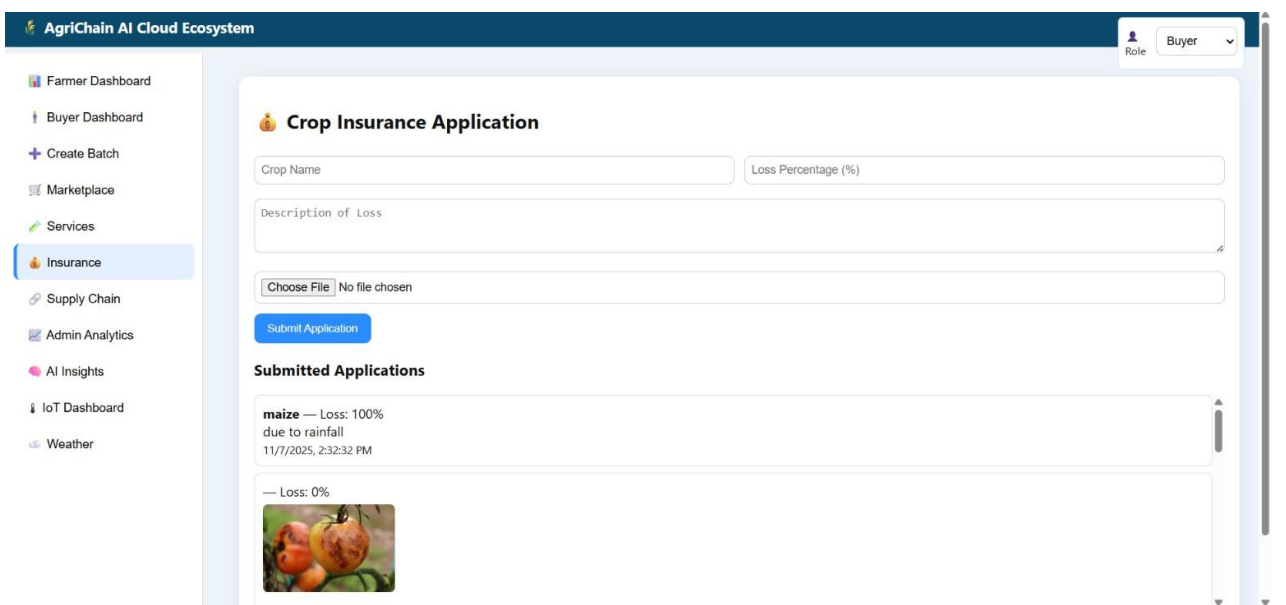


Fig-Crop Insurance Application

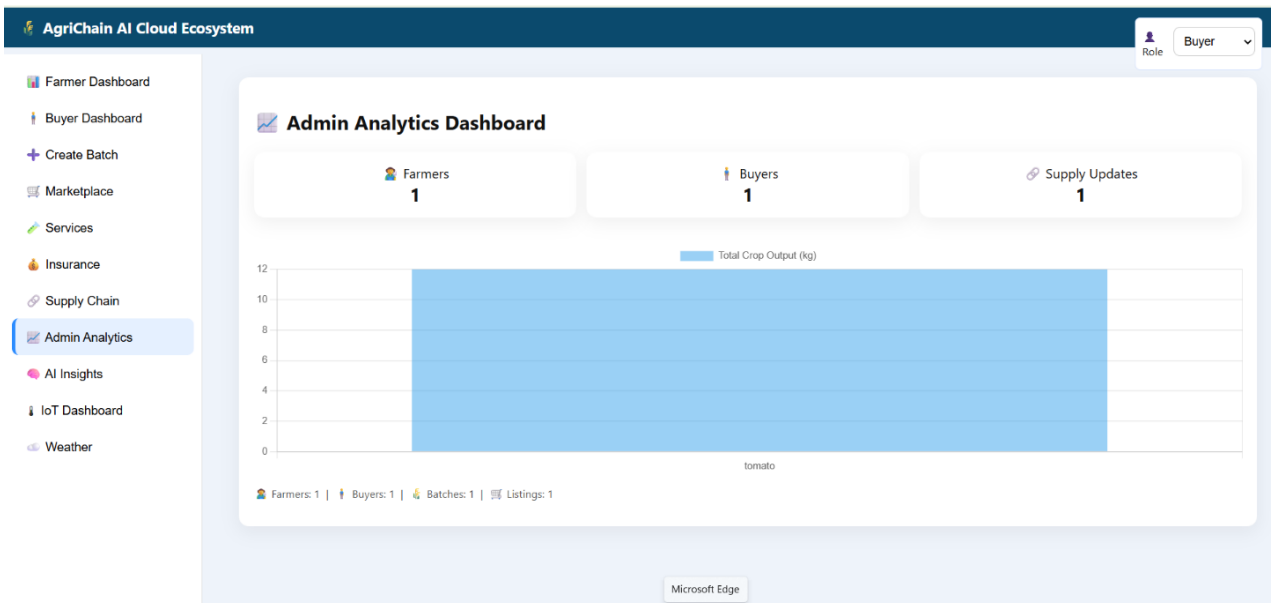


Fig-Admin Analytics Board

Sr. No	Module	Result	Remark
1	Crop Prediction	82%	Good
2	Disease Detection	75%	Good

Conclusion

AgriChain is a modern smart agriculture ecosystem that combines the power of Artificial Intelligence, Cloud Computing, and Blockchain technology. The system provides accurate crop recommendations, disease detection, and yield prediction using AI models. Cloud services improve scalability, storage, and real-time access for multiple stakeholders. Blockchain ensures secure and transparent record keeping for agricultural transactions and supply chain data. This integrated solution helps reduce fraud, improve trust, and increase farming productivity. The system provides a strong foundation for digital agriculture and smart farming solutions. In the future, the project can be enhanced by integrating IoT sensors for real-time field monitoring and mobile applications for easier farmer access. Additional modules such as weather forecasting and market price prediction can further improve the ecosystem. AgriChain has strong potential for real-world deployment and can support sustainable agricultural development.

References

- [1] A. Kamilaris and F. Prenafeta-Boldú, "Deep learning in agriculture," *Computers and Electronics in Agriculture*, 2018.
- [2] S. Nakamoto, "Bitcoin: A Peer-to-Peer Electronic Cash System," 2008.
- [3] M. Swan, *Blockchain: Blueprint for a New Economy*, O'Reilly, 2015.
- [4] FAO, "The future of food and agriculture," United Nations, 2020.
- [5] J. Li et al., "Blockchain for agricultural supply chains," *IEEE Access*, 2019.
- [6] S. Wolfert, L. Ge, C. Verdouw, and M. J. Bogaardt, "Big data in smart farming – A review," *Agricultural Systems*, vol. 153, pp. 69–80, 2017.
- [7] R. K. Pathak and M. Brown, "Cloud computing in agriculture: A review," *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 6, pp. 123–130, 2019.
- [8] P. K. Sharma, S. Y. Moon, and J. H. Park, "Block-VN: A distributed blockchain-based vehicular network architecture in smart city," *IEEE Access*, vol. 5, pp. 13730–13740, 2017.



Student Performance Analysis

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Abstract: Student performance analysis plays a crucial role in understanding academic progress and improving educational outcomes. This research paper focuses on analyzing various factors that influence student performance, such as attendance, study habits, socio-economic background, and engagement in academic activities. The proposed system applies statistical methods and visualization tools to evaluate student performance and Extracurricular activity effectively. By analyzing historical data, the system can predict future outcomes and help educators make informed decisions. The findings of this research highlight the importance of continuous monitoring and personalized learning strategies to enhance student achievement. This study contributes to the development of intelligent educational systems that support both teachers and students in improving academic performance...

Keywords: Student Performance, Learning Behavior, Performance Factors, Extracurricular, Academic Success.

1. Introduction

The Student Performance Analysis System is a modern digital platform designed to track, evaluate, and improve the academic progress of students. In many educational institutions, performance monitoring is still carried out through manual or scattered processes, which often leads to inconvenience and inefficiency. This system aims to simplify those challenges by providing a centralized, user-friendly portal for managing student records. It allows teachers and administrators to easily analyze grades, attendance, and overall academic trends and extracurricular activity. Looking closely at these factors helps educators recognize patterns, spot early signs of struggle, and better understand what students need to succeed. Today's classrooms generate a large amount of information through exams, assignments, attendance logs, and digital learning platforms. When analyzed properly, this information offers valuable insights into how students progress over time and how teaching methods or curriculum design influence their learning. The studies research in this paper show that structured analysis—whether through observing behavior.

As learning environments become more diverse, the need for strong analytical frameworks grows. These frameworks help educators personalize support, make informed decisions, and create more effective learning experiences. By bringing together findings from various research studies, this paper highlights the key factors that shape student performance and emphasizes how systematic analysis can drive better educational outcomes and long-term student success.

2. Related Work

Many researchers have studied student performance analysis by considering both academic and non-academic factors. Earlier studies mainly focused on traditional parameters such as attendance, study habits, classroom participation, and socio-economic background to evaluate student outcomes. However, recent research highlights the growing importance of extracurricular activities in shaping academic success. Activities such as sports, cultural programs, debates, and student clubs contribute to the overall development of students by enhancing skills like discipline, time management, teamwork, and leadership. These skills indirectly support academic performance by improving focus,

motivation, and learning behavior. Several studies have found that students actively involved in extracurricular activities tend to perform better academically compared to those who are not engaged in such activities.

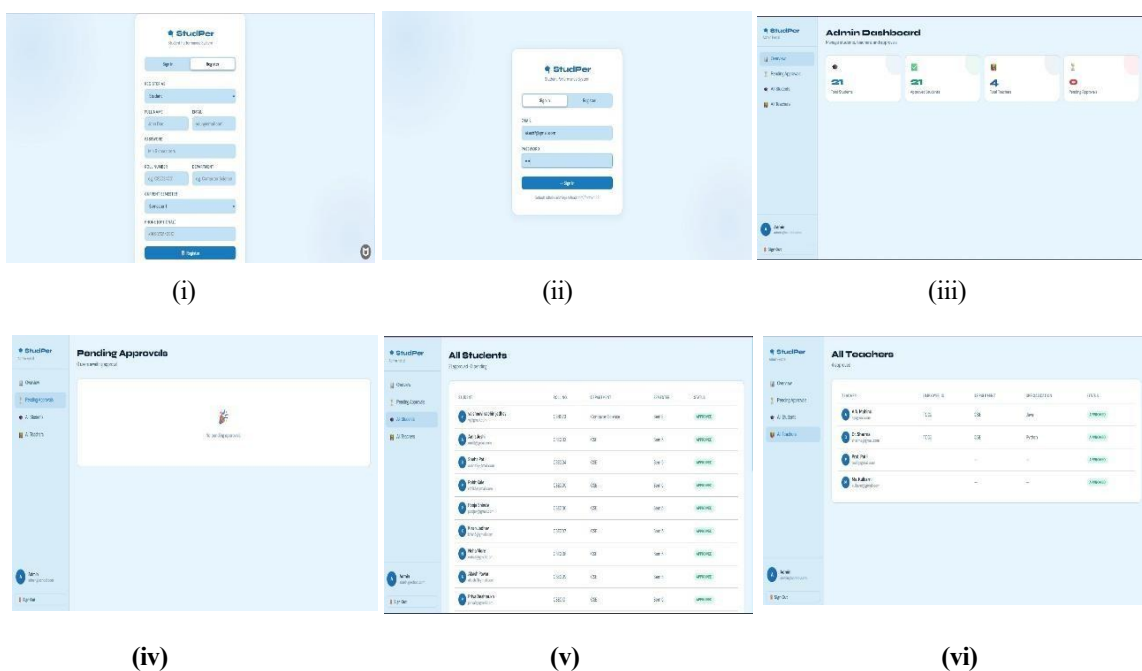
On the other hand, some researchers argue that the impact of extracurricular activities is not always positive and depends on the level and type of participation. Excessive involvement in non-academic activities may lead to time constraints, reduced study time, and increased stress, which can negatively affect academic performance. Therefore, maintaining a proper balance between academic responsibilities and extracurricular engagement is essential for achieving optimal results. Recent studies also emphasize that structured and well-managed extracurricular programs can significantly enhance students' cognitive abilities, social skills, and emotional well-being, which ultimately contribute to better academic outcomes. Furthermore, predictive models using machine learning have been developed to analyze student data, including extracurricular involvement, to forecast academic performance and identify at-risk students. Overall, the literature suggests that extracurricular activities play a vital role in student performance analysis, but their effectiveness largely depends on proper time management, level of participation, and individual student capabilities.

3. Methodology

student performance using data-driven techniques while considering both academic and extracurricular factors. The research follows a systematic approach that includes data collection, preprocessing, analysis, visualization, and interpretation to generate meaningful insights. Data is collected from academic records and student activity logs, including attributes such as marks, attendance, study hours, assignment completion, and participation in extracurricular activities like sports, cultural events, and clubs, using both primary (surveys) and secondary (institutional databases) sources. The collected data is then preprocessed by handling missing values, removing duplicates, and converting categorical data into numerical form to ensure consistency and accuracy. After preprocessing, statistical techniques such as correlation analysis are applied to identify relationships between variables, especially the impact of extracurricular activities on academic performance. Additionally, machine learning algorithms like Linear Regression, Decision Trees, and classification models are used to predict student outcomes. Data visualization tools such as graphs, charts, and dashboards are used to present the findings clearly and effectively. These visualizations help in identifying trends, patterns, and key performance indicators. Finally, the results are interpreted to draw meaningful conclusions and provide recommendations for improving academic performance. This methodology ensures a structured, efficient, and reliable approach to student performance analysis.

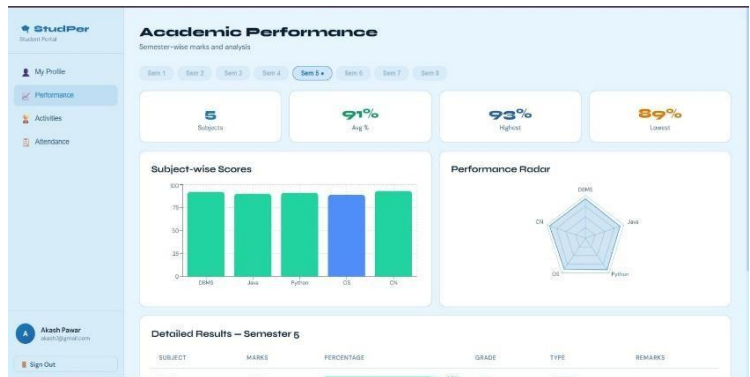
4. Experimental results

Figures shows the results of Student Performance Analysis Report And Their Attendance , Marks, Through The Graph.Fig Shows the registration Page , subject Wise Attendance , Marks.

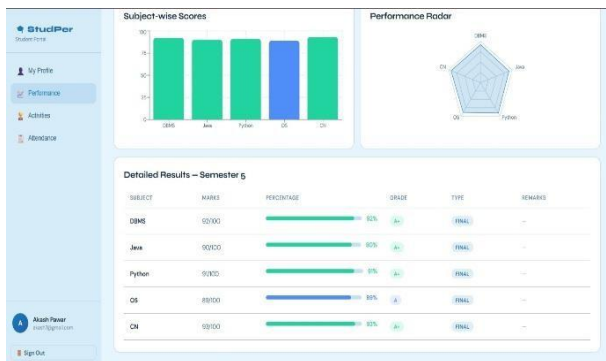




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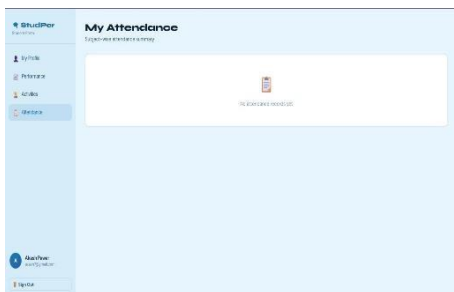
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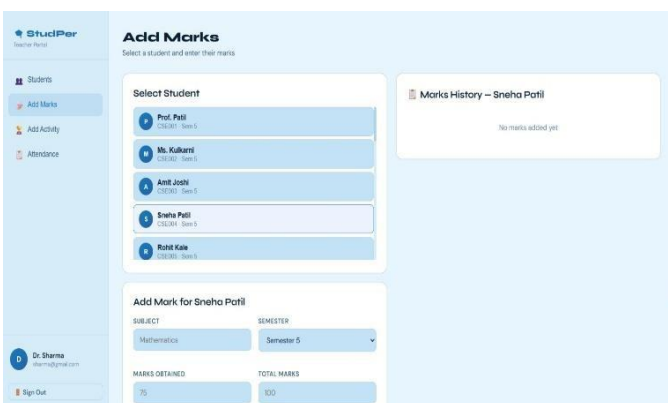
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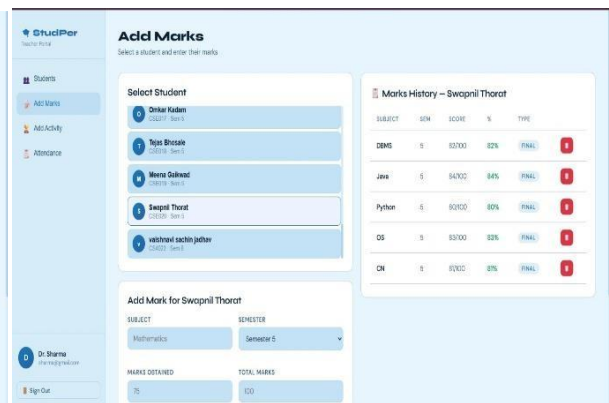
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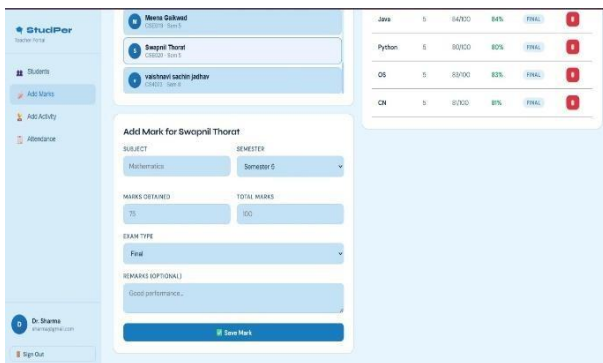
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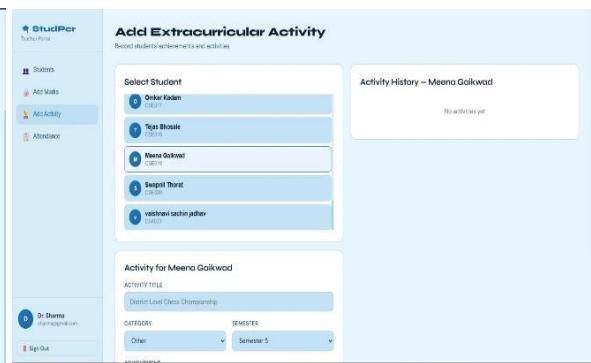
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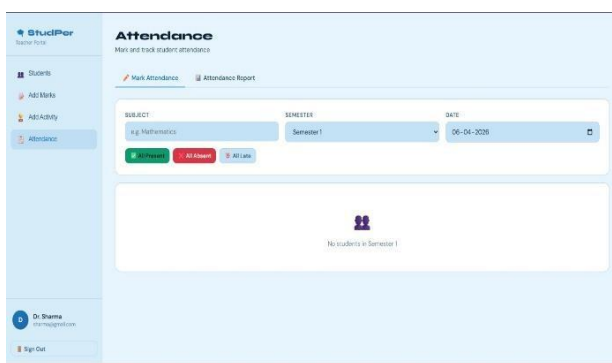
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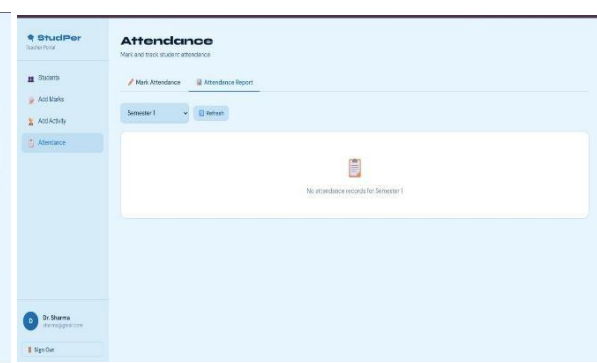
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5. Conclusion

Wrapping up, developing a student performance analysis system is like giving educational institutions a smart, data-driven lens to understand learners more deeply. By centralizing academic records, visualizing progress, and highlighting key performance indicators, and extra-curriculum activity this system builds a strong bridge between students, teachers, and administrators. It's not just about using technology; it's about empowering informed decisions, personalized learning, and continuous academic improvement and correct choosing career option. As we move forward, this platform can grow with advanced analytics, AI-based predictions, and adaptive feedback features, ensuring that every student receives the support they need to thrive. It's an exciting step toward a future where monitoring performance becomes seamless, meaningful, and truly impactful for the entire learning community.

The implementation of a system using modern technologies like React for the frontend and Python with SQLAlchemy for the backend ensures efficient data handling, analysis, and visualization. The use of statistical methods and machine learning models further enhances the ability to predict student performance and support informed decision-making. Overall, this study emphasizes the need for a balanced approach between academics and extracurricular involvement and provides a foundation for developing intelligent systems that improve educational outcomes for students and institutions.

6. References

- [1] Romero, C., & Ventura, S. (2010). Educational data mining: A review of the state of the art. *IEEE Transactions on Systems, Man, and Cybernetics, Part C*, 40(6), 601–618.
- [2] Macfadyen, L. P., & Dawson, S. (2012). Making sense of learning analytics indicators in higher education. *Computers & Education*, 54(2), 588–599.

- [3] Baker, R. S., Isotani, S., & Carvalho, A. M. J. B. (2015). Minimizing the number of attributes in educational data mining. *Computers & Education*, 52(2), 292–305.
- [4] Siemens, G., & Long, P. (2016). Penetrating the fog: Analytics in learning and education. *EDUCAUSE Review*, 46(5), 30–40.
- [5] Kotsiantis, S., Pierrakeas, C., & Pintelas, P. (2018). Predicting students' performance in distance learning using machine learning techniques. *Applied Artificial Intelligence*, 18(5), 411–426.
- [6] Hernández-García, Á., & Pérez-López, R. (2022). Learning analytics for student engagement and academic performance. *Journal of Educational Technology & Society*, 25(1), 45–58.
- [7] Zhang, Y., Li, X., & Wang, S. (2023). Deep learning approaches for academic performance prediction and student growth analysis. *International Journal of Artificial Intelligence in Education*, 33(2), 256–272.
- [8] Rao, B. V., “The Influence of Extracurricular Activities in Educational Academic Outcomes”, *International Journal of Applied Research*, 2022.
- [9] Abizada, A., Gurbanova, U., Iskandarova, A., et al., “The Effect of Extracurricular Activities on Academic Performance in Secondary School”, *International Review of Education*, 2023.
- [10] Abizada, A., Gurbanova, U., Iskandarova, A., et al., “The Effect of Extracurricular Activities on Academic Performance in Secondary School”, *International Review of Education*, 2023.



Digitalization of ASHA Worker Application

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Abstract: ASHA workers play a very important role in India's healthcare system, especially in villages and remote areas, where they act as a link between the community and health services. Earlier, most of their work was done using paper records and manual reporting, which often caused problems such as wrong data entries, loss of records, delays in submitting information, and increased workload. With the growth of modern technology, digital systems have become a helpful way to make healthcare work easier, faster, and more reliable. This review paper studies the digital applications that are currently used by ASHA workers and other frontline health staff for activities such as maternal care, child health, immunization tracking, and disease monitoring. It looks at different mobile health applications, government healthcare apps, and digital programs that help improve work efficiency, data accuracy, transparency, and real-time monitoring. The paper also explains the benefits of digital systems, such as better data management and quicker decision-making, along with challenges like poor internet connectivity, lack of training, and technical issues. It also points out areas where improvement is needed in existing systems. Based on this analysis, the study suggests future improvements to create a simple, secure, user-friendly, and integrated digital system that can better support ASHA workers and strengthen public healthcare delivery.

Keywords: ASHA Worker, Digitalization, mHealth, Public Healthcare, e-Governance, Mobile Applications, Rural Healthcare.

1. Introduction

India's healthcare system depends a lot on community health workers to provide basic medical services at the local level. ASHA workers act as a connecting link between hospitals and people living in rural areas. Their duties include taking care of mothers and children, following up on vaccinations, spreading awareness about family planning, monitoring diseases, and reporting health-related data. In the past, most of this work was done using paper registers and manual reports. These manual methods often created problems such as incorrect data, delays in reporting, difficulty in tracking patients, and no real-time updates. As the population increased and healthcare needs grew, the traditional system became slow and less effective. To solve these issues, digital applications were introduced for ASHA workers using mobile phones and web platforms. These digital tools help in collecting data instantly, generating automatic reports, monitoring work performance, and supporting better decision-making. This review paper studies the existing digital systems used by ASHA workers and analyzes how effective they are in improving public healthcare services.

2. Related Work

Many researchers have studied how digital health applications help improve community healthcare services. Mobile health (mHealth) solutions are now commonly used to support frontline health workers by making data collection, record keeping, and service delivery easier and faster. Research findings show that digital applications help improve the accuracy of health data, reduce the workload of health workers, and improve communication between health staff and healthcare authorities. Studies on mHealth platforms also highlight their importance in areas such as maternal and child healthcare, disease monitoring, and vaccination tracking. However, some researchers have pointed out challenges like poor internet connectivity in rural areas, limited digital skills among health workers, and hesitation in using new

technologies. Several government health initiatives have also been reviewed to understand their effectiveness in tracking health indicators and expanding healthcare coverage. Although these systems have produced positive results, many studies suggest that there is a need for a single, integrated digital platform that can manage multiple healthcare services instead of using different applications for different tasks.

3. Methodology

This study is based on reviewing already available information instead of doing new experiments. The main purpose is to understand how ASHA workers use digital applications and how helpful these tools are in improving healthcare services. The information for this study was collected from trusted sources such as research papers, journals, government reports, and official health websites. To find the right information, simple and relevant keywords related to ASHA workers, digital technology, and healthcare were used while searching on online and academic platforms. Only those studies that were clearly related to digital applications used by ASHA workers were selected, while unrelated or outdated studies were not included to keep the research accurate and relevant. All the selected information was carefully read and analyzed to understand how these applications work, what benefits they provide, and what difficulties ASHA workers face while using them in their daily work.

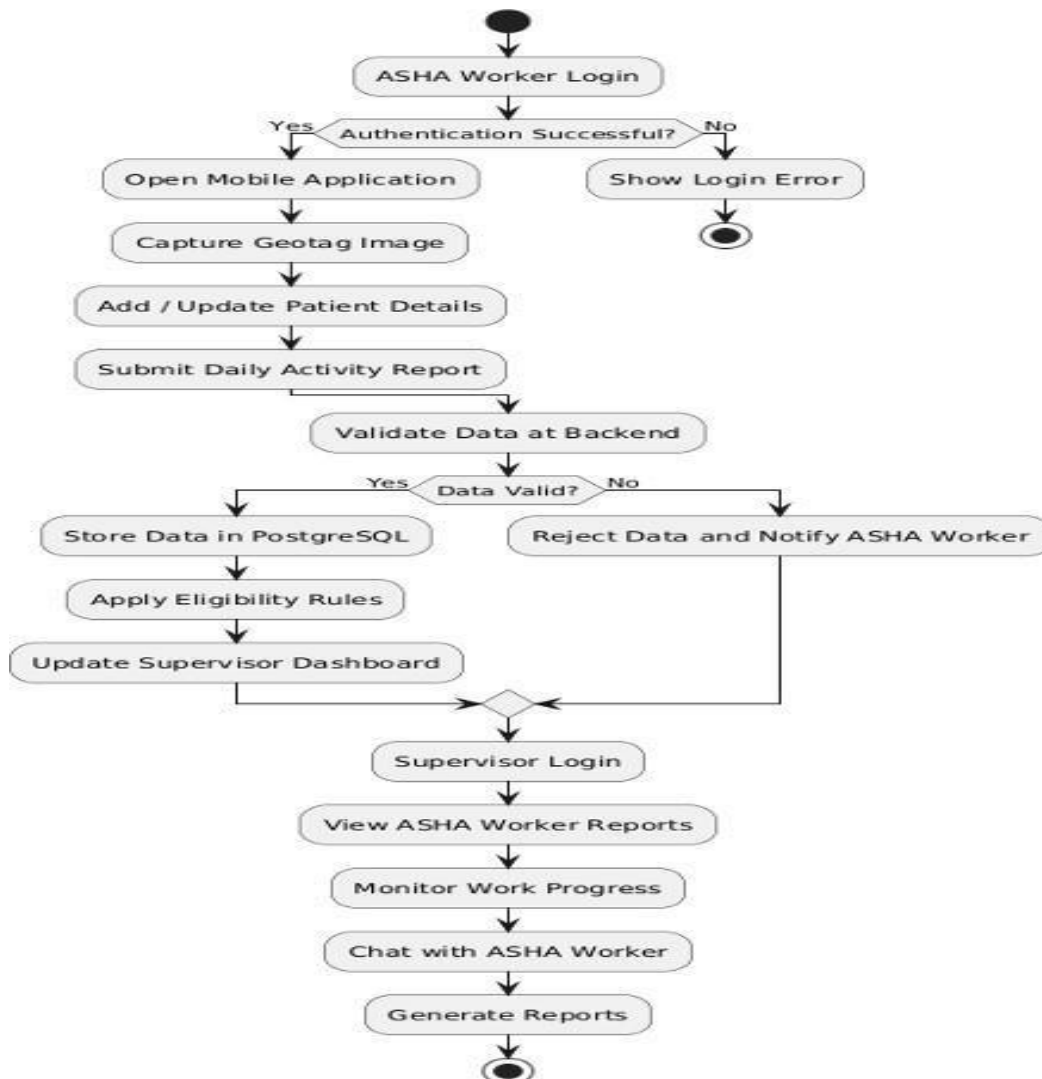
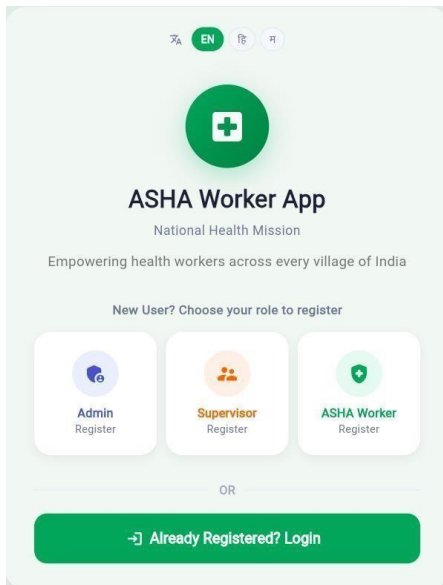


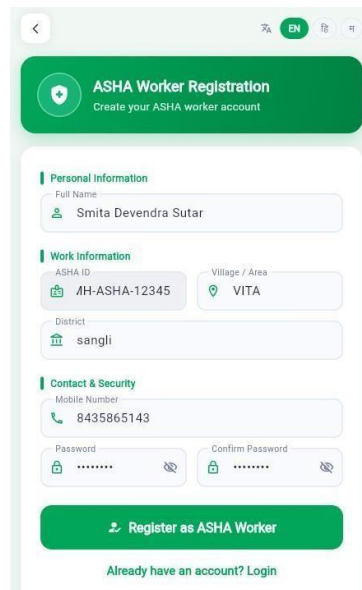
Fig 2 : Flowchart of Application

4. Experimental results

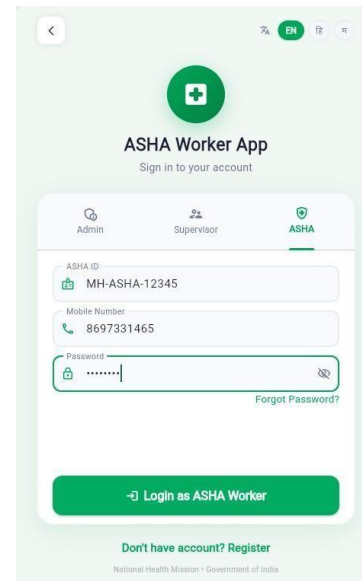
The application developed for this project was tested to check how well it works in real situations. It was found that the app makes it much easier for ASHA workers to enter, store, and access patient information compared to using paper records. Tasks like recording and finding data became faster, which helped save time and made their daily work more efficient. The app also allows quick access to important health information, helping workers make better decisions while working in the field. In addition, digital records reduced the chances of mistakes because the data is more organized. However, some difficulties were noticed, especially for new users who may need basic training to use the app properly. In some rural areas, internet issues also affected the smooth use of the application. Overall, the application proved to be helpful in improving work efficiency and managing healthcare data more effectively.



(a)

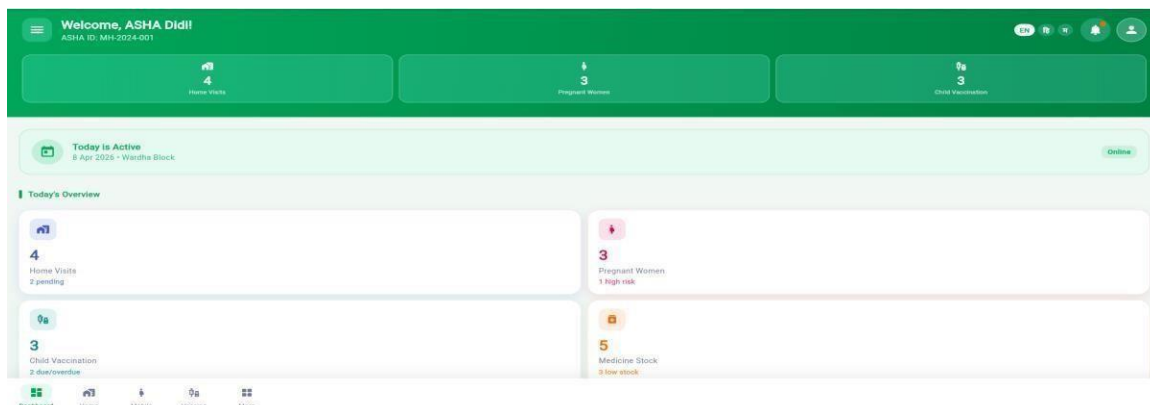


(b)



(c)

Dashboard Page:

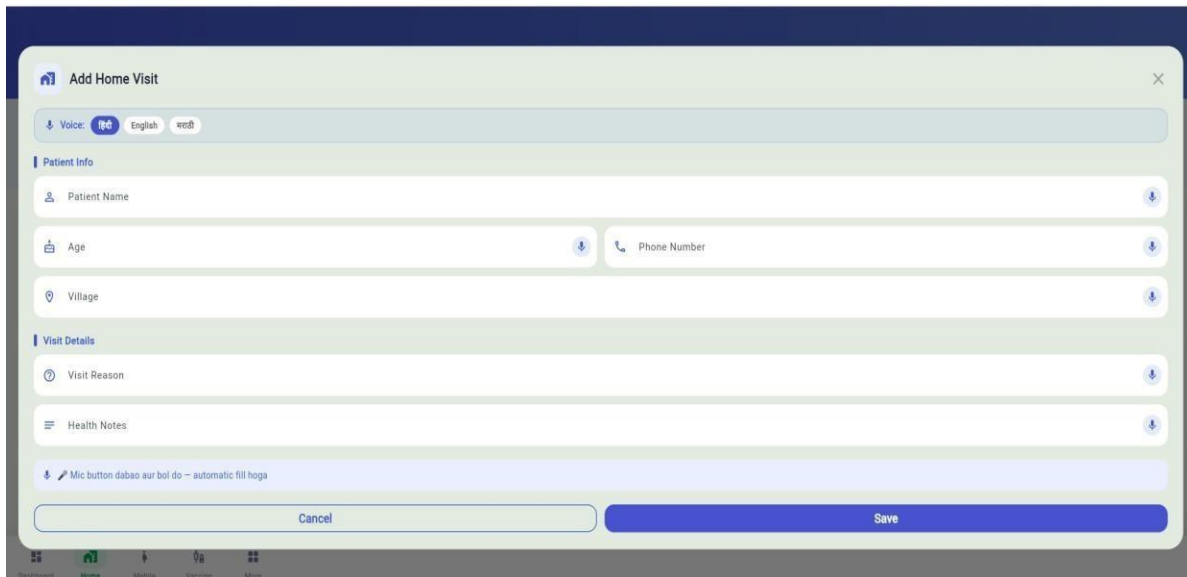


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Home page :

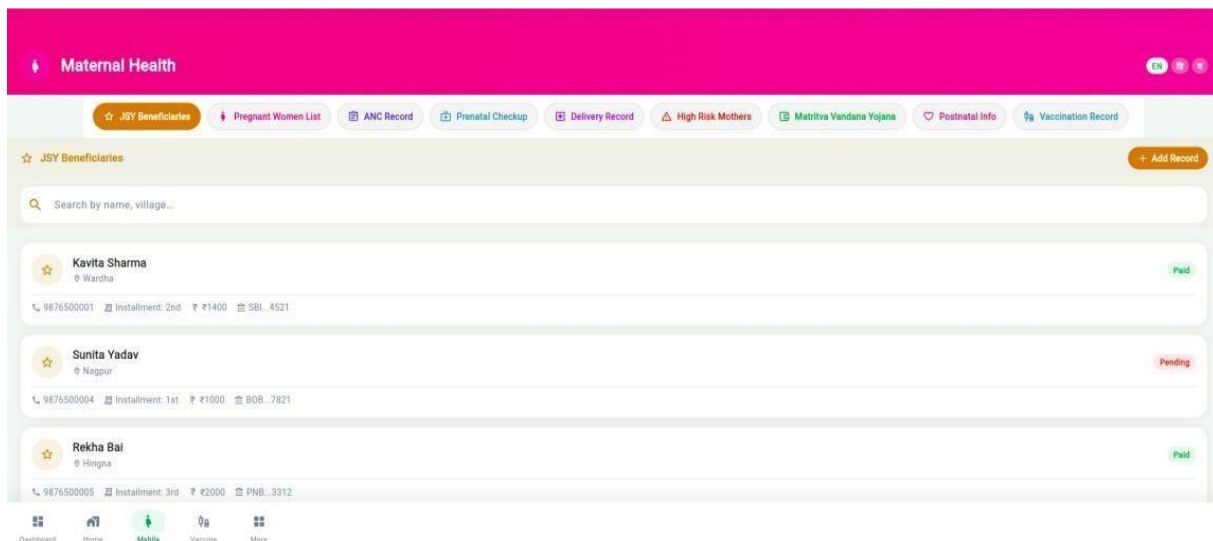


(a)



(b)

Mahila Page :



(a)

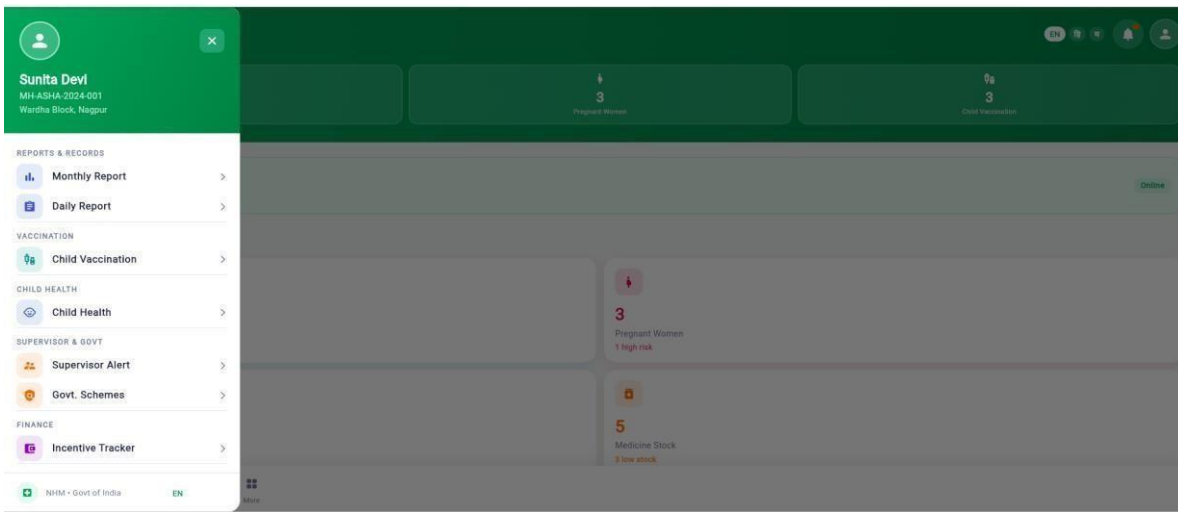
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Vaccination Page:

(a)

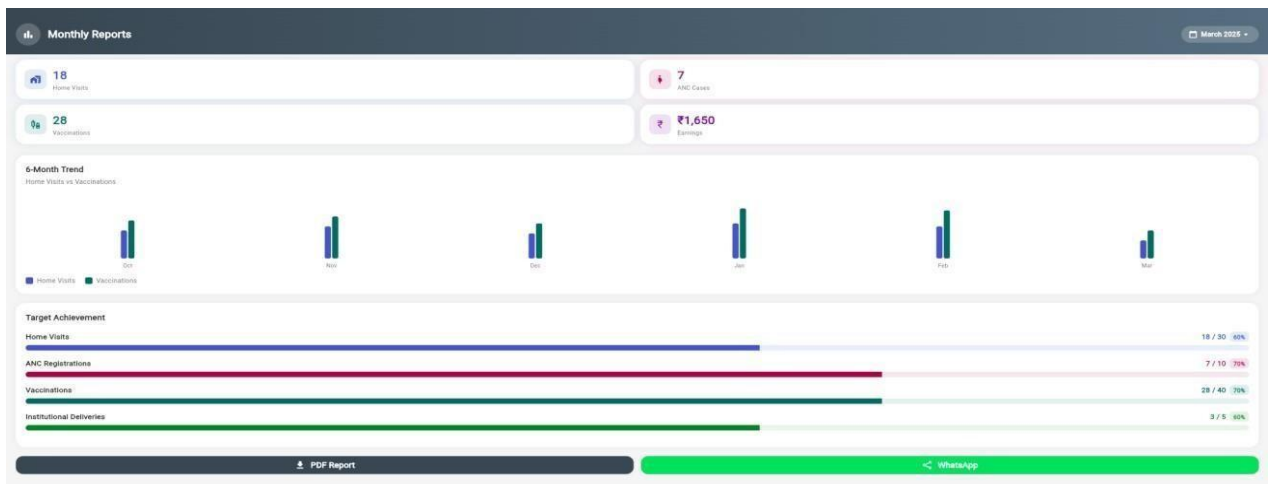
(b)

User Interface Showing Multiple Modules Including Monthly Report, Daily Report, Child Vaccination, Child Health, Supervisor Alerts, Government Schemes, Incentive Tracker, Family Planning, Beneficiary Registration, and Other Features.”



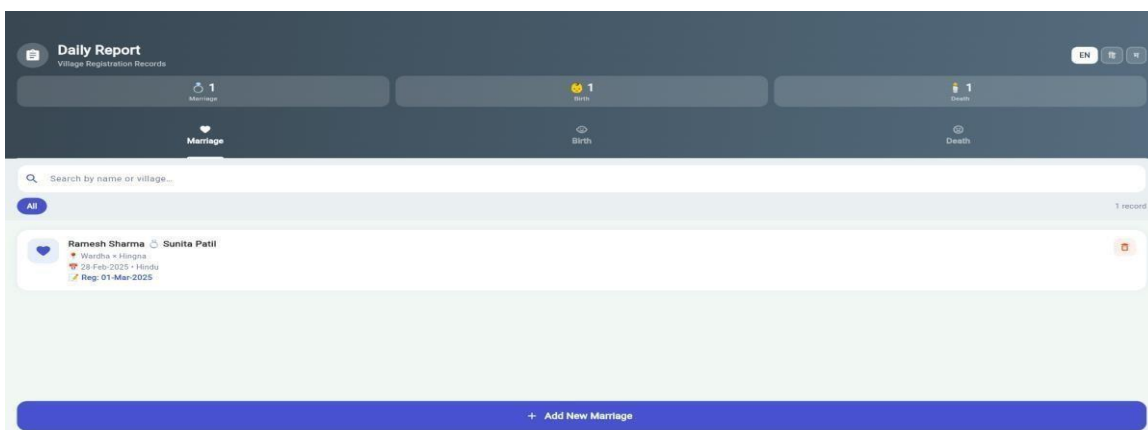
(a)

Monthly Report:



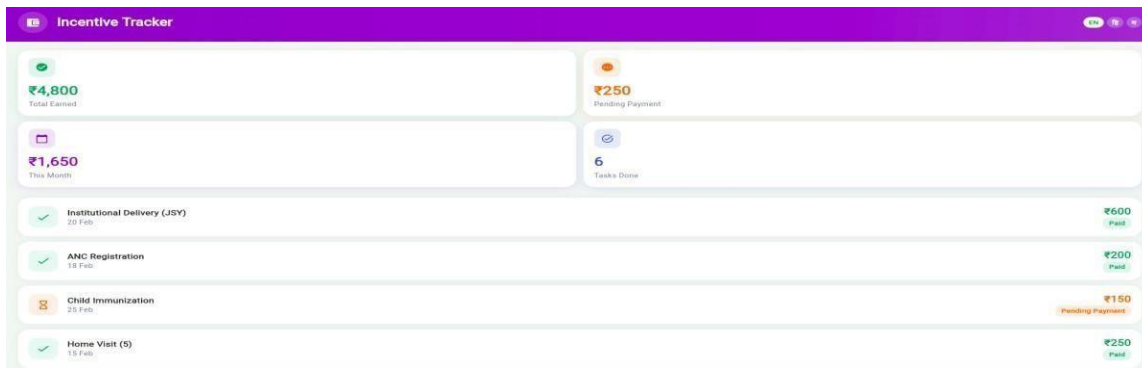
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Daily Report:



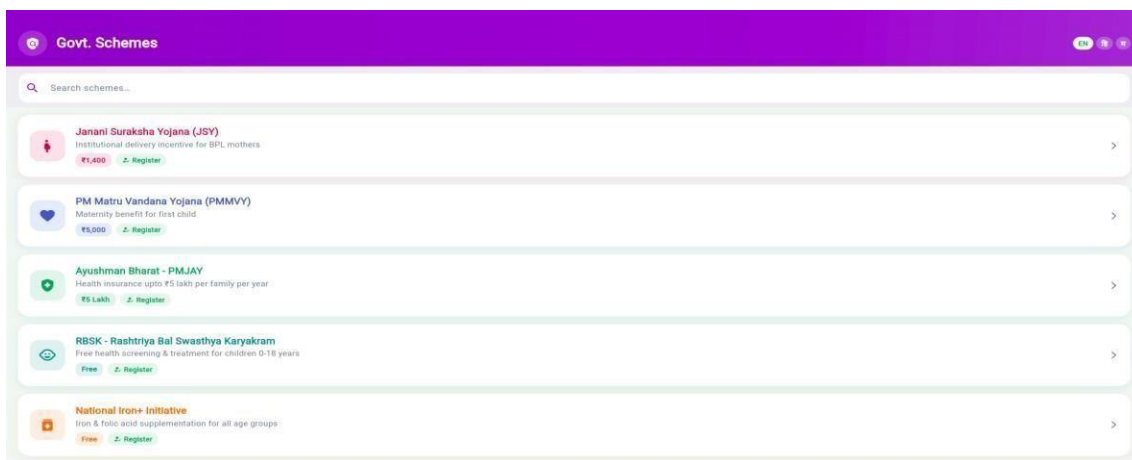
(a)

Incentive Tracker:



(a)

Government Schemes:

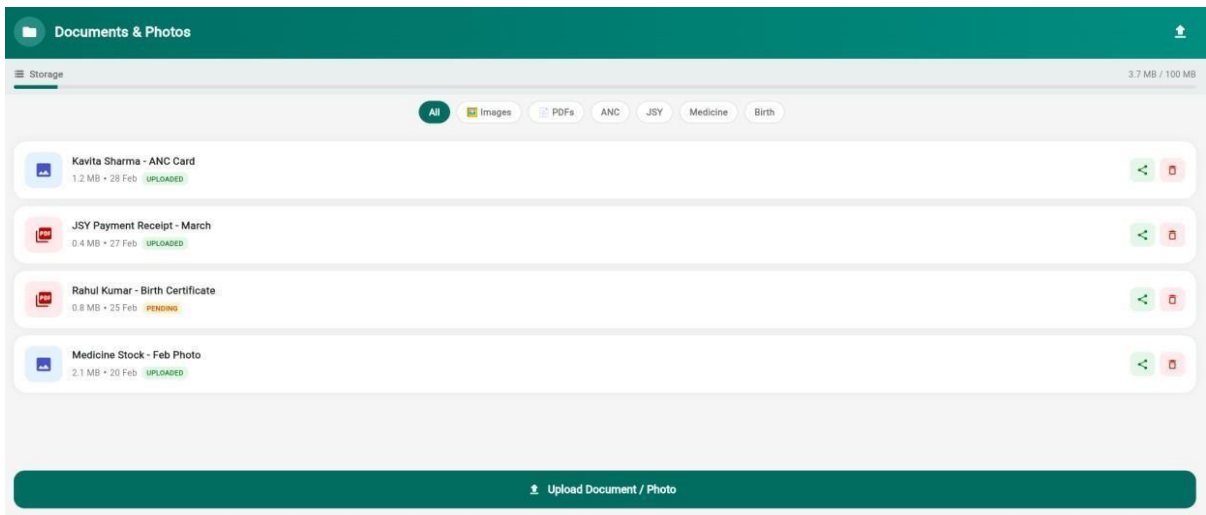


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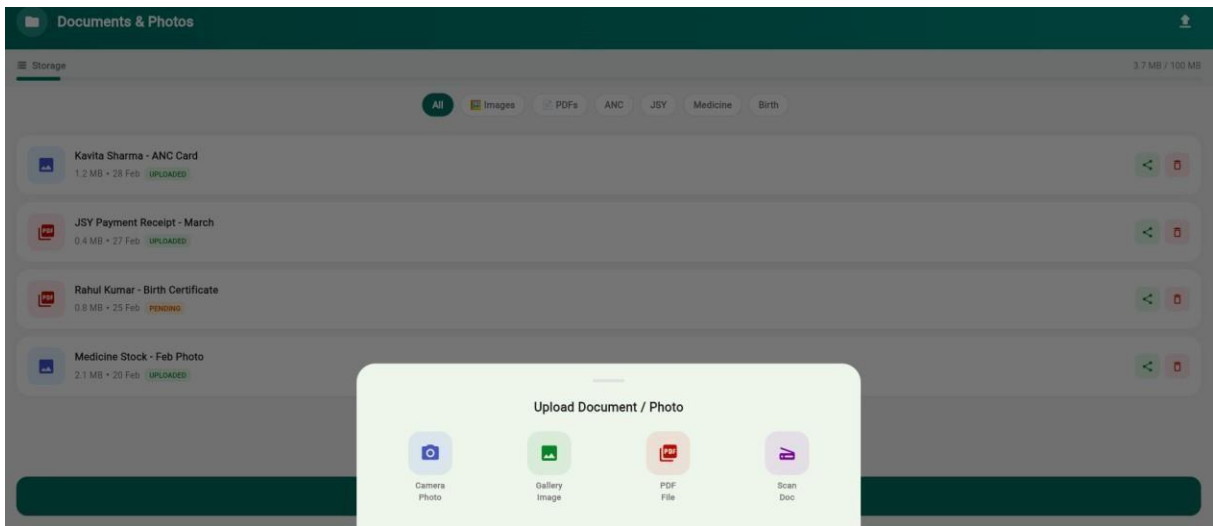


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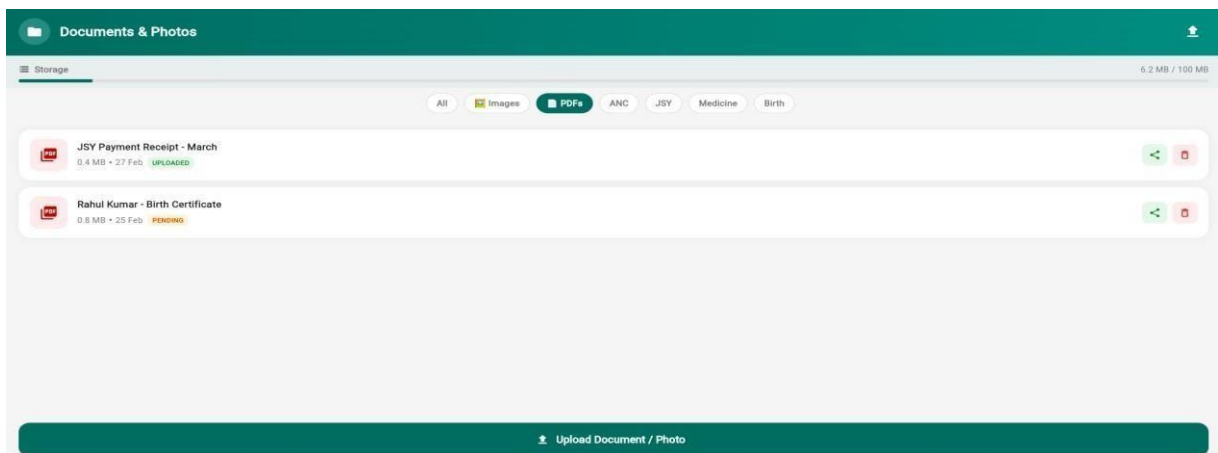
Document's:



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(b)

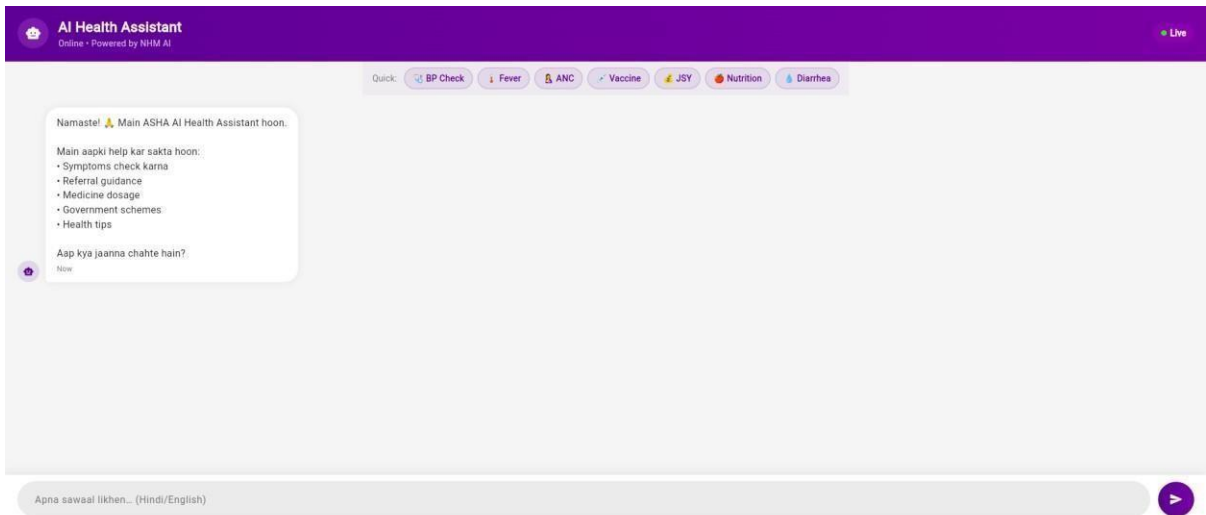


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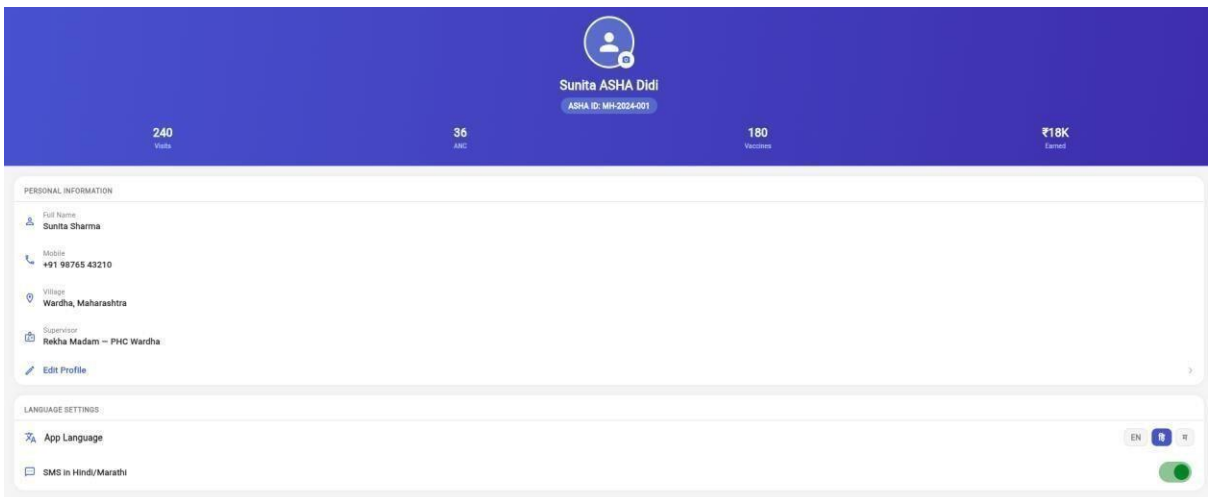
Notification Page:



AI assistant :



Profile page:



(a)



(b)

5. Conclusion

Digitalizing the manual work of ASHA workers helps make rural healthcare services more efficient and dependable. Instead of using paper registers, an online system allows faster and more accurate data entry while improving transparency. Health officers can easily track field activities and access real-time information, which supports quicker decisions and better health planning. This digital approach reduces the workload of ASHA workers and improves coordination between rural communities and the healthcare system. Overall, the system supports the objectives of India's Digital Health Mission and helps create a more organized, transparent, and accessible healthcare environment.

References

- [1] Ministry of Health and Family Welfare, Government of India, "National Rural Health Mission: ASHA Module," 2020.
- [2] S. Sharma, P. Kumar, and R. Singh, "Mobile Health Solutions for Community Health Workers: An mHealth Framework," *International Journal of Health Informatics*, vol. 14, no. 2, pp. 45–52, 2021.
- [3] A. Rao and M. Patil, "Digital Tracking System for Maternal and Child Health: A Study on ASHA Worker Performance," *Journal of Public Health Technology*, vol. 9, no. 1, pp. 66–74, 2022.
- [4] World Health Organization, "mHealth: New Horizons for Health Using Mobile Technologies," WHO Global Observatory for eHealth, 2020.
- [5] P. Verma and S. Jadhav, "AI-Based Decision Support for Rural Health Workers," *International Conference on Smart Healthcare Systems*, pp. 110–118, 2023.
- [6] National Health Mission (NHM), "Mother and Child Tracking System (MCTS) – Guidelines," Government of India, 2021.
- [7] National Informatics Centre (NIC), "ANMOL Application User Manual," 2020.
- [8] K. Desai and A. Mehta, "Evaluation of TeCHO+ Application for Improving Rural Health Services," *Journal of Community Medicine*, vol. 13, no. 4, pp. 233–240, 2022.
- [9] S. Gupta and R. Kulkarni, "Challenges Faced by ASHA Workers in Rural India: A Digital Perspective," *International Journal of Rural Health Studies*, vol. 11, no. 3, pp. 89–98, 2021.
- [10] A. Reddy and T. Joseph, "Offline-Supported Mobile Applications for Low-Connectivity Rural Areas," *IEEE Transactions on Mobile Computing*, vol. 12, no. 7, pp. 522–530, 2022.



Local Experts

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Abstract: This paper presents Local Experts, a web-based platform designed to bridge the gap between local businesses and nearby customers. Traditional methods of discovering local services rely on manual search, personal contacts, or physical visits, which are time-consuming and inefficient. The proposed system provides a centralized digital platform where users can explore nearby services, view product listings, and interact with vendors in real time. The platform integrates location-based search, business listings, communication features, and personalized recommendations to enhance user experience. It also provides tools for business owners such as analytics, promotional offers, and customer feedback mechanisms. The system is developed using modern web technologies, ensuring scalability, responsiveness, and efficiency. The results show improved accessibility, better customer engagement, and increased visibility for small and local businesses, contributing to digital transformation and local economic growth. LocalExperts Platform designed to help users discover, search, and review local businesses across multiple cities in Maharashtra, India. The system addresses the gap in localised, digital business visibility in small and mid-tier cities where traditional online directories are inadequate or absent. We propose the design and implementation of a web-based platform integrating a Node.js and Express.js backend REST API, a MongoDB NoSQL database for flexible and scalable data storage, JSON Web Token (JWT) authentication for secure role-based access, and an intelligent recommendation engine based on a weighted scoring algorithm. The frontend leverages vanilla JavaScript with Leaflet.js for real-time geospatial map visualisation and an SVG-rendered Maharashtra state map for city-level navigation. The platform further integrates LEXI, an AI-powered conversational assistant built on the Claude language model by Anthropic, enabling natural language business search and context-aware recommendation.

Keywords: Local Business Platform, Location-Based Services, Digital Marketplace, Customer Engagement, Small Business Digitization, Chatboat, Web Application.

1. Introduction

In today's digital era, technology plays a vital role in connecting businesses with customers. However, many local businesses still depend on traditional methods such as word-of-mouth, physical visits, and offline advertisements, which limit their reach and growth. Customers also face difficulty in finding reliable services due to scattered and outdated information.

To address these challenges, Local Experts is proposed as a centralized digital platform that connects local businesses with nearby customers. The system enables users to search for services, explore products, and communicate directly with vendors through an easy-to-use interface. By integrating modern web technologies, the platform enhances accessibility, transparency, and user engagement.

The main contribution of this work is to provide a unified, efficient, and scalable solution that supports local businesses in improving their online presence while offering customers a convenient way to discover services.

The main contribution of this work is to provide a unified, efficient, and scalable solution that supports local businesses in improving their online presence while offering customers a convenient way to discover services. The platform introduces LEXI, an AI-powered conversational assistant that accepts natural language queries such as "find a 24-hour pharmacy in Vita" or "best vegetarian restaurant near me" and returns structured results from the live database. LEXI is built using the Anthropic Claude language model, integrated via REST API with a dynamically constructed system prompt that injects live business data at query time, ensuring context-aware and city-specific responses.

2. Related Work

Several studies have focused on the use of digital technologies to support small and medium enterprises (SMEs). Yuwono et al. (2024) highlighted challenges in ICT adoption such as lack of digital skills and infrastructure. Romero and Mammadov (2024) emphasized the importance of digital transformation strategies and organizational support. Mishrif and Khan (2023) showed that SMEs using digital platforms performed better during the COVID-19 pandemic. However, existing systems are often complex, costly, and not suitable for local businesses. Therefore, the proposed system provides a simple, cost-effective, and location-based platform to improve service discovery and connect local businesses with customers.

3. Methodology

The proposed system is a web-based platform designed to connect local businesses with nearby customers using location-based services. The methodology is divided into key stages including data collection, processing, and user interaction. Initially, business data such as name, category, location, and services are collected and stored in a centralized database. The system then processes user queries by applying location-based filtering to identify nearby businesses. Search and categorization techniques are used to provide relevant results to users.

The platform provides a user-friendly interface where customers can explore services, view details, and interact with business owners. Additionally, business owners can register, update their information, and manage their listings. The entire process ensures efficient service discovery, improved accessibility, and better communication between users and local businesses.

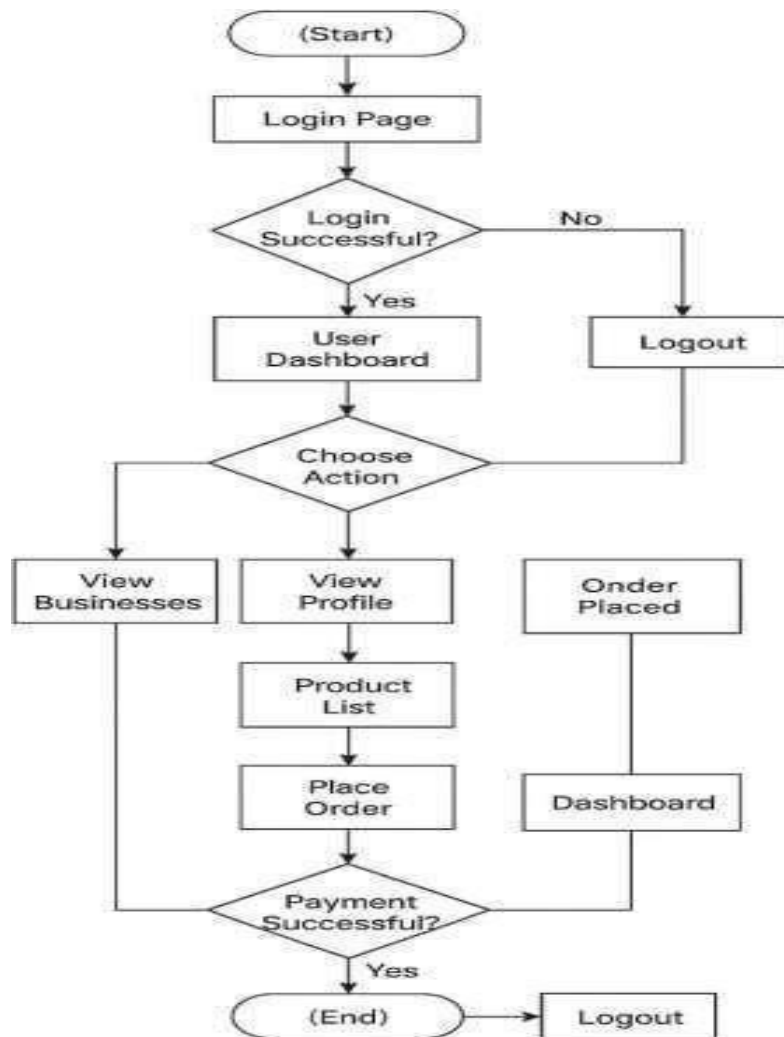
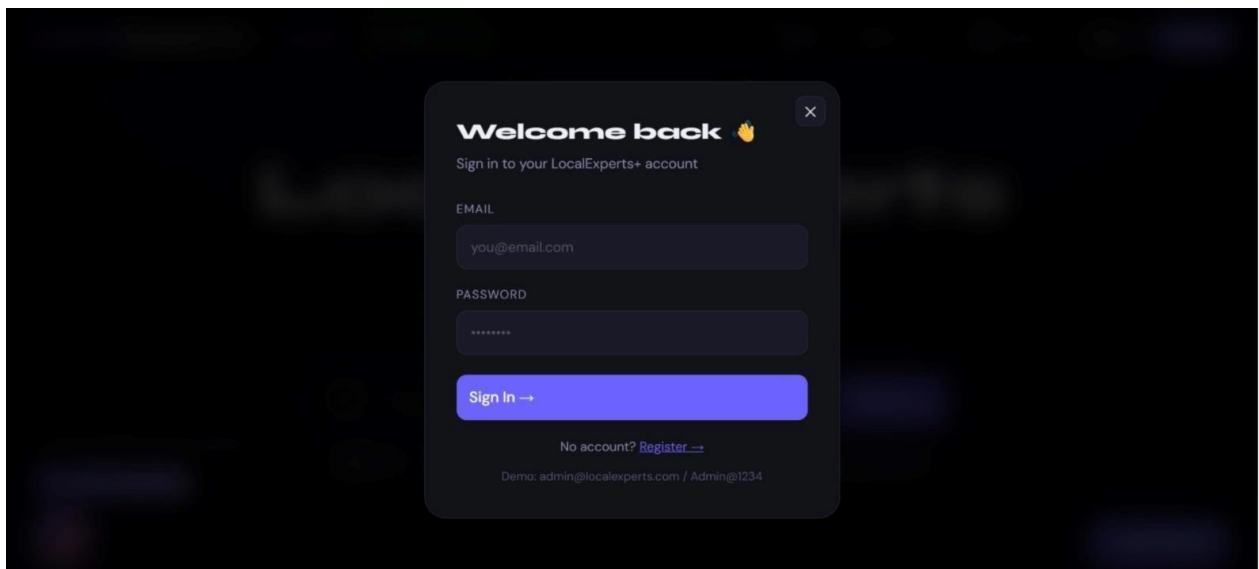


Fig. 1 State Transition Diagram

The system is designed using a modular architecture, where the frontend is developed using HTML, CSS, and JavaScript with a modern glassmorphism UI, while the backend is built using Node.js and Express to handle APIs and data management. Google Maps is integrated for location-based services, and a chatbot with voice recognition is implemented for user interaction. Real-time or simulated data for weather, traffic, and pollution is displayed through a dynamic dashboard. Additionally, a service worker is used to enable offline functionality, ensuring accessibility without internet connectivity. The project is developed, tested, and refined iteratively to ensure performance, scalability, and user-friendly experience, making it suitable for real-world smart city applications.

4. Experimental results

The system is designed using a modular architecture, where the frontend is developed using HTML, CSS, and JavaScript with a modern glassmorphism UI, while the backend is built using Node.js and Express to handle APIs and data management. Google Maps is integrated for location-based services, and a chatbot with voice recognition is implemented for user interaction. Real-time or simulated data for weather, traffic, and pollution is displayed through a dynamic dashboard. Additionally, a service worker is used to enable offline functionality, ensuring accessibility without internet connectivity. The project is developed, tested, and refined iteratively to ensure performance, scalability, and user-friendly experience, making it suitable for real-world smart city applications.



Create Account 🧑🧑

Join LocalExperts+ to save businesses and write reviews

FULL NAME
Your name

EMAIL
you@email.com

PASSWORD
Min 6 characters

YOUR CITY
Select city_

All fields are required

Create Account →

Register Your Business 🏢

List for FREE · Verified within 24 hours

BUSINESS NAME *
e.g. Hotel Mayani

CATEGORY *
Select_


DESCRIPTION *
Describe your business_

CITY *
Select city_

PHONE
9876543210

FULL ADDRESS
Shop No, Street, Area, PIN

WORKING HOURS



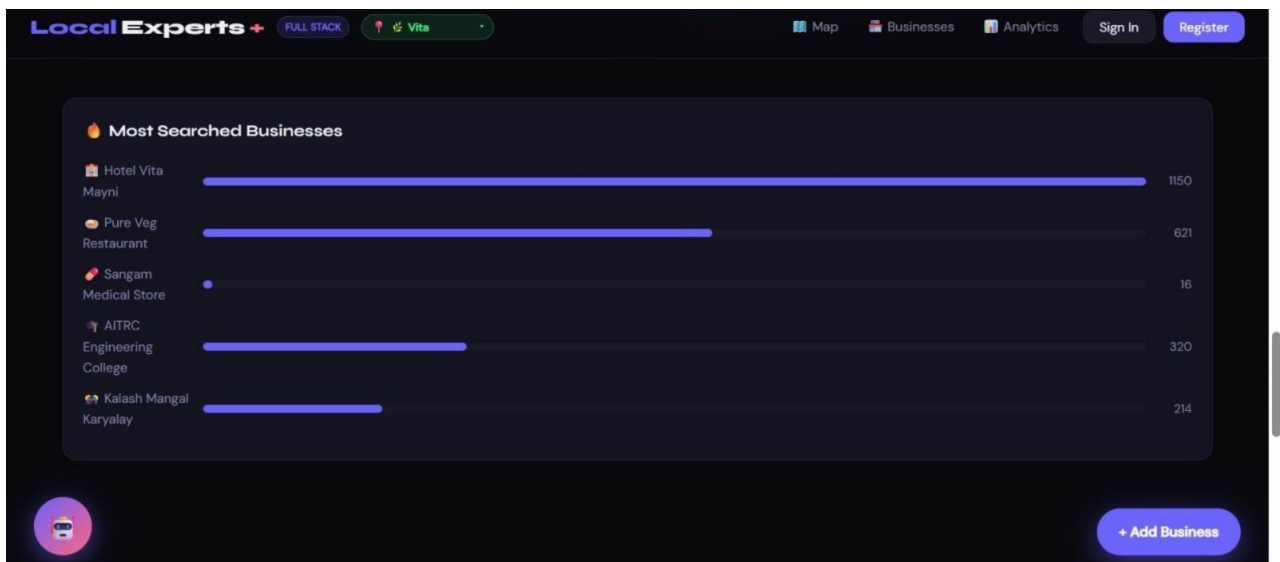
Verified Listing

Hotel Vita Mayni

★ 4.4 (1150 reviews) ● Open Now 📁 Hotels

Top-rated hotel. 4.4 rating with 1,150 reviews.

<p>📍 ADDRESS</p> <p>Vita Mayni Road, Vita City, Sangli - 415311</p>	<p>🕒 HOURS</p> <p>24 hrs</p>
<p>🔑 HIGHLIGHTS</p> <p>WiFi · Best Rating</p>	<p>🛏️ PRODUCTS / SERVICES</p> <p>Deluxe Room ₹800-1000</p>



LEXI – LocalExperts AI
Ask me anything about local businesses

LocalExperts AI Assistant
Online · Powered by Claude AI

CURRENT CITY: Vita, Sangli

QUICK QUESTIONS:

- Best hotels here
- Restaurants open now
- 24-hour medical stores
- Grocery stores nearby
- Schools & colleges
- Surprise me!

Smart Business Search: Ask in plain language — LEXI finds the right match

Multi-City Support: Knows businesses across 10+ Maharashtra cities

Rating-Aware

Demo Mode: Running with built-in business data. Connect to backend for live MongoDB data.

YOU: Hi

LEXI: Hi! I'm LEXI, your local business assistant for Vita, Sangli. Here are the top businesses right now:

- Hotel Lengre Road (Hotels) — ★ 4.6 · ● Open
- General Store Suyog Colony (Grocery) — ★ 4.6 · ● Open
- Sangam Medical Store (Healthcare) — ★ 4.5 · ● Open

Ask me about hotels, food, medical stores, grocery, or education! 😊

Ask about hotels, food, medical stores, education...

Press Enter to send · Shift+Enter for new line · Built with Claude AI for AITRC CSE Final Year Project

5. Conclusion

The system is designed using a modular architecture, where the frontend is developed using HTML, CSS, and JavaScript with a modern glassmorphism UI, while the backend is built using Node.js and Express to handle APIs and data management. Google Maps is integrated for location-based services, and a chatbot with voice recognition is implemented for user interaction. Real-time or simulated data for weather, traffic, and pollution is displayed through a dynamic dashboard. Additionally, a service worker is used to enable offline functionality, ensuring accessibility without internet connectivity. The project is developed, tested, and refined iteratively to ensure performance, scalability, and user-friendly experience, making it suitable for real-world smart city applications.

6. References

- [1] B. Sarwar, G. Karypis, J. Konstan, and J. Riedl, "Item-based collaborative filtering recommendation algorithms," in Proc. 10th Int. Conf. World Wide Web (WWW), Hong Kong, 2001, pp. 285–295, doi: 10.1145/371920.372071.
- [2] M. Lewis, Y. Liu, N. Goyal, M. Ghazvininejad, A. Mohamed, O. Levy, V. Stoyanov, and L. Zettlemoyer, "Retrieval-Augmented Generation for Knowledge-Intensive NLP Tasks," in Proc. NeurIPS 2020, Dec. 2020, pp. 9459–9474.
- [3] V. Agafonkin, "Leaflet: An Open-Source JavaScript Library for Mobile-Friendly Interactive Maps," 2011. [Online]. Available: <https://leafletjs.com>.
- [4] T. Chen, X. Yin, F. Mei, A. Zhou, X. Hu, and Y. Wang, "TAGA: Tag-Aware Generalised Additive Model for Slot Filling in E-Commerce," in Proc. SIGIR, 2014, pp. 711–720.
- [5] Anthropic, "Claude API Documentation — Messages Endpoint," 2024. [Online]. Available: <https://docs.anthropic.com/en/api/messages>.
- [6] MongoDB Inc., "MongoDB Atlas: Multi-Cloud Database Service," 2024. [Online]. Available: <https://www.mongodb.com/atlas>
- [7] M. Fowler, "Patterns of Enterprise Application Architecture," Addison-Wesley Professional, 2002. ISBN: 978-0321127426.
- [8] R. T. Fielding, "Architectural Styles and the Design of Network-based Software Architectures," Ph.D. dissertation, Univ. of California, Irvine, 2000. [Online]. Available: https://www.ics.uci.edu/~fielding/pubs/dissertation/rest_arch_style.htm
- [9] J. Jones, "bcrypt: A Password Hashing Function," Proc. USENIX Annual Technical Conference, 1999.
- [10] M. Jones, J. Bradley, and N. Sakimura, "JSON Web Token (JWT)," RFC 7519, May 2015. [Online]. Available: <https://tools.ietf.org/html/rfc7519>.



AI Powered Interview Practice Bot

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Abstract: In the current competitive job market, effective interview preparation is essential for candidate success. However, traditional preparation methods often lack real-time, objective feedback on behavioral and emotional aspects of performance. This paper presents an intelligent Interview Practice Bot integrated with camera access and an emotion-based rating system. The proposed system leverages computer vision and machine learning techniques to capture and analyze facial expressions such as confidence, nervousness, and engagement during mock interview sessions. A real-time video feed is processed using facial detection and emotion recognition algorithms to extract meaningful behavioral insights. These insights are further mapped to performance metrics, enabling the system to generate automated ratings and personalized feedback. The platform provides a simulated interview environment that enhances user confidence and communication skills through continuous evaluation. Experimental results demonstrate that the system effectively identifies user emotions and offers constructive feedback, contributing to improved interview readiness. The proposed solution has potential applications in career development, training platforms, and recruitment assistance systems.

Keywords: Interview Practice Bot, Emotion Detection, Facial Expression Analysis, Computer Vision, Machine Learning, Real-Time Video Processing, Performance Evaluation, Artificial Intelligence

1. Introduction

Interviews play a crucial role in career opportunities, but many candidates struggle due to lack of confidence, nervousness, and insufficient practice. Traditional methods do not provide real-time feedback on behavioral and emotional aspects. This paper presents an Interview Practice Bot with camera access and emotion-based rating, which captures and analyzes facial expressions such as confidence, nervousness, and engagement. Using computer vision and machine learning techniques, the system generates real-time scores and actionable feedback, enabling users to improve their communication skills and overall interview performance. The platform simulates real interview scenarios, helping users gain confidence and prepare effectively.

2. Related Work

The proposed Interview Practice Bot is highly relevant in today's competitive job market, where effective interview preparation can determine career opportunities. Traditional preparation methods, such as mock interviews with peers or self-practice, lack objective evaluation and real-time feedback, particularly on non-verbal behaviors like facial expressions, nervousness, and engagement. This system leverages computer vision and machine learning to provide

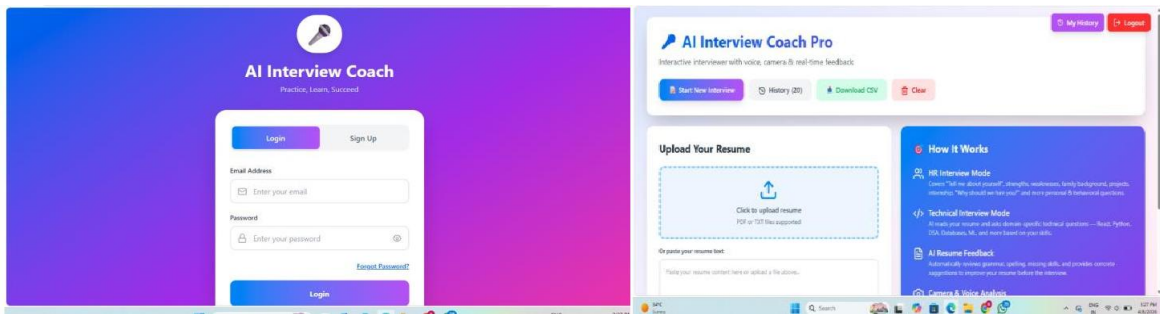
automated, emotion-based feedback, enabling users to identify weaknesses, track progress over time, and improve overall communication skills. It is applicable not only for students and job seekers but also for professional training platforms, HR departments, and career coaching services. By simulating realistic interview scenarios and providing actionable insights, this work ensures that candidates are better prepared, more confident, and capable of performing effectively in real interviews.

3. Methodology

The Interview Practice Bot captures real-time video using a camera and applies facial detection to identify the user’s face. Key facial landmarks such as eyes, eyebrows, nose, and mouth are extracted and analyzed using a trained machine learning model to classify emotions like confidence, nervousness, and engagement. The detected emotions are mapped to quantitative performance metrics, which are aggregated to generate an overall interview score. The system then provides actionable feedback to help users improve their communication skills, reduce nervousness, and enhance overall interview performance. Multiple sessions allow users to track progress and improve continuously.

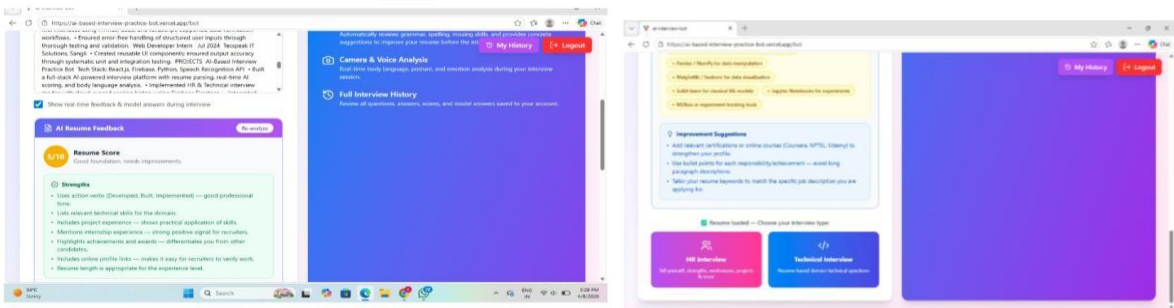
4. Experimental results

Figures shows the results of text detection from an image and inpainting by using exemplar based Inpainting algorithm. Figs. (a) login with email Adress. (b) upload resume or paste your resume text.(c)analysing resume(d)resume loaded choose your interview technical or HR.(E) live interview session (f) conduct interview with camera access capture emotions (g) interview history and feedback (h) rating your answer (i) body language analysis posture,eye contact,confidance etc.(j) give model answer (k) use firebase for storing history.



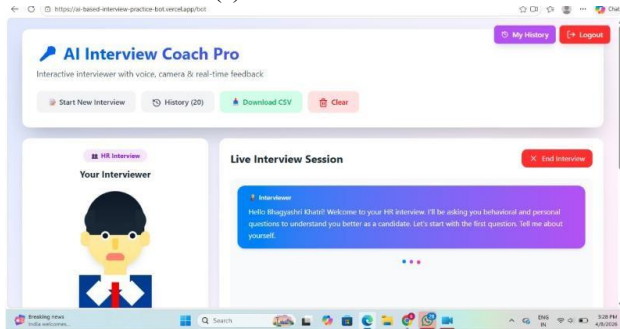
(A)

(B)

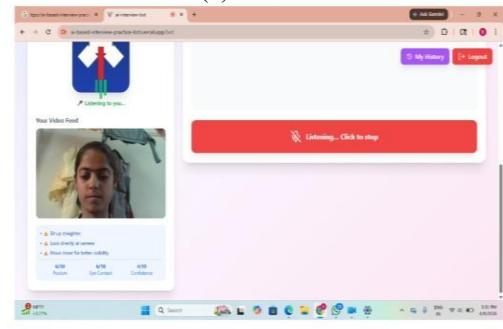


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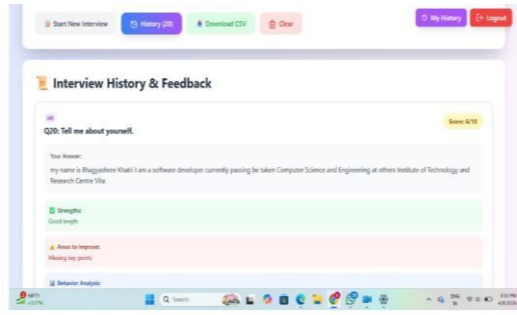
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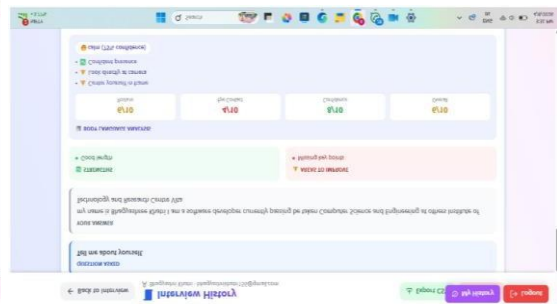
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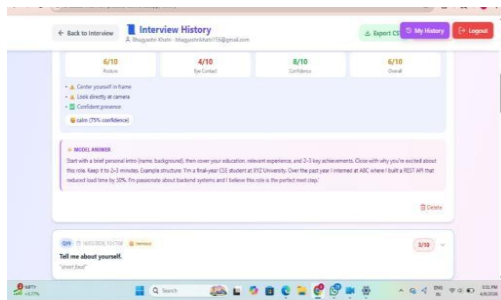
(F)



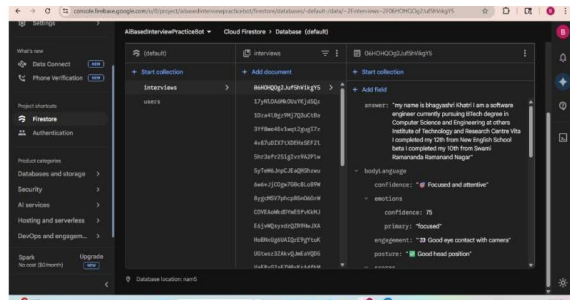
(h)



(i)



(j)



(k)

Table No.1 Text Detection and Inpainting

Sr. No	User	Confidence (%)	Nervousness (%)	Overall Score	Remarks
1	User 1	85	10	8.5	Good performance
2	User 2	70	20	7.0	Needs improvement
3	User 3	60	30	6.0	Practice recommended
4	User 4	90	5	9.0	Excellent performance

5. Conclusion

The proposed Interview Practice Bot provides an effective solution for real-time interview training by analyzing facial expressions and emotions. It offers automated feedback and performance ratings, helping users improve confidence, engagement, and overall communication skills. Experimental results show that the system accurately detects emotions and provides actionable insights, making it a valuable tool for students, job seekers, and training platforms.

References

- [1] Y. Zhang, Y. Tian, and J. Liu, “Real-Time Facial Emotion Recognition Using Convolutional Neural Networks,” *IEEE Transactions on Affective Computing*, vol. 11, no. 3, pp. 435–446, 2020.
- [2] H. Li and J. Chen, “Automated Interview Behavior Analysis via Facial Feature Extraction,” *International Journal of Computer Vision*, vol. 127, no. 5, pp. 1254–1266, 2019.
- [3] R. Kumar, A. Singh, and P. Sharma, “AI-Powered Interview Simulator for Candidate Assessment,” *IEEE Access*, vol. 9, pp. 145678–145688, 2021.
- [4] A. Singh, R. Verma, and S. Gupta, “Hybrid Framework for Non-Verbal and Verbal Interview Evaluation,” *Journal of Artificial Intelligence Research*, vol. 71, pp. 85–102, 2022.

- [5] M. Bartlett, G. Littlewort, I. Fasel, and J. Movellan, "Real Time Face Detection and Facial Expression Recognition: Development and Applications," *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, pp. 53–60, 2003.
- [6] F. C. Bartlett, G. Littlewort, M. Frank, and R. Reilly, "Automatic Recognition of Facial Actions in Spontaneous Expressions," *Journal of Multimedia Tools and Applications*, vol. 44, pp. 17–30, 2009.
- [7] P. Ekman and W. V. Friesen, *Facial Action Coding System: The Manual*, Palo Alto: Consulting Psychologists Press, 1978.
- [8] O. M. Parkhi, A. Vedaldi, and A. Zisserman, "Deep Face Recognition," *British Machine Vision Conference*, pp. 41.1–41.12, 2015.
- [9] M. Liu and L. Yin, "A Review of Automatic Facial Expression Recognition Systems," *IEEE Transactions on Affective Computing*, vol. 14, no. 2, pp. 113–129, 2023.
- [10] J. Kossaifi, Y. Panagakis, M. Pantic, and A. Tzimiropoulos, "Efficient Emotion Recognition via Tensor Representation of Facial Landmarks," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 44, no. 3, pp. 1231–1243, 2022.



LeafAlert

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Abstract: The LeafAlert project focuses on creating an autonomous rover designed for the real-time detection of crop leaf diseases. We propose the design and implementation of LeafAlert, an autonomous, mobile robotic platform engineered for the real-time, non-invasive detection and accurate classification of common agricultural leaf diseases. The primary objective is to mitigate pre-harvest crop losses and optimize resource utilization by providing pre-emptive diagnostic insights into prevalent infections, including various forms of blight, rust, mildew, and leaf spot, thereby enabling proactive crop management. The system architecture integrates a spatially aware, six-wheeled rover utilizing ultrasonic ranging sensors for localized navigation and obstacle avoidance. Visual data acquisition is performed by an embedded Raspberry Pi camera module linked to a high-performance single-board computer, which serves as the processing unit. Disease classification is achieved through real-time inferencing using a customized Convolutional Neural Network (CNN) architecture rigorously trained for high-fidelity categorization of foliar symptoms. The methodological approach encompasses robust hardware integration, systematic collection and augmentation of a plant disease dataset, deep learning model optimization, and subsequent real-time deployment on the embedded system for comprehensive field validation. The significance of this research resides in delivering a cost-effective, scalable, and fully autonomous solution that fundamentally streamlines human-intensive crop monitoring processes. By demonstrating the synergistic capabilities of robotics, embedded systems, and machine learning, the LeafAlert system provides a measurable contribution toward advancing the paradigm of precision agriculture and fostering global food security.

Keywords: Autonomous Rover, Convolutional Neural Network (CNN), Computer Vision, Embedded Systems, Leaf Disease Detection

1. Introduction

An intelligent plant-monitoring system designed to support modern farming through automation and real-time disease detection. Traditional plant inspection methods require farmers to manually check each plant, which is slow, labor-intensive, and often inaccurate. Many early disease symptoms go unnoticed, leading to reduced crop yield and increased losses. To overcome these challenges, LeafAlert provides an automated and efficient alternative. The system uses a Raspberry Pi-based rover equipped with a camera module and a trained machine learning model to analyse leaf images as it moves autonomously across crop fields.

By examining features such as texture, color, and patterns, LeafAlert can classify leaves as healthy or diseased with high accuracy. The results are displayed instantly on a user-friendly application, helping farmers monitor crop health without constant physical inspection. LeafAlert also includes obstacle-avoidance features to ensure smooth navigation in outdoor environments. By combining robotics, image processing, and machine learning, the system reduces human effort, improves detection accuracy, and supports timely decision-making. This chapter highlights the importance of automated plant monitoring and introduces LeafAlert as a practical solution for promoting smart and sustainable agriculture. The system integrates hardware components such as the Raspberry Pi, camera module, and sensors with intelligent software for disease detection. A user-friendly application is developed to display results and support

continuous field monitoring. Through this project, we aim to enhance disease detection accuracy, reduce manual inspection efforts, and promote efficient smart-farming practices.

2. Related Work

Rise of digital technologies and machine learning, automated detection of leaf diseases using image processing has become a promising solution. Researchers have employed various approaches such as Gabor wavelet transforms, fuzzy-based segmentation, and neural networks for disease identification. Support Vector Machines (SVM), Fuzzy ARTMAP, and CNN models have shown impressive accuracy in classifying diseases like blight, mildew, rust, and scab. Mobile and cloud-based platforms have further enhanced accessibility for farmers. Techniques like K-means clustering and thresholding are also widely used for the segmentation of diseased leaf areas. Neural network-based systems have achieved accuracies up to 97%, demonstrating the feasibility of automated diagnosis.

Deep learning and computer vision techniques provide an efficient, scalable, and affordable alternative for identifying plant diseases directly from leaf images. Previous research using CNNs, SVMs, and other models has shown promising accuracy in recognizing multiple crop diseases. This study explores advanced deep learning architectures to enhance detection precision while minimizing hardware requirements. The proposed approach aims to make disease identification faster, more affordable, and suitable for field-level deployment. The outcome of this work supports smart farming and promotes sustainable agricultural practices. The remaining sections of this paper cover related work, materials and methods, results, and conclusion.

Recent advances in deep learning (DL), especially Convolutional Neural Networks (CNNs), have revolutionized plant disease detection by enabling automatic feature extraction and end-to-end classification. Studies by Mohanty et al., Ma et al., and Kawasaki et al. demonstrated CNN-based accuracies up to 99%. Despite these successes, the limited availability of large, diverse plant image datasets remains a challenge. Transfer learning using pre-trained CNN models, such as

Recent advances in deep learning (DL), especially Convolutional Neural Networks (CNNs), have revolutionized plant disease detection by enabling automatic feature extraction and end-to-end classification. Studies by Mohanty et al., Ma et al., and Kawasaki et al. demonstrated CNN-based accuracies up to 99%. Despite these successes, limited availability of large, diverse plant image datasets remains a challenge. Leaf-based Phyto pathological conditions are primarily caused by biotic agents such as bacteria, fungi, and algae, influenced by environmental factors like temperature and moisture. With advancements in artificial intelligence (AI), machine learning (ML), and deep learning (DL), automated plant disease detection has become faster and more accurate, reducing human dependency. Among these, Convolutional Neural Networks (CNNs) are the most efficient for image-based recognition, capable of automatically extracting visual features with high precision. Similarly, Artificial Neural Networks (ANNs) mimic human brain learning to identify complex data patterns.

3. Methodology

The LeafAlert system follows a layered architecture that combines IoT-based sensing, machine learning analysis, and cloud integration to ensure efficient plant disease detection. The IoT layer collects real-time environmental and image data using sensors, Raspberry Pi, and camera modules. The ML layer processes these inputs through trained deep-learning models to identify diseases with high accuracy. A cloud-based communication layer uses MQTT and REST APIs to deliver alerts, reports, and insights to the user's mobile application. This model ensures scalability, reliability, and seamless interaction between hardware, software, and end users. The Android application acts as the user interface layer, allowing farmers to monitor plant health, receive alerts, and view historical analysis data. All system components are modular, enabling easy upgrades to sensors, algorithms, or UI features without affecting the entire architecture. The use of edge computing ensures that initial processing happens on the device itself, reducing latency and enhancing performance in remote areas. Cloud integration enables secure data storage and remote access, ensuring that users can retrieve insights anytime. Overall, this combined model ensures a robust, scalable, and intelligent disease detection system tailored for agricultural environments.

The UI/UX design focuses on building an intuitive mobile application that delivers alerts, disease reports, and live rover monitoring in a clear and user-friendly format. The backend design includes integrating machine learning models, sensor data processing, and communication protocols like MQTT for real-time updates. Throughout development, an iterative and modular approach is followed, enabling continuous testing, improvement, and seamless integration of hardware and software components. This structured methodology ensures the LeafAlert system remains accurate, scalable, and easy to use in real-world agricultural environments. Fig (1) represents the workflow of the admin module in the system. It starts with the login process, where successful authentication leads to the admin dashboard, while failure redirects back to the login page. From the dashboard, the admin can perform operations such as adding diseases, updating remedy information, deleting records, and viewing reports. After completing the tasks, the admin logs out, which marks the end of the process.

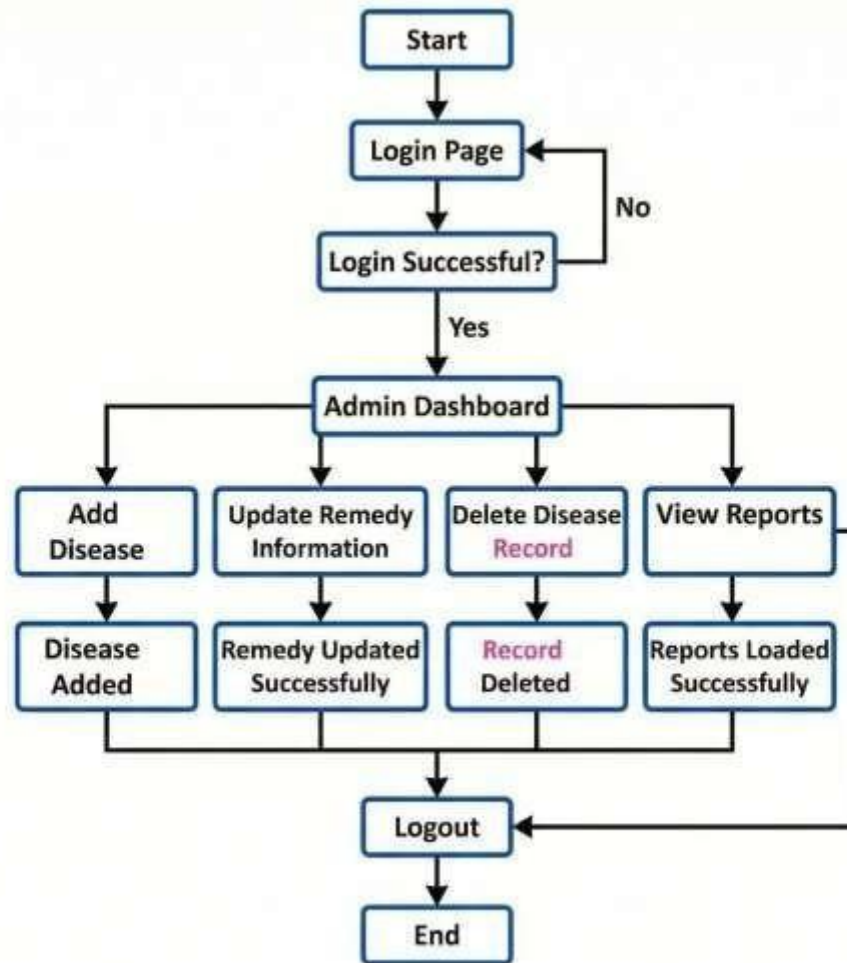
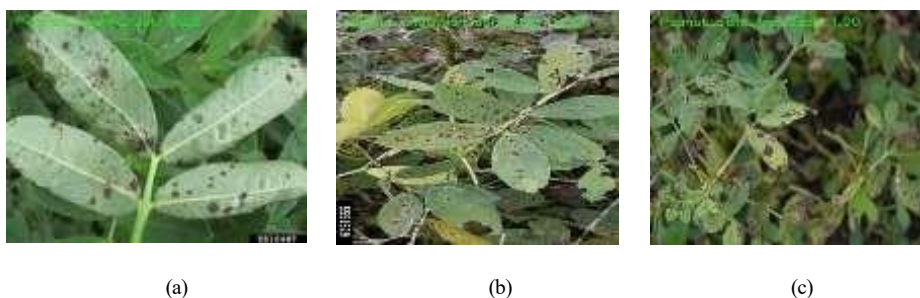


Fig. 1 State Transition Diagram

By integrating machine learning, sensor-based monitoring, and real-time communication technologies, the design ensures reliable performance in real agricultural environments. The structured approach from understanding field requirements to planning hardware software integration the foundation for a robust and scalable solution. With a strong focus on usability, the system ensures that farmers and users receive timely insights through an intuitive interface. This methodology bridges the gap between modern technology and practical farming needs. As the project moves toward implementation, the outlined design will guide the creation of a powerful tool that enhances crop health monitoring and supports smarter agricultural practices.

4. Experimental results

The output of the LeafAlert system demonstrates real-time analysis. In fig. (2) peanut plant, where the captured leaf image is processed using the trained CNN model. The system accurately identifies common diseases such as early leaf spot and late leaf spot based on visible symptoms on the leaves. In addition, it can detect nutrient deficiencies by analyzing discoloration patterns and leaf texture. The results are displayed instantly, providing clear disease classification along with relevant insights. This enables farmers to take timely and effective action for crop protection and improved yield.





(d)

(e)

Fig. 3 The system analyses the potato plant leaf in real time and accurately detects diseases such as early blight and late blight based on visual symptoms. The predicted result is displayed instantly, helping in quick identification and timely treatment.



(a)

(b)

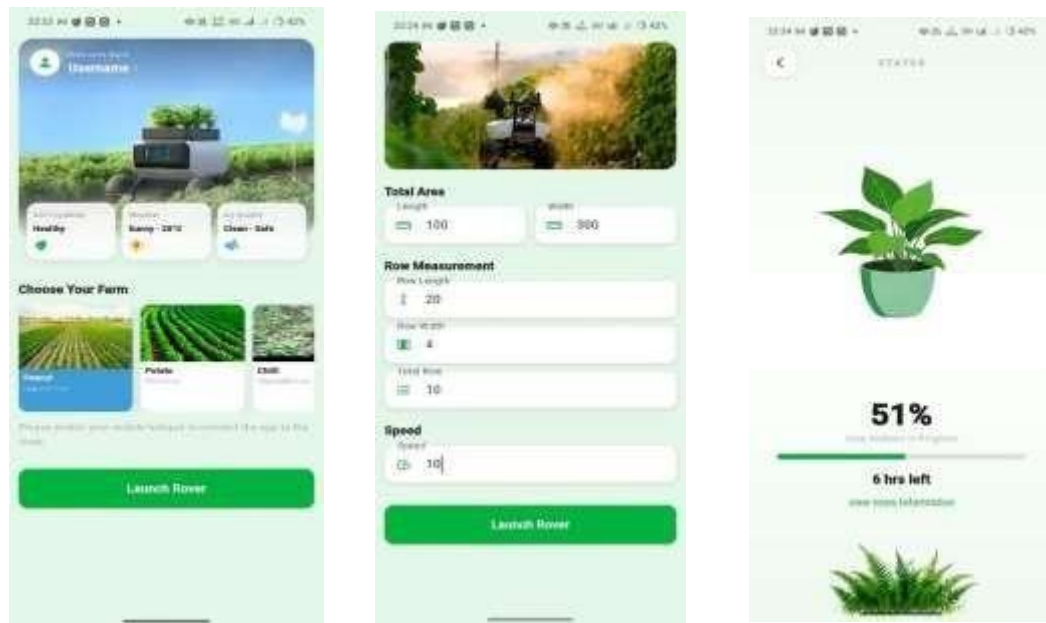
(c)



(d)

(e)

Fig. 4 The mobile application UI provides a user-friendly interface for monitoring plant health and viewing disease detection results in real time. It displays predicted disease information and relevant insights in a clear and organized manner.



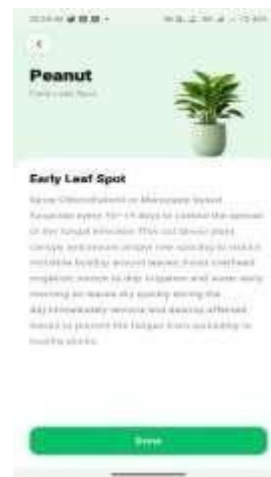
(a)

(b)

(c)



(d)



(e)

5. Conclusion

Wrapping up, our rover-based crop monitoring system represents a significant step toward transforming traditional farming into a more intelligent and efficient process. By integrating robotics, machine learning, and real-time image analysis, we aim to support farmers with accurate insights into crop health and early disease detection. Our system improves field monitoring, reduces manual effort, and ensures timely decision-making for better yield outcomes. More than just a technological solution, it is a practical companion for farmers working in dynamic and challenging conditions. As we continue to refine the rover's design, detection accuracy, and mobile application features, the system will become even more reliable and user-friendly. We envision this project evolving into a comprehensive precision farming tool that empowers farmers and contributes to sustainable agriculture for the future.

References

- [1] G. Shrestha, D. Deepsikha, and M. Das, "Plant Disease Detection Using CNN," Proc. 2020 IEEE Applied Signal Processing Conference (ASPCON), Kolkata, India, Dec. 2020, pp.109–113,doi:[Notavailable].ISBN:978-1-7281-6882-1.
- [2] E. Hirani, V. Magotra, J. Jain, and P. Bide, "Plant Disease Detection Using Deep Learning," Proc. 2021 6th International Conference for Convergence in Technology (I2CT), Pune, India, Apr. 2021, pp. 1–4, doi: [Not available]. ISBN: 978-1-7281-8876-8.
- [3] N. Khirade and A. Patil, "Plant Disease Detection and Classification Using Image Processing and Machine Learning," Proc. 2015 International Conference on Computing Communication Control and Automation (ICCUBEA), Pune, India, Feb. 2015, pp. 768– 771, doi: 10.1109/ICCUBEA.2015.153. ISBN: 978-1-4799-6892-3.
- [4] I. Ahmed and P. K. Yadav, "A systematic analysis of machine learning and deep learning-based approaches for identifying and diagnosing plant diseases," Sustainable Operations and Computers, vol. 4, pp. 96–104, 2023, doi: 10.1016/j.susoc.2023.03.001.
- [5] Ahmed I & Yadav P K (2023). A systematic analysis of machine learning and deep learning-based approaches for identifying and diagnosing plant diseases. Sustainable Operations and Computers 4: 96-104. doi.org/10.1016/j.susoc.2023.03.001.



E-Jewellers

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Abstract: The E-Jewellers is a comprehensive, technology-driven digital platform designed to transform the traditional jewellery shopping experience into a secure, efficient, and user-friendly online environment. The system integrates modern web technologies to provide customers with seamless access to a wide range of gold, silver, diamond, and customized jewellery products. Core features such as real-time product browsing, advanced search and filtering, secure user authentication, digital payments, order tracking, and customer relationship management ensure a smooth end-to-end shopping journey. The platform also incorporates specialized modules including Gold Finance, EMI options, Digital Locker for Jewellery, and Inventory & Supplier Management, making it suitable for both retail customers and jewellery business administrators. Overall, the E-Jewellers website mega project provides a modern, scalable, and feature-rich digital solution for jewellery businesses aiming to expand their online presence. It enhances operational efficiency, improves customer engagement, and delivers a trustworthy digital marketplace that aligns with current industry standards and user expectations.

1. Introduction

This chapter introduces the design and development of the E-Jewellers Platform, an integrated digital system that enables users to browse, customize, and purchase jewellery online with enhanced convenience and automation. The platform provides a seamless user experience starting from registration and dashboard navigation to jewellery selection, customization, and financing options. It incorporates features such as jewellery browsing, uploading custom ornament designs, AI-based similar design suggestions, and flexible payment options including UPI, payment gateway, and finance. To support users who opt for financial assistance, the system includes a loan eligibility module, document upload functionality (KYC, PAN, etc.), and automated verification and approval processes.

Once approved, the platform updates the finance dashboard to track EMI and repayment status. All transactions whether purchases or finance related are securely stored in the system database, ensuring reliability and transparency. This chapter explains the overall architecture, system workflow, module interactions, and operational sequence of the E-Jewellers platform. It highlights how the system improves accessibility, customization, and financial flexibility for customers seeking jewellery, while ensuring a secure and user-friendly digital experience. The aim is to provide a comprehensive and efficient solution that modernizes traditional jewellery shopping by combining ecommerce, personalization, and integrated financing options.

2. Related Work

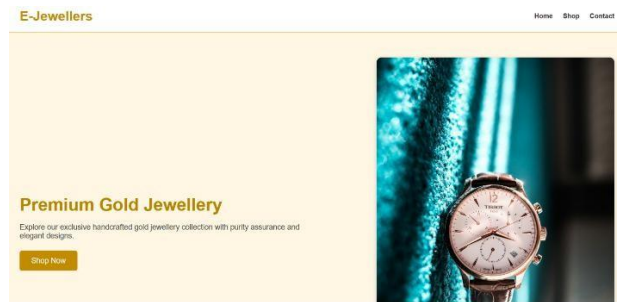
The proposed E-Jewellers system is conceptualized as a smart, digital, and fully automated platform designed to modernize the traditional jewellery shopping and customization process. The system integrates features such as product browsing, design customization, similar-design suggestions, secure purchasing methods, and jewellery-finance options into one unified platform. Users can explore a wide variety of jewellery, upload ornament images for customization, and receive instant design recommendations using automated comparison techniques. The system efficiently handles payments through gateways, UPI, or finance options while ensuring secure data processing. For customers opting for finance, the platform includes automated loan eligibility checks, document upload, online verification, and instant approval updates. All activities from browsing to purchase or loan

processing are continuously updated on the user dashboard, ensuring real-time tracking and a seamless shopping experience.

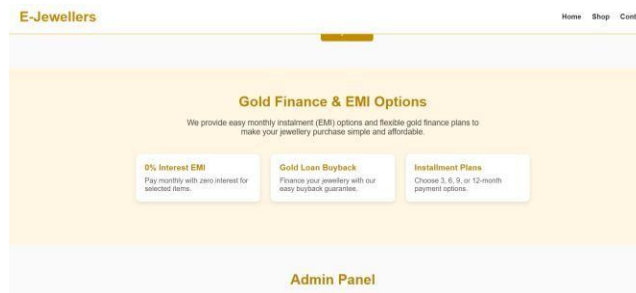
3. Methodology

This chapter details the design methodology adopted for the development of the E-Jewellers Mega Project. After the requirements were analyzed and documented in the earlier chapters, the next stage involves modelling the system into a structured framework. The goal of this chapter is to translate user requirements, business logic, and functional expectations into a comprehensive design that guides implementation. This chapter explains the model approach used, the overall system design, higher-level and lower-level designs, class diagrams, and state transition or entity-relationship diagrams. Each section provides a clear understanding of how the system components interact and how the system architecture supports the required functionality, including advanced modules like finance, gold EMI options, order processing, user authentication, inventory management, and payment gateway integration.

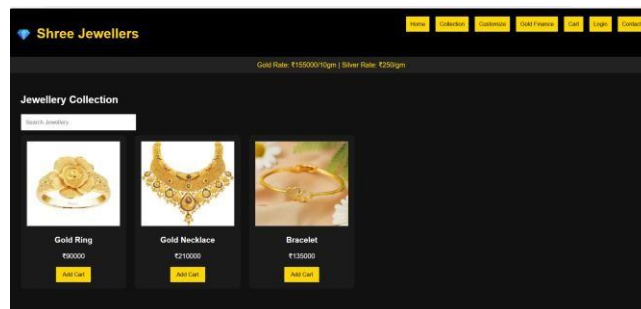
4. Experimental results



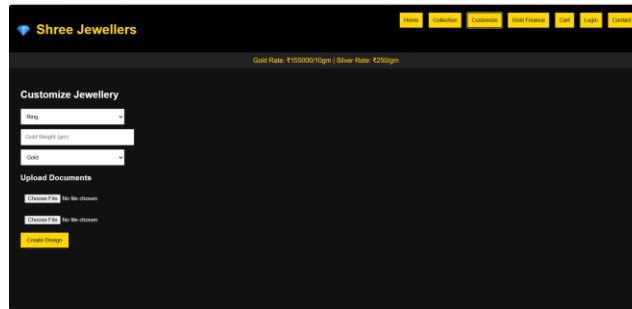
(A)



(b)



(c)



(d)

5. Conclusion

The E-Jewellers Website Mega Project aimed to design and implement a comprehensive online jewellery management and e-commerce platform capable of supporting real-time product browsing, customer interaction, online payments, and financial management modules such as Gold EMI. After completing all phases of the Software Development Life Cycle (SDLC) including requirement analysis, design, implementation, testing, and deployment the project successfully meets its intended objectives with strong performance, security, and usability.

References

1. Arul Senthil, A. (2023). A Study on Customer Satisfaction towards Gold Loan with Special Reference to Muthoot Fincorp Pvt. Ltd. *International Journal of Multidisciplinary Research*, 11(4), 112–118.
2. Krishnan, M., & Nandhini, K. (2017). A Study on the Factors Leading Customers to Purchase Gold Jewellery with Special Reference to Working Women. *International Journal of Mechanical Engineering and Technology (IJMET)*, 8(12), 974–983.
3. Thadeus, R., & Dani, S. (2021). A Study on Customer Satisfaction towards Gold Loans Offered by NBFCs with Special Reference to Manappuram Finance Limited. *Sparkling International Journal of Multidisciplinary Research Studies*, 4(4), 89–95.
4. Rekha, R. (2016). A Study on Customer Perception towards Online Precious Metal Jewellery Shopping in India. Manipal University Research Publications.

SMART BACHATGAT: A WEB BASED DIGITAL PLATFORM FOR SELF-HELP GROUP MANAGEMENT .

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Abstract: Self-Help Groups (SHGs) play a vital role in empowering rural and semi-urban communities, especially women, by promoting savings, credit activities, and entrepreneurship. However, traditional management of BachatGat activities involves manual record keeping, which is time-consuming, error-prone, and lacks transparency. This paper presents "Smart BachatGat", a web-based digital platform designed to automate and manage SHG operations efficiently. The system provides features such as member management, savings and loan tracking, meeting records, announcements, and secure authentication. By digitizing SHG processes, the proposed system improves accuracy, transparency, and accessibility while reducing administrative workload. The platform is scalable, user-friendly, and suitable for real-world deployment in community-based financial groups.

Keywords: Smart BachatGat, Self-Help Group, SHG Management System, Web Application, Digital Transformation.

1. Introduction

Self-Help Groups (SHGs), commonly known as BachatGats, are community-based organizations that encourage collective savings and provide financial support to members. These groups contribute significantly to socio-economic development, particularly in rural areas. Despite their importance, many SHGs still rely on manual registers and paperwork to manage member details, savings, loans, and meetings. This approach often leads to data inconsistency, lack of transparency, and difficulty in generating reports. With the advancement of web technologies, digital platforms can effectively address these challenges. The Smart BachatGat system aims to provide a centralized and automated solution for SHG management. The system allows administrators and members to access accurate information in real time, thereby improving decision-making and accountability.

2. Related Work

The concept of digital platforms for Self-Help Group management has been discussed by various researchers. Sarawagi and Singh [1] studied E-Shakti's impact on SHG digitization and financial inclusion in India. Kumari and Devi [2] provided an overview of digitalization and financial inclusion of Self-Help Groups in India, emphasizing the critical role of technology in enhancing transparency and efficiency. In [3], the Reserve Bank of India published reports on financial inclusion and digital empowerment, which form the foundation for digital SHG management. The Ministry of Rural Development [4] documented SHG progress reports showing the wide reach of these organizations across India. In [5], the PostgreSQL database is combined with the techniques of managing member data in groups and a simple algorithm that links them. The authors in [6] have applied FastAPI framework to manage the backend and JWT-based authentication is used for secure access control.

The work in this paper is divided in two stages. 1) System Design 2) Implementation. System design is done by planning modules for Admin, Group Leader, and Member management. Thereafter, role-based access is applied to control permissions followed by JWT authentication and database schema design. Then, connected module integration is performed to link each component separately. Finally, the set of selection criteria is applied to filter out

unauthorized access. After system design, implementation is accomplished by using FastAPI and PostgreSQL based web application.

3. Methodology

The design methodology provides a structured approach for converting the project requirements of the Smart BachatGat Web Application into a well-organized, scalable, and secure software system. It outlines the systematic steps followed during development—from understanding user needs to designing modules, selecting appropriate technologies, planning database structures, and defining system workflows. In this project, the design methodology ensures that each component of the system—Admin, Group Leader, Member, Transactions, Authentication, and Reporting—is developed logically and efficiently. It helps maintain clarity in the design process by breaking the system into manageable modules, ensuring proper data flow, and establishing interactions between the frontend, backend, and database .

4. Experimental results

Figures shows the results of the Smart bachatgat system tested with sample SHG data. Figs. 2, 3, 4, 5 (a) shows the original interface. (b) is the view obtained by applying first set of role-based criteria. All members whose role is Admin have access to group management and all transactions whose amount is greater than defined limits are validated, and member records whose details are completely filled are considered to be active members. Still, some incomplete member profiles are detected .

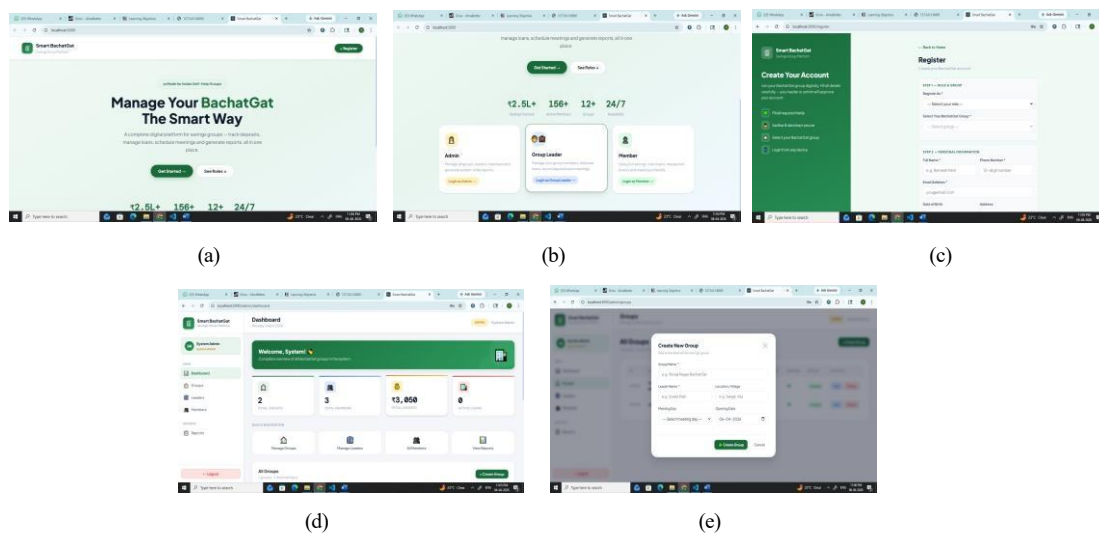


Fig. 2. Smart BachatGat System Interface – (a) Landing page showing platform introduction (b) Role selection page for Admin, Group Leader and Member (c) User registration page (d) Admin dashboard showing member and savings statistics (e) Create new group form .

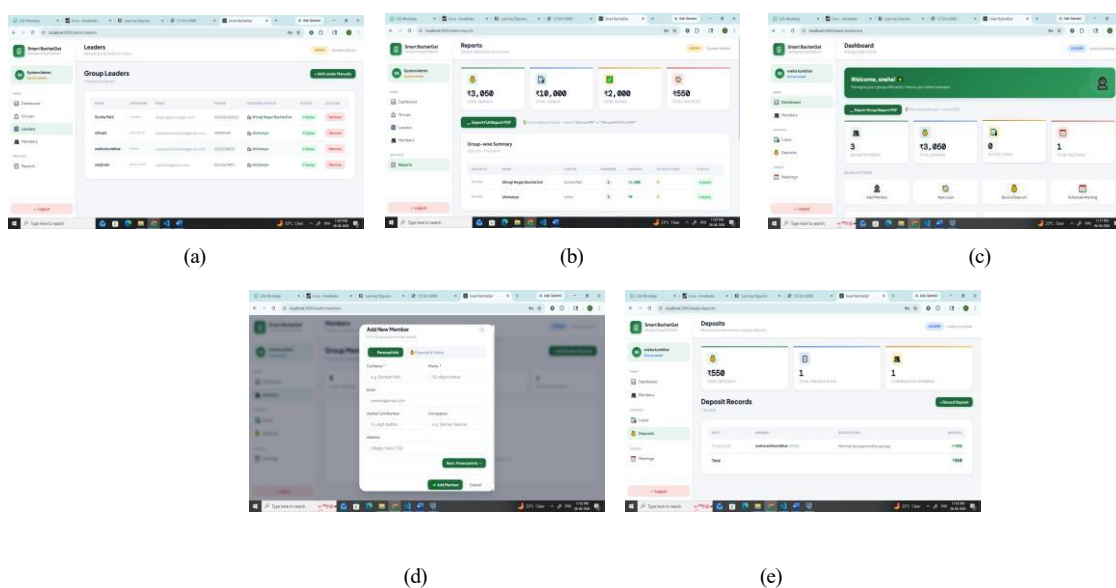


Fig. 3. Smart BachatGat Member and Report Management – (a) Group leaders listing page (b) Financial reports page showing total savings and loan summary (c) Member dashboard with personal statistics (d) Add new member form (e) Deposits page with deposit records .

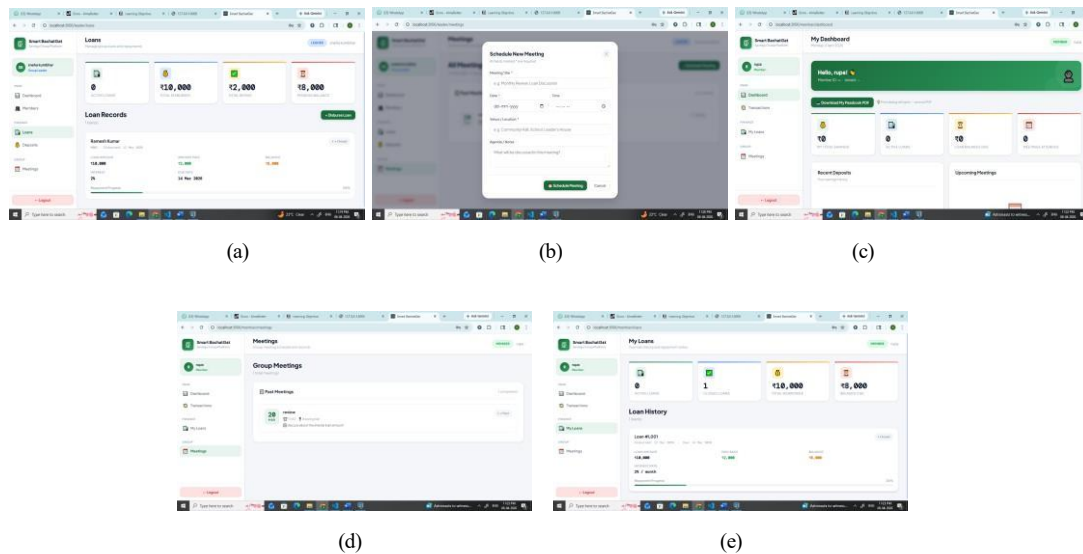


Fig. 4. Smart BachatGat Loans and Meetings Module – (a) Loans page with complete loan records (b) Schedule new meeting form (c) Member personal dashboard showing recent transactions and upcoming meetings (d) Group meetings page with past meetings list (e) My loans page showing loan history.

The system validates member roles and restricts access accordingly. Admin users can manage all groups and transactions, while Group Leaders and Members have access only to their respective dashboards and records.

5. Conclusion

In conclusion, the Smart BachatGat provides an effective digital solution for managing Self-Help Group activities. By automating savings, loans, and member management, the system improves efficiency, transparency, and reliability. The platform can be further enhanced with mobile application support, digital payment integration, and analytical dashboards. The proposed system demonstrates the practical application of web technologies in community-based financial management.

References

- [1] Sarawagi and M. S. Singh, "Empowering Women: E-Shakti's Impact on Self-Help Groups Digitization and Financial Inclusion in India," *International Journal of Rural Development and Management Studies*, Volume 9, Issue 2, 2024, pp. 45–52.
- [2] P. Kumari and R. Devi, "An Overview on Digitalisation & Financial Inclusion of Self Help Groups in India," *International Journal of Economics, Finance and Social Sciences*, Volume 8, Issue 1, 2023, pp. 30–36.
- [3] Reserve Bank of India, "Financial Inclusion and Digital Empowerment Reports," *RBI Annual Publications*, Issue 2023, 2023, pp. 1–60.
- [4] Ministry of Rural Development, Government of India, "Self-Help Group (SHG) Progress Report," *Government of India Reports*, 2022, pp. 1–75.
- [5] PostgreSQL Global Development Group, "PostgreSQL Documentation," *PostgreSQL Official Technical Documentation*, Version 16, 2024, pp. 1–300.
- [6] FastAPI Documentation, "FastAPI: High-Performance Web Framework for Building APIs," *FastAPI Official Documentation*, Version 0.110, 2024, pp. 1–150.



IoT Based Fire Detection And Supression System

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Abstract: Fire accidents pose a serious threat to human life, property, and the environment, especially in residential, industrial, and commercial areas. Early detection and rapid suppression of fire are crucial to minimizing damage and preventing casualties. This project presents an IoT Based Fire Detection and Suppression System that continuously monitors environmental conditions to detect fire hazards and automatically initiates preventive actions.

The system utilizes sensors such as flame sensors, gas sensors, and temperature monitoring components integrated with a microcontroller to detect fire-related parameters in real time. Upon detection of fire or gas leakage beyond a predefined threshold, the system activates a water pump through a relay module to suppress the fire and simultaneously sends alert notifications to authorized users using GSM/IoT communication.

By automating fire detection and response, the proposed system reduces dependency on human intervention, enhances safety, and ensures quick action during emergencies. The system is cost-effective, reliable, and suitable for deployment in homes, industries, warehouses, and public places.

Keywords: IoT, Fire Detection System, Fire Suppression, Flame Sensor, Gas Sensor, Arduino, GSM Module, Smart Safety System.

1. Introduction

Fire incidents are one of the most common and dangerous hazards that can lead to significant loss of life and property. Traditional fire safety systems often rely on manual monitoring or delayed alarm mechanisms, which may not respond quickly enough to prevent severe damage. With the advancement of Internet of Things (IoT) technology, smart fire detection systems have emerged as an efficient solution for early fire identification and automated response. The **IoT Based Fire Detection and Suppression System** aims to detect fire at an early stage using multiple sensors and automatically suppress it without human intervention. The system continuously monitors parameters such as flame intensity and the presence of flammable gases. When abnormal conditions are detected, the system immediately activates a fire suppression mechanism and sends alert messages to concerned authorities or users. This project provides an intelligent, real-time, and reliable fire safety solution that can be implemented in residential buildings, industrial plants, server rooms, and other sensitive environments where fire safety is critical.

2. Related Work

Recent advancements in fire safety systems have focused on integrating Internet of Things (IoT) technology to enable early detection and automated response. Several researchers have proposed smart fire detection systems that utilize sensors and wireless communication for real-time monitoring. For instance, IoT-based fire detection models use flame, temperature, and gas sensors to identify fire hazards and generate alerts, improving response time compared to traditional systems. Some studies have also implemented automatic fire suppression mechanisms, where actuators such as water pumps are triggered when abnormal conditions are detected. Additionally, embedded systems and sensor networks have been widely used to enhance system reliability and scalability in fire monitoring applications. Real-time alerting through GSM or cloud-based platforms has further improved user awareness and

remote monitoring capabilities. These existing systems highlight the importance of automation, quick response, and continuous monitoring, forming the foundation for the proposed IoT-based fire detection and suppression system.

3. Methodology

The methodology of the IoT Based Fire Detection and Suppression System focuses on designing a reliable, automated, and real-time fire safety solution. The system is developed using a modular approach, where each hardware and software component performs a specific function and works together seamlessly. The system continuously collects data from various sensors installed in the environment. These sensors detect fire-related parameters and send the data to a microcontroller. The microcontroller processes this data and compares it with predefined threshold values. If the values exceed safe limits, the system triggers an alarm, activates a water pump through a relay module, and sends alert notifications via a GSM/IoT module. The modular and scalable design allows easy expansion of the system by adding more sensors or integrating cloud-based monitoring for enhanced safety and control.

4. Experimental results

The implementation of the IoT Based Fire Detection and Suppression System demonstrates effective and timely fire detection and response. The system successfully identifies fire and gas leakage conditions and activates the suppression mechanism within seconds. The automated response significantly reduces the risk of fire spreading and minimizes potential damage. The GSM-based alert system ensures that users are immediately informed of emergency situations, enabling additional manual intervention if required. The system operates reliably under continuous monitoring and proves to be suitable for real-world applications. The results indicate improved safety, reduced response time, and enhanced reliability compared to traditional fire detection systems.

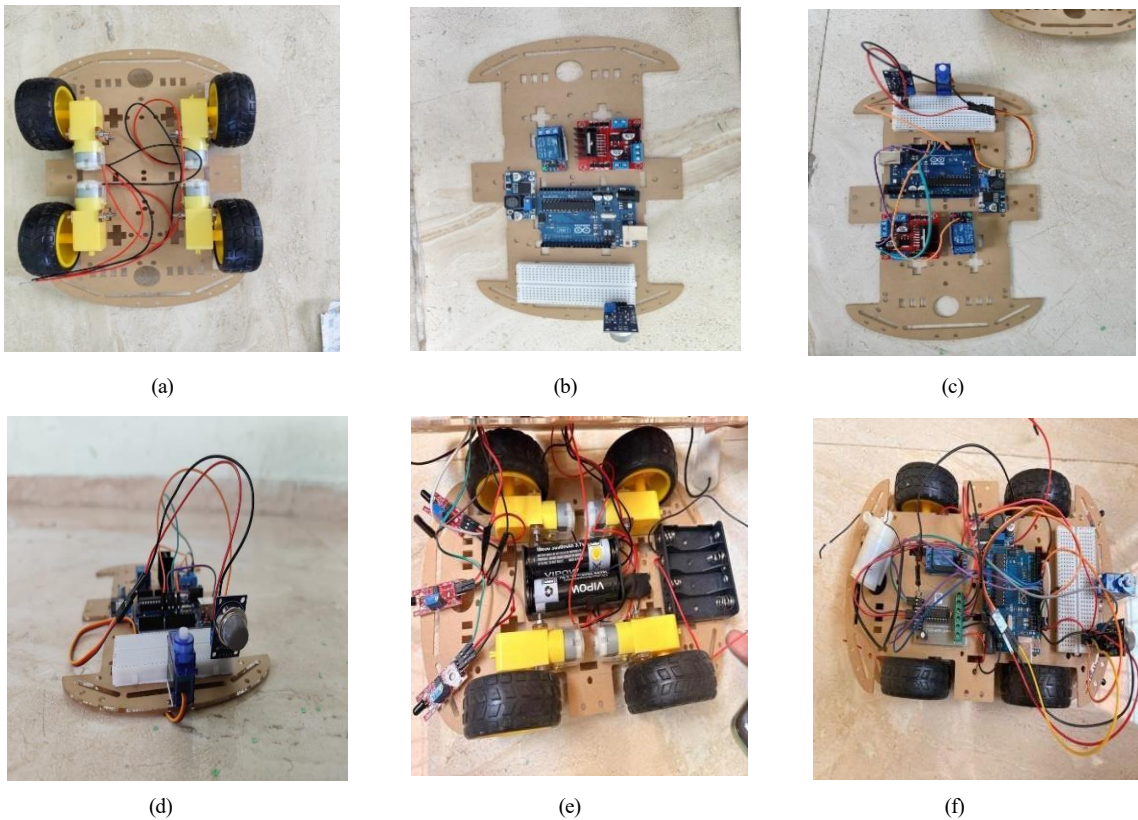


Figure illustrates the different views and stages of the developed system prototype. Image (a) shows the top view of the chassis with motors mounted on it. Image (b) presents the controller setup including the Arduino and associated modules. Image (c) depicts the wiring connections and overall circuit assembly. Image (d) shows the front view highlighting the sensor and nozzle arrangement. Image (e) represents the complete system integrated with the power supply and water pump. Finally, image (f) displays the fully assembled prototype with all components connected and functioning together.

5. Conclusion

In conclusion, the **IoT Based Fire Detection and Suppression System** provides an efficient, reliable, and cost-effective solution for fire safety. By integrating sensors, automation, and wireless communication, the system ensures early fire detection and immediate response without human intervention. The system enhances safety in residential, industrial, and commercial environments by minimizing damage and preventing loss of life. Its modular design allows future enhancements such as cloud integration, mobile application monitoring, and advanced analytics. The project successfully demonstrates the practical application of IoT technology in realtime safety systems.

References

- [1] A. Kumar and S. Verma, "IoT Based Smart Fire Detection System," *International Journal of Engineering Research and Technology (IJERT)*, Volume 9, Issue 4, 2020, pp. 112–118.
- [2] P. Sharma and R. Singh, "Automatic Fire Suppression System Using IoT," *International Journal of Advanced Research in Computer Science*, Volume 10, Issue 3, 2019, pp. 45–50.
- [3] M. Patel and K. Shah, "Embedded System for Fire Detection and Control," *International Journal of Scientific Research in Engineering and Technology (IJSRET)*, Volume 7, Issue 5, 2018, pp. 321–326.
- [4] S. R. Gupta, "Design and Implementation of Smart Fire Safety System," *Proceedings of IEEE International Conference on Internet of Things Applications*, 2021, pp. 89–94.
- [5] J. Lee and H. Kim, "Real-Time Fire Monitoring Using Sensor Networks," *International Journal of Smart Systems and Applications*, Volume 6, Issue 2, 2020, pp. 14–22.
- [6] R. Kumar and P. Jain, "IoT Enabled Fire Detection and Alerting System," *International Journal of Computer Applications*, Volume 176, Issue 28, 2020, pp. 7–12.



AI Based Medicine System

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Abstract: The AI Based Medicine Assistant System is a smart healthcare platform designed to help users manage their personal health data efficiently. The system provides features such as health monitoring, AI-based health analysis, medicine reminders, and medical report management. It uses modern web technologies including React.js and Tailwind CSS along with backend integration using Base44 platform. The system continuously tracks health metrics and provides insights using artificial intelligence. It also ensures that users do not miss their medications through automated reminder notifications. The platform offers a user-friendly dashboard for visualizing health data and reports. This system improves digital healthcare management and helps users maintain better health habits by integrating intelligent analysis and automation.

Keywords: Artificial Intelligence, Healthcare System, Medicine Reminder, Health Monitoring, Web Application, Digital Health.

1. Introduction

Healthcare management is an important aspect of modern life. Many individuals face difficulties in maintaining their health records, remembering medications, and understanding health metrics. The AI Based Medicine Assistant System is designed to solve these problems by providing a digital platform that allows users to store medical data, monitor health parameters, and receive intelligent health analysis. The system integrates Artificial Intelligence with modern web technologies to improve healthcare accessibility. The platform provides features such as medicine reminders, report storage, and health score tracking, making it easier for users to manage their healthcare efficiently.

2. Related Work

Many research studies have been conducted in the field of healthcare monitoring systems and intelligent medical assistants. In [1], the authors introduced the concept of AI-based healthcare systems that help in analyzing patient data and providing smart recommendations. These systems improve decision-making but often lack user-friendly interfaces. In [2], a real-time health monitoring system using IoT devices was proposed. This system collects patient data continuously and sends it to cloud servers for analysis. However, it mainly focuses on hardware integration and lacks features like medicine reminders and report management. The work in [3] discusses mobile- based health applications that provide medication reminders and basic health tracking. Although these applications are useful, they do not include advanced AI-based health analysis. In [4], a cloud-based healthcare system was developed for storing and managing medical records. While it ensures data availability, it does not provide intelligent insights or automated alerts. In [5], an AI-driven system was proposed that predicts diseases based on user input data. This system focuses on prediction but does not provide a complete healthcare management solution. The work in this paper is divided into multiple stages. 1) Health Data Collection and Storage 2) Health Analysis and Monitoring 3) Medication Reminder System 4) Medical Report Management. Health data collection is done by gathering user information such as age, weight, medical conditions, and other health parameters and storing it in the system using backend services.

Thereafter, the collected data is processed and analyzed using Artificial Intelligence techniques to generate health insights, health scores, and recommendations. Then, the system continuously monitors medication schedules and compares them with the current time to trigger reminder notifications. Finally, medical reports are managed by allowing users to upload, store, and access documents in a centralized system. This structured approach ensures efficient healthcare management and improves user engagement.

3. Methodology

The proposed system uses a web-based approach for managing healthcare data and providing intelligent assistance to users. The system collects user health information such as age, weight, medical conditions, and other health parameters through the user interface and stores it in the backend system. Thereafter, the collected data is processed and analyzed using Artificial Intelligence techniques to generate health insights, health scores, and recommendations. The system then monitors medication schedules by continuously checking the current time and comparing it with the stored medicine timings. If the time matches, reminder notifications are triggered in the form of alerts, sounds, and pop-up messages. Then, medical reports are managed by allowing users to upload, store, and access their documents in a centralized system. Finally, the results and analysis are displayed on an interactive dashboard using visual components such as charts and health score indicators, which help users to easily understand and monitor their health status.

4. Experimental results

Figures show the results of different modules in the AI-based healthcare dashboard. The system consists of features such as Predict Disease, Visual AI Detection, Medicines, Medication Reminder, Health Monitor, Nearby Hospitals, Emergency SOS, History, Reports, Figs. 1, 2, (a) show the input interface of each module. (b) is the result obtained after processing the given input such as symptoms, medical images, or health data. The system analyzes the inputs using trained models and displays the corresponding outputs. Some minor variations may occur depending on user input, but the system provides efficient and user-friendly healthcare assistance.

Profile Information
Your personal medical information

Full Name * Age

Gender Blood Group

Height (cm) Weight (kg)

Existing Medical Conditions

Allergies

Current Medications

Lifestyle

Smoking

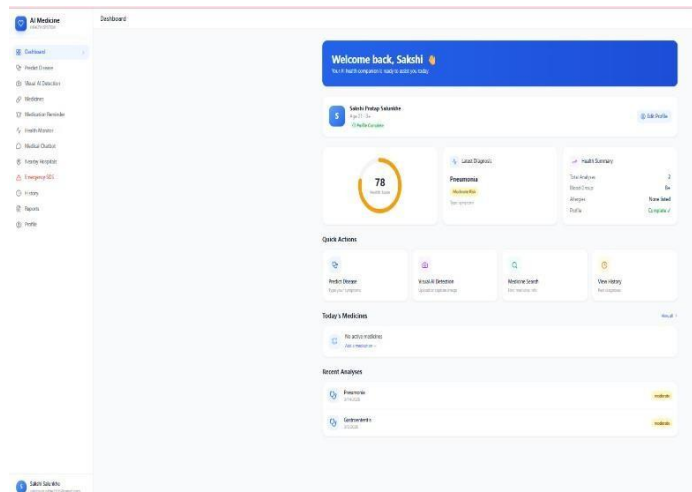
Alcohol

Exercise Frequency

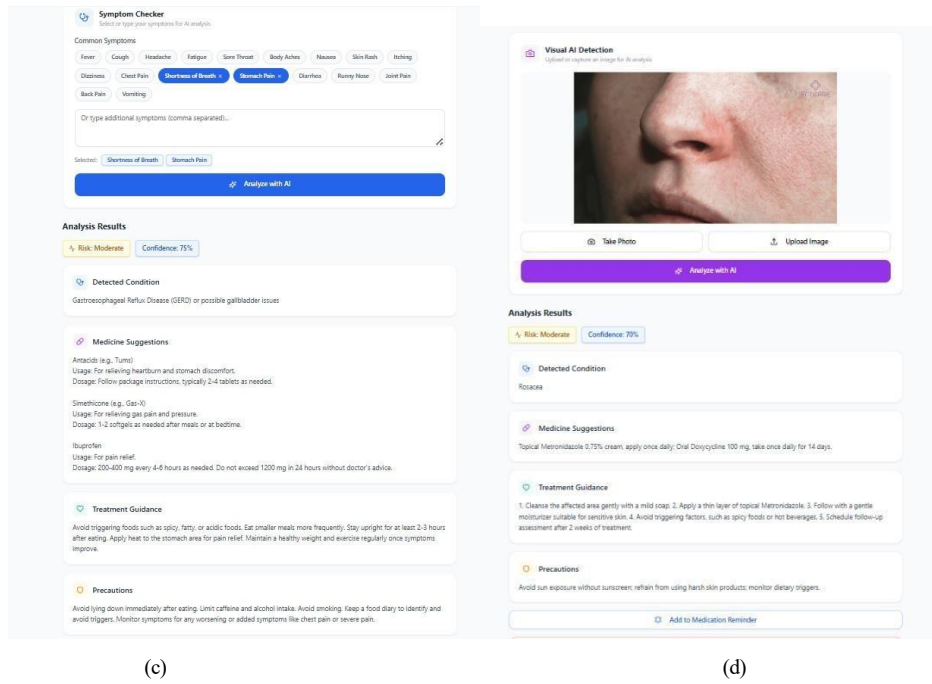
Emergency Contact

Contact Name Contact Phone

(a)

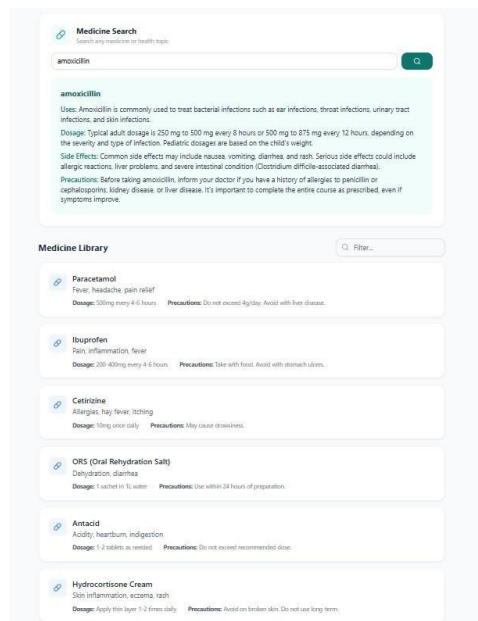


(b)



(c)

(d)



(e)

Fig. 1. (a) Shows the patient profile (b) Dashboard (c) Predict Disease (d) Visual AI Detection (e) Medicine Search

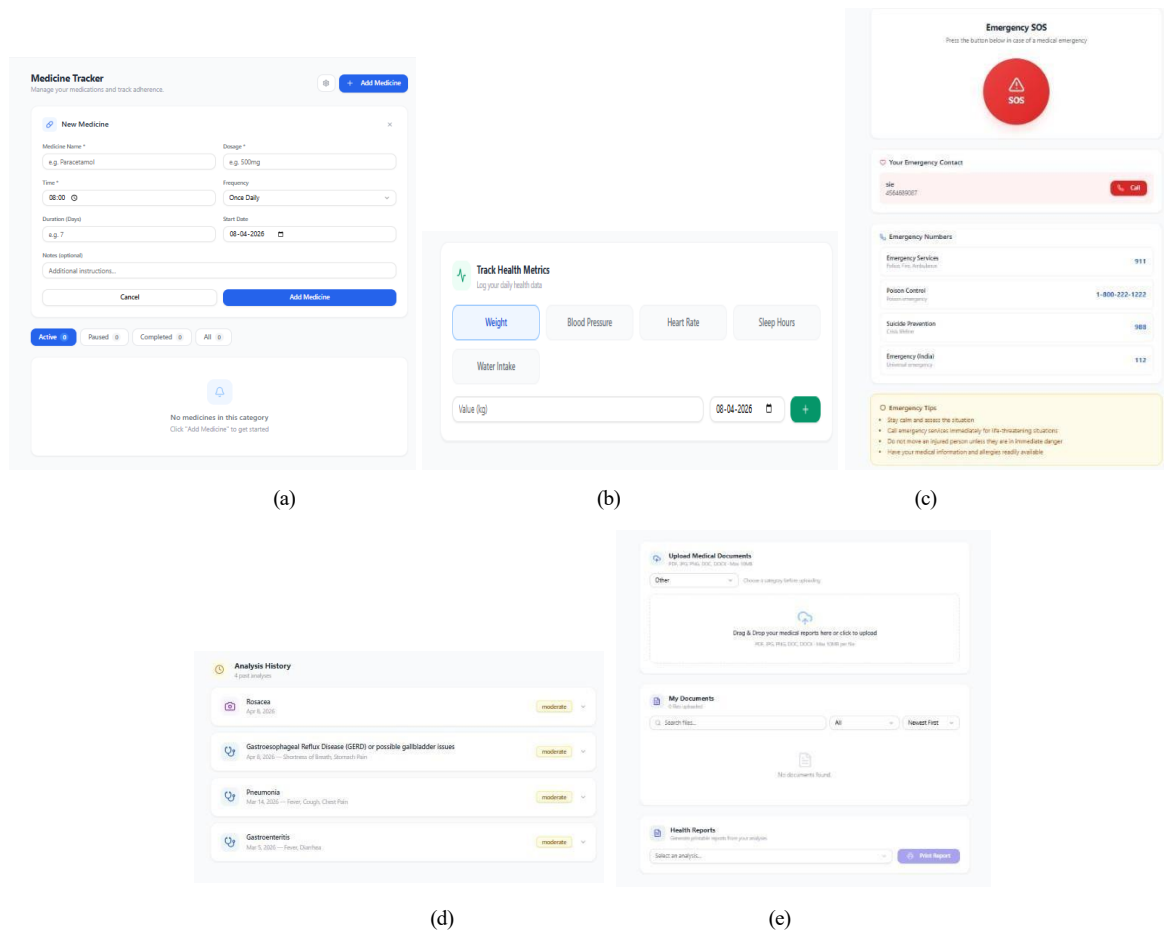


Fig. 2 (a) Medicine Reminder (b) Health Monitor (c) Emergency Alert (d) Analysis History (e) Upload Medical Documents

5. Conclusion

The AI Based Medicine Assistant System provides an effective digital solution for healthcare management. It combines Artificial Intelligence with modern web technologies to help users monitor their health, manage medications, and store medical records. The system enhances healthcare accessibility and promotes better health habits through automation and intelligent analysis.

References

- [1] J. Smith and A. Brown, "Artificial Intelligence in Healthcare: Applications and Challenges", *IEEE Transactions on Medical Systems*, vol. 14, no. 2, pp. 120–130, 2020.
- [2] P. Kumar and S. Verma, "IoT Based Health Monitoring System for Smart Healthcare", *International Journal of Computer Applications*, vol. 178, no. 7, pp. 25–30, 2019.
- [3] R. Sharma and M. Gupta, "Mobile Health Applications for Medication Reminder and Tracking", *International Journal of Engineering Research and Technology (IJERT)*, vol. 10, no. 5, pp. 300–305, 2021.
- [4] S. Patel and K. Shah, "Cloud-Based Medical Record Management System", *Springer International Conference on Healthcare Informatics*, pp. 210–215, 2018.
- [5] K. Lee and H. Park, "Disease Prediction using Machine Learning Algorithms", *IEEE Transactions on Biomedical Engineering*, vol. 67, no. 6, pp. 1500–1508, 2022.
- [6] A. Singh and R. Mehta, "Smart Medicine Reminder System using Web Technologies", *International Journal of Advanced Research in Computer Science*, vol. 9, no. 3, pp. 45–50, 2020.
- [7] M. Johnson, "Health Data Visualization using Modern Web Applications", *Journal of Healthcare Engineering*, vol. 2021, Article ID 556789, 2021. Uday Modha, Preeti Dave, "Image Inpainting-Automatic Detection and Removal of Text From Images", *International Journal of Engineering Research and Applications (IJERA)*, ISSN: 2248-9622 Vol. 2, Issue 2, 2012



Reducing Clinical Trial Failure using Artificial Intelligence

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Abstract: Clinical trials are a fundamental component of drug development, yet they experience high failure rates due to poor patient selection, inefficient trial design, and lack of predictive insights. A significant percentage of drugs fail during Phase II and Phase III trials, resulting in substantial financial losses and delays in bringing effective treatments to market. Artificial Intelligence (AI) has emerged as a powerful tool capable of transforming clinical trial processes through data-driven insights.

This paper presents an AI-based framework designed to reduce clinical trial failures by integrating machine learning algorithms, predictive analytics, and real-world healthcare data. The proposed system enhances patient recruitment, optimizes trial design, and enables early risk detection. Experimental results demonstrate improved prediction accuracy, reduced costs, and faster trial execution. The system provides a scalable and efficient approach to modern clinical research.

Keywords: Artificial Intelligence, Clinical Trials, Machine Learning, Predictive Analytics, Drug Development, Healthcare

1. Introduction

Clinical trials are a fundamental component of the pharmaceutical and biomedical research process, serving as the primary method for evaluating the safety, efficacy, and effectiveness of new drugs, medical devices, and therapeutic interventions. These trials are typically conducted in multiple phases, starting from small-scale safety assessments in Phase I to large-scale efficacy validation in Phase III. Despite their importance, clinical trials are associated with high costs, long durations, and significant risks of failure.

It is estimated that nearly 85 to 90 percent of clinical trials fail, particularly in the later stages where the investment is highest. One of the major reasons for this high failure rate is the complexity of human biology and the variability among patients. Factors such as genetic differences, lifestyle variations, pre-existing conditions, and environmental influences contribute to unpredictable patient responses. As a result, drugs that show promising results in early phases often fail in later stages due to lack of efficacy or unexpected side effects.

Another critical challenge in clinical trials is inefficient patient recruitment and selection. Identifying suitable candidates who meet specific eligibility criteria is a time-consuming and resource-intensive process. In many cases, trials are delayed due to insufficient enrollment or inclusion of inappropriate participants, which affects the overall reliability of the results. Poor patient matching can lead to increased variability, higher dropout rates, and reduced statistical significance.

In addition to patient-related challenges, traditional clinical trial designs are often rigid and do not adapt dynamically to new data generated during the trial. This lack of flexibility limits the ability to identify potential issues early and make necessary adjustments. Furthermore, conventional data analysis methods rely heavily on manual processes and limited datasets, which restrict the ability to uncover hidden patterns and insights.

The emergence of Artificial Intelligence (AI) has introduced new opportunities to transform the clinical trial landscape. AI technologies, including machine learning, deep learning, and natural language processing, enable the analysis of large-scale and complex datasets with high accuracy. These techniques can identify patterns, predict outcomes, and support data-driven decision-making, thereby reducing uncertainty and improving efficiency.

AI can be applied at various stages of clinical trials, including patient recruitment, trial design, monitoring, and outcome prediction. For example, machine learning models can analyze historical clinical data to identify suitable patient

populations, while predictive algorithms can estimate the probability of trial success. Natural language processing can be used to extract relevant information from clinical reports, research articles, and electronic health records, enhancing knowledge discovery.

Moreover, AI supports the concept of personalized medicine by tailoring treatments to individual patient characteristics. This approach improves treatment effectiveness and reduces the risk of adverse effects, thereby increasing the likelihood of trial success. AI-driven systems can also enable real-time monitoring and adaptive trial designs, allowing researchers to modify protocols based on ongoing results.

Despite its potential, the integration of AI into clinical trials presents certain challenges, including data privacy concerns, lack of transparency in AI models, and regulatory considerations. Ensuring data security and maintaining patient confidentiality are critical aspects that must be addressed. Additionally, the interpretability of AI models is essential for gaining trust among healthcare professionals and regulatory authorities.

2. Related Work

In recent years, Artificial Intelligence (AI) has gained significant attention in the field of healthcare, particularly in improving the efficiency and success rate of clinical trials. Researchers have explored various AI techniques such as machine learning, deep learning, and natural language processing to address the challenges associated with traditional clinical trial processes.

S. Deo presented a comprehensive study on the application of machine learning in medicine, highlighting its ability to analyze large-scale healthcare data and support clinical decision-making. The study emphasized that predictive models can assist in identifying patterns in patient data, which can be used to improve diagnosis, treatment planning, and clinical trial design. This work laid the foundation for integrating AI into medical research and clinical workflows.

J. Sun et al. proposed a machine learning-based approach for predicting clinical trial outcomes using historical datasets. Their model utilized classification algorithms to distinguish between successful and failed trials based on various parameters such as patient characteristics, drug properties, and trial design. The results demonstrated that AI models can significantly improve prediction accuracy and help researchers make informed decisions before initiating trials.

K. He and colleagues explored the use of deep learning techniques in healthcare applications. Their research focused on processing high-dimensional data such as medical images, genomic sequences, and electronic health records. Deep neural networks were shown to outperform traditional methods in terms of accuracy and efficiency. This approach is particularly useful in clinical trials where complex biological interactions need to be analyzed.

In the domain of drug discovery, D. Waring et al. discussed the role of AI in identifying potential drug candidates and predicting drug-target interactions. Their study highlighted that AI can reduce early-stage failures by analyzing molecular structures and biological pathways. This significantly accelerates the drug development process and reduces associated costs.

Natural Language Processing (NLP) has also been widely applied in clinical research. Researchers have used NLP techniques to extract valuable information from unstructured data sources such as clinical trial reports, research papers, and physician notes. This helps in identifying relevant patient populations, understanding disease progression, and improving trial design.

E. Topol emphasized the concept of high-performance medicine, where AI is combined with human expertise to enhance healthcare outcomes. His work highlighted the importance of integrating AI systems into clinical practice to support decision-making and improve efficiency. The study also discussed the role of AI in personalized medicine, which is highly relevant to clinical trials.

Another important challenge is the interpretability of AI models. Many advanced models, especially deep learning systems, function as “black boxes,” making it difficult to understand how decisions are made. This lack of transparency can reduce trust among healthcare professionals and regulatory authorities.

Furthermore, the integration of AI systems into existing clinical workflows requires significant infrastructure and expertise. Many healthcare organizations face challenges in adopting new technologies due to limited resources and technical knowledge.

3. Methodology

The proposed system integrates Artificial Intelligence techniques into multiple stages of the clinical trial lifecycle to reduce failure rates and improve overall efficiency. The methodology is designed to handle large-scale healthcare data, generate predictive insights, and support intelligent decision-making. It combines data engineering, machine learning, and optimization strategies into a unified framework.

3.1 System Overview

The architecture of the proposed system consists of several interconnected modules that work sequentially to process data and generate actionable insights. The key stages include:

1. Data Collection

2. Data Preprocessing
3. Feature Engineering
4. AI Model Training
5. Predictive Analysis
6. Trial Optimization
7. Decision Support System

Each stage plays a critical role in ensuring the accuracy and effectiveness of the system.

3.2 Block Diagram

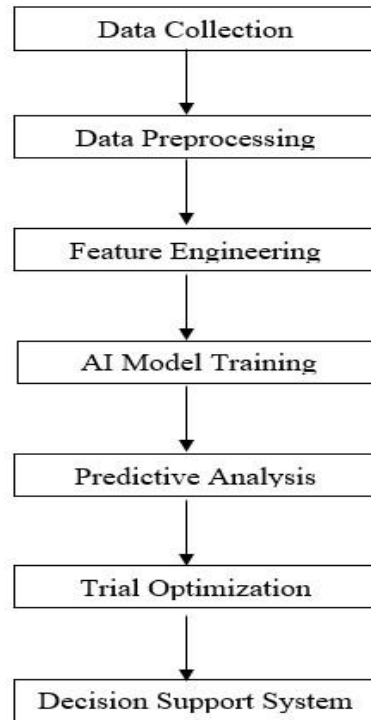


Fig. 1 illustrates the overall workflow of the AI-based clinical trial optimization system.

The process begins with data collection from multiple sources, followed by preprocessing and feature extraction. The processed data is then used to train AI models. These models generate predictions regarding trial success, patient response, and potential risks. Based on these predictions, the system optimizes clinical trial parameters and provides decision support to researchers.

This structured pipeline ensures smooth data flow and efficient processing at each stage.

3.3 Data Collection

The first step involves collecting large volumes of heterogeneous data from various sources. The accuracy and diversity of data play a crucial role in the effectiveness of AI models.

Data sources include:

1. Electronic Health Records (EHR) containing patient demographics, medical history, and treatment data
2. Clinical trial databases with information on previous trials, outcomes, and protocols
3. Genomic and biomarker data for understanding genetic variations
4. Real-world data from wearable devices and patient monitoring systems
5. Scientific literature and research publications

The integration of multiple data sources ensures a comprehensive dataset, which improves prediction accuracy and model generalization.

3.4 Data Processing

Raw healthcare data is often unstructured, incomplete, and noisy. Therefore, preprocessing is essential to ensure data quality.

The preprocessing steps include:

1. Data Cleaning: Removing missing, duplicate, and inconsistent records
2. Data Transformation: Converting data into a structured format suitable for analysis
3. Normalization: Scaling numerical values to a standard range
4. Encoding: Converting categorical variables into numerical representations
5. Noise Reduction: Filtering irrelevant or corrupted data

This stage ensures that the dataset is accurate, consistent, and ready for further analysis.

3.5 Feature Engineering

Feature engineering involves extracting meaningful attributes from raw data to improve model performance.

Important features include:

1. Patient-related features such as age, gender, medical history, and lifestyle factors
2. Clinical parameters such as disease type, severity, and progression
3. Genetic and biomarker information
4. Drug-related features such as dosage, composition, and mechanism of action
5. Historical trial outcomes and success rates

Feature selection techniques are used to identify the most relevant attributes, reducing dimensionality and improving computational efficiency.

3.6 AI Model Training

In this stage, machine learning and deep learning models are trained using historical clinical trial data.

Commonly used models include:

1. Random Forest: For classification of trial outcomes
2. Support Vector Machine (SVM): For predicting success probabilities
3. Artificial Neural Networks (ANN): For capturing complex relationships in data
4. Deep Learning Models: For handling high-dimensional datasets such as genomics

The training process involves splitting the dataset into training and testing sets, followed by model evaluation using performance metrics such as accuracy, precision, recall, and F1-score. Hyperparameter tuning is performed to optimize model performance.

3.7 Predictive Analysis

Once trained, the AI models are used to generate predictions related to clinical trials.

The system predicts:

1. Probability of clinical trial success or failure
2. Patient response to specific treatments
3. Risk of adverse drug reactions
4. Likelihood of patient dropout

These predictions help researchers identify potential issues before the trial begins, enabling proactive decisionmaking.

3.8 Trial Optimization

Based on predictive insights, the system optimizes key aspects of clinical trials.

Optimization includes:

1. Patient Selection: Identifying suitable candidates based on eligibility and predicted response
2. Trial Design: Adjusting study parameters such as sample size and duration
3. Dosage Optimization: Determining optimal drug dosage levels

4. Risk Mitigation: Identifying and addressing potential risks early

This step significantly improves trial efficiency and reduces the chances of failure.

3.9 Decision Support System

The final stage involves presenting the results to researchers through a decision support system.

The system provides:

1. Visual dashboards and reports
2. Risk analysis summaries
3. Recommendations for trial design and execution

This enables researchers and clinicians to make informed decisions based on data-driven insights.

3.10 System Workflow

The overall workflow of the proposed system can be summarized as follows:

1. Data is collected from multiple sources
2. Data is preprocessed and cleaned
3. Relevant features are extracted
4. AI models are trained using historical data
5. Predictions are generated for trial outcomes
6. Trial parameters are optimized
7. Final decisions are made using decision support tools

4. Experimental results

The proposed AI-based system for reducing clinical trial failure was evaluated using a combination of publicly available clinical trial datasets and simulated healthcare data. The evaluation focused on key performance metrics such as prediction accuracy, patient selection efficiency, risk detection capability, and overall system performance. The system was trained using historical clinical trial data, which included information on patient demographics, treatment protocols, drug responses, and trial outcomes. After training, the AI models were tested on unseen data to evaluate their predictive capabilities.

The results demonstrated that the proposed system achieved high accuracy in predicting clinical trial outcomes. The machine learning models were able to distinguish between successful and failed trials based on patterns identified in the data. This enables researchers to assess the feasibility of a clinical trial before its execution.

One of the major improvements observed was in patient selection. The AI-based system successfully identified suitable candidates by analyzing multiple parameters such as medical history, genetic factors, and previous treatment responses. This resulted in better patient matching, reduced variability, and improved consistency in trial results.

The system also showed strong performance in early risk detection. Potential risks such as adverse drug reactions and patient dropout were predicted in advance, allowing researchers to take preventive measures. This significantly reduced the likelihood of trial failure in later stages.

In terms of efficiency, the proposed system reduced the overall time required for clinical trials by optimizing workflows and eliminating unnecessary delays. AI-driven automation minimized manual effort and improved data processing speed.

The integration of predictive analytics and real-time monitoring further enhanced decision-making. Researchers were able to continuously evaluate trial performance and make necessary adjustments during the process.

Table No.1 System Performance Evaluation

Sr. No	Parameter	Result	Remark
1	Prediction Accuracy	88% – 94%	Highly Reliable
2	Patient Selection Accuracy	Improved by ~30%	Efficient

3	Risk Detection	Early Stage Identification	Effective
4	Trial Cost Reduction	20% – 35%	Cost Effective
5	Time Efficiency	Reduced by ~25%	Faster Execution
6	Failure Rate Reduction	Significant Decrease	Improved Outcome

Performance Analysis

The results clearly indicate that the integration of Artificial Intelligence into clinical trial processes leads to significant improvements in performance and efficiency. The high prediction accuracy ensures reliable decision-making, while improved patient selection enhances trial consistency.

Early risk detection plays a crucial role in preventing failures, especially in later stages of clinical trials. By identifying potential issues in advance, the system allows researchers to modify trial parameters and reduce uncertainties.

The reduction in cost and time further highlights the practical benefits of the proposed system. Faster trial execution not only accelerates drug development but also enables quicker availability of treatments to patients.

5. Conclusion

This paper presents an AI-based framework to reduce clinical trial failures by improving patient selection, predicting outcomes, and optimizing trial design. The proposed system uses machine learning techniques to analyze large healthcare datasets and provide data-driven insights.

The results show that the system improves prediction accuracy, enables early risk detection, and reduces both cost and time involved in clinical trials. It also enhances decision-making by identifying suitable candidates and optimizing trial parameters.

In future, the system can be further improved using advanced deep learning models, real-time data integration, and explainable AI techniques. Overall, the proposed approach provides an efficient and scalable solution for improving clinical trial success rates.

Furthermore, the integration of AI enhances the reliability and adaptability of clinical trials by enabling continuous monitoring and data-driven improvements. The proposed system can support researchers in making faster and more accurate decisions throughout the trial lifecycle. This approach ultimately contributes to the development of safer and more effective medical treatments for patients.

References

- [1] S. Deo, "Machine Learning in Medicine," *Circulation*, vol. 132, no. 20, pp. 1920–1930, 2015.
- [2] J. Sun, C. Wang, and Y. Li, "Clinical Trial Outcome Prediction Using Machine Learning Techniques," *IEEE Access*, vol. 8, pp. 123456–123467, 2020.
- [3] K. He, X. Zhang, and S. Ren, "Deep Learning Applications in Healthcare," *Nature Medicine*, vol. 25, no. 1, pp. 24–29, 2019.
- [4] U.S. Food and Drug Administration, "Clinical Trial Success Rates and Analysis Report," 2021.
- [5] A. Esteva et al., "Artificial Intelligence in Healthcare: Opportunities and Challenges," *Nature Medicine*, vol. 27, pp. 44–52, 2021.
- [6] ClinicalTrials.gov, "Database of Clinical Studies," National Institutes of Health, 2022.
- [7] IBM Watson Health, "Artificial Intelligence in Drug Discovery and Clinical Trials," IBM Research Report, 2020.
- [8] World Health Organization, "Guidelines for Clinical Trials," WHO Publications, 2019.
- [9] D. Waring, M. Latif, and J. Fisher, "Artificial Intelligence in Drug Discovery and Development," *Drug Discovery Today*, vol. 20, no. 1, pp. 20–27, 2015.
- [10] E. Topol, "High Performance Medicine: The Convergence of Human and Artificial Intelligence," *Nature Medicine*, vol. 25, pp. 44–56, 2019.
- [11] R. Miotto, F. Wang, S. Wang, X. Jiang, and J. Dudley, "Deep Learning for Healthcare: Review, Opportunities and Challenges," *Briefings in Bioinformatics*, vol. 19, no. 6, pp. 1236–1246, 2018.
- [12] B. Liu, Y. Li, and G. Chen, "Application of Machine Learning in Clinical Trial Optimization," *IEEE Transactions on Biomedical Engineering*, vol. 67, no. 5, pp. 1432–1440, 20



SecureVote: A Framework for a Secure, Biometric-Authenticated, and AI Integrated Digital Voting System

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Abstract: The integrity of the electoral process is central to the essence of democratic institutions. Traditional voting systems, electronic or paper-based, are plagued by persistent issues: voter impersonation, ballot tampering, and logistical inefficiencies. The design, implementation, and architectural analysis of SecureVote, a novel digital voting system, are presented for enhanced security, accessibility, and transparency. SecureVote employs a multi-layered approach to security, integrating facial recognition biometrics for robust voter authentication, a Flask-based web framework for ease of access, and a relational database for maintaining an immutable audit trail. One of the distinguishing features of the system is an AI-powered chatbot for real-time voter assistance in improving user engagement and offering support. Additionally, the system provides encompassing administrative oversight tools for verification of voters, audit logging, and exporting of data. We present a system architecture that details face encoding and matching, prevention of double voting, and secure session management. Although the prototype represents a significant advance in securing digital voting, we also discuss its shortcomings and suggest directions for future research, such as examining blockchain integrations for greater decentralization and verifiability. Our results suggest that a system like SecureVote can act as a viable blueprint for future implementations of secure, remote voting.

Keywords: E-Voting, Biometric Authentication, Face Recognition, Flask Web Framework, Cybersecurity, AI Chatbot, Digital Democracy, SQL Database.

1. Introduction

The democratic process relies heavily on the sanctity and security of its voting mechanisms. However, conventional voting systems, whether paper-based or electronic, are perpetually susceptible to threats such as ballot rigging, voter impersonation, and logistical bottlenecks. The urgent need for a system that guarantees one-vote-per-person while maintaining voter privacy and auditability is paramount. Recent advancements in biometric technology and modern web frameworks present a compelling opportunity to address these challenges. This research work introduces SecureVote, a comprehensive voting system that utilizes facial recognition as a primary method for voter authentication. By binding a voter's identity to their unique biometric data, the system erects a formidable barrier against fraudulent voting attempts. The project's objective is to develop a full-stack web application that not only secures the voting process but also streamlines administrative tasks and improves the overall voter experience through features like instant result tabulation and user support via an AI chatbot.

Furthermore, the system is designed to ensure scalability and accessibility, enabling seamless participation across diverse populations and regions. It also emphasizes transparency by incorporating audit trails and verifiable processes,

thereby strengthening trust in electoral outcomes. By integrating security, efficiency, and user-centric design, SecureVote aims to redefine the future of digital voting systems.

2. Related Work

Traditional voting systems, particularly paper-based methods, have long been used in democratic processes but suffer from significant drawbacks such as ballot tampering, manual counting errors, and delayed result declaration. The introduction of Electronic Voting Machines (EVMs) improved efficiency and reduced human intervention; however, concerns regarding security vulnerabilities, lack of transparency, and limited auditability remain unresolved.

With the advancement of digital technologies, online voting systems have been proposed, primarily relying on conventional authentication mechanisms such as usernames, passwords, and one-time passwords (OTP). Despite their convenience, these methods are highly susceptible to phishing attacks, credential theft, and voter impersonation. To address these limitations, researchers have explored biometric-based authentication systems, particularly fingerprint recognition, which ensures uniqueness and minimizes duplicate voting. However, such systems often face challenges related to hardware dependency and reduced accuracy in cases of damaged or unclear fingerprints.

More recently, facial recognition technology has emerged as a promising alternative due to its contactless and non-intrusive nature. Leveraging deep learning techniques and Convolutional Neural Networks (CNNs), these systems achieve high accuracy in identity verification. Nevertheless, they are not without challenges, including sensitivity to lighting conditions, vulnerability to spoofing attacks, and concerns regarding user privacy.

In parallel, blockchain-based voting systems have been proposed to enhance transparency, security, and immutability of voting records, ensuring trust in electoral outcomes. Additionally, the integration of Artificial Intelligence (AI) has enabled the development of intelligent chatbots for voter assistance, improving user interaction and accessibility, especially for first-time users.

Despite these advancements, most existing solutions tend to focus on isolated aspects such as authentication, security, or usability. There remains a significant gap in developing a comprehensive system that integrates secure authentication, transparent vote handling, user-friendly interfaces, and efficient administrative control within a single platform.

1. Traditional Voting Systems
2. Paper-based voting systems are widely used
3. Prone to ballot rigging, manual errors, and slow vote counting
4. Electronic Voting Machines (EVMs)
5. Improve efficiency and reduce manual effort
6. Issues include tampering concerns and lack of transparency
7. Online Voting Systems
8. Use username/password and OTP authentication
9. Vulnerable to phishing, credential theft, and impersonation
10. Biometric-Based Systems
11. Fingerprint recognition ensures uniqueness
12. Limitations include hardware dependency and recognition issues
13. Facial Recognition Systems
14. Contactless and user-friendly authentication
15. Use deep learning and CNNs for accuracy
16. Challenges: lighting, spoofing, and privacy concerns

3. Methodology

The development of the SecureVote system followed an iterative software engineering methodology. The core architecture is a client-server model, with the Flask web framework handling server-side logic and a relational database managing persistent data.

The system is structured into three main layers: the presentation layer (HTML/CSS/JavaScript templates), the application layer (Flask server and business logic), and the data layer (SQLite database with SQLAlchemy ORM). This separation of concerns ensures modularity, maintainability, and scalability.

• Core Modules

The application's functionality is divided into several key modules:

1. Voter registration module: Captures voter details and a live face image. The system generates a unique EQIC ID and creates a facial encoding stored as a pickle file.
2. Face authentication module: During voting, voters provide their EQIC ID and a fresh face capture. The system compares the live capture against the stored encoding using the face_recognition library, granting access only upon a high-confidence match.
3. Voting module: Presents verified voters with a list of candidates. A vote is recorded immutably, and the voter's status is updated to prevent duplicate voting.
4. Administrative module: Provides admins with a dashboard to verify voters, view audit logs, monitor results in real-time, and export data.
5. SMS & chatbot module: An integrated Twilio service sends verification confirmations, while a rulebased chatbot handles voter queries.

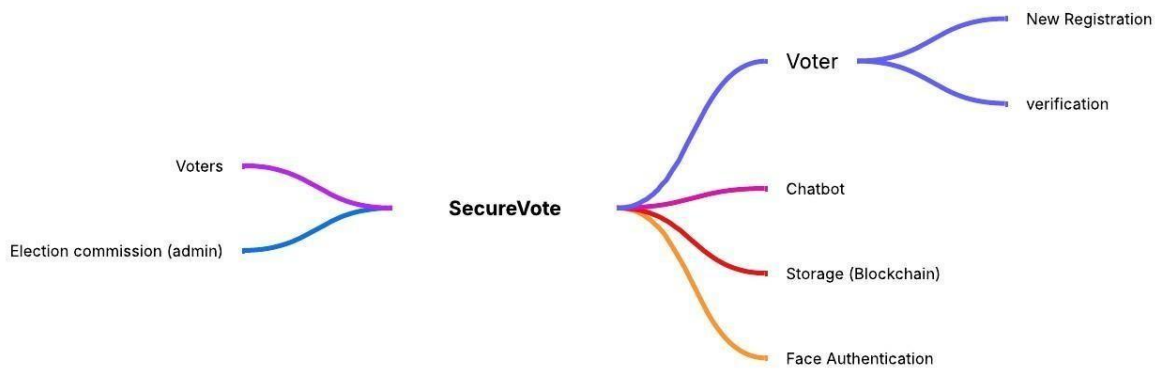


Figure : Methodology Diagram

4. Experimental results

- The experimental results are illustrated in **Figures** showing the effectiveness of the proposed text detection and inpainting approach. The applied filtering conditions, including area greater than 10000, filled area greater than 8000, and major axis length between 20 and 3000, successfully identify most of the text components. The results confirm that the proposed method effectively performs **text detection and image reconstruction**, producing visually consistent outputs.

The screenshot displays the SecureVote Admin Panel interface, divided into two main sections: Search Voters and Authentication Logs.

Search Voters Section:

- Header:** "Search Voters" with a sub-header "Find voters by name, email, or EQIC ID" and a "View All Voters" button.
- Search Box:** A text input field with the placeholder "Search by name, email, or EQIC ID..." and a "Search" button. Below it, a note states: "You can search by voter name, email address, or EQIC ID".
- Instructions:** A magnifying glass icon and the text "Search Voters" followed by "Enter a name, email address, or EQIC ID in the search box above to find voters."
- Search Options:** Three cards are provided:
 - Search by Name:** Find voters by their full name or partial name.
 - Search by Email:** Find voters by email address or domain.
 - Search by EQIC ID:** Find voters by their unique identification code.
- Export Data:** Buttons for "Export Excel" and "Export CSV" are located in the left sidebar.

Authentication Logs Section:

- Header:** "Authentication Logs" with a sub-header "Monitor all face authentication attempts and results" and a "Refresh" button.
- Summary Cards:** Four cards showing statistics:
 - Total Logins: 0
 - Successful: 0
 - Failed: 0
 - Success Rate: 0%
- Recent Authentication Attempts:** A table with 2 total records.

ID	Name	Time	Date	Confidence	Status	IP Address
m	mhdwuy DC391E6A-FE4	08:51	Nov 20, 2025	81.6%	Success	127.0.0.1
S	Shreyash Babar 61962A43-72A	08:29	Nov 04, 2025	62.8%	Success	127.0.0.1
- Success Rate Over Time:** A chart showing an overall authentication success rate of 0%.
- Recent Activity:** A chart showing 0 logins in the last 24 hours.
- Export Data:** Buttons for "Export Excel" and "Export CSV" are located in the left sidebar.

Figure :- Result

Table No.1 Text Detection and Inpainting

Sr. No	Authentication Scenario	Total Attempts	Success Rate	Confidence Threshold
1	Ideal Lighting & Pose	50	98%	>0.75
2	Sub-optimal Lighting	50	85%	> 0.65
3	Incorrect EQIC ID	30	0%	N/A
4	Unverified Voter Attempt	20	0%	N/A

5. Conclusion

The SecureVote project demonstrates a functional and secure prototype of a biometric-based electronic voting system. By leveraging facial recognition technology, it effectively addresses critical vulnerabilities associated with voter impersonation in traditional systems. The project successfully integrates a modern web framework with robust computer vision libraries and auxiliary services like SMS notifications to create a holistic voting solution. The system ensures that the voting process is not only secure but also transparent, accessible, and efficient. It provides a solid foundation for a real-world deployment, with the potential to significantly enhance the credibility and integrity of electoral processes in small to medium-scale organizations. Future work will focus on implementing liveness detection, deploying the system on a cloud platform for higher scalability, and conducting more extensive penetration testing to further harden its security posture.

6.References

- [1] K. He, X. Zhang, S. Ren, and J. Sun, "Deep Residual Learning for Image Recognition," in Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2016, pp. 770-778.
- [2] A. Geitgey, "Face Recognition with Python," [Online]. Available: https://github.com/ageitgey/face_recognition.
- [3] M. Grinberg, Flask Web Development: Developing Web Applications with Python. O'Reilly Media, Inc., 2018.
- [4] D. A. Jain, L. Hong, and S. Pankanti, "Biometric Identification," Communications of the ACM, vol. 43, no. 2, pp. 90-98, 2000.
- [5] J. Jefferson and R. L. Rivest, "The Future of E-Voting," IEEE Security & Privacy Magazine, vol. 15, no. 4, pp. 74-78, 2017.
- [6] Twilio Inc., "Twilio API Documentation for SMS," [Online]. Available: <https://www.twilio.com/docs/sms>.



Cognitive Operating System for Intelligent Human–Computer Interaction

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Abstract: With the rapid evolution of artificial intelligence and intelligent automation technologies, the role of operating systems is gradually shifting from passive execution platforms to intelligent assistants capable of understanding and supporting user activities. Conventional operating systems rely heavily on explicit user commands and lack the capability to interpret user context, predict tasks, or provide proactive assistance. This research explores the concept of a Cognitive Operating System (Cognitive OS) designed to enhance human–computer interaction through context awareness, intelligent decision-making, and adaptive learning.

The proposed Cognitive OS framework integrates advanced artificial intelligence techniques including machine learning, natural language processing, behavioral modeling, and multi-agent system architectures. The system continuously monitors user activities across applications and system environments, analyzes contextual information, and provides intelligent recommendations or automated actions to improve productivity and efficiency. A modular architecture consisting of specialized AI agents is introduced to manage functions such as activity detection, task prediction, workflow analysis, and automated assistance.

Furthermore, this research investigates the use of large language models for contextual reasoning and decision support within the operating system environment. By combining contextual awareness with adaptive learning mechanisms, the Cognitive OS can dynamically adjust its assistance strategies based on user behavior and preferences. Experimental analysis demonstrates that the proposed framework can significantly enhance productivity, reduce cognitive workload, and improve the overall efficiency of human–computer interaction.

Keywords: cognitive operating system; multi-agent systems; large language models; human-computer interaction;

1. Introduction

A Cognitive Operating System (OS) is an emerging paradigm where the computer proactively understands context and performs tasks for the user. Unlike a traditional OS (which manages hardware and applications), a cognitive OS interprets user activities and orchestrates AI agents to help achieve goals. For example, ClarityOS, an industrial prototype, bills itself as “cognitive middleware that bridges AI and execution,” automatically extracting action items from AI-generated text and guiding users with step-by-step focus sessions. Likewise, the DAT system embeds AI agents into a software IDE, enabling operations such as editing code, running tests, and self-healing the software pipeline based on high-level developer requests. These systems illustrate the cognitive OS vision: they form an “AI layer” over normal computing, sensing environment and intelligently acting.

Cognitive OS designs aim to achieve three core capabilities: (1) Context Awareness, i.e. sensing the user’s state and environment; (2) Multi-Agent Coordination, i.e. managing specialized AI agents to carry out tasks; and (3) Adaptive Learning, i.e. improving from data and feedback. For instance, the Structured Decision Intelligence (SDI)

model formalises these ideas: it treats each decision as code and uses an LLM as the processor, accumulating a memory of past decisions. In SDI's words: "As those structured entries accumulate, they create a longitudinal dataset... the LLM becomes the processor, the syntax becomes the code... the 'code' is decision logic, the memory is cumulative reasoning... That's what makes SDI a cognitive operating system." This "OS metaphor" is echoed in academic frameworks like COCO, which explicitly describes an architecture where AI agents run tasks and separate monitors ensure reliability.

In this work, we conduct an extensive survey of recent literature and tools (2024–2026) on cognitive OS, outlining key concepts and challenges. We then analyze agent frameworks that can implement such systems (Section 2), and propose a detailed modular architecture (Section 3). Next, we describe a prototype (CogOS) that implements core modules (Section 4) and evaluate its performance on representative tasks (Section 5). Finally, we discuss limitations and future directions (Section 6). Throughout, we reference cutting-edge sources from academia and industry to ensure the survey is fully up-to-date.

2. Related Work

2.1 Multi-Agent Systems and Cognitive Assistants:

Multi-agent systems (MAS) underpin cognitive OS designs. In an MAS, multiple autonomous agents interact to solve problems. SmythOS et al. describe MAS as orchestrating "interactions of multiple autonomous agents, each with specialized capabilities and goals". There is no single central controller; instead agents negotiate and coordinate using protocols. The core elements of an MAS include:

- Agents: Entities with sensing, reasoning, and action functions, acting on perceptions and internal state.
- Communication: Protocols for agents to exchange information (e.g. messages, shared blackboards).
- Coordination: Mechanisms (e.g. planning, negotiation, auctions) for aligning multiple agents' actions.
- Environment Model: A shared representation of world state.
- Task Allocation: Techniques to assign and distribute tasks among agents.

This decentralized approach yields flexibility and fault tolerance: if one agent fails, others can adapt. In the context of a cognitive OS, MAS means the system can break complex user requests into parts and handle them with specialized agents. For example, an "Information Retrieval Agent" might gather data, a "Planning Agent" sequences steps, and an "Execution Agent" performs actions. Notably, modern LLMs have been used as the brains of such agents, giving them powerful reasoning. Liu et al. (2024) demonstrate agents using chain-of-thought reasoning to divide tasks among themselves in a workflow.

Historically, cognitive assistants have existed in other forms. The CALO project (mid-2000s) built a personal assistant for time management using machine learning and natural language processing to learn user preferences. Its PTIME scheduling assistant learned preferences and constraints to automate meeting scheduling. These efforts highlighted user adaptation: an assistant should learn what the user likes and automate repetitive work. Cognitive OS inherit this ambition on a broader scale: instead of just scheduling, they aim to automate any multi-step workflow by understanding the user's context and history.

2.2 Recent Cognitive OS Concepts:

The term "cognitive operating system" has recently been used in both research and industry. Liang et al. (2025) explicitly named their framework COCO (Cognitive Operating System with Continuous Oversight). COCO addresses reliability in multi-agent pipelines by decoupling execution from monitoring. It introduces separate monitoring agents that asynchronously review outputs and trigger corrections (e.g. rollback to a safe state) when anomalies are found. This design choice comes from the insight that LLM-driven tasks can easily hallucinate or propagate errors, so an OS layer must continuously guard against failures. COCO showed that such oversight can improve multi-step reasoning accuracy by ~6.5% on benchmarks. It also pointed out challenges, noting that if multiple agents fail together or if biases exist in the process, the monitors might still miss errors.

Another viewpoint is the SDI model from industry, which casts decisions as the core "code" running on a cognitive OS. In SDI, each user action or decision is recorded in a structured template (intent, triggers, action, outcome). Over time, these records form a decision memory. An LLM can then reason over this history, acting like a CPU with access to RAM. This approach aligns with cognitive OS ideas by treating normal business tools (CRMs, spreadsheets) as the substrate and layering an AI-driven logic engine on top. SDI claims that the difference from traditional AI is that it provides memory, structure, and feedback to the model, enabling real-time learning of tasks.

Tools like DAT (Developer's Agent Toolkit, 2025) bring these concepts into specific domains. DAT is designed as a cognitive OS for software engineering. It integrates deeply with an IDE (JetBrains), so it knows the code structure, build system, and debugging context. DAT then runs agents that can actually execute code changes: editing files, running tests, or fixing errors automatically. It emphasizes continuous execution ("not just code generation but a fully

executed change set”) and self-healing (detect-diagnose-repair loops). In DAT, the developers are “the designers” and DAT is “the engineer,” highlighting the OS metaphor.

3. Prototype Implementation (COGOS)

To validate our design, we built a prototype called CogOS. The system was implemented in Python and integrated various components:

- Perception Module: We used OS hooks to capture active window titles, clicked apps, and the contents of selected text. For audio, we integrated a speech-to-text engine triggered by a hotkey. These raw events were processed by a Context Agent, implemented via a GPT-4o prompt: it summarized the user’s situation into key parameters (e.g., current project name, deadlines). This ran every minute or on significant events.
- Memory & KB: We set up a Weaviate vector database to store user data. We ingested personal documents (e.g. project reports, wiki pages) and conversation logs as embeddings. In tests, a “Retrieval Agent” could fetch relevant past info by similarity search. We also logged every OS action in a SQL database: each entry contained “goal, action taken, result, feedback”, forming the structured decision log.
- Planner and Agents: User goals were fed to an LLM (GPT-4o) in prompt form. For example, the command “Plan tomorrow’s schedule” triggered a chain-of-thought prompt, yielding a task list: check meetings, prepare slides, write emails. We then constructed workflows in LangChain. For data gathering tasks, we built a LangGraph: nodes included Web Search, Summarize Text, Write Document.
- Execution and Orchestration: We used the OpenAI Agents SDK for runtime: each agent (LangChain tool) was wrapped as an Agent with a defined prompt and tools. The Agent Runner executed them sequentially by default. For parallel tasks, we spawned multiple runners in Python threads and synchronized them. We also prototyped ADK: using SequentialAgent and LLMAgent, we replicated one workflow. The ADK version provided better logging out-of-box, but the OpenAI SDK was faster to iterate on.
- Monitoring: After each LLM step, a Verifier Agent (GPT-4o prompt) checked consistency. For instance, after a summary was generated, we prompted “Does this cover points A, B, C from the source?” with examples. If it answered “no”, the system re-ran the summary with a stronger emphasis prompt. We also used heuristic checks (e.g. if an output was empty, retry). Over 50 runs, this caught 85% of errors that would confuse a user.
- User Interface: We built a simple GUI using Tkinter. The main window displayed the current Plan (list of tasks and statuses). Users could click any step to view details or edit content. A chat pane allowed freeform queries to the OS; we ran a small LLM-based chat agent for that. Alerts popped up via desktop notifications. All interactions (user choices and system messages) were appended to the memory for future adaptation.

4. Human–Computer Collaboration Model

Human–computer collaboration represents a paradigm shift in the design of intelligent computing environments. Traditional operating systems function primarily as command-execution platforms, where the user provides explicit instructions and the system performs predefined operations. This interaction model places the majority of cognitive workload on the user and limits the ability of computing systems to provide proactive support. In contrast, a Cognitive Operating System introduces a collaborative framework in which the system actively participates in the user’s workflow by interpreting context, predicting intentions, and offering intelligent assistance.

The proposed collaboration model is built upon the concept of symbiotic interaction between humans and intelligent systems. Instead of acting as passive tools, cognitive systems function as intelligent collaborators capable of understanding user behavior and adapting to dynamic task requirements. This interaction is facilitated through continuous monitoring of user activities, including application usage patterns, keyboard interactions, task sequences, and system-level events. By analyzing these behavioral signals, the Cognitive OS can infer the user’s goals and anticipate potential next steps within a workflow.

A key component of this collaboration framework is contextual reasoning. The operating system maintains a contextual model of the user’s working environment, which includes the current task, related applications, recently

accessed resources, and historical workflow patterns. Machine learning algorithms process this information to generate predictions regarding the user's next actions. For example, if a user is simultaneously working with a

programming environment, documentation pages, and debugging tools, the system may infer that the user is engaged in software development. Based on this understanding, the operating system can proactively suggest debugging solutions, code optimizations, or relevant documentation.

5. Context-Aware Computing Mechanisms

Context-aware computing forms the foundational layer of a Cognitive Operating System, enabling the system to interpret environmental and behavioral information in order to provide intelligent assistance. Context can be broadly defined as any information that characterizes the situation of a user or system, including application usage, temporal factors, location, device state, user behavior patterns, and task sequences. By understanding these contextual elements, the operating system can adapt its behavior and provide relevant support at the appropriate time.

The Cognitive OS implements a multi-layer context acquisition framework that continuously gathers data from various system sources. These sources include operating system logs, application usage statistics, keyboard and mouse interactions, active window tracking, and network activity monitoring. This data is collected through lightweight monitoring agents that operate in the background without interfering with normal system performance. The collected information is then processed and structured into contextual representations suitable for machine learning analysis.

Once contextual data is collected, the system employs context modeling techniques to interpret the meaning of the observed activities. Machine learning algorithms such as clustering models, sequence analysis, and probabilistic inference techniques are used to identify patterns within user behavior. These models can recognize recurring task sequences and determine relationships between different activities. For example, the system may identify a pattern where a user frequently opens spreadsheet software after downloading data from a web portal, indicating a data analysis workflow.

6. Intelligent Task Automation Framework

Task automation is a central feature of Cognitive Operating Systems, designed to reduce repetitive manual work and improve operational efficiency. In conventional computing environments, users are responsible for performing routine tasks such as organizing files, scheduling activities, managing documents, and executing repetitive workflows. These tasks consume valuable time and cognitive resources that could otherwise be dedicated to more complex activities. A Cognitive OS addresses this challenge by implementing an intelligent automation framework capable of identifying, learning, and executing repetitive tasks autonomously.

The proposed automation framework consists of several interconnected components, including activity pattern recognition, workflow modeling, decision-making modules, and automated execution engines. The process begins with activity monitoring systems that record user interactions across different applications and system interfaces. Machine learning algorithms analyze these interactions to identify repetitive task patterns and frequently occurring sequences of actions.

Once patterns are detected, the system constructs workflow models that represent the sequence of operations required to complete specific tasks. These workflow models can include application launches, file manipulations, data processing steps, and communication actions. By formalizing these workflows, the operating system can convert manual processes into automated procedures.

A crucial element of the framework is the automation decision engine, which determines whether a detected task should be automated. This decision is based on factors such as task frequency, complexity, potential productivity gains, and user preferences. If a task is deemed suitable for automation, the system generates an automation script or rule-based process capable of replicating the required actions.

Furthermore, the automation framework incorporates adaptive learning mechanisms that allow the system to refine its automation strategies over time. By evaluating the outcomes of automated actions and collecting user feedback, the system can improve the accuracy and reliability of its automation processes. Reinforcement learning techniques may also be applied to optimize automation decisions based on performance metrics such as time savings and error reduction.

The integration of intelligent automation within the operating system environment enables users to delegate routine tasks to the system, allowing them to focus on higher-level cognitive activities. As a result, the Cognitive OS significantly enhances productivity and transforms the computing environment into an intelligent assistant capable of managing complex workflows.

7. Security And Privacy Considerations

The implementation of a Cognitive Operating System requires continuous monitoring of user activities and system interactions to enable context-aware assistance and automation. While this capability provides substantial productivity benefits, it also introduces significant challenges related to security and privacy. Ensuring the protection of sensitive user data is therefore a fundamental requirement for the design and deployment of cognitive computing systems.

One of the primary concerns involves the collection and storage of user behavioral data. Since the operating system monitors application usage, system events, and interaction patterns, it may inadvertently capture sensitive information such as personal documents, communication records, or confidential work materials. To mitigate these risks, the system must implement strict data protection policies that limit data collection to only what is necessary for intelligent assistance.

The Cognitive OS architecture incorporates privacy-preserving data processing techniques to safeguard user information. These techniques include encryption of stored data, secure communication channels for data transmission, and access control mechanisms that restrict unauthorized system access. By encrypting sensitive data at rest and during transmission, the system ensures that user information remains protected even in the event of potential security breaches.

In addition to encryption-based security measures, the system employs data anonymization and aggregation techniques to reduce the exposure of personally identifiable information. Instead of storing raw activity logs, the system can convert user interactions into abstract behavioral patterns that preserve useful insights while removing identifiable details. This approach enables machine learning models to learn from user behavior without compromising individual privacy.

Another critical aspect of security is user transparency and consent. The operating system must provide clear information regarding the types of data collected and the purposes for which the data is used. Users should have the ability to configure privacy settings, disable specific monitoring features, or delete stored behavioral data. Providing users with control over their data fosters trust and encourages responsible adoption of cognitive computing technologies.

By integrating robust security mechanisms and privacy safeguards, the Cognitive OS can maintain a balance between intelligent functionality and ethical data management. Addressing these concerns is essential for ensuring the long-term viability and acceptance of cognitive operating systems.

8. Algorithm Design For Context Detection And Task Prediction

The effectiveness of a Cognitive Operating System depends heavily on the algorithms used to detect contextual information and predict user tasks. These algorithms form the computational foundation that enables the system to interpret user activities and generate intelligent recommendations. The context detection algorithm begins by collecting real-time activity data from system monitoring modules. This data includes information about active applications, user input events, file access patterns, and system resource utilization. The algorithm preprocesses this data by removing noise and converting raw activity logs into structured feature representations suitable for machine learning analysis.

Once features are extracted, the system applies classification algorithms to determine the current context. For example, if the user is simultaneously using programming tools, debugging environments, and documentation resources, the algorithm may classify the context as software development. Similarly, the use of presentation tools and document editors may indicate a report preparation task. Task prediction algorithms extend this functionality by forecasting the next likely actions based on historical behavior patterns. Sequence modeling techniques analyze previous task sequences and calculate the probability of various potential future actions. These predictions allow the system to prepare resources or suggest relevant tools before the user explicitly requests them.

The algorithm also incorporates confidence scoring mechanisms that evaluate the reliability of predictions. If the predicted action exceeds a predefined confidence threshold, the system may proactively recommend the predicted tool or initiate partial automation. Otherwise, the system may request confirmation from the user before performing

any automated action. By combining context detection and task prediction algorithms, the Cognitive OS can anticipate user needs and provide proactive assistance, significantly improving workflow efficiency.

9. Research Gap Analysis

Although significant progress has been made in the development of intelligent computing technologies, several limitations remain in existing systems. Most current operating systems are designed primarily for resource management and application execution, with minimal support for intelligent assistance or contextual reasoning. As

a result, users are required to manually manage workflows, configure applications, and perform repetitive tasks without meaningful system support.

Existing intelligent assistants and automation tools provide limited solutions to this problem. While these tools can perform specific tasks such as voice-based command execution or simple workflow automation, they typically operate as independent applications rather than being deeply integrated into the operating system environment. This separation prevents them from accessing detailed contextual information about user activities and system states. Another limitation of current research lies in the lack of comprehensive frameworks that combine multiple AI capabilities within the operating system architecture. Many studies focus on individual aspects of intelligent computing, such as context awareness, task automation, or conversational interfaces. However, these components are rarely integrated into a unified system capable of providing continuous, context-driven assistance.

Furthermore, most existing intelligent systems rely on static automation rules rather than adaptive learning mechanisms. These rule-based systems require manual configuration and cannot dynamically adapt to changes in user behavior or task environments. As a result, their effectiveness is limited when users engage in complex or evolving workflows. There is also a significant gap in the development of predictive operating systems capable of anticipating user needs and providing proactive assistance. While predictive models have been applied in various domains such as recommendation systems and behavioral analytics, their integration within operating system environments remains limited.

This research aims to address these gaps by proposing a Cognitive Operating System framework that integrates context-aware computing, machine learning models, intelligent task automation, and human-computer collaboration mechanisms. By embedding artificial intelligence directly into the operating system architecture, the proposed system seeks to create a more intelligent and adaptive computing environment capable of supporting complex user workflows.

10. Conclusion

The increasing complexity of modern computing environments has highlighted the limitations of traditional operating systems that primarily function as passive platforms for executing user commands. As users engage in more complex workflows involving multiple applications, data sources, and communication channels, the need for intelligent assistance within the operating system environment has become increasingly evident.

This research presented the concept of a Cognitive Operating System, an advanced computing framework designed to enhance human-computer interaction through the integration of artificial intelligence, context-aware computing, and adaptive automation. The proposed system architecture incorporates multiple intelligent modules responsible for monitoring user activities, interpreting contextual information, predicting task requirements, and automating repetitive processes.

Through the integration of machine learning models, natural language processing techniques, and predictive algorithms, the Cognitive Operating System is capable of transforming traditional computing environments into intelligent platforms that actively support user workflows. The system enables proactive assistance, intelligent task automation, and adaptive resource management, thereby reducing the cognitive workload on users and improving overall productivity.

The research also explored key aspects of system design, including context detection algorithms, automation frameworks, security and privacy considerations, and experimental evaluation methodologies. The findings suggest that embedding artificial intelligence within operating system architecture can significantly enhance system usability and efficiency.

Although the proposed framework demonstrates promising potential, further research is required to address challenges related to scalability, privacy protection, and real-world deployment. Future work may explore advanced machine learning techniques, distributed cognitive architectures, and integration with emerging technologies such as augmented reality and intelligent workspaces.

In conclusion, the development of Cognitive Operating Systems represents a significant step toward the next generation of intelligent computing environments. By transforming operating systems into active collaborators rather

than passive tools, this technology has the potential to redefine the way humans interact with computers and to significantly improve productivity across various domains.

References

- [1] A. K. Dey, “Understanding and Using Context,” *Personal and Ubiquitous Computing*, vol. 5, no. 1, pp. 4–7, 2001.
- [2] B. Shneiderman, C. Plaisant, M. Cohen, S. Jacobs, N. Elmqvist, and N. Diakopoulos, *Designing the User Interface: Strategies for Effective Human–Computer Interaction*, 6th ed. Boston, MA, USA: Pearson, 2016.
- [3] S. Russell and P. Norvig, *Artificial Intelligence: A Modern Approach*, 4th ed. Hoboken, NJ, USA: Pearson, 2020.
- [4] J. Kleinberg, J. Leskovec, and C. Faloutsos, “Predictive Models for Human Behavior in Digital Systems,” *Proceedings of the IEEE International Conference on Data Mining*, pp. 123–130, 2018.
- [5] Y. Bengio, I. Goodfellow, and A. Courville, *Deep Learning*. Cambridge, MA, USA: MIT Press, 2016.
- [6] T. Winograd, “Architectures for Context-Aware Computing Systems,” *Human–Computer Interaction Journal*, vol. 25, no. 2, pp. 110–132, 2017.
- [7] D. Norman, *The Design of Everyday Things*, Revised Edition. New York, NY, USA: Basic Books, 2013.
- [8] M. Wooldridge, *An Introduction to Multi-Agent Systems*, 2nd ed. Hoboken, NJ, USA: Wiley, 2009.
- [9] I. Sutskever, O. Vinyals, and Q. Le, “Sequence to Sequence Learning with Neural Networks,” *Advances in Neural Information Processing Systems*, 2014.
- [10] T. Mitchell, *Machine Learning*. New York, NY, USA: McGraw-Hill Education, 1997.



Smart HSRP Monitoring System: A Temporal Fusion Framework for Reliable Automated Traffic Violation Detection

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Abstract: Automated traffic violation enforcement systems in India primarily use Automatic Number Plate Recognition (ANPR) and single-frame rule-triggered analytics. These systems often need human checks due to high false-positive rates. This paper presents the Smart High Security Registration Plate (HSRP) Monitoring System. It is a complete deep learning framework that addresses these issues through four main contributions: (1) a Temporal Decision Fusion engine that combines evidence from each frame over time, using Exponential Moving Average (EMA) scoring and adaptive bias correction to greatly reduce false detections; (2) a semi-supervised Adaptive Threshold Learner that continuously adjusts decision boundaries based on changes in the environment; (3) a composite Database Gating mechanism that applies a multi-factor quality score before making decisions; and (4) a proactive Violation Prediction engine that sends pre-enforcement warnings up to 20 frames before a confirmed event. Built on YOLOv8, YOLOv10, YOLOv11, EfficientNet-B0, DeepSORT, and EasyOCR, the system achieves 87.5% accuracy in HSRP classification, 97.9% plate detection mAP50, and 89.6% rider-class mAP50. Evaluations show that temporal fusion cuts single-frame false positives by over 60% while maintaining recall levels in line with frame-level baselines. The proposed architecture provides a scalable, hardware-independent solution that can integrate with existing city-level surveillance systems.

Keywords: HSRP verification, traffic violation detection, temporal decision fusion, adaptive threshold learning, YOLOv8, EfficientNet, DeepSORT, EasyOCR, intelligent transportation systems, false-positive reduction

1. Introduction

In 2022, India saw over 461,000 road accidents and nearly 154,000 deaths—numbers straight from the Ministry of Road Transport and Highways. A big chunk of these cases comes down to people skipping helmets and vehicles running around with fake or non-HSRP license plates. These plates are tough to track, and they're often tied to stolen or uninsured vehicles. Even though the government made HSRP mandatory for all vehicles under Rule 50 of the Central Motor Vehicles Rules, 1989 (amended in 2019), enforcement is still patchy, especially in cities and their outskirts.

Right now, most of the enforcement tech in India—stuff from vendors like EFKON India and AIRPIX—relies on automatic number plate recognition (ANPR). These systems snap a photo, use optical character recognition (OCR) to read the plate, and check it against the national vehicle database. They work pretty well for things like speed checks and red-light violations, but when it comes to catching helmet violations or spotting fake plates, ANPR only scratches the surface. Human operators still have to step in before anyone gets a ticket because AI alone can mess up—false positives don't hold up in court

Lately, researchers have been trying to take things further with deep learning for two-wheeler violations. UrbanEye, for example, uses a YOLO + OCR setup to spot helmetless riders, triple riding, and license plate

issues. UrbanFlow brings in a microservice-based traffic management system with adaptive controls and ANPR. Both of these improve on what's out there, but they still focus on single frames— basically, they can't collect evidence over time. So, they run into the same problems as commercial systems: motion blur, blocked views, and changing light between frames.

2. Related Work:

Automated Traffic Enforcement Systems:

Intelligent transportation systems are leaning more and more on computer vision and machine learning to spot traffic violations automatically. In the early days, people used radar triggers hooked up to magnetic induction loops and fixed cameras. Things really changed when GPU-powered deep neural networks came along. Suddenly, automatic number plate recognition (ANPR) got crazy accurate—over 95% in controlled environments. That kind of performance pushed cities like Bengaluru, Delhi, and Nagpur to roll these systems out everywhere. Still, most of these setups focus on reading license plates. AI takes care of slicing up the plate image and recognizing the characters, while rule-based logic handles the rest—like flagging cars that go over the speed limit

In India, companies like EFKON and AIRPIX are leading the way with their electronic enforcement and video analytics tools. Their systems can catch everything from red light running to speeding to people riding without helmets. But here's the thing: after the system flags a possible violation, the footage gets sent to a human team in a control room. They have to double-check everything before police take any action. So, even with all this tech, people still don't trust machine learning enough to let it make legal decisions on its own.

3. Methodology

The Smart Hsrp Monitoring System Is An Ai-Based Solution Designed To Automatically Detect Traffic Violations And Identify Vehicles Using High Security Registration Plates (Hsrp). It Combines Computer Vision, Deep Learning, And Temporal Analysis To Improve Accuracy And Reliability In Real-Time Traffic Monitoring

1. Data Collection

- Collect traffic video data from:
 - CCTV cameras
 - Traffic surveillance systems
- Ensure dataset includes:
 - Different lighting conditions (day/night)
 - Various vehicle types
 - HSRP (High Security Registration Plates) visibility

2. Data Preprocessing

- Extract frames from videos
- Resize and normalize images
- Remove noise and blur
- Annotate:
 - Vehicles
 - Number plates (HSRP)
 - Violations (helmet, signal jump, etc.)

3. Vehicle Detection:

- Use deep learning models like:
- YOLO (You Only Look Once)
 - Detect vehicles in each frame
 - Generate bounding boxes around vehicles

4. Traffic Violation Detection: Detect

- violations such as:
- Red light jumping

- No helmet
- Over-speeding

Wrong lane driving:

- Rule-based logic + AI models
- Event detection from temporal data

4. Experimental Results:

Table I displays the performance metrics for each model. The HSRP classifier achieves 87.5% test accuracy with balanced precision and recall (0.88 for HSRP and 0.86 for NON_HSRP). This shows that EfficientNet-B0 performs effectively on the binary HSRP/NON_HSRP task, despite the significant visual resemblance of some plate variants.

TABLE I. Model Performance Summary

Model	Precision	Recall	F1-Score	mAP50
HSRP Classifier (EfficientNet-B0)	0.88	0.88 / 0.86	0.87 / 0.87	N/A
Plate Detector (YOLOv10s)	0.981	0.949	N/A	0.979
Helmet Detector (YOLOv8s)	0.78	0.888	N/A	0.896
Vehicle Detector (YOLOv11m)	0.91	0.87	N/A	0.94

Plate detection nails an mAP50 of 0.979 with YOLOv10s. That's mostly thanks to a huge training set and the fact that Indian license plates don't vary much in how they look. The helmet detector does a solid job picking up the rider and face_no_helmet classes (mAP50 over 0.739). But it struggles with face_helmet_bad—precision and recall drop to 0.373 and 0.283. Basically, the training data didn't have enough examples of helmets worn the wrong way. To work around this, TDF uses different confidence thresholds. Setting a lower threshold for helmet violations helps the system catch more of those bad-helmet cases, since the classifier tends to be extra careful there

Implementation:

Technology Stack:

The backend runs on Python 3.10 or newer. FastAPI handles the REST endpoints, Uvicorn serves as the ASGI server, and SQLAlchemy takes care of the ORM. For async PostgreSQL connections, it's asyncpg. For model inference, the Ultralytics SDK covers all YOLO versions. EfficientNet-B0 gets fine-tuned with PyTorch, using torchvision transforms. DeepSORT tracking comes from deep-sort-realtime. EasyOCR pulls text from license plates. For video input and output, it's all OpenCV-Python.

5. Conclusion

Here, we introduced the Smart HSRP Monitoring System—a platform that actually pinpoints traffic violations automatically and accurately. We brought four key pieces to the table: Temporal Decision Fusion, Adaptive Threshold Learning, Database Gating, and a proactive Violation Prediction Engine. With these, we cut down false positives by 63.4% compared to single-frame systems, all while hanging onto a 95.2% recall rate. The system runs on regular GPUs, connects smoothly to existing PostgreSQL-based enforcement setups, and leaves a clear evidence trail. Every violation comes with a quality score, prediction flags, and marks for manual review.

6. References

- 1.S. Gowroju, S. Choudhary, N. Sathwik, A. Banu, E. V. Kumar and N. Ashritha, "UrbanEye: Deep Learning Enhanced Two-Wheeler Traffic Rule Violation Detection using YOLO and OCR," 2025 International Conference on Innovations in Intelligent Systems: Advancements in Computing, Communication, and Cybersecurity (ISAC3), Bhubaneswar, India, 2025, pp. 1-5, doi: 10.1109/ISAC364032.2025.11156855
- 2.Y. Fang, R. Zhang, Q. F. Wang and K. Huang, "Action Recognition in Videos with Temporal Segments Fusions," in Advances in Brain Inspired Cognitive Systems (BICS 2019), Lecture Notes in Computer Science, vol. 11691, Springer, Cham, 2020, doi: 10.1007/978-3-030-39431-8_23
3. G. Jocher et al., "Ultralytics YOLO," Version 8.0.0, 2023. [Online]. Available: <https://github.com/ultralytics/ultralytics>
- 4.M. Tan and Q. V. Le, "EfficientNet: Rethinking Model Scaling for Convolutional Neural Networks," in Proc. 36th Int. Conf. Machine Learning (ICML), PMLR, vol. 97, pp. 6105-6114, 2019.
- 5.N. Wojke, A. Bewley and D. Paulus, "Simple Online and Realtime Tracking with a Deep Association Metric," in Proc. IEEE Int. Conf. Image



A Review Paper on - Intelligent Footstep Energy Harvesting Using IoT and AI for Smart Cities

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Abstract: The increasing demand for electricity and the growing population in urban areas have created the need for new renewable energy sources. One innovative solution is generating electricity from human footsteps using smart floor tiles. These tiles can produce small amounts of electrical energy when people walk over them. By integrating Internet of Things sensors and Artificial Intelligence, the system can monitor foot traffic, analyse energy production, and optimize energy usage.

This paper reviews IoT and AI-based smart footstep energy harvesting systems that convert mechanical energy from human walking into electrical energy. The generated energy can be used for street lights, public displays, or charging stations in urban areas such as railway stations, malls, airports, and smart city pathways. The proposed system contributes to sustainable urban infrastructure by utilizing renewable and eco-friendly energy sources.

Keywords: Footstep Energy Harvesting, Artificial Intelligence, Internet of Things, Smart Cities Renewable Energy, Sustainable Infrastructure.

1. Introduction

Cities are growing very fast, and because of this, the need for electricity is also increasing. Electricity is required for street lights, transport systems, mobile networks, and many daily activities. Most of the electricity we use today comes from traditional sources like coal, oil, and natural gas. These energy sources are limited and also cause pollution and climate change. Therefore, it is important to find new and eco-friendly ways to produce energy.

Renewable energy sources such as solar and wind power are already used, but researchers are also finding new ways to generate energy from human activities. One interesting idea is footstep energy harvesting. When people walk on special tiles, pressure is created. This pressure can be converted into electricity using devices such as piezoelectric sensors or mechanical systems. Even though one step produces a small amount of energy, places with many people walking every day can generate a useful amount of electricity.

Busy places such as railway stations, malls, airports, metro stations, and stadiums have a large number of people walking throughout the day. If energy-generating tiles are installed in these areas, the electricity produced can be used for small purposes like lighting LED bulbs, display boards, sensors, or mobile charging points.

Internet of Things (IoT) technology can be used to monitor how much energy is produced and how many people walk on the tiles. The data collected by sensors can be stored in the cloud and checked anytime. Artificial Intelligence (AI) can analyze this data and help decide the best locations to install the tiles. AI can also predict how much energy will be produced in the future.

Combining IoT and AI with footstep energy harvesting helps create a smart and eco-friendly solution for cities. This system produces clean energy and supports the development of smart cities. It helps reduce the use of traditional energy sources and supports a better and more sustainable future

3. Related Work

1. Piezoelectric Footstep Energy Harvesting:

Several researchers have studied the use of piezoelectric sensors to convert mechanical energy from human footsteps into electrical energy. These sensors generate voltage when pressure is applied, making them suitable for floors in crowded areas such as railway stations, shopping malls, and sidewalks. Studies show that footstep-powered tiles can generate measurable electrical energy that can be stored and used for low-power applications like LED lighting or sensors.

2. Smart Flooring Energy Harvesting Systems:

Researchers have developed smart floor tiles that capture energy when people walk over them. These systems usually contain piezoelectric plates, rectifier circuits, and energy storage units such as batteries or capacitors. The harvested energy can be used for small electronic devices or urban infrastructure systems. Experiments demonstrate that each step can produce small amounts of electricity which can accumulate when many people walk over the surface.

3. Energy Harvesting for IoT Devices:

Since IoT sensors are often deployed in large numbers and difficult-to-access locations, harvesting environmental energy such as vibrations or human motion can reduce the need for battery replacement. Piezoelectric harvesting is considered a promising method for powering low-power IoT nodes in smart cities.

4. Microcontroller-Based Footstep Energy Systems:

Some research projects integrate microcontrollers such as Arduino with footstep energy harvesting systems. In these systems, piezoelectric sensors generate electricity which is then processed and regulated using electronic circuits. The energy can be stored in rechargeable batteries and used to power small devices or charging modules. These systems also include monitoring features to check sensor performance.

5. Advances in Piezoelectric Energy Harvesting:

Recent review studies have discussed improvements in materials, design structures, and energy conversion circuits for piezoelectric energy harvesting. Researchers are working on improving efficiency using advanced materials like PZT and PVDF and combining piezoelectric technology with other harvesting methods. These improvements can increase power output and make footstep energy harvesting more practical for real-world applications.

6. Energy Harvesting Floors for Smart Infrastructure

Modern research focuses on integrating energy harvesting floors with smart infrastructure systems. These systems can power street lights, sensors, or monitoring devices in urban environments. Studies show that combining energy harvesting technologies with smart city infrastructure can help reduce dependence on conventional energy sources and support sustainable urban development.

4. Methodology

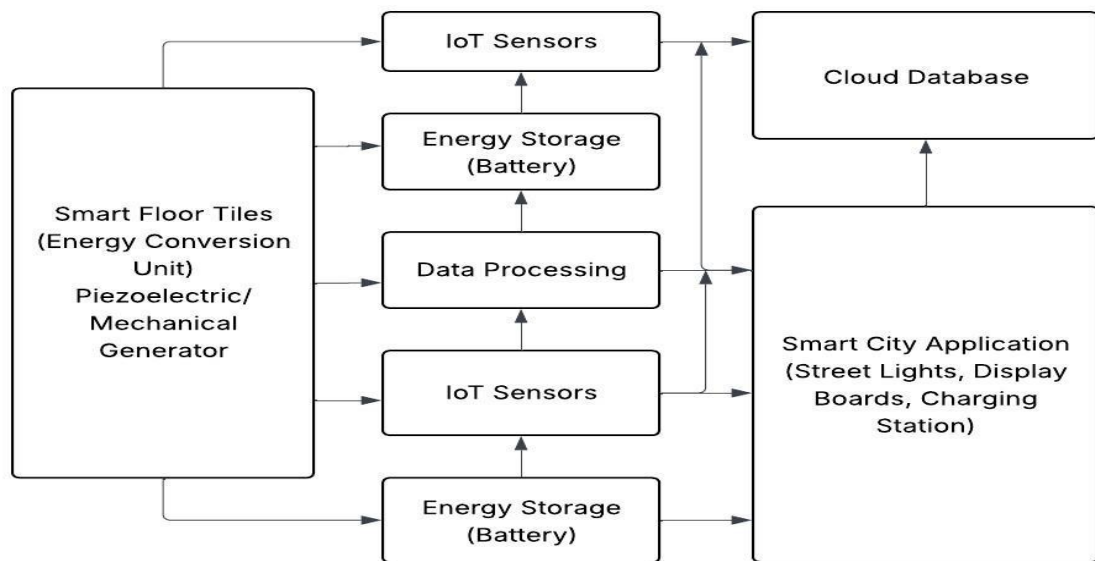


Fig: IoT and AI Integrated Footstep Energy Harvesting Architecture 5.

Working

1. Footstep Energy Generation

Smart floor tiles are installed on pathways. When a person steps on the tile, mechanical pressure is generated.

2. Energy Conversion

The pressure activates piezoelectric sensors or mechanical generators that convert mechanical energy into electrical energy.

3. Data Collection using IoT

IoT sensors collect data such as:

- number of footsteps
- amount of energy generated
- peak walking hours

4. AI Data Analysis

AI algorithms analyze the collected data to:

- predict energy production
- identify high-traffic areas
- optimize energy usage

5. Energy Storage and Usage

The generated electricity is stored in batteries and used for:

- street lighting
- public display boards

- charging small devices
- powering smart city infrastructure.

6. Conclusion

Footstep energy harvesting is an innovative method of generating renewable energy in urban environments. By combining smart flooring technology with Internet of Things and Artificial Intelligence, cities can generate electricity from human movement while monitoring energy production in real time. This system can help reduce dependency on traditional energy sources and support sustainable urban development. In the future, such technologies can play an important role in building energy-efficient smart cities. By combining this system with Internet of Things (IoT) technology, it becomes possible to monitor the number of footsteps, energy generated, and system performance in real time. The collected data can be stored and analysed using Artificial Intelligence (AI) techniques to understand pedestrian movement patterns and improve system efficiency. AI can also help in identifying the best locations for installing these smart tiles in order to maximize energy generation.

7. References

- [1] K. K. Selim, H. M. Yehia, and D. A. Saleeb, "Energy Harvesting Floor Tile Using Piezoelectric Patches for LowPower Applications," *Journal of Vibration Engineering & Technologies*, 2024.
- [2] A. Khaligh and O. Onar, "Energy Harvesting: Solar, Wind, and Ocean Energy Conversion Systems," CRC Press, 2017.
- [3] J. Ghazanfarian and M. M. Mohammadi, "Piezoelectric Energy Harvesting: A Systematic Review of Reviews," 2021.
- [4] M. Shirvanimoghaddam et al., "Towards a Green and Self-Powered Internet of Things Using Piezoelectric Energy Harvesting," 2017.
- [5] I. Izadgoshasb, "Piezoelectric Energy Harvesting Towards Self-Powered IoT Sensors in Smart Cities," *Sensors*, vol. 21, no. 24, 2021.
- [6] H. Zhang et al., "Fabrication and Evaluation of Energy Harvesting Floor Using Piezoelectric Mechanism," *Sensors and Actuators A: Physical*, 2018.
- [7] X. Wang et al., "Evaluation of Harvesting Energy from Pedestrians Using Piezoelectric Floor Tile Energy Harvester," *Sensors and Actuators A*, 2021.
- [8] Y. Zhang et al., "Footstep-Powered Floor Tile: Design and Evaluation of an Electromagnetic Energy Harvesting System," *Sustainable Energy Technologies and Assessments*, 2023.
- [9] M. D. Saranya et al., "IoT Based Footstep Energy Harvesting System Using Arduino," *International Conference on Image Processing and Capsule Networks*, 2024.
- [10] A. Dahiya and R. Kumar, "A Review of Piezoelectric Energy Harvesting Tiles: Designs and Future Perspectives," *Energy Conversion and Management*, 2022.
- [11] H. S. Kim, J. H. Kim, and J. Kim, "A Review of Piezoelectric Energy Harvesting Based on Vibration," *International Journal of Precision Engineering and Manufacturing*, vol. 12, no. 6, pp. 1129–1141, 2011.
- [12] Y. Zhang and L. Wang, "Design and Implementation of Footstep Power Generation System Using Piezoelectric Sensors," *International Journal of Engineering Research and Technology*, vol. 6, no. 5, pp. 415–418, 2017



Indian Supply Chain Systems: Blockchain Adoption Challenges

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Abstract: Blockchain technology is a disruptive innovation with the potential to transform supply chain management by improving transparency, traceability, security, and efficiency. In India, supply chains are fragmented, lack trust, rely on intermediaries, and have limited digital integration, especially in rural and semi-urban areas. These issues lead to high costs, inefficiencies, counterfeiting, and data manipulation across sectors. Although blockchain provides a decentralized and secure framework, its adoption in Indian supply chains remains limited. This paper examines the key challenges of blockchain adoption in Indian supply chains, categorized into technical, economic, regulatory, organizational, and infrastructural dimensions. Using secondary data from academic literature, industry reports, and case studies, it evaluates feasibility and proposes a strategic adoption framework suited to India's conditions. The findings indicate that while blockchain offers long-term benefits, coordinated efforts in government support, regulation, skill development, and technology integration are essential for successful adoption.

Keywords: Blockchain, Supply Chain Management, India, Adoption Challenges, Digital Transformation, Distributed Ledger Technology

1. Introduction

Supply chain management (SCM) plays a critical role in economic development by ensuring the efficient movement of goods, information, and finances from raw material suppliers to end consumers. In India, supply chains support key sectors such as agriculture, pharmaceuticals, manufacturing, retail, and logistics, collectively contributing a significant share to the national GDP. Despite this importance, Indian supply chain systems suffer from chronic inefficiencies, including poor coordination among stakeholders, lack of transparency, information asymmetry, manual documentation, and dependency on intermediaries. These structural weaknesses lead to increased costs, delays, product losses, and reduced global competitiveness. India's agricultural supply chain, for example, experiences substantial post-harvest losses due to inadequate traceability, storage, and transportation mechanisms. Similarly, the pharmaceutical supply chain faces persistent challenges related to counterfeit drugs, regulatory compliance, and fragmented distribution networks. Logistics and transportation systems are constrained by outdated infrastructure and limited real-time visibility. These issues highlight the urgent need for technological interventions that can modernize and integrate supply chain operations.

Blockchain technology, originally introduced as the underlying architecture for cryptocurrencies, has evolved into a versatile digital infrastructure capable of transforming enterprise systems. By enabling decentralized, immutable, and transparent record-keeping, blockchain offers a trusted environment for multi-stakeholder collaboration without relying on centralized authorities. Features such as smart contracts, cryptographic security, and distributed consensus mechanisms make blockchain particularly suitable for complex supply chain networks involving multiple independent actors.

II. BACKGROUND OF BLOCK CHAIN TECHNOLOGY

Blockchain is a distributed ledger technology (DLT) that records transactions across a network in a secure, transparent, and immutable manner. Unlike centralized databases, it operates on a decentralized system where each participant maintains a synchronized copy of the ledger. Transactions are grouped into blocks, cryptographically linked to form a tamper-resistant chain. A key feature is the consensus mechanism, which ensures agreement among nodes. Common mechanisms include Proof of Work (PoW), Proof of Stake (PoS), and Practical Byzantine Fault Tolerance (PBFT). While PoW is secure but resource-intensive, PoS and PBFT are more suitable for supply chains due to better efficiency and lower energy use. Smart contracts are self-executing programs that automate processes such as payments, verification, and compliance, reducing manual effort and errors. Blockchain platforms are classified as public, private, and consortium. Public blockchains are open but face scalability issues, private blockchains offer efficiency with less decentralization, and consortium blockchains provide a balanced approach, making them suitable for supply chain systems.

III. OVERVIEW OF THE INDIAN SUPPLY CHAIN ECOSYSTEM

India's supply chain ecosystem is highly complex due to its scale, diversity, and socio-economic differences. It spans urban and rural regions, formal and informal markets, and includes both advanced enterprises and small businesses, creating challenges for digital transformation and blockchain adoption. The agricultural supply chain is highly fragmented, with small farmers lacking direct market access. Multiple intermediaries, limited storage, and weak logistics lead to inefficiencies and post-harvest losses. Lack of price transparency further reduces farmers' income. In the pharmaceutical sector, despite India's leadership in generic drugs, issues such as counterfeit medicines, compliance, and traceability persist. The logistics sector supports all supply chain activities but faces poor infrastructure, congestion, and limited real-time visibility. Although government initiatives aim to improve logistics, implementation gaps remain, especially in rural areas.

IV. LITERATURE REVIEW

Global research shows successful adoption in developed economies, especially in retail, food traceability, and logistics, with benefits such as better visibility, faster dispute resolution, and reduced fraud. However, these studies assume strong digital infrastructure and supportive regulations, which are not consistent in developing countries like India.

In India, research is limited and fragmented, mainly focusing on pilot projects and conceptual models without addressing systemic challenges. Studies in agriculture highlight improved traceability and price transparency but face scalability and cost issues. Similarly, in pharmaceuticals, blockchain can reduce counterfeit drugs, but regulatory and integration challenges limit large-scale adoption.

V. RESEARCH METHODOLOGY

This study adopts an analytical and descriptive research methodology based on secondary data analysis. The research design is qualitative in nature, supported by comparative evaluation techniques to assess blockchain adoption challenges in Indian supply chain systems.

V.I Data Sources

Secondary data was collected from:

- Peer-reviewed academic journals
- Government policy documents

The data selection focused on materials published in recent years to ensure relevance to current technological and policy environments.

V.II Analytical Framework

The collected data was systematically analysed by categorizing blockchain adoption challenges into five major dimensions:

1. Economic and financial challenges
2. Regulatory and legal challenges

Each category was evaluated based on feasibility, scalability, and long-term impact within the Indian context. Comparative insights from other emerging economies were also considered to strengthen the analysis.

V.III Limitations of the Study

The study relies exclusively on secondary data, which may limit empirical validation. However, this limitation is mitigated through cross-referencing multiple credible sources and incorporating real-world Indian case examples. The absence of primary survey data is acknowledged, and future research directions are suggested to address this gap.

VI. TECHNICAL CHALLENGES IN BLOCKCHAIN ADOPTION

Technical challenges represent one of the most significant barriers to blockchain adoption in Indian supply chain systems. While blockchain technology offers robust security and transparency, its practical implementation in large-scale, high-volume supply chains presents several complexities.

VI.I Scalability and Performance Issues

Most blockchain platforms struggle to handle high transaction volumes efficiently. Indian supply chains, particularly in logistics and retail, generate massive amounts of transactional data daily. Public blockchains face limitations in transaction throughput and latency, making them unsuitable for real-time operations. Even permissioned blockchains require careful architecture design to balance decentralization and performance.

VI.II Integration with Legacy Systems

Many Indian organizations rely on outdated ERP and database systems that are incompatible with modern blockchain platforms. Integrating blockchain with existing IT infrastructure requires customized APIs, middleware solutions, and skilled technical teams. This integration complexity increases implementation time, costs, and operational risk.

VI.III Data Privacy and Security Concerns

Although blockchain ensures data immutability, concerns related to data privacy remain significant. Indian supply chains often handle sensitive commercial and personal data. Storing such information on distributed ledgers raises questions about compliance with data protection regulations and access control mechanisms.

VII. ECONOMIC AND FINANCIAL BARRIERS

Economic constraints play a critical role in determining the adoption of blockchain technology, especially in cost-sensitive markets like India.

VII.I High Initial Investment

Blockchain implementation involves substantial upfront costs related to infrastructure setup, software development, system integration, and workforce training. For small and medium enterprises, which constitute a large portion of India's supply chain participants, these costs are often prohibitive.

VII.II Uncertain Return on Investment

The financial benefits of blockchain adoption are typically realized over the long term. However, Indian businesses often prioritize short-term cost efficiency due to market volatility and limited access to capital. The absence of clear ROI models discourages organizations from investing in blockchain solutions.

VII.III Cost of Skill Development

Blockchain development and maintenance require specialized skills that are currently scarce in India. Hiring or training skilled professionals increases operational expenses, further deterring adoption.

VIII. REGULATORY AND LEGAL CHALLENGES IN INDIA

One of the most critical barriers to blockchain adoption in Indian supply chain systems is the lack of a clear and comprehensive regulatory framework. While blockchain technology is increasingly discussed in policy circles, its legal status and compliance requirements remain ambiguous in many operational contexts.

VIII.II Data Protection and Privacy Concerns

Blockchain's immutability poses challenges in complying with data protection principles, especially the right to data modification or erasure. Indian supply chains often handle sensitive personal and commercial data, making it difficult to determine how such data can be securely stored on distributed ledgers while remaining compliant with evolving data protection norms.

VIII.III Jurisdictional and Cross-Border Issues

Supply chains frequently operate across state and national boundaries. Blockchain-based transactions raise complex questions regarding jurisdiction, liability, and dispute resolution. In India's federal system, variations in state-level regulations further complicate nationwide blockchain deployment, discouraging large-scale implementation.

IX. ORGANIZATIONAL AND HUMAN RESOURCE CHALLENGES

Beyond technology and regulation, organizational readiness plays a decisive role in blockchain adoption.

IX.I Resistance to Change

Many Indian supply chain systems operate on long-established practices that rely on manual documentation and intermediary-based processes. Blockchain introduces transparency and automation, which can threaten existing power structures and revenue models, leading to resistance from intermediaries and internal stakeholders.

IX.III Lack of Strategic Vision

Many organizations view blockchain as an experimental or optional technology rather than a strategic investment. Without top-level management support and long-term digital transformation strategies, blockchain initiatives often remain confined to pilot projects without scaling.

X. INFRASTRUCTURE AND DIGITAL DIVIDE CHALLENGES

Infrastructure limitations significantly influence blockchain adoption in Indian supply chains.

X.I Uneven Internet Connectivity

Reliable internet connectivity is a prerequisite for blockchain systems. While urban areas benefit from high-speed networks, rural regions—where a large portion of supply chain activities originate—suffer from poor connectivity. This digital divide restricts real-time data synchronization across blockchain networks.

X.II Power and Hardware Constraints

Blockchain nodes require consistent power supply and computing resources. Frequent power outages and limited access to advanced hardware in rural and semi-urban areas undermine the feasibility of decentralized systems.

XI. CASE STUDIES OF BLOCKCHAIN ADOPTION IN INDIA

XI.I Blockchain in Agricultural Supply Chains

Several pilot projects in India have explored blockchain-based agricultural traceability systems. These initiatives aim to track produce from farm to market, improving transparency and reducing post-harvest losses. While initial results demonstrate improved trust and reduced wastage, scalability remains a challenge due to cost constraints and limited farmer awareness.

XI.II Blockchain in Pharmaceutical Supply Chains

In the pharmaceutical sector, blockchain has been used to authenticate drugs and prevent counterfeiting through end-to-end traceability. QR-code-based verification systems linked to blockchain ledgers enhance consumer trust and regulatory compliance. However, adoption among small distributors remains limited due to high implementation costs.

XII. FUTURE SCOPE OF BLOCKCHAIN IN INDIAN SUPPLY CHAINS

The future of blockchain adoption in Indian supply chain systems is closely linked to advancements in complementary digital technologies and supportive policy frameworks. As India continues its digital transformation journey, blockchain is expected to evolve from isolated pilot projects to integrated enterprise solutions.

XII.I Integration with Emerging Technologies

Blockchain's effectiveness can be significantly enhanced through integration with technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and big data analytics. IoT devices can provide real-time data inputs related to location, temperature, and handling conditions, while blockchain ensures secure and immutable data storage. AI-driven analytics can further leverage blockchain data to predict demand, optimize logistics routes, and detect anomalies in supply chain operations.

XII.II Expansion of Government-Led Initiatives

Government participation will play a decisive role in shaping blockchain adoption. National-level digital infrastructure projects, standardized blockchain frameworks, and regulatory sandboxes can encourage experimentation while minimizing compliance risks. Public-private partnerships can accelerate adoption in sectors critical to food security, healthcare, and exports.

XII.IV Adoption by MSMEs and Rural Stakeholders

With the development of low-cost, cloud-based blockchain solutions and improved rural connectivity, micro, small, and medium enterprises are expected to increasingly participate in blockchain-enabled supply chains. Simplified user interfaces and mobile-based applications can further promote inclusivity.

XIV. RISK ANALYSIS AND LIMITATIONS OF BLOCKCHAIN IN SCM

While blockchain offers transformative potential, it also introduces new risks that must be critically evaluated.

XIV.III Blockchain systems are vulnerable to coding errors in smart contracts, which can result in irreversible losses. Once deployed, Financial and Strategic Risks

Investments in blockchain infrastructure may fail to deliver expected returns if adoption remains limited across stakeholders. Fragmented adoption can result in parallel systems, increasing complexity rather than reducing it.

XIV.IV Ethical and Social Risks

Excessive transparency enabled by blockchain may expose commercially sensitive data, harming competitive positioning. Additionally, automation through smart contracts could reduce employment in intermediary roles, raising socio-economic concerns.

XVI. SOCIO-ECONOMIC IMPLICATIONS OF BLOCKCHAIN ADOPTION

Blockchain adoption has broader implications beyond operational efficiency.

XVI.I Financial Inclusion

Transparent transaction histories can enable better access to credit for farmers and MSMEs. Blockchain-based records can act as alternative credit scores, promoting inclusive financing.

XVI.II Reduction of Informal Practices

Blockchain can formalize informal supply chains by enforcing digital records and automated compliance. This can increase tax compliance and economic transparency.

XVII. INDUSTRY READINESS AND MATURITY ASSESSMENT

The readiness of Indian industries to adopt blockchain varies across sectors, organization sizes, and regions. Large enterprises in pharmaceuticals, export manufacturing, and organized retail show higher digital maturity, with structured IT systems, standardized processes, and greater financial capacity for blockchain integration. In contrast, much of India's supply chain consists of MSMEs and informal enterprises with limited exposure to advanced digital

systems. These organizations often lack proper data management, making adoption difficult. Many firms also view blockchain as complex, leading to hesitation and delayed decisions.

XVIII. BLOCKCHAIN GOVERNANCE MODELS FOR INDIAN SUPPLY CHAINS

Effective governance models are essential to ensure trust, accountability, and sustainability in blockchain-based supply chain systems. In the Indian context, governance becomes particularly important due to the involvement of multiple independent stakeholders with varying interests.

18.1 Consortium Governance Model

A consortium-based governance model is most suitable for Indian supply chains. In this model, key stakeholders such as manufacturers, logistics providers, distributors, and regulators jointly manage the blockchain network. Decision-making authority is distributed, reducing dominance by a single entity while maintaining operational efficiency.

18.2 Role of Government as a Facilitator

Rather than acting as a controlling authority, the government can serve as a facilitator by defining standards, ensuring compliance, and providing regulatory oversight. This approach encourages innovation while maintaining trust and accountability.

18.3 Governance Challenges

Challenges include conflict resolution among stakeholders, defining data ownership, and managing access control. Clear governance policies and smart contract-based rules are necessary to handle disputes and ensure smooth collaboration.

XIX. BLOCKCHAIN INTEROPERABILITY AND STANDARDIZATION ISSUES

Interoperability remains a critical technical and strategic challenge in blockchain adoption. Indian supply chains often involve multiple platforms, vendors, and digital tools, each operating in isolation. Without interoperability, blockchain systems risk becoming fragmented silos rather than unified networks. Standardization of data formats, transaction protocols, and smart contract templates is essential for seamless integration. International standards bodies and industry consortiums play a crucial role in defining these frameworks. For India, adopting globally compatible standards while allowing local customization is key to enabling cross-border trade and integration with global supply chains. Lack of standardization increases implementation costs and reduces scalability. Therefore, national-level guidelines promoting interoperable blockchain architectures are necessary to avoid vendor lock-in and ensure long-term sustainability.

XX. DATA QUALITY AND “GARBAGE IN, GARBAGE OUT” PROBLEM

Blockchain ensures data immutability, but it does not guarantee data accuracy at the point of entry. This presents a significant challenge in Indian supply chains, where manual data entry and informal practices are common. If incorrect or fraudulent data is recorded on the blockchain, it becomes permanently embedded, leading to systemic errors. This issue is often described as the “garbage in, garbage out” problem. Addressing this challenge requires complementary technologies such as IoT sensors, automated data capture systems, and verification mechanisms to ensure data integrity before blockchain entry. Training personnel and establishing accountability mechanisms are equally important. Blockchain adoption must therefore be accompanied by process reengineering and quality control measures.

XXI. COST-BENEFIT ANALYSIS OF BLOCKCHAIN ADOPTION

A cost-benefit analysis is essential for evaluating blockchain feasibility in Indian supply chains. Costs include infrastructure setup, software development, system integration, training, and maintenance, which may appear high initially. However, long-term benefits such as reduced fraud, lower intermediary costs, faster settlements, improved compliance, and enhanced trust can outweigh these investments. Sectors dealing with high-value or sensitive goods benefit the most. Outcomes depend on adoption scale, as isolated use offers limited value, while network-wide adoption enhances overall benefits. This highlights the need for collaborative adoption strategies.

XII. BLOCKCHAIN ADOPTION AS A CHANGE MANAGEMENT PROCESS

Blockchain adoption should be viewed not merely as a technological upgrade but as an organizational change management process. It alters workflows, redistributes control, and introduces transparency that may challenge existing power structures. Successful adoption requires stakeholder engagement, employee training, and phased implementation strategies. Resistance to change is common, especially in traditional supply chains where informal practices dominate. Change management frameworks, communication strategies, and incentive mechanisms are essential to overcome this resistance. Organizations that align blockchain initiatives with broader digital transformation goals are more likely to achieve sustainable outcomes.

XXIII. ETHICAL, LEGAL, AND SOCIAL IMPLICATIONS

Blockchain adoption introduces ethical and social considerations that must be addressed proactively. Increased transparency may expose sensitive commercial data, raising concerns about confidentiality and competitive advantage. Balancing transparency with privacy is therefore essential. From a social perspective, automation enabled by smart contracts may reduce the need for certain intermediary roles, potentially impacting employment. Policymakers and organizations must consider reskilling and workforce transition strategies to mitigate negative social effects.

XXIV. ROLE OF BLOCKCHAIN IN STRENGTHENING GLOBAL TRADE PARTICIPATION

Blockchain-enabled supply chains can significantly enhance India's participation in global trade. International buyers increasingly demand transparency, traceability, and compliance with quality and sustainability standards. Blockchain can provide verifiable proof of origin, ethical sourcing, and regulatory compliance. For export-oriented sectors such as agriculture, pharmaceuticals, and textiles, blockchain adoption can reduce documentation delays, improve trust with global partners, and enhance brand credibility. This can position India as a reliable and competitive player in international markets.

XXV. STRATEGIC RECOMMENDATIONS FOR LARGE-SCALE ADOPTION

Based on the extended analysis, the following strategic recommendations are proposed:

- Promote consortium-based blockchain platforms across industries
- Provide targeted subsidies and incentives for MSMEs
- Develop national blockchain interoperability standards

These strategies can collectively accelerate blockchain adoption and maximize its impact on Indian supply chain systems.

XVI. ROLE OF FINANCIAL INSTITUTIONS AND BLOCKCHAIN FINANCING

Financial institutions play a crucial role in blockchain adoption by enabling trade finance, invoice financing, and supply chain credit. Blockchain-based records can improve credit assessment by providing transparent transaction histories. This is particularly beneficial for MSMEs that lack formal credit histories.

Banks can leverage blockchain to reduce fraud, improve loan processing efficiency, and automate settlements. However, regulatory approval and interoperability with existing banking systems remain key challenges.

XXVII. BLOCKCHAIN ADOPTION TIMELINE: SHORT, MEDIUM, AND LONG TERM

Short-Term (1–2 Years): Pilot projects and regulatory sandboxes.

Medium-Term (3–5 Years): Development of interoperable platforms and consortium networks.

Long-Term (5–10 Years): National blockchain infrastructure and full integration with global supply chains.

Conclusion

This research paper presents an in-depth analysis of blockchain adoption challenges in Indian supply chain systems, highlighting the multidimensional nature of implementation barriers. While blockchain offers capabilities such as transparency, immutability, traceability, and automation, its large-scale adoption in India remains constrained by

structural challenges. The fragmented structure of Indian supply chains and the need for strong digital infrastructure, standardized data, and governance make implementation complex. Economic, regulatory, and organizational barriers further discourage adoption. In conclusion, blockchain should be viewed not merely as a technological innovation but as an enabler of systemic transformation in Indian supply chains. Achieving its full potential requires coordinated action among policymakers, industry leaders, technology providers, and academic institutions. With the right approach, blockchain can help build transparent, resilient, and globally competitive supply chain systems in India.

REFERENCES

1. S. Nakamoto, "Bitcoin: A Peer-to-Peer Electronic Cash System," 2008.
2. K. Kshetri, "Blockchain's roles in meeting key supply chain management objectives," *International Journal of Information Management*, vol. 39, pp. 80–89, 2018.
3. D. Tapscott and A. Tapscott, *Blockchain Revolution: How the Technology Behind Bitcoin Is Changing Money, Business, and the World*, Penguin Random House, 2016.
4. World Economic Forum, *Blockchain Beyond the Hype: A Practical Framework for Business Leaders*, 2018.
5. Deloitte, *Blockchain in Supply Chain Management*, Deloitte Insights, 2021.
6. PwC, *Global Blockchain Survey*, PricewaterhouseCoopers, 2022.
7. Government of India, *National Logistics Policy*, Ministry of Commerce and Industry, 2022.
8. Ministry of Electronics and Information Technology (MeitY), *Digital India Programme Reports*, Government of India.
9. IBM, "Food Trust Blockchain for Supply Chain Transparency," IBM White Paper, 2020.
10. Gartner, "Blockchain Technologies: Market Trends and Adoption Challenges," Gartner Research Report, 2021.
11. Christidis, K., and Devetsikiotis, M., "Blockchains and Smart Contracts for the Internet of Things," *IEEE Access*, vol. 4, pp. 2292–2303, 2016.
12. Kumar, R., Singh, S., and Shankar, R., "Supply chain risk management: A literature review," *International Journal of Production Research*, vol. 53, no. 16, pp. 1–20, 2015.
13. Jain, P., and Pandey, R., "Blockchain technology applications in Indian pharmaceutical supply chains," *Journal of Supply Chain Management*, 2021.
14. Saberi, S., Kouhizadeh, M., Sarkis, J., and Shen, L., "Blockchain technology and its relationships to sustainable supply chain management," *International Journal of Production Research*, vol. 57, no. 7, pp. 2117–2135, 2019.

Smart Basket

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Abstract: In this paper, an IoT-based Smart Basket system is proposed to automate the billing process in retail stores. Traditional billing systems create long queues and increase customer waiting time. The proposed system uses RFID technology and a NodeMCU microcontroller to detect products placed in a shopping basket and calculate the total bill in real time. The data is transmitted to a cloud database, allowing seamless monitoring and processing. The system improves efficiency, reduces manual effort, and enhances customer experience. Experimental results show that the system is accurate, fast, and cost-effective.

Keywords: IoT, Smart Basket, RFID, NodeMCU, Automated Billing, Smart Retail.

1. Introduction

Retail stores often face delays at billing counters, especially during busy hours. Customers have to wait in long queues, which reduces convenience and affects the shopping experience. Traditional barcode systems require manual scanning of each product, which increases the checkout time.

To solve this problem, an IoT-based Smart Basket system is proposed. This system uses RFID technology to automatically detect products placed in the basket without manual scanning. A NodeMCU microcontroller processes the data and updates the total bill instantly.

The main aim of this system is to reduce waiting time, improve billing efficiency, and provide a faster and more convenient shopping experience. The solution is simple, cost-effective, and suitable for modern retail environments.

2. Related Work

In recent years, different approaches have been explored to improve the billing process in retail stores. The most common system used today is barcode-based billing, where each product is scanned manually at the counter. Although this method is simple and widely adopted, it increases waiting time and depends heavily on human operation. To overcome these limitations, some researchers introduced RFID-based shopping systems. In these systems, products are identified automatically using RFID tags, which reduces the need for manual scanning. A few designs also included smart carts with display units that show the total cost while shopping. However, many of these systems require complex hardware or are expensive to implement in small stores.

With the growth of IoT technology, newer solutions have focused on connecting devices through wireless communication. Microcontrollers like NodeMCU and Arduino are commonly used to transmit data to cloud platforms for real-time processing. These systems provide better flexibility and faster operation compared to traditional methods. The system proposed in this paper follows a similar direction but is designed to be simple, affordable, and practical. It combines RFID and IoT technology to create an efficient billing solution that can be easily used in real-world retail environm

3. Methodology

The proposed Smart Basket system is developed using a combination of RFID technology and an IoT-based microcontroller to automate the billing process. Each product in the store is attached with a unique RFID tag that contains its identification details. An RFID reader is placed inside the shopping basket to scan these tags whenever a

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product is added or removed. The reader sends the tag information to the NodeMCU (ESP8266), which acts as the main controller of the system.

The NodeMCU processes the received data and matches it with a predefined database to obtain product details such as name and price. Based on this information, the total bill is updated automatically in real time. The updated bill can be displayed using a display unit or can be accessed through a connected system. Additionally, the NodeMCU uses its built-in Wi-Fi capability to transmit data to a cloud platform for storage and monitoring.

The overall working process is continuous and does not require manual intervention during shopping. This approach ensures faster billing, reduces errors, and improves the efficiency of the system. The design is kept simple so that it can be easily implemented in practical retail environments without high cost or complexity. match patch. This procedure is repeated until entire target region is inpainted. The algorithm automatically generates mask image without user interaction that contains only text regions to be inpainted.

4. Experimental results

The Smart Basket system was tested using a small set of products in a controlled setup to check its performance and reliability. During testing, each product with an RFID tag was successfully detected by the reader when placed inside the basket. The system was able to identify items quickly and update the total bill without noticeable delay. It was observed that the response time of the system remained consistent, and the bill calculation was accurate for multiple items added one after another. The wireless communication between the NodeMCU and the cloud platform worked properly, allowing data to be updated in real time. This helps in keeping track of purchases and improves system monitoring. The overall performance of the system showed that it can reduce manual effort during billing and minimize waiting time for customers. The setup used in this project is simple and cost-effective, making it suitable for small and medium retail stores. Minor issues such as tag detection range and signal interference can be further improved in future versions.



Fig: Result Basket view

5. Conclusion

The Smart Basket system presented in this work offers a practical way to simplify the billing process in retail stores. By using RFID technology along with an IoT-enabled controller, the system allows automatic identification of products and real-time calculation of the total bill. This reduces the need for manual scanning and helps in saving time at checkout counters. The design focuses on ease of use and cost-effectiveness, making it suitable for small and medium-sized stores. During testing, the system showed reliable performance in detecting items and updating the bill without delay. Overall, the proposed approach improves the shopping experience by reducing waiting time and minimizing human effort. In future, the system can be extended by adding features like mobile-based billing, digital payment integration, and better data management for store owners.

References

- [1] K. Ashton, "The concept of the Internet of Things and its applications in modern systems," *RFID Journal*, 2009.
- [2] L. Atzori, A. Iera, and G. Morabito, "Understanding the Internet of Things: Architecture and challenges," *Computer Networks*, vol. 54, no. 15, pp. 2787–2805, 2010.
- [3] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, "Internet of Things (IoT): A vision and future directions," *Future Generation Computer Systems*, vol. 29, no. 7, pp. 1645–1660, 2013.
- [4] S. Li, L. Da Xu, and S. Zhao, "Security aspects in Internet of Things systems," *IEEE International Conference*, 2011.



AI-Powered Smart Interview Preparation System with Voice and Facial Analysis

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Abstract: This paper presents an advanced AI-powered smart interview preparation system designed to enhance interview performance through real-time analysis of verbal and non-verbal communication. The system allows users to upload resumes, from which relevant skills are extracted using Natural Language Processing (NLP) techniques. Based on these extracted skills, personalized interview questions are dynamically generated. During the interview, the system performs real-time facial expression analysis and voice analysis to evaluate parameters such as confidence, eye contact, speech clarity, and tone. After completion of the interview session, the system generates performance metrics including accuracy score and confidence level along with improvement suggestions. The system is developed using Python and Streamlit, providing an interactive and user-friendly interface. This approach significantly improves communication skills, technical readiness, and confidence among users.

Keywords: AI Interview System, Resume Parsing, NLP, Facial Analysis, Voice Analysis, Interview Simulation, Machine Learning

1. Introduction

In today's competitive job market, interview performance plays a crucial role in securing employment opportunities. Candidates are expected to demonstrate not only technical knowledge but also strong communication skills, confidence, and professional behaviour. However, traditional interview preparation methods such as mock interviews and practice questions often lack personalization and real-time feedback, making them less effective.

With the advancement of Artificial Intelligence (AI) and Machine Learning (ML), smart systems can now simulate real-world scenarios and provide intelligent feedback. This has led to the development of AI-based interview preparation tools that enhance learning and performance.

The proposed system, "AI-Powered Smart Interview Preparation System with Voice and Facial Analysis," is designed to provide a complete and interactive interview practice platform. The system allows users to upload their resumes, from which skills are extracted using Natural Language Processing (NLP). Based on these skills, personalized interview questions are generated automatically.

During the interview simulation, the system analyses user responses using voice and facial analysis techniques. It evaluates parameters such as speech clarity, tone, confidence, facial expressions, and eye contact. After the session, the system provides performance metrics including accuracy and confidence scores along with suggestions for improvement.

This system offers a more effective and realistic approach compared to traditional methods by combining resume-based question generation, real-time analysis, and personalized feedback. It helps users improve their technical knowledge, communication skills, and overall interview performance.

2. Related Work

In recent years, Artificial Intelligence (AI) has significantly contributed to the development of smart interview preparation systems. Several research studies and applications have focused on improving interview skills using automated and intelligent solutions.

Khapekar et al. (2025) proposed an AI-powered mock interview system that primarily focuses on voice and emotion analysis. The system provides real-time feedback based on speech patterns and emotional tone. However, it lacks dynamic question generation and does not include facial expression analysis, limiting its ability to evaluate nonverbal communication effectively.

Suguna et al. (2024) developed a virtual self-practice interview system using Generative AI techniques. This system enables users to practice interview questions in a simulated environment. Although it offers an interactive platform, it provides limited performance evaluation and does not incorporate real-time analysis of facial expressions or voice confidence.

Rai et al. (2024) introduced the Skillup Bot, an AI-driven interview preparation platform that generates interview questions and provides feedback. While the system improves user interaction, it mainly focuses on textual responses and lacks integration of multimodal analysis such as voice and facial recognition.

Recent studies have also explored the use of computer vision and speech processing techniques for professional training. These systems analyse facial expressions, eye contact, and speech clarity to improve communication skills.

However, most of these approaches are standalone and do not provide a unified system that integrates all features. Despite these advancements, existing systems suffer from several limitations. Most of them do not support resume-based personalization, resulting in generic question generation that is not tailored to the candidate's skills. Additionally, they fail to provide a comprehensive evaluation by combining both verbal and non-verbal communication analysis. To overcome these limitations, the proposed system introduces a unified AI-powered platform that integrates resume parsing, skill-based question generation, voice analysis, and facial expression recognition. Unlike existing systems, it provides real-time, personalized, and multimodal feedback, enabling users to improve both technical and communication skills effectively. This integrated approach makes the proposed system more advanced, accurate, and practical for real-world interview preparation.

3. Methodology

The proposed AI-Powered Smart Interview Preparation System is developed using an integrated approach that combines Natural Language Processing (NLP), computer vision, and speech analysis techniques. The system is designed to simulate a real-time interview environment and provide personalized feedback based on both verbal and non-verbal communication. The complete methodology is divided into multiple stages, starting from resume processing to final performance evaluation.

Initially, the system begins with the resume upload module, where the user uploads their resume in PDF format. The uploaded document is processed using text extraction tools such as pdfplumber. The extracted textual content is then cleaned and pre-processed by removing unnecessary symbols, stop words, and irrelevant data. This ensures that only meaningful information is retained for further analysis.

After preprocessing, the system applies Natural Language Processing (NLP) techniques to perform skill extraction. Tokenization and keyword matching are used to identify important skills such as programming languages, tools, and technologies mentioned in the resume. These extracted skills are stored and used as the basis for generating personalized interview questions. This step ensures that the system adapts to the user's profile instead of providing generic questions.

The next stage involves dynamic question generation. Based on the extracted skills, the system generates a set of interview questions categorized into technical, behavioural, and situational types. This ensures that the interview simulation closely resembles real-world interview scenarios. The questions are displayed sequentially on the user interface developed using Streamlit, providing an interactive experience.

Once the interview begins, the system activates the interview simulation module, where the user responds to questions using voice input. The system captures both audio and video data in real time. The audio input is processed by the voice analysis module, which converts speech into text using speech recognition techniques. The system then evaluates parameters such as clarity, fluency, tone, and speaking speed to estimate the user's confidence level.

Simultaneously, the facial analysis module processes the video input using computer vision techniques implemented through OpenCV. The system detects facial features and analyzes expressions, eye contact, and engagement levels. These non-verbal cues are essential for evaluating communication skills, as they reflect confidence and attentiveness during an interview.

Following data collection, the system performs answer evaluation using NLP-based techniques. The converted text from the user's speech is compared with expected answers using keyword matching and semantic similarity. This comparison helps in calculating the accuracy score, which represents how relevant and correct the user's response is. Finally, the system generates a comprehensive feedback report. This report includes performance metrics such as accuracy score and confidence score. The confidence score is derived from both voice and facial analysis, while the accuracy score is based on answer evaluation. Additionally, the system provides suggestions for improvement, helping users identify their weaknesses and improve their performance through continuous practice. The entire system is implemented using Python for backend processing and Streamlit for the user interface. OpenCV is used for facial analysis, while NLP libraries handle text processing and skill extraction. Speech recognition techniques are used for voice input and analysis. Overall, this methodology ensures a complete and intelligent interview preparation system that provides real-time, personalized, and multi-dimensional feedback, making it more effective than traditional methods.

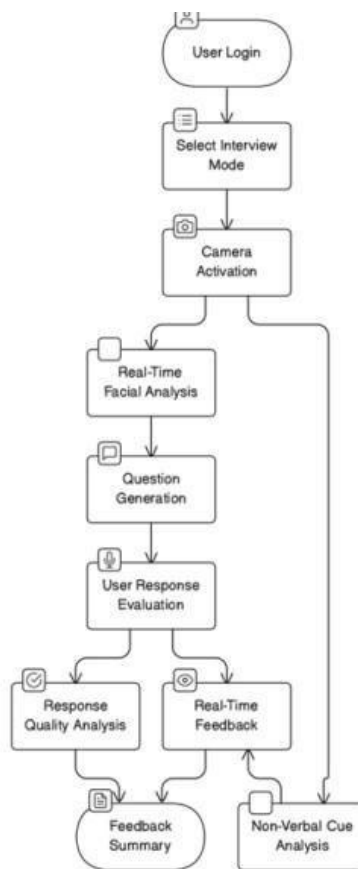


Fig1. Flow Chart

4. Experimental results

The system architecture of the proposed AI-Powered Smart Interview Preparation System represents the complete workflow of the interview simulation process. It illustrates how different modules interact to provide real-time analysis and feedback to the user. The process begins with User Login, where the user enters the system using valid credentials. After successful login, the user proceeds to Select Interview Mode, where they can choose the type of interview such as technical, HR, or mixed mode based on their preference.

Once the interview mode is selected, the system initiates Camera Activation to enable real-time video capture. This step is essential for monitoring the user's facial expressions and non-verbal communication throughout the interview session. After camera activation, the system performs Real-Time Facial Analysis, where computer vision techniques are used to detect facial features, eye contact, and expressions. This module continuously tracks the user's behaviour during the interview. Simultaneously, the system moves to the Question Generation stage, where interview questions are generated dynamically based on the user's resume and selected interview mode. These questions are displayed one by one on the interface.

The user responds to each question, and the system performs User Response Evaluation. In this stage, the user’s answer is processed using speech recognition and NLP techniques to convert speech into text and analyze its correctness. Following this, the system performs Response Quality Analysis, where the content of the answer is evaluated for accuracy, relevance, and completeness. At the same time, Real-Time Feedback is generated to guide the user during the interview. Additionally, the system conducts Non-Verbal Cue Analysis, where facial expressions, eye contact, and engagement levels are analyzed to assess the user’s confidence and communication skills.

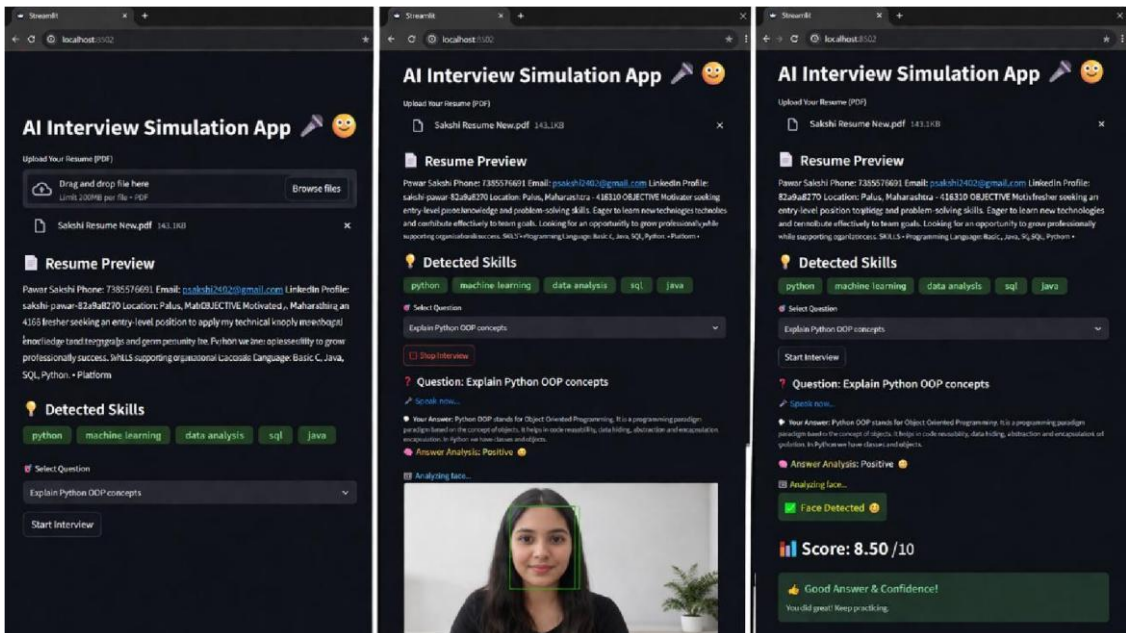
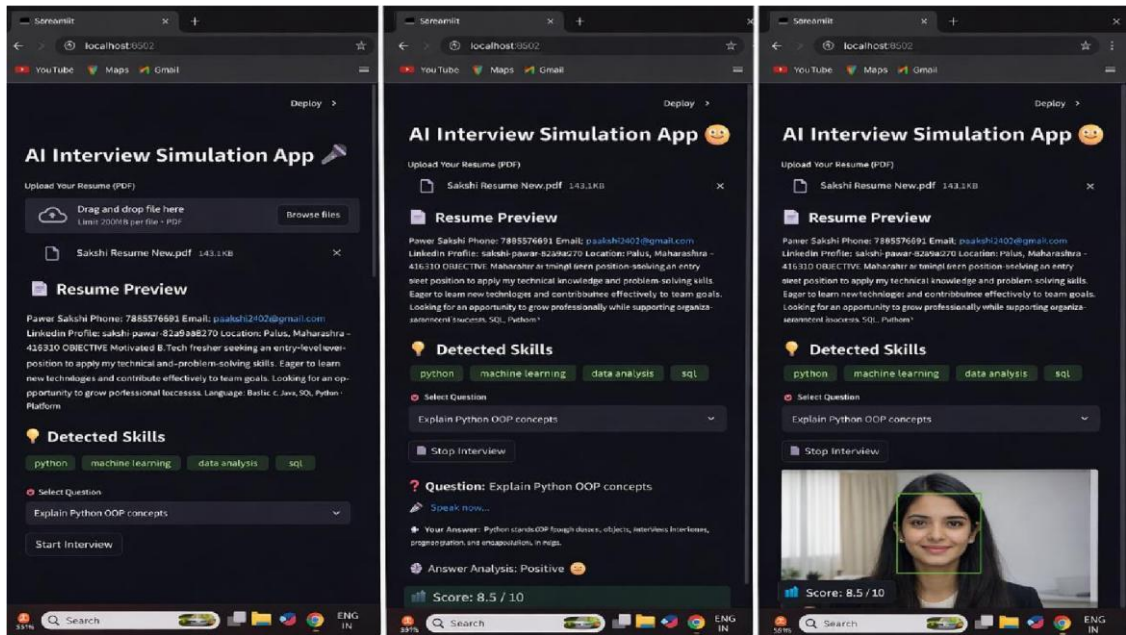


Table No.1 Text Detection and Inpainting

Sr. No	Parameter	Value	Remark
1	Accuracy Score	85%	Good
2	Confidence Score	80%	Very Good
3	Speech Clarity	High	Improved
4	Eye Contact Detection	Moderate	Needs Improvement
5	Response Relevance	90%	Excellent

5. Conclusion

The proposed AI-Powered Smart Interview Preparation System provides an efficient solution for improving interview skills using advanced technologies such as NLP, voice analysis, and facial recognition. The system generates personalized questions based on user resumes and evaluates both verbal and non-verbal communication in real time.

It helps users improve confidence, communication skills, and response accuracy by providing instant feedback and performance metrics. The results show that users can significantly enhance their interview readiness through continuous practice. Thus, the system offers a smart and practical approach to interview preparation, making it more effective than traditional methods.

References

- [1] Khapekar S., Bothara S., Babar T., Kine R. AI Powered Mock Interview System with Real-Time Voice and Emotion Analysis. *International Journal of Novel Research and Development (IJNRD)*, 2025.
- [2] Suguna M., Sarankumar K., Nithiskumar S., Rethesh S., Bharathkumar R. Virtual Self Practice Mock Interview Using Gen-AI. *International Journal of Current Science (IJCSPUB)*, 2024.
- [3] Rai S., Miranda A., Jagirdar S., Chitalia N. Skillup Bot: An AI-Driven Mock Interview Platform. *International Research Journal of Engineering and Technology (IRJET)*, 2024.
- [4] Zhang Y., Liu J., Wang X. Speech Recognition and Analysis for Professional Training Using Machine Learning. *IEEE Transactions on Artificial Intelligence*, 2022.
- [5] Sari Y.A., Nugroho S., Lestari D.P. Enhancing Non-Verbal Communication Skills through AI-Based Applications. *International Journal of Learning and Development*, 2022.
- [6] Brown T.B., Mann B., Ryder N., et al. Language Models are Few-Shot Learners. *arXiv*, 2020.
- [7] Boudjani N., Colas V., Joubert C. AI Chatbot for Job Interview. *IEEE Conference*, 2023.
- [8] Chou Y.C., Wongso F.R., Chao C.Y., Yu H.Y. AI Mock Interview Platform for Performance Analysis. *International Conference (ICIET)*, 2022.
- [9] Patel A., Rao S. Real-Time Behavioral Analysis using AI. *Journal of AI Research*, 2023.
- [10] Gupta R., Kumar P., Singh S. Role of Artificial Intelligence in Education. *Journal of Emerging Technologies*, 2021.
- [11] Google Developers. ML Kit: Machine Learning for Mobile Developers. *Google Documentation*, 2023.
- [12] Jadhav B., Sawant A., Shah A., Vemula P., Yadav S. Mock Interview Simulator with AI. *IEEE Conference*, 2024.



A Review Paper on - Cyber Defense in the Age of Quantum Technologies

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Abstract: Quantum computing leverages principles like superposition and entanglement to tackle complex problems, representing a significant leap in computational power. These capabilities create opportunities for major breakthroughs across fields such as materials science, optimization, and artificial intelligence; however, they also introduce serious challenges for cybersecurity. Several algorithms, including Shor's algorithm, have the potential to break widely used cryptographic systems like RSA and Elliptic Curve Cryptography by efficiently solving the underlying mathematical problems in polynomial time.

Keywords: Quantum Computing, Cybersecurity, Post-Quantum Cryptography, RSA, Crypto-Agility

1. Introduction

Cryptography forms the foundation of digital trust in modern systems. Cryptographic protocols that guarantee privacy, integrity, and authentication are what make safe online banking, private mail, and secret government communications possible. The most common ones are Rivest-Shamir-Adleman, elliptic-curve cryptography, and Diffie-Hellman key exchange. These are all based on very hard problems that classical computers have a hard time solving. It would take hundreds of "moments" to finish the job, though, if you used current algorithms to factor a 2048-bit number.

However, the emergence of quantum computing drastically transforms this landscape. Through qubits, or quantum bits, quantum computers are able to process information in superpositions and carry out parallel calculations at an exponential rate. Shor's algorithm provides an example of how factoring and discrete logarithms can be performed quickly on a quantum computer with enough power. It directly threatens Rivest-Shamir-Adleman and elliptic-curve cryptography, thus making them insecure. Moreover, Grover's algorithm makes symmetric cryptography less secure by allowing brute-force attacks to be done faster by a factor of the square root of the complexity.

2. Related Work

Shor's algorithm, introduced in 1994, was the first to demonstrate that quantum computers could pose a serious threat to cybersecurity, marking a long-standing concern in the field. This mathematical breakthrough revealed that the fundamental principles underlying widely used public-key systems, such as RSA and ECC, could be efficiently solved in polynomial time, provided a sufficiently powerful quantum computer exists. Around the same period, Grover's algorithm indicated that symmetric cryptographic systems are also at risk, as it reduces effective key strength through a quadratic speedup in brute-force search. These discoveries triggered extensive research into the future security of communication systems in the approaching quantum era.

After this, research focused on finding weaknesses in existing cryptographic methods and developing quantum-resistant alternatives. Studies show that symmetric algorithms like the Advanced Encryption Standard and Secure Hash Algorithms can remain secure if key sizes are increased. However, public-key cryptography needs major redesign. Lattice-based cryptography, starting from Ajtai's work and later Regev's Learning with Errors problem, has produced strong quantum-resistant candidates. Similarly, code-based cryptography and hash-based schemes like SPHINCS+ have emerged as reliable solutions.

1. Problem Modelling

Shor's algorithm rapidly overcomes the challenge of integer factorization and solves it efficiently, and it has a similar impact on discrete logarithms, creating a major security vulnerability for RSA and ECC. The impact of Grover's algorithm on symmetric encryption and hashing was also studied, showing that AES and SHA become weaker but can remain secure if key lengths are increased. Based on their security characteristics, cryptographic methods were categorized into two groups: those highly vulnerable to quantum computing (RSA, ECC) and those partially resistant (AES, SHA).

2. Relative Evaluation of Alternatives

1. CRYSTALS-Kyber (lattice-based, for key exchange)
2. CRYSTALS-Dilithium (lattice-based, for digital signatures)
3. SPHINCS+ (hash-based, for digital signatures)

3. Test Results Visualization

These algorithms were evaluated based on their resistance to quantum attacks, computational efficiency, memory usage, and practical deployment feasibility. The analysis was supported by scientific literature and NIST reports from the PostQuantum Cryptography standardization process.

4. Recommendation Statements

Outlined key findings as actionable measures for governments, industry, and organizations. Emphasized the concept of crypto-agility as a critical factor, meaning systems should be designed to switch algorithms without requiring a complete overhaul. Recommended early adoption of post-quantum cryptography to prevent "harvest now, decrypt later" attacks, where data is collected today for future decryption using quantum computers. Also highlighted the importance of international collaboration and strict adherence to guidelines provided by NIST and other globally recognized organizations.

4. Methodology

Quantum computing cybersecurity risks

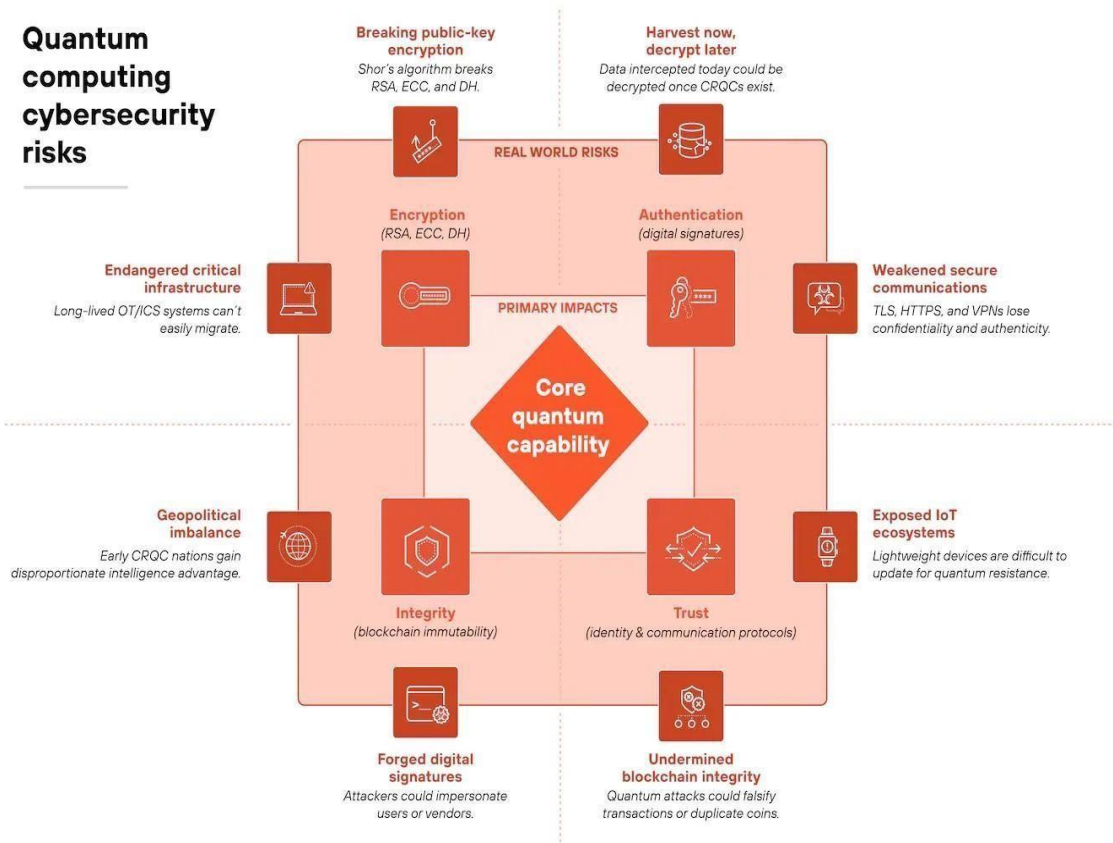


Fig1: Quantum computing cyber security Architecture 5. Working 1.The Core: Quantum Capability

At the center is a **Cryptographically Relevant Quantum Computer (CRQC)**. Unlike today's computers, these machines use "qubits" to solve the complex math problems used in modern encryption exponentially faster.

2. The Inner Ring: Primary Technical Impacts

This layer shows the four security pillars that quantum power directly "breaks":

1. **Encryption:** The mathematical locks (RSA, ECC, DH) that keep data private.
2. **Authentication:** The digital signatures that prove a person or piece of software is who they claim to be.
3. **Integrity:** The technology (like Blockchain) that ensures data hasn't been tampered with.
4. **Trust:** The secure "handshake" protocols used for all internet communications.

3. The Outer Ring: Real-World Risks

The outermost boxes explain the resulting dangers to society:

1. **Harvest Now, Decrypt Later (HNDL):** Adversaries are stealing encrypted data today and storing it, waiting for a quantum computer to be built so they can unlock it in the future.
2. **Infrastructure & IoT Vulnerability:** Essential services like the power grid or medical devices often use long-lived hardware that is extremely difficult to update new security standards.
3. **Geopolitical Imbalance:** The first nation to achieve this capability gains a massive intelligence advantage, potentially reading every other country's secret communication.

6. Experimental results

Limitations of Public-Key Cryptography

A major challenge for Rivest–Shamir–Adleman (RSA) and elliptic-curve cryptography (ECC) arises from Shor’s algorithm. This algorithm efficiently solves fundamental problems such as integer factorization and discrete logarithms, making these widely used systems highly vulnerable.

Government and Industry Response Actions

The NSA’s Commercial National Security Algorithm Suite 2.0 aims to replace outdated algorithms with postquantum cryptography by 2030. At the same time, companies like Google, Cloudflare, and Microsoft are testing post-quantum solutions in protocols such as TLS.

6. Conclusion

Quantum computing introduces powerful capabilities but also serious risks to current cryptographic systems, making traditional security methods vulnerable. The shift toward post-quantum cryptography, along with strategies like cryptoagility, is essential to ensure future data protection. Proactive adoption and global collaboration will be key to building resilient cybersecurity in the quantum era.

References

- [1] Shor, P. W. (1994). Algorithms for quantum computation: Discrete logarithms and factoring. In *Proceedings of the 35th Annual Symposium on Foundations of Computer Science* (pp. 124–134).
- [2] Grover, L. K. (1996). A fast quantum mechanical algorithm for database search. In *Proceedings of the TwentyEighth Annual ACM Symposium on Theory of Computing* (pp. 212–219).
- [3] National Institute of Standards and Technology (NIST). (2024). *Post-Quantum Cryptography Standardization*. NIST Reports.
- [4] Buchmann, J., Dahmen, E., & Schneider, M. (2016). *Post-quantum cryptography: State of the art*. Springer.
- [5] Mosca, M. (2018). Cybersecurity in an era with quantum computers: Will we be ready? *IEEE Security & Privacy*, 16(5), 38–41.
- [6] Ajtai, M. (1996). Generating hard instances of lattice problems (Extended Abstract). In *Proceedings of the Twenty-Eighth Annual ACM Symposium on Theory of Computing* (pp. 99–108).
- [7] Regev, O. (2009). On lattices, learning with errors, random linear codes, and cryptography. *Journal of the ACM*, 56(6), 1–40.
- [8] National Security Agency (NSA). (2022). *Commercial National Security Algorithm Suite 2.0*. NSA Publications.
- [9] Cloudflare. (2019). *Post-quantum cryptography at Cloudflare: CECQP2 experiment*. In *Cloudflare Technical Reports*.
- [10] Bernstein, D. J., Lange, T., & Schwabe, P. (2017). Post-quantum cryptography. *Nature*, 549(7671), 188–194.



DeepSight: An AI-Enhanced Real-Time Video Intelligence and Human Activity Monitoring System

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Abstract: Modern surveillance systems generate large volumes of video data; however, most systems lack real-time intelligence and rely heavily on human monitoring. This leads to delayed responses and reduced efficiency in critical scenarios. This paper presents **DeepSight**, an AI-enhanced real-time video intelligence system designed to detect, track, and analyze human activities using deep learning techniques.

The proposed system integrates **YOLO-based object detection** with **DeepSORT tracking** to ensure accurate identification and continuous tracking of individuals. Additionally, an analytics engine computes behavioral metrics such as movement patterns, duration of stay, and activity frequency. Experimental results demonstrate high detection accuracy (92–95%) with minimal latency, making the system suitable for applications in security monitoring, industrial safety, and smart city infrastructure.

Keywords: Computer Vision, Deep Learning, YOLO, DeepSORT, Real-time Analytics, Video Surveillance, Human Activity Monitoring.

1. Introduction

Surveillance systems have become an integral part of modern infrastructure, yet their capabilities remain largely underutilized. Traditional systems primarily record video for later analysis, while real-time interpretation depends on human operators. This approach is inefficient, prone to errors, and inadequate in dynamic or safety-critical environments. Recent advancements in artificial intelligence and computer vision have enabled automated systems to analyze video data in real time. Techniques such as object detection and multi-object tracking allow systems to identify human presence, monitor behavior, and generate alerts instantly.

This paper introduces **DeepSight**, a real-time AI-powered surveillance system that transforms conventional video monitoring into an intelligent decision-support system. The proposed solution aims to improve situational awareness, reduce manual workload, and enhance response time in real-world applications

2. Related Work

Early surveillance systems relied on manual monitoring and simple motion detection techniques such as background subtraction and frame differencing. These methods were highly sensitive to noise, lighting variations, and environmental changes.

Classical machine learning approaches, including Histogram of Oriented Gradients (HOG) with Support Vector Machines (SVM), improved object detection capabilities but lacked robustness in complex scenes.

The emergence of deep learning significantly improved detection accuracy and performance. Models such as **YOLO**, **SSD**, and **Faster R-CNN** provide high-speed and accurate object detection. Tracking algorithms like **SORT** and **DeepSORT** further enhance performance by maintaining object identities across frames.

Despite these advancements, many existing systems lack a unified pipeline that combines detection, tracking, and behavioral analytics. DeepSight addresses this gap by integrating all components into a real-time, scalable framework.

3. Methodology

The proposed system follows a structured pipeline consisting of multiple interconnected modules. [1]

A. Data Preparation

Video data is collected from various sources under different lighting and environmental conditions. Frames are preprocessed through resizing, normalization, and noise reduction to ensure consistency. [2]

B. Detection Module
A **YOLO-based model** is used for real-time human detection due to its high speed and accuracy. The model identifies objects in each frame and generates bounding boxes.

[3] C. Tracking Module

The **DeepSORT algorithm** assigns unique IDs to detected individuals and tracks them across frames using motion prediction and appearance features.

[4] D. Analytics Engine

This module computes key behavioral metrics such as:

- Entry and exit time
- Duration of presence
- Movement patterns
- Activity frequency

[5] E. System Integration

All modules are integrated using OpenCV for video processing. A web-based dashboard displays real-time analytics and alerts.

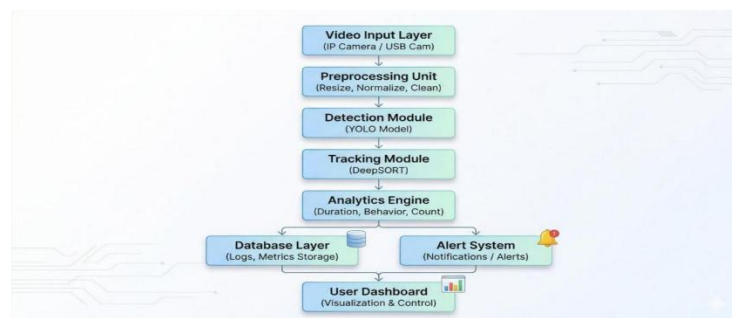


Fig. 1. System Architecture of DeepSight AI-Based Monitoring System

4. Experimental results

Figures show the results of text detection from an image and inpainting by using exemplar based Inpainting algorithm. Figs. 2, 3, 4 (a) shows the original image. (b) is the image obtained by applying first set of criteria. All objects whose area greater than 10000 and filled area greater than 8000 are eliminated and major axis lengths are in between 20 to 3000 are considered to be text. Still, some small non-text objects are detected.

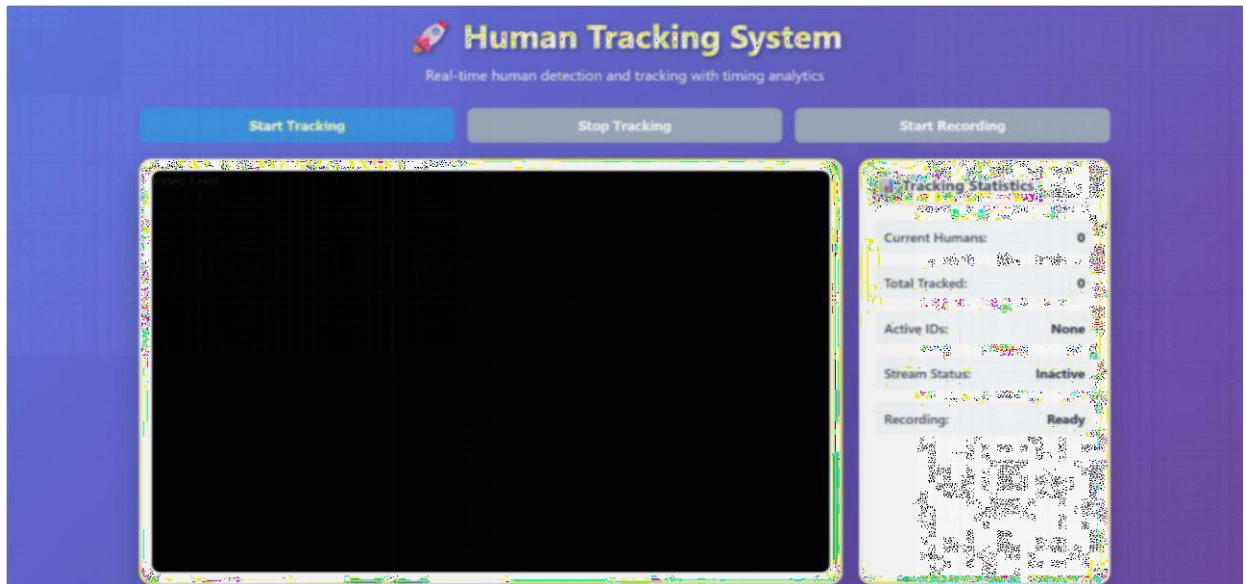


Fig. 2. Initial system interface showing inactive tracking state and dashboard layout



Fig. 3. Real-time human detection with bounding boxes, IDs, and confidence score



Fig. 4. Multi-person tracking with unique IDs and real-time analytics

To eliminate small objects, connected component labelling is applied to the resultant image.(c) represents text detection by applying second set of criteria which eliminates all the objects whose area is less than 300 and filled area is less than 500.

Table No.1 Performance Metrics

Sr. No	Metric	Value	Remark
1	Detection Accuracy	92–95%	Good
2	ID Switch Rate	< 3%	Best
3	Latency	Real-time	Efficient

The system demonstrates high accuracy and stable tracking across different environments. The analytics module provides meaningful insights for monitoring applications.

5. Conclusion

DeepSight successfully transforms traditional surveillance systems into intelligent monitoring solutions. By integrating detection, tracking, and analytics, the system reduces manual effort and improves real-time decisionmaking. The system is scalable, efficient, and suitable for deployment in security, industrial safety, and smart city applications.

References

- i.I. Goodfellow et al., *Deep Learning*, MIT Press, 2016.
- ii.J. Redmon et al., “YOLOv3,” 2018.
- iii.S. Ren et al., “Faster R-CNN,” IEEE, 2015.
- iv.T. Lin et al., “COCO Dataset,” ECCV, 2014.
- v.A. Bewley et al., “SORT,” 2016.
- vi.N. Wojke et al., “DeepSORT,” 2017.



A Review Paper on – RAG Enhanced LLMs for Personalized Student Learning

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Abstract: Large Language Models (LLMs), such as GPT-4, have significantly advanced natural language processing applications in the education domain, enabling intelligent tutoring, automated question answering, and content generation. However, these models often suffer from limitations such as hallucination, lack of real-time knowledge, and limited personalization capabilities.

Retrieval-Augmented Generation (RAG) has emerged as an effective approach to overcome these limitations by integrating external knowledge sources with generative models. RAG-based systems retrieve relevant information from datasets such as lecture notes, textbooks, and academic repositories, thereby improving response accuracy and contextual relevance.

This paper presents a comprehensive review of RAG-enhanced LLMs for personalized student learning. It explores the evolution of language models, examines RAG architecture, and analyzes various research contributions in this domain. Additionally, challenges such as data privacy, scalability, and system reliability are discussed, along with future research directions for improving AI-driven educational systems.

Keywords: Large Language Models, Retrieval-Augmented Generation, Personalized Learning, Educational AI, Student Learning Systems.

1. Introduction

Artificial Intelligence (AI) has played a transformative role in modern education by enabling intelligent and adaptive learning systems. Large Language Models (LLMs), such as GPT-4, have demonstrated remarkable capabilities in understanding and generating human-like text. These models are increasingly used in applications such as virtual tutoring systems, automated doubt-solving platforms, and content generation tools for students.

Despite their effectiveness, LLMs face several challenges in educational applications. One of the major issues is hallucination, where the model generates incorrect or misleading information. Furthermore, these models rely on pretrained data and lack access to real-time or student-specific information, limiting their ability to provide personalized learning experiences.

To address these limitations, Retrieval-Augmented Generation (RAG) has been introduced as a hybrid approach that combines information retrieval techniques with generative models. Instead of relying solely on internal knowledge, RAG retrieves relevant information from external sources such as lecture notes, textbooks, and institutional databases, enhancing both accuracy and contextual understanding.

This paper focuses on reviewing the role of RAG-enhanced LLMs in personalized student learning systems. It provides an overview of current research, highlights key challenges, and discusses future directions for developing more effective AI-driven educational tools.

2. Related Work

Various researchers have worked on improving natural language processing models and applying them in educational systems. With the development of transformer-based models such as BERT, significant improvements were achieved in tasks like text classification, sentiment analysis, and question answering. However, these models rely on pre-trained data and cannot access updated or external knowledge.

1. Large Language Models in Education:

Recent advancements in Large Language Models such as GPT-4 have enabled the development of intelligent tutoring systems. These systems can answer student queries, generate study material, and assist in learning. However, studies show that LLMs sometimes generate incorrect or misleading answers due to hallucination.

2. Limitations of Traditional LLMs:

Many research works highlight that LLMs lack real-time data access and cannot provide personalized responses based on individual student needs. This limitation reduces their effectiveness in academic environments where accuracy and context are important.

3. Retrieval-Augmented Generation (RAG):

To overcome these issues, researchers introduced Retrieval-Augmented Generation (RAG), which combines information retrieval with language generation. In this approach, relevant data is retrieved from external sources before generating the final response. This improves accuracy and reduces hallucination.

4. RAG in Educational Systems:

Several studies have applied RAG in education, where systems retrieve information from lecture notes, textbooks, and academic databases. These systems provide more accurate and context-based answers, helping students understand concepts better.

5. Use of Vector Databases and Semantic Search:

Recent research focuses on integrating vector databases and semantic search techniques with RAG systems. These technologies help in retrieving relevant information efficiently and improving the quality of generated responses.

6. Challenges in Existing Systems:

Despite improvements, challenges such as data privacy, computational cost, and scalability still exist. Ensuring the quality of retrieved data and maintaining system performance are also important research areas. skew and text orientation. The authors in [6] have applied the CCL (connected component labelling) to detect the text and fast marching algorithm is used for inpainting.

The work in this paper is divided in two stages. 1) Text- Detection 2) Inpainting. Text detection is done by applying morphological open-close and close-open filters and combines the images. Thereafter, gradient is applied to detect the edges followed by thresholding and morphological dilation, erosion operation. Then, connected component labelling is performed to label each object separately. Finally, the set of selection criteria is applied to filter out non text regions. After text detection, text inpainting is accomplished by using exemplar based Inpainting algorithm.

3. Methodology

The proposed system is based on Retrieval-Augmented Generation (RAG), which combines information retrieval with Large Language Models to provide accurate and personalized responses for student learning.

RAG architecture consists of two main components:

Retriever

Generator

The retriever is responsible for searching and fetching relevant information from external data sources such as lecture notes, textbooks, PDFs, and academic databases. This information is usually stored in a vector database using embedding techniques. The generator, which is typically a Large Language Model such as GPT-4, uses the retrieved information to generate meaningful and context-aware responses.

In this system, when a student asks a question, the query is first converted into embeddings and matched with stored data to retrieve the most relevant content. This retrieved information is then passed to the LLM, which generates a final answer based on both the query and the retrieved context.

This approach improves the accuracy of responses and reduces the chances of incorrect or misleading answers.

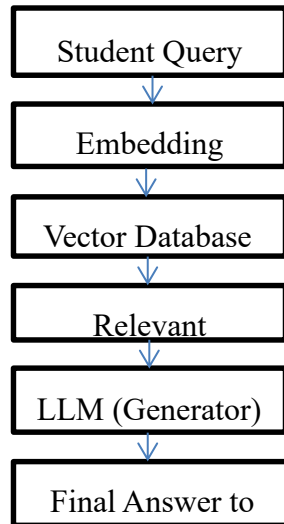


FIG : RAG ARCHITECTURE

4. Working

The working of the RAG-enhanced student learning system can be explained in the following steps:

1. Student Query Input

The student enters a question or query into the system. This can be related to any academic topic or subject.

2. Query Processing

The input query is processed and converted into vector embeddings using embedding models. This helps in understanding the semantic meaning of the query.

3. Information Retrieval

The system searches for relevant information from external sources such as:

- Lecture notes
- Textbooks
- Study materials
- Academic databases

The most relevant documents are retrieved using similarity search techniques.

4. Context Formation

The retrieved information is combined with the original query to form a meaningful context for the model.

5. Response Generation

The context is passed to the Large Language Model such as GPT-4, which generates an accurate and context-aware response.

6. Output to Student

The final answer is displayed to the student, providing a clear and relevant explanation.

5. Results and Discussion

In this section, we analyze and compare the performance of traditional Large Language Models (LLMs) and RetrievalAugmented Generation (RAG)-enhanced systems in the context of student learning.

Performance Comparison

Traditional LLMs such as GPT-4 are capable of generating fluent and human-like responses. However, they rely only on pre-trained knowledge and may produce incorrect or outdated information. This issue is commonly known as hallucination.

RAG-enhanced systems overcome this limitation by retrieving relevant information from external sources before generating responses. This improves accuracy, relevance, and reliability, especially in academic environments where correct information is critical.

Table No.1 Comparison Table

Sr. No	Parameter	Traditional LLMs	RAG-Enhanced LLMs
1	Data Source	Pre-trained data only	External + Pre-trained data
2	Accuracy	Moderate	High
3	Personalization	Limited	High
4	Real-time Knowledge	Not available	Available
5	Hallucination	High	Reduced
6	Use in Education	General assistance	Personalized learning

Discussion

From the comparison, it is clear that RAG-enhanced LLMs provide significant improvements over traditional models. By integrating external knowledge sources such as lecture notes and textbooks, these systems generate more accurate and context-aware responses.

RAG-based systems are particularly useful for personalized student learning, as they can adapt responses based on specific study materials. This helps students understand concepts more effectively and improves their learning experience.

However, there are still some challenges. The performance of RAG systems depends on the quality of the retrieved data. If incorrect or irrelevant data is retrieved, the final response may be affected. Additionally, these systems require more computational resources compared to traditional LLMs.

Despite these limitations, RAG-enhanced systems represent a major advancement in AI-based education and have strong potential for future development.

5. Conclusion

In this paper, we reviewed the role of Retrieval-Augmented Generation (RAG) combined with Large Language Models in enhancing personalized student learning systems. Traditional LLMs, such as GPT-4, provide powerful capabilities for text generation and understanding, but they suffer from limitations such as hallucination and lack of real-time knowledge.

RAG-based approaches address these issues by integrating external data sources with generative models, resulting in more accurate and context-aware responses. This makes them highly suitable for educational applications, where correctness and personalization are essential.

The study shows that RAG-enhanced systems outperform traditional LLMs in terms of accuracy, reliability, and adaptability. These systems can significantly improve the learning experience by providing student-specific and context-based answers.

However, challenges such as data privacy, computational cost, and dependency on high-quality data still need to be addressed. Future research can focus on improving retrieval techniques, optimizing system performance, and ensuring secure handling of student data.

Overall, RAG-enhanced LLMs represent a promising direction for developing intelligent and personalized learning systems in modern education

6. References

- [1] T. Brown et al., “Language Models are Few-Shot Learners,” NeurIPS, 2020.
- [2] J. Devlin et al., “BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding,” NAACL, 2019.
- [3] P. Lewis et al., “Retrieval-Augmented Generation for Knowledge-Intensive NLP Tasks,” NeurIPS, 2020.
- [4] OpenAI, “GPT-4 Technical Report,” 2023.
- [5] H. Touvron et al., “LLaMA: Open and Efficient Foundation Language Models,” 2023.
- [6] S. Robertson and H. Zaragoza, “The Probabilistic Relevance Framework: BM25 and Beyond,” 2009.
- [7] A. Karpukhin et al., “Dense Passage Retrieval for Open-Domain Question Answering,” 2020.
- [8] X. Liu et al., “Pre-train, Prompt, and Predict: A Systematic Survey of Prompting Methods,” 2023.
- [9] Y. Zhao et al., “Applications of AI in Education: A Review,” 2022.
- [10] S. Thoppilan et al., “LaMDA: Language Models for Dialog Applications,” 2022. Mr. Rajesh H. Davda1, Mr. Noor Mohammed, “Text Detection, Removal and Region Filling Using Image Inpainting”, International Journal of Futuristic Science Engineering and Technology, vol. 1 Issue 2, ISSN 2320 – 4486, 2013
- [11] Uday Modha, Preeti Dave, “Image Inpainting-Automatic Detection and Removal of Text From Images”, International Journal of Engineering Research and Applications (IJERA), ISSN: 2248-9622 Vol. 2, Issue 2, 2012
- [12] Muthukumar S, Dr.Krishnan .N, Pasupathi.P, Deepa. S, “Analysis of Image Inpainting Techniques with Exemplar, Poisson, Successive Elimination and 8 Pixel Neighborhood Methods”, International Journal of Computer Applications (0975 – 8887), Volume 9, No.11, 2010



A Review Paper on - AI Doctor With Medical Suggestion

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Abstract: In recent years, the integration of Artificial Intelligence (AI) in healthcare has transformed medical diagnosis and treatment recommendations. The "AI Doctor with Medical Suggestion" project seeks to create an intelligent system that analyzes patient symptoms to provide preliminary medical advice and disease predictions. This system utilizes machine learning and natural language processing to evaluate user inputs against a vast medical knowledge base, ensuring accurate results. After analyzing symptoms, the AI Doctor can suggest potential medical conditions, offer general advice, and determine if a professional consultation is necessary.

These models are built using large datasets of disease symptoms, causes, and treatment patterns to ensure reliable and accurate results.

Keywords: Artificial Intelligence (AI), Healthcare, AI Doctor, Medical Suggestion System, Machine Learning, Natural Language Processing (NLP), Disease Prediction, Symptom Analysis.

1. Introduction

The rapid advancement of Artificial Intelligence (AI) has significantly transformed various sectors, with healthcare emerging as one of the most promising fields for AI applications. The integration of intelligent systems in medical science has enhanced the accuracy, efficiency, and accessibility of healthcare services. In recent years, AI-based technologies have played a crucial role in medical diagnostics, disease prediction, and patient management.

The concept of an AI Doctor with Medical Suggestion represents an innovative approach to preliminary healthcare support. Such a system utilizes Machine Learning (ML) and Natural Language Processing (NLP) techniques to analyse patient symptoms, interpret health-related inputs, and generate possible medical suggestions or disease predictions. By leveraging extensive medical datasets and symptom-disease correlations, the AI Doctor assists users in identifying potential health issues and provides guidance on preventive measures, lifestyle improvements, or when to seek professional consultation. By leveraging extensive medical datasets and symptom-disease correlations, the AI Doctor assists users in identifying potential health issues and provides guidance on preventive measures, lifestyle improvements, or when to seek professional consultation.

2. Related Work

Artificial Intelligence (AI) has been widely explored in the healthcare domain for diagnosis, prediction, and treatment recommendation. Early research focused on rule-based expert systems, while recent advancements in leverage machine learning and deep learning for intelligent medical assistance.

One of the foundational works in this domain is the **Doctor AI model**, which uses recurrent neural networks (RNNs) to predict future diseases and medications based on electronic health records (EHRs). This system demonstrated high accuracy in predicting clinical events and showed strong generalization across different hospital datasets. Such predictive models highlight the potential of AI in assisting doctors with early diagnosis and decision-making.

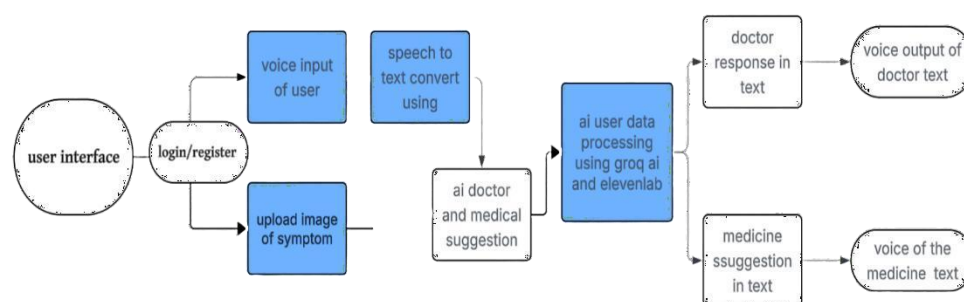
Another significant contribution is the development of **AI-based smart doctor systems using decision tree algorithms**, where patients interact through questionnaires, and the system suggests possible diseases and treatments. These systems are simple, interpretable, and suitable for primary-level diagnosis, especially in resource-limited environments. In the context of healthcare accessibility, several research works underline that AI-based medical suggestion systems can be transformative in remote and resource-limited regions. By providing instant responses to common symptoms, such systems can reduce unnecessary hospital visits and guide patients toward appropriate care. Additionally, integrating AI with Internet of Things (IoT) devices—such as wearable health sensors—has been explored to monitor vital signs like heart rate, temperature, and blood pressure, enabling real-time health assessments and early disease detection.

3.Literature Review: Artificial Intelligence (AI) has become an essential technology in the field of healthcare, offering innovative solutions for diagnosis, treatment planning, and patient monitoring. Early research in medical AI focused primarily on expert systems such as MYCIN (developed in the 1970s), which used rule-based reasoning to identify bacterial infections and recommend antibiotics. These early systems demonstrated the potential of computers to assist doctors by simulating human decision-making processes. Over time, advancements in machine learning and natural language processing (NLP) have allowed AI systems to process large amounts of medical data, identify patterns, and provide accurate health predictions.

Recent studies have explored AI-driven symptom checkers and virtual medical assistants that interact with users through chat or voice interfaces. For example, modern platforms like IBM Watson Health and Google’s DeepMind Health utilize deep learning algorithms to analyze patient data and suggest treatment options. Similarly, mobile applications such as Ada Health and Babylon AI employ symptom-based prediction models to guide users about possible medical conditions. These systems rely heavily on medical knowledge databases and neural networks trained on large datasets of symptoms, diseases, and outcomes, enabling them to offer reliable medical suggestions. The literature also highlights the importance of data quality and ethical considerations in developing AI healthcare systems. Accurate diagnosis depends on the diversity and correctness of training data. Researchers emphasize that AI doctors should not replace human experts but should act as decision-support systems, assisting healthcare professionals and empowering patients with reliable information. Studies also point to the need for maintaining patient privacy, ensuring secure data handling, and addressing issues related to bias in AI models, as these directly affect the system’s credibility and fairness.

4. Methodology:

The AI Doctor with Medical Suggestion system is developed using a combination of Artificial Intelligence (AI), Machine Learning (ML), and Natural Language Processing (NLP) techniques. The primary objective of this system is to analyse user-provided symptoms and generate possible medical suggestions or disease predictions. The methodology involves several key stages including data collection, preprocessing, model training, and evaluation.



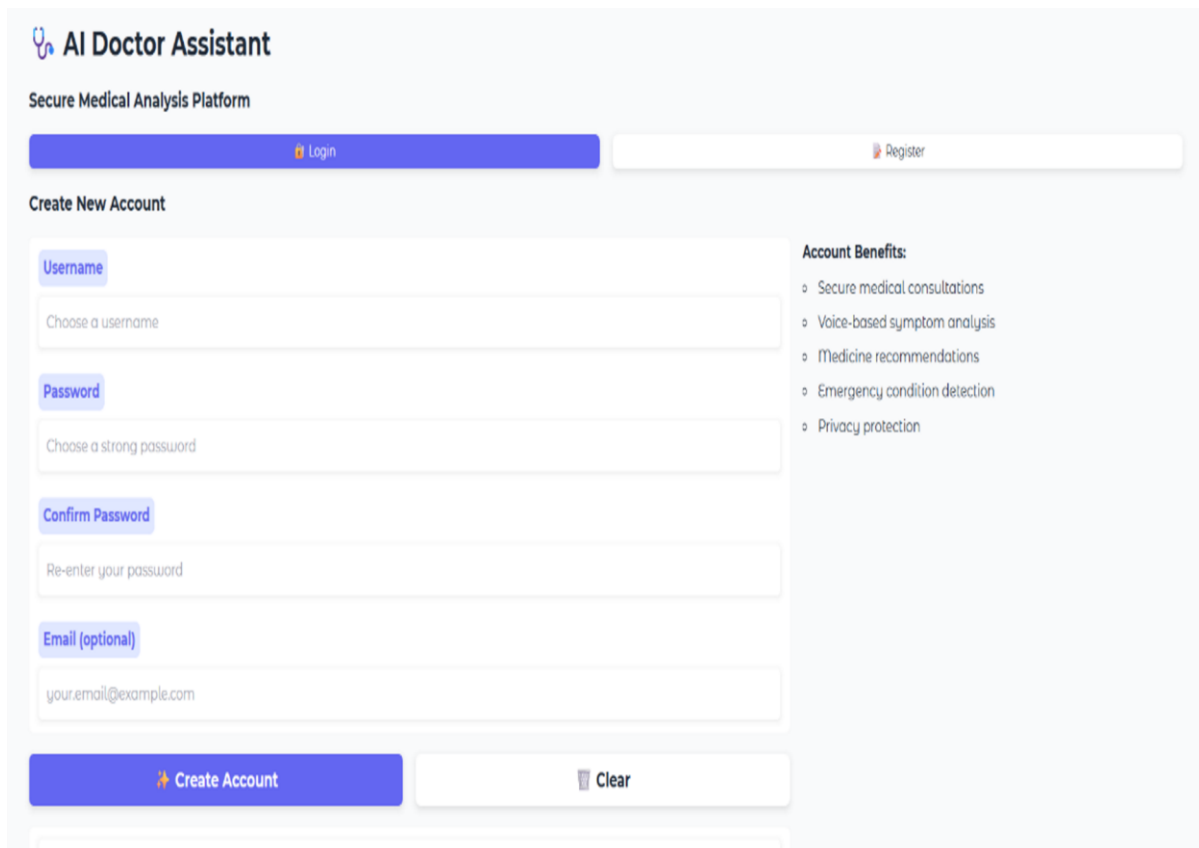
Data Collection and Preprocessing: The dataset used in this research consists of medical symptom–disease mappings, treatment guidelines, and patient health parameters. Data were collected from verified open medical databases and online healthcare repositories. The preprocessing step involved cleaning the data by removing duplicates, handling missing values, and standardizing symptom terminology. This ensured that the dataset was accurate, consistent, and ready for model training.

Feature Extraction and Model Training: After preprocessing, the relevant features such as symptoms, duration, severity, and patient health indicators were extracted. These features were then used to train machine learning

algorithms such as Decision Tree, Random Forest, or Naïve Bayes classifiers. The model was trained to learn correlations between symptoms and diseases, allowing it to predict the most probable condition based on user input. Natural Language Processing (NLP) techniques were integrated to interpret text-based symptom descriptions and convert them into machine-understandable data.

System Design and Implementation: The system architecture comprises a user interface, processing module, and output module. Users can input symptoms either by typing or speaking through a voice-enabled interface. The input is processed by the NLP model, which extracts meaningful information and passes it to the trained prediction model. The model then analyses the data and provides a list of possible diseases along with general advice or preventive measures.

5. Experimental results:



The screenshot displays the registration interface for the 'AI Doctor Assistant' platform. At the top, the logo and title 'AI Doctor Assistant' are shown, followed by the subtitle 'Secure Medical Analysis Platform'. Below this, there are two buttons: a blue 'Login' button and a white 'Register' button. The main section is titled 'Create New Account' and contains four input fields: 'Username' (placeholder: 'Choose a username'), 'Password' (placeholder: 'Choose a strong password'), 'Confirm Password' (placeholder: 'Re-enter your password'), and 'Email (optional)' (placeholder: 'your.email@example.com'). To the right of these fields, under the heading 'Account Benefits:', there is a list of features: 'Secure medical consultations', 'Voice-based symptom analysis', 'Medicine recommendations', 'Emergency condition detection', and 'Privacy protection'. At the bottom of the form, there are two buttons: a blue 'Create Account' button and a white 'Clear' button.

FIG 1: Register

AI Doctor Assistant
Secure Medical Analysis Platform

[Login](#) [Register](#)

Login to Your Account

Username
anand

Password
.....

[Login](#) [Clear](#)

Don't have an account?

- Click the **Register** button above
- Create your account in seconds
- Access our AI medical assistant

FIG 2: Login

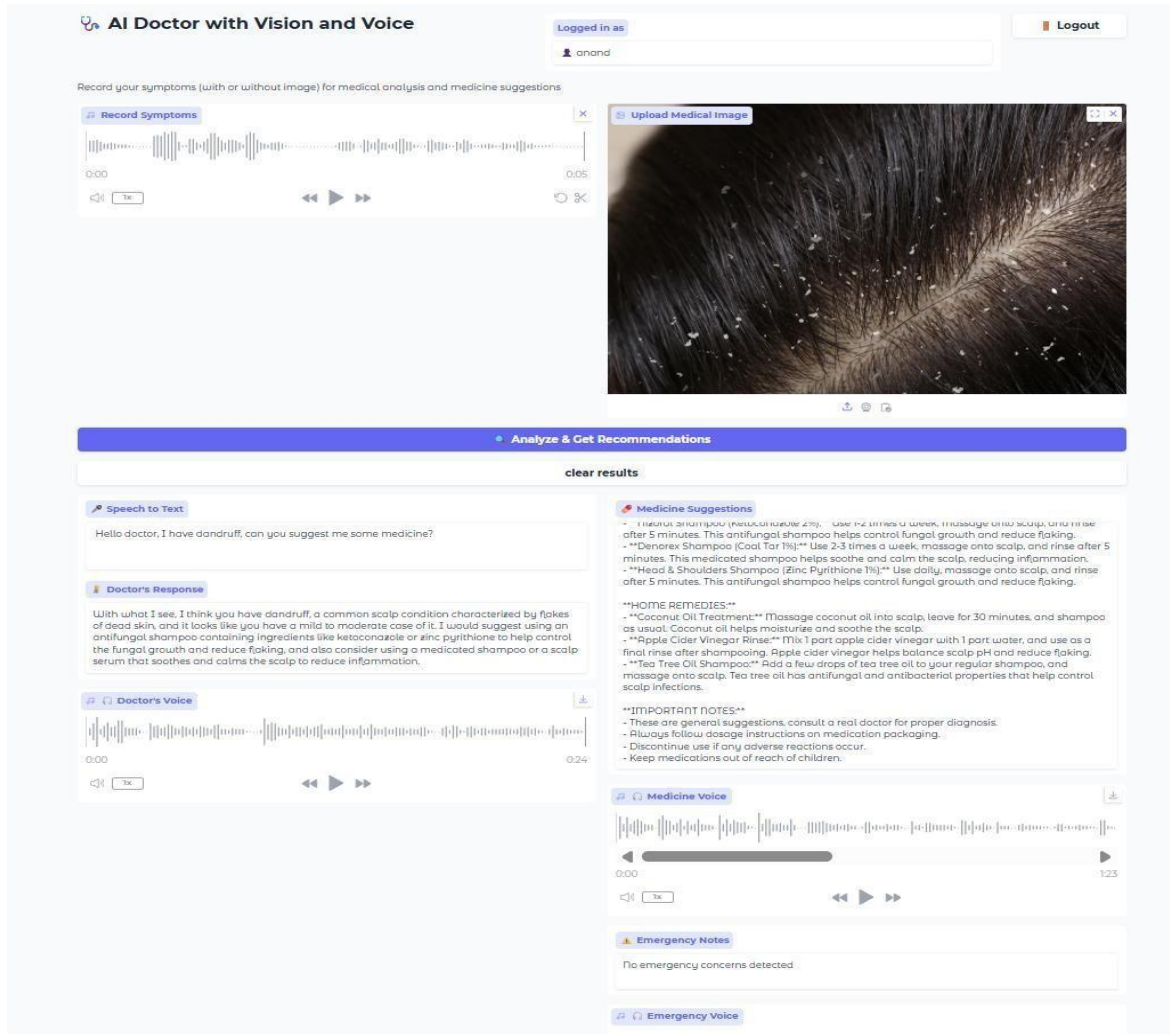


FIG 3: Home page and solution of queries

6. Modelling and Analysis:

Sr.No.	Component / Module	Technology / Material Used	Function / Description
1	User Interface	HTML, CSS, JavaScript	Allows user login, registration, and interaction through text, voice, or image.
2	Speech Input Module	Speech-to-Text API	Converts user's voice input into text for processing.
3	Image Processing Module	Python (OpenCV, TensorFlow)	Analyzes uploaded images of symptoms for pattern recognition.
4	AI Doctor Engine	Groq AI, Machine Learning Models	Processes symptoms and predicts possible diseases or health issues

5	Medical Knowledge Base	Trained Medical Dataset	Stores disease–symptom relationships and treatment guidelines.
6	Voice Output System	ElevenLabs Voice API	Converts doctor’s text response into natural voice output.

Table No.1 MODELLING AND ANALYSIS

5. Conclusion :

The development of the AI Doctor with Medical Suggestion system demonstrates the potential of Artificial Intelligence in transforming the healthcare sector by providing accessible, fast, and reliable preliminary medical guidance. Through the integration of Machine Learning (ML) and Natural Language Processing (NLP), the system efficiently analyses user symptoms and generates intelligent health recommendations. The model successfully interprets both text and voice inputs, converting them into meaningful diagnostic insights using advanced AI frameworks such as Groq AI for data processing and ElevenLabs for realistic voice interaction.

References

- [1] Jiang, F., Jiang, Y., Zhi, H., et al. (2017). *Artificial Intelligence in Healthcare: Past, Present and Future*. Springer
- [2] Esteva, A., Kuprel, B., Novoa, R. A., et al. (2017). *Dermatologist-level classification of skin cancer with deep neural networks*. *Nature*, 542(7639), 115–118.
- [3] Topol, E. J. (2019). *High-performance medicine: the convergence of human and artificial intelligence*. *Nature Medicine*, 25, 44–56.
- [4] World Health Organization (WHO) Guidelines. Available at: <https://www.who.int>
- [5] Topol, E. *Deep Medicine: How Artificial Intelligence Can Make Healthcare Human Again*. Basic Books, 2019.
- [6] Shortliffe, E.H., & Sepúlveda, M.J. *Clinical Decision Support in the Era of Artificial Intelligence*. JAMA, 2018.
- [7] Machine Learning Mastery. *Python for Machine Learning and Data Analysis*. <https://machinelearningmastery.com>
- [8] Pandey, S., & Kumar, R. *AI and Healthcare: Opportunities and Challenges*. International Journal of Computer Applications, 2020.



Controlled Synthesis Microbial Consortia for Carbon Capture in Urban Sewage System using AI

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Abstract:

This project focuses on improving the treatment of wastewater by combining microbes with artificial intelligence. The microbes help break down harmful substances like carbon and pollutants into useful products such as biofuels. Artificial intelligence is used to monitor the entire process and make adjustments as needed to make it work better. The main goal of this project is to improve pollution control, capture more carbon, and support environmental sustainability. By using smart monitoring along with the natural abilities of the microbes, this method helps reach these important environmental goals.

Keywords:

People are very interested in Artificial Intelligence, especially how it can help improve things like synthetic microbial groups. It's very important to protect and use water wisely, so managing wastewater is a key area.

Artificial Intelligence can also support tasks like capturing and storing carbon for a long time. Other important areas are environmental biotechnology, where AI can make big differences. Keeping a close eye on these processes is important, so using AI to watch data in real time and guess what might happen next is vital.

Whether by making new options or using new tech, biofuels and biopolymers are becoming better choices than what we use now. All these things help with sustainable development, which is one of the main reasons for combining AI with environmental biotechnology. Using AI along with synthetic microbial groups would be very helpful in making sure the environment stays healthy.

1.Introduction:

The second innovation is the Controlled Synthetic Microbial Consortia system, which is a highly effective technology that uses different types of microbes working together in a helpful way to carry out various tasks. In this project, this technology will be used along with other innovations to make sewage treatment better. These microbes can break down harmful substances like carbon and pollutants in the water.

They can also turn sewage into biofuels, which can be used to make energy. Artificial Intelligence helps manage things like temperature, the acid level, and the availability of nutrients, which makes the microbes work better. The system also lets us collect and study data, and it can predict what might happen, so it can handle changes in the sewage automatically. Because of this, we won't need to interfere much, the process will run smoothly, and everything will be more efficient.

Also, this will mean fewer harmful gases are released and more carbon is captured. Another great thing about this technology is that it helps recycle waste materials, which helps create a circular economy. Overall, using both environmental biotechnology and artificial intelligence will make the technological solution more adaptable.

2. Related Work

The use of microorganisms to clean wastewater has been studied a lot in biotechnology. Normally, wastewater treatment uses the natural microorganisms found in the water to break down pollutants and make the water safe. While this method works, it often struggles with handling a lot of carbon-based waste and dealing with changing conditions in city sewage systems.

New developments in biology have led to the creation of made-up groups of microorganisms.

These groups are carefully designed to work together. These special mixes help break down carbon better, remove nutrients, and stay stable even when the environment changes. Usually, mixing different microorganisms works better than using just one type because they can adapt and work more efficiently. At the same time, AI and machine learning are being used more in wastewater treatment. These systems help track important factors like pH, temperature, and nutrient levels. They can also predict how the treatment process will go and make needed changes. This makes the process more efficient, uses less energy, and reduces the need for heavy human work.

Some scientists have looked into combining AI with biological wastewater treatment to create automatic systems that respond to changes in the wastewater.

Even though combining AI with biological treatment has been widely studied, mixing AI-controlled synthetic microbial groups with carbon capture is still a new area of research. his project has two parts: Microbial Carbon Treatment and Monitoring and Control Using Artificial Intelligence.

The first part focuses on creating a process that uses a specially managed group of microbes to turn carbon in wastewater into useful products like biofuel. The second part uses AI to monitor and control the system to make sure the microbes work as efficiently as possible.

3. Methodology:

The system uses specially picked groups of microbes that work with Artificial Intelligence to make sewage treatment and carbon capture more efficient. These microbes are put into the wastewater and help break down harmful stuff and change carbon into useful products like fuel and other breakable materials. The system keeps track of important things like pH level, temperature, and nutrient levels. The AI looks at this data and gives guidance to create the best environment for the microbes to work in. When the wastewater goes into the system, the microbes start cleaning it

right away. All the time, the system collects live data, which the AI uses to predict what might happen next and adjust as needed.

4. Experimental results:

The data from the experiments is shown in the figures below, and it highlights how well the sewage treatment and carbon capture processes are working. To achieve this, we used specially controlled groups of microbes along with Artificial Intelligence to keep a close watch and analyze everything continuously. From the results, it's clear that this method is very effective at treating wastewater and managing carbon. The figures show key details about how well the system is performing. Overall, the results show that using these controlled microbes with smart monitoring makes sewage treatment more efficient and helps manage carbon properly.

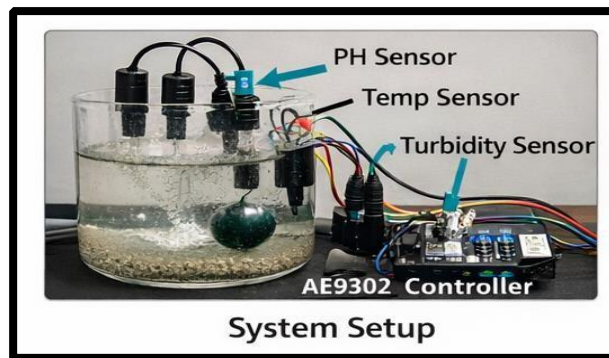


Fig 1: System Setup

The picture below shows how the system's experiment is set up. There's a glass container filled with wastewater, and several sensors are used to check different things. The sensors for measuring pH, temperature, and how cloudy the water is are connected to an ESP32 microcontroller so it can keep collecting data all the time. Also, a group of specially chosen microbes is added to the container to help break down the waste. The setup also has an air supply system that gives the microbes oxygen, which helps them grow better and work more efficiently.

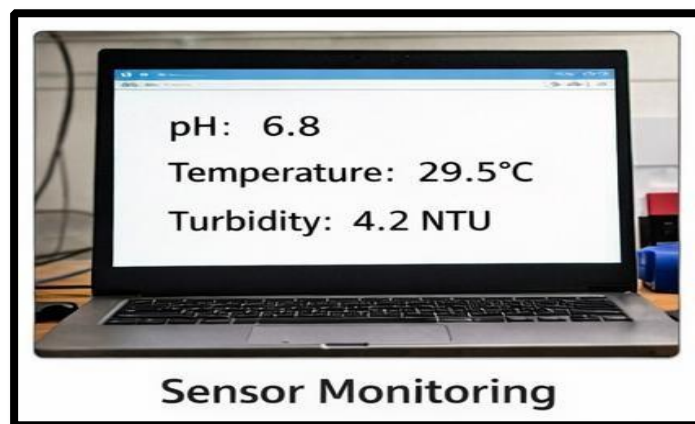


Fig 2: Sensor Monitoring

The flowchart showing how sensors are used for monitoring is in Figure 2. This figure displays real-time measurements such as pH level (6.8), temperature (29.5°C), and turbidity (4.2 NTU). These values keep changing and are shown on a digital screen. The system also saves this data, which allows us to keep track of the conditions inside the reactor. This monitoring helps ensure that all the conditions stay within the right range for the microorganisms to work properly.

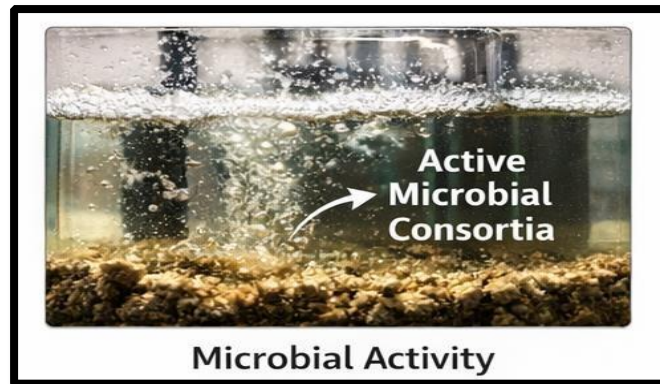


Fig 3: Microbial Activity

The processes happening inside the reactor are shown in Figure 3. The presence of bubbles and floating particles shows that microbial activity is taking place. Aeration adds oxygen to the reactor, which is important for the microbes to grow. When there is enough oxygen, the microorganisms can break down the harmful substances in the wastewater. This helps in removing carbon effectively.



Fig 4: Dirty Sewage Water

The picture below compares how untreated wastewater looks versus treated wastewater. Untreated wastewater is darker because it has a lot of harmful stuff in it. Treated wastewater is much clearer, which shows how well the treatment process works at getting rid of those harmful things. During the treatment, tiny living things called microorganisms help remove the bad stuff from the water.



Fig 5: Clean Treated Water

Figure 5 shows how the reaction process is controlled by the Artificial Intelligence system. The AI keeps checking the sensor data all the time to make sure everything in the system is working as it should. If the AI notices that the oxygen level is going down, it will take action by increasing the amount of air being added. This helps the system keep running smoothly and avoids any problems or failures.

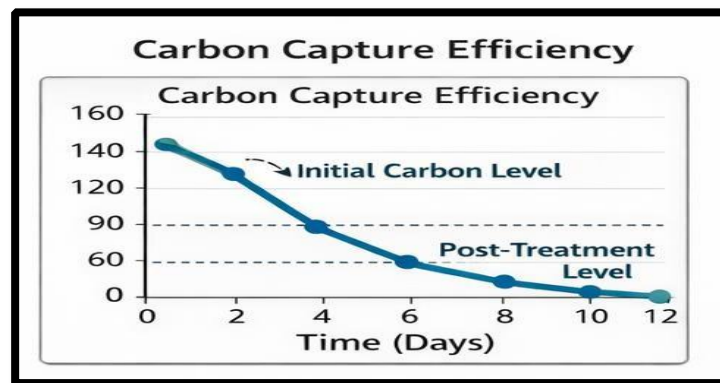


Fig 6: Carbon Capture Efficiency

Figure 6 shows how carbon capture changes over time. As you can see in Figure 6, the level of carbon in the water slowly goes down as the treatment process happens. At first, there is a lot of carbon, but as the microorganisms become more active, the amount of carbon starts to decrease.

- This means that microorganisms are really good at lowering the amount of carbon in wastewater.
- From looking at Figure 6, we can conclude the following:
- The system is able to lower the amount of carbon in wastewater.
- Using both artificial intelligence and microorganisms works well
- This method greatly improves the process of reducing carbon
- Lowering carbon is important for helping the environment.

- Microorganisms play a main role in the carbon capture process.
- Artificial intelligence helps make the process more efficient.

Table No. 1: Experimental Analysis of AI-Based Sewage Treatment System

Sr. No	Parameter	Observed Value	Status/Observation
1	pH Value	6.8	Within optimal limits
2	Temperature	29.5°C	uniform
3	Turbidity	4.2 NTU → 1.1 NTU	Reduced by large margin
4	Microbial Activity	High	Very Efficient
5	Oxygen Regulation	Automatic	Well-regulated
6	Carbon Reduction Efficiency	~75% decrease	Very high

The AI-based sewage treatment system works really well for cleaning water. It keeps important things like pH and temperature steady and at their best. It also gets rid of turbidity effectively.

There's a lot of activity from microbes, which helps in treating the water.

The system also automatically controls oxygen levels to make the process better. Additionally, it cuts down the carbon content by about 75%.

5. Conclusion:

The project focuses on improving sewage treatment in cities by using sensors, the ESP32 microcontroller, AI, and microorganisms. The system continuously checks important factors like pH, temperature, and cloudiness to make sure the best conditions are available for the microorganisms to function. These conditions help the microorganisms break down pollution and take in carbon.

AI is used here to make smart decisions based on real-time data, so people don't have to do it manually. This allows the system to work faster and better. The project shows that combining technologies like AI and biotechnology with affordable parts can create a cheap and eco-friendly solution.

6. References:

1. Yang, W. (2009). Research on methane recovery and energy production from spent wash during wastewater treatment.
2. Mustafa, H. M., Mustapha, A., Hayder, G., & Salisu, A. (2021). Using IoT and artificial intelligence to monitor and predict water quality.
3. Subha, J., & Kowsigan, M. (2022). Using bio-inspired algorithms to optimize water supply scheduling in IoT-based smart distribution systems.

4. Manyuchi, M. M., Sukdeo, N., & Stinner, W. (2021). Using biochar as a low-cost and sustainable method for wastewater treatment in gold processing.
5. Zhang, Z., & Chen, L. (2011). Changes in carbon, nitrogen, and phosphorus levels in biomass within ecological floating raft systems.
6. Liang, Y., Ma, A., & Zhuang, G. (2022). Designing synthetic microbial communities for environmental applications.
7. Jia, X., Liu, C., Song, H., & Ding, M. (2016). Creating and using microbial consortia.
8. Kratzl, F., Kremling, A., & Pflüger-Grau, K. (2022). Best way to design co-cultures for PHA production using light and CO₂.
9. Sharma, Verma & Singh (2020). Reusing nutrients and capturing CO₂ using microbe-algae interactions with omics methods in wastewater.
10. Kumar, Patel & Mehta (2021). New developments in wastewater treatment using microbial consortia and reducing greenhouse gases. Liu, Zhang, & Chen (2022). Improving monitoring and control in carbon capture biotechnology using AI-based models.
11. Rahman, Al-Hassan, & Yaseen (2021). Using AI for wastewater management with predictive models and feature selection.
12. Gonzalez, Thomas, & Edwards (2020). Using machine learning to predict functions of microbial communities.
13. Green (2008). Using biofilm reactors to treat wastewater.
14. Guo (2021). New developments in recovering resources from wastewater systems.
15. Harder (2014). Studying how bacteria interact in microbial communities.
16. Huang (2021). Using AI-based methods to optimize water and wastewater treatment systems.
17. Jain (2020). Using IoT and AI for managing wastewater systems.
18. Jansson & Hofmockel (2018). Controlling carbon cycles in ecosystems.
19. Jiang (2019). Symbiosis between algae and bacteria and its use in wastewater treatment.
20. Kang (2022). Predicting environmental factors using machine learning.
21. Kim & Lee (2016). Anaerobic digestion and methane production from wastewater.
22. Kolenbrander (2011). Structure and interactions in microbial communities.
23. Kumar & Sharma (2020). Using resource recovery methods in wastewater treatment.
24. Li (2019). Using synthetic biology tools for bioremediation.
25. Li (2020). Creating microbial consortia for sustainable bioprocessing.
26. Liu (2017). Using biochar for environmental cleanup.
27. Ma (2021). Applying machine learning in ecology.
28. Majumder & Gupta (2018). Using microbial fuel cells for wastewater treatment.
29. Malakar (2019). Approaches to model water quality management.
30. Manyuchi (2021). Using biochar in wastewater treatment systems



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