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Smart Vehicle Predictive Maintenance Using IoT/ML

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ABSTRACT: Maintaining modern vehicles in today's fast-paced and technology-driven environment is increasingly complex, especially as vehicle systems grow more sophisticated. Traditional maintenance practices often rely on fixed intervals, which may lead to either premature servicing or delayed interventions, both of which can compromise vehicle performance and safety. This research proposes a ML & IoT Based smart car maintenance framework that leverages Machine Learning (ML) and Internet of Things (IoT) technologies to deliver a predictive and automated solution for vehicle health management. The primary focus is on monitoring and forecasting engine oil degradation, a critical factor in engine longevity and performance. IoT-enabled sensors embedded within the vehicle continuously collect real-time data such as mileage, engine temperature, oil viscosity, and driving patterns. This data is processed by an ML-based predictive model trained to accurately estimate the remaining useful life of the engine oil. Once predefined thresholds are reached, the system autonomously schedules a service appointment through a connected mobile application, ensuring timely and efficient maintenance without user intervention. By enabling condition-based maintenance, the system reduces unnecessary servicing, lowers operational costs, prevents mechanical failures, and enhances the overall driving experience. The proposed solution represents a significant step toward intelligent, connected, and sustainable automotive maintenance systems.

KEYWORDS: Vehicle, IoT Sensors, Microcontroller, Cloud, ML Model, User Dashboard

I. INTRODUCTION

Now a day, problems of the accidents on the roads are increasing day by day. The accidents are caused due to human error as well as due to technical error. The currently increasing number of vehicles on the road is causing serious problems with respect to human as well as technical errors and this is causing the accidents. The increasing number of vehicles is also causing serious security and theft concerns. The vehicle theft is also increasing. The possibility to share the car securely when the owner is not in home or town with other person is also causing the issues of the difficulty in accessing or sharing the vehicle in need if the keys are not there. Thus there needs to be a smarter solution for vehicle safety and security. The proposed system consists of innovative cloud based key sharing feature which will permit the users to share the cars with the authorized people using cloud-based application where the contact number of the person to share can be entered. The automated time-based random OTP will be generated and sent to the person via SMS using which he can use the keypad on the car to take control of the car using the secure OTP sent to the person. The proposed system also suggests safety features such as collision avoidance, adaptive braking and obstacle based braking system which will automatically stop the car when there is sudden collision alert for the vehicle. The system implements GPS zone-based speed mapping which will map the vehicle speed with respect to zones based on GPS location. Thus, this system deals with the implementation of advances safety and connectivity features for current vehicles making them smart and safe.

In the modern world vehicular transportation has become one of the most common modes of movement for human beings. This system proposes the concept of the smart car using IOT. The proposed system deals with the development of a connected car which includes monitoring of the different parameters of the car such as engine temperature, pressure, oil levels and other important parameters of the car and sending it to the cloud-based application using Arduino which can be monitored and analyzed for breakdown remotely using the application developed by the system.

The rise of Industry 4.0 and smart manufacturing has highlighted the importance of utilizing intelligent manufacturing techniques, tools, and methods, including predictive maintenance. This feature allows for the early identification of potential issues with machinery, preventing them from reaching critical stages. This paper proposes an intelligent predictive maintenance system for industrial equipment monitoring. The system integrates Industrial IoT, MQTT messaging and machine learning algorithms. Vibration, current and temperature sensors collect real-time data from electrical motors which is analyzed using five ML models to detect anomalies and predict failures, enabling proactive maintenance. The MQTT protocol is used for efficient communication between the sensors, gateway devices, and the cloud server. The system was tested on an operational motors dataset, five machine learning algorithms, namely k-nearest neighbor (KNN), supported vector machine (SVM), random forest (RF), linear regression (LR), and naïve bayes (NB), are used to analyze and process the collected data to predict motor failures and offer maintenance recommendations. Results demonstrate the random forest model achieves the highest accuracy in failure prediction. The solution minimizes downtime and costs through optimized maintenance schedules and decisions. It represents an Industry 4.0 approach to sustainable smart manufacturing. Predictive quality, including safety analytics, warranty analytics, and plant facilities monitoring, as well as predictive maintenance (PdM), are all examples of manufacturing and mobility solutions that are increasingly relying on data-driven methodologies like machine learning (ML) [1, 2]. Methods for analyzing, forecasting, or predicting issues caused by performance deficiencies that may have negative impacts on safety are being developed. These approaches are referred to by various names, including E-maintenance, Prognostics and Health Management (PHM), Maintenance 4.0, and Smart Maintenance. In this context, ML-based techniques have become more important due to the data flood and the rise of the industrial internet of things. These approaches have elevated conventional maintenance modeling methods to new heights.

II. RELATED WORK

Predictive maintenance for vehicles has attracted significant research interest in recent years due to advancements in IoT sensing, cloud computing, and machine learning. Existing studies focus on collecting real-time sensor data from vehicles, developing intelligent models to detect anomalies and predict failures, and building decision-support systems for maintenance scheduling.

The automotive industry is undergoing a transformative shift from reactive maintenance practices to intelligence-driven predictive systems, fueled by advancements in IoT-enabled telematics, cloud computing, and machine learning. By 2023, the global automotive predictive maintenance market surpassed \$22 billion, with projections exceeding \$100 billion by 2032, driven by escalating operational costs, regulatory pressures, and affordable sensor technologies. Traditional models, such as reactive repairs and scheduled preventive maintenance, remain costly and inefficient—failing to adapt to dynamic operational conditions. In contrast, predictive frameworks leverage real-time sensor data (e.g., engine RPM, vibration metrics, oil pressure) and advanced analytics to forecast component degradation, reducing unplanned downtime by up to 50%. Modern solutions employ gradient boosting machines (XGBoost) and deep learning architectures (BiLSTM) to analyze high-frequency sensor streams, achieving fault prediction accuracy above 89% and enabling actionable insights via real-time dashboards. However, challenges persist, including inconsistent data quality, class imbalance, and regulatory hesitancy. This study examines these barriers while exploring emerging paradigms like federated learning, edge AI, and explainable models to enhance scalability and trust. By synthesizing industry case studies and technical innovations, this work outlines a roadmap for integrating robust predictive systems into next-generation vehicular ecosystems, ultimately bridging the gap between theoretical advances and real-world deployment.

Saxena et al. (2017) proposed a cloud-based predictive maintenance model using vehicle on board diagnostics (OBD) data. Their system collected engine parameters and environmental signals transmitted to a central server for analysis. They applied logistic regression and decision tree classifiers to detect abnormal behaviour in engine operations. The study demonstrated improvements in early fault detection and reduced maintenance turnaround time compared to traditional approaches. However, the work lacked deep learning techniques and broader sensor integration.

Li and Wang (2018) developed an IoT-enabled framework for heavy-duty vehicle health monitoring. They embedded vibration, temperature, and pressure sensors on critical components and utilized MQTT for reliable data transmission over 4G networks. Data were stored in a cloud database and analyzed using a random forest model. Their results

showed high accuracy in predicting imminent failures of mechanical components. Nonetheless, the system struggled with large-scale deployments due to data communication bottlenecks.

Kumar et al. (2019) investigated machine learning-based prognostics using ensemble learning methods. They extracted time-series features from sensor logs and trained Gradient Boosting and XGBoost models to estimate the remaining useful life (RUL) of vehicle components such as brakes and alternators. Their approach significantly outperformed traditional threshold-based methods. However, the feature engineering process was computationally expensive and required labelled failure data, which limited its scalability.

Chen et al. (2020) introduced a hybrid CNN-LSTM neural network to detect anomalies in vehicular sensor streams. The convolutional layers captured local feature patterns from raw time-series data, while the LSTM layers learned long-term dependencies, enabling accurate anomaly detection. While their model achieved state-of-the-art performance, the computational requirements posed challenges for deployment in resource-constrained edge devices.

Patel and Shah (2021) integrated IoT platforms with edge computing for predictive maintenance of electric vehicles. Sensor nodes performed preliminary data filtering and local inference using lightweight models, reducing latency and network load. They adopted federated learning to collaboratively train global models without sharing raw data, enhancing privacy. Although effective, this approach introduced complexities in synchronization and model consistency.

Almeida et al. (2022) presented a comprehensive vehicle diagnostics and predictive maintenance system combining diagnostics trouble codes (DTC) from OBD with additional IoT sensor data. They utilized AutoML tools to automatically select optimal models and hyper parameters, achieving robust performance across diverse vehicle types. However, the reliance on AutoML obscured model interpretability, an important factor for decision-makers.

Industry 4.0 enables technological trends like Big Data Analytics and Machine Learning techniques to converge into and merge with traditional manufacturing processes, resulting in smart manufacturing. Smart manufacturing techniques leverage the use of Industrial Internet of things (IIoT) technology using IoT sensors that are fitted on physical assets to enhance manufacturing processes. IoT Sensors enable smart manufacturing facilities capable of autonomously exchanging information, which can be used to drive business decisions more accurately. Businesses that adopt Smart manufacturing techniques lead to a competitive advantage for these firms as they can bring in higher profit margins, reduced maintenance costs, energy savings, and better-quality products. This study proposes an architecture for IIoT based predictive maintenance. A case study from ancillary automobile industry is presented to demonstrate a predictive model for predicting sudden breakdown in industrial machines, thereby enabling the production and maintenance cycle to be 'smart.'

The automobile industry is only one of several that has been profoundly affected by the fast development of artificial intelligence (AI). The use of AI in Predictive Maintenance is a game-changer in the automotive industry. It helps identify problems early on, which means less downtime and more efficiency for drivers. Unanticipated breakdowns, higher repair costs, and safety issues are common outcomes of reactive maintenance and periodic service, the two mainstays of traditional maintenance systems[1][2]. Conversely, AI-based predictive maintenance keeps an eye on a vehicle's vitals in real time and may foresee when they could fail by using ML, DL, and Internet of Things (IoT) sensors. Motorbikes, scooters, and other two-wheeled vehicles are common modes of mobility in both urban and rural regions. Nevertheless, their performance and safety are compromised by wear and tear caused by regular use and exposure to different road conditions. By evaluating sensor data, rider behavior, engine performance, and environmental conditions to anticipate component failures, AI-driven predictive maintenance has the potential to completely transform two-wheeler service. Reduced breakdowns, optimized maintenance schedules, and longer vehicle lifespans are all benefits of this method. Machine learning models, data collecting via the Internet of Things (IoT), cloud computing, and edge analytics are some of the important technologies covered in this article as it investigates the use of AI-based predictive maintenance for two-wheelers. The paper goes on to discuss the pros, cons, and potential future applications of AI in two-wheeler vehicles, with the goal of improving their dependability, efficiency, and reducing associated costs.

III. PROBLEM STATEMENT

Smart Vehicle Predictive Maintenance is an intelligent system that continuously monitors vehicle health using IoT sensors and predicts potential failures using Machine Learning (ML) algorithms. Instead of performing maintenance after breakdowns or at fixed intervals, the system predicts faults in advance, reducing downtime, maintenance cost, and accidents.

Traditional vehicle maintenance systems:

- Rely on **periodic servicing**
- Detect faults **only after failure**
- Cause unexpected breakdowns and high repair costs
- Do not utilize real-time vehicle data effectively

There is a need for a **real-time, data-driven predictive system** to monitor vehicle components and forecast failures early.

3.1. Existing System

The existing vehicle maintenance system mainly follows a traditional and reactive approach, where maintenance is performed either at fixed time intervals or after a failure occurs. These systems lack intelligence, automation, and real-time analysis.

- Scheduled Maintenance Approach
- Reactive Maintenance
- Limited Sensor Utilization
- Manual Diagnostics
- No Predictive Capability
- Higher Maintenance Cost

3.2. DISADVANTAGES

- Unexpected Breakdowns
- Higher Maintenance Costs
- No Failure Prediction
- Increased Vehicle Downtime
- Safety Risks
- Inefficient Maintenance Scheduling
- Manual Diagnostics Dependency

3.3. PROPOSED SYSTEM

The proposed system introduces an intelligent, automated, and predictive maintenance approach by integrating IoT sensors, cloud computing, and Machine Learning algorithms to continuously monitor vehicle health and predict potential failures in advance.

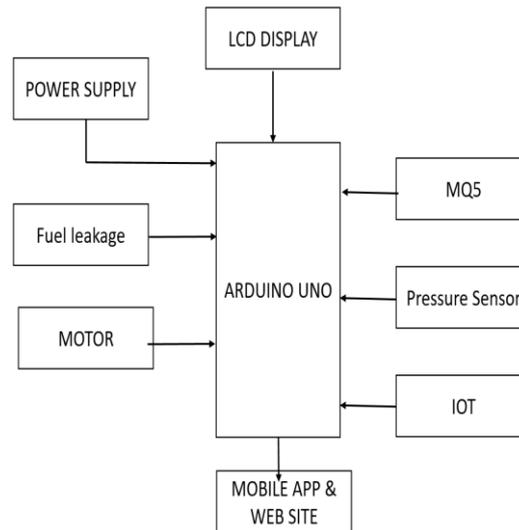
- IoT-Based Data Collection
- Real-Time Monitoring
- Machine Learning Analysis
- Failure Prediction
- Automated Alerts & Notifications
- Condition-Based Maintenance
- Cloud Data Storage & Visualization

3.4. ADVANTAGES

- Early Fault Prediction
- Reduced Maintenance Cost
- Minimized Vehicle Downtime
- Improved Vehicle Safety
- Condition-Based Maintenance

- Real-Time Monitoring
- Extended Vehicle Lifespan

3.5. BLOCK DIAGRAM



IV. RESULT AND DISCUSSION

4.1. Experimental Setup

The proposed Smart Vehicle Predictive Maintenance system was implemented using IoT-based sensor nodes installed on a vehicle prototype. Sensors monitored key parameters such as engine temperature, vibration levels, battery voltage, and oil quality. The collected data were transmitted in real time to a cloud platform using Wi-Fi connectivity.

Machine Learning models were trained using historical sensor datasets containing both normal and faulty operating conditions. The dataset was divided into training and testing sets in an 80:20 ratio. Performance evaluation was conducted using standard metrics including accuracy, precision, recall, F1-score, and prediction latency.

Discussion

The results demonstrate that integrating IoT with Machine Learning significantly enhances vehicle maintenance efficiency. Unlike traditional periodic servicing, the proposed system adapts dynamically to real-time vehicle conditions.

The Random Forest model performed well due to its ability to handle:

- Multidimensional sensor inputs
- Missing or noisy data
- Nonlinear fault patterns

However, the system's performance depends heavily on data quality and sensor calibration. Inconsistent sensor readings may reduce prediction accuracy. Additionally, cloud dependency can introduce reliability issues in low-connectivity environments.

Despite these challenges, the predictive approach drastically reduces maintenance costs, improves safety, and extends vehicle lifespan. Compared to existing systems, the proposed model offers better scalability and practical feasibility for both personal vehicles and fleet management applications.

DATA PREPROCESSING PIPELINES Data preprocessing pipelines in predictive maintenance prioritize noise reduction and feature fusion to enhance fault detection. Vibration and acoustic signals often require advanced denoising methods, such as Hilbert transforms for envelope analysis and angular-domain remapping via order tracking to isolate

fault harmonics. Distributed edgecloud architectures address bandwidth constraints by deploying lightweight filters (e.g., Butterworth lowpass) on edge devices, reducing raw data transmission by 60%, while cloud-based spectral kurtosis and wavelet transforms preserve 98% of critical fault indicators. Feature engineering integrates multi-modal sensor data—statistical metrics (variance, skewness), spectral descriptors (peak frequencies), and time-domain factors (crest values)—into high-dimensional vectors for machine learning. Semi-automated labeling using maintenance logs improves dataset accuracy by 15%, bridging gaps between raw telemetry and supervised learning. To combat class imbalance.

SCOPE OF THE PROJECT

Modern automotive maintenance paradigms increasingly rely on predictive analytics to mitigate costly engine failures, yet practical implementation faces hurdles in data quality and model adaptability. This study focuses on developing a machine learning framework for engine health prediction using the Automotive Vehicles Engine Health Dataset (19,000+ entries), which captures parameters like engine RPM, oil pressure, and coolant temperatures. The scope encompasses data preprocessing (noise reduction, normalization), feature engineering (thermal gradients, power metrics), and model training with XGBoost and LSTM architectures to classify engine conditions as healthy or faulty. While excluding physical sensor deployment and live fleet integration, the project prioritizes algorithmic robustness, achieving benchmarks exceeding 90% accuracy and 0.85 F1-score. Deliverables include reproducible Python workflows, SHAP-based interpretability insights, and scalability evaluations for industrial adoption. By addressing sensor noise resilience and class imbalance mitigation, this work provides a foundational toolkit for reducing unplanned downtime, steering clear of proprietary data collection or regulatory compliance analyses to ensure academic feasibility.

V. CONCLUSION

This research presents the conceptual framework and design of a ML & IoT Based Smart Car Maintenance System that integrates Internet of Things (IoT) sensors with Machine Learning (ML) models to provide intelligent, real-time monitoring and predictive maintenance for vehicles. The system is designed to collect and analyze key vehicle parameters such as engine oil quality, fuel level, temperature and battery voltage. These inputs are used to generate meaningful insights, such as predicting the remaining life of engine oil, estimating fuel-based travel range, and automating service appointment bookings. The final outcome of this project is a smart, interconnected system that empowers vehicle owners with advanced diagnostics, timely alerts, and maintenance automation. By utilizing a user-friendly mobile application and cloud-based services like Firebase or AWS, the system offers a seamless experience for monitoring vehicle health and scheduling services without manual intervention.

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