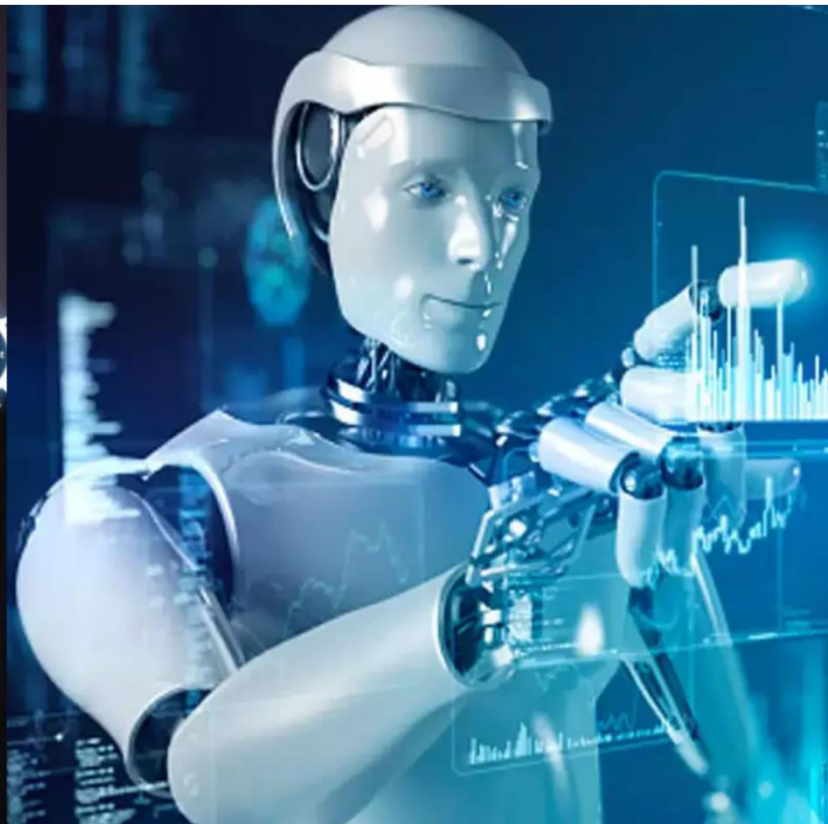




International Journal of Innovative Research in Science Engineering and Technology (IJIRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.699

Volume 14, Issue 5, May 2025

Design and Implementation of IoT Enabled Device for Real-Time Monitoring of Greenhouse Gas Emissions, and Pressure in Anaerobic Reactors

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ABSTRACT: In recent times, the management of indoor greenhouse environments has become a critical concern, especially in the context of precision agriculture. Efficient monitoring of environmental conditions such as temperature, humidity, CO₂ levels, and light intensity is essential for optimizing plant growth. However, existing methods for greenhouse management often lack an integrated approach for real-time monitoring and adaptive control, making it challenging to maintain consistent growth conditions. Current techniques typically rely on isolated systems that lack the ability to effectively monitor multiple environmental parameters simultaneously. Additionally, many systems fail to provide accurate localization for autonomous robots that navigate these spaces, limiting their efficiency and precision. more efficient agricultural practices rises. This study introduces an innovative solution by combining advanced technologies such as Wireless Sensor Networks (WSN), IoT, Infrared (IR) navigation, and Radio Frequency Identification (RFID) localization. The proposed framework utilizes low-power autonomous sensor nodes to continuously gather data on essential environmental factors while enabling precise robot navigation within the greenhouse. By employing a Kalman-based algorithm, the system merges sensor data with localization signals to improve navigation accuracy and environmental control. The primary goal is to create a system that enhances both environmental monitoring and autonomous movement of robots in indoor greenhouses. By integrating these technologies, the system aims to offer real-time feedback on environmental conditions and optimize robot navigation. Preliminary tests in real-world conditions have shown that the system successfully integrates environmental sensing with localization capabilities, providing reliable data transmission and accurate robot movement.

KEYWORDS: Crop Health Monitoring, Smart Farming, Precision Agriculture, Plant Disease Detection, Pesticide Spraying, Image Classification.

I. INTRODUCTION

In the realm of modern agriculture, the growing challenge of plant diseases poses a significant threat to global food security, crop yield, and economic stability. Traditional approaches to disease detection and pesticide application are often inefficient, time-consuming, and prone to human error, leading to excessive use of chemicals and environmental degradation. The evolution of agricultural technologies now enables the development of smart systems that combine automation, artificial intelligence, and wireless communication to address these issues effectively. This project introduces an autonomous agricultural robot equipped with a deep learning-based disease detection system and wireless control to ensure accurate and timely pesticide spraying. The aim is to optimize agricultural practices, reduce chemical waste, and promote sustainable farming through real-time disease monitoring and targeted treatment.

The core functionality of the proposed system lies in its ability to detect plant diseases through image analysis using a pre-trained ResNet deep learning model implemented in MATLAB. This enables precise identification of infected plant areas by analyzing visual symptoms, such as leaf discoloration or abnormal patterns. Once a disease is detected, the system sends a signal to the Arduino Nano microcontroller, which activates the pesticide sprayer. This targeted approach eliminates the need for blanket spraying, conserving chemicals and reducing potential harm to non-

affected crops and the environment.

II. RELATED WORK

The integration of Internet of Things (IoT) technologies into anaerobic digestion systems has significantly advanced the real-time monitoring of greenhouse gas emissions and pressure within reactors. Recent studies have demonstrated the effectiveness of low-cost microcontrollers, such as ESP32, in capturing critical parameters like methane (CH₄), carbon dioxide (CO₂), hydrogen sulfide (H₂S), temperature, and pressure. For instance, a study by Andrade et al. developed an IoT-based system that enhanced the understanding and optimization of the anaerobic digestion process by providing real-time data on various gas concentrations and environmental conditions. Similarly, Ortega Kai et al. implemented an instrumentation and control system incorporating sensors connected through a Programmable Logic Controller (PLC), enabling real-time data visualization and remote monitoring via platforms like Power BI. These advancements not only improve the efficiency and safety of anaerobic reactors but also facilitate data-driven decision-making, contributing to more sustainable and effective waste-to-energy conversion processes.

III. EXISTING METHODOLOGIES

In systems in the field of robotics, automation, and smart agriculture have predominantly focused on core functionalities such as obstacle detection, behavior tracking of humans and robots, and environmental mapping. These foundational capabilities form the basis of autonomous navigation and decision-making in dynamic and unpredictable environments. Numerous research efforts have thus emphasized the development of compact, efficient systems using sensors and microcontrollers tailored specifically for mapping and localization tasks. These systems often rely on lightweight hardware setups to ensure portability and adaptability in both indoor and outdoor settings. For instance, in the development of wireless control systems for agricultural motors, one notable study implemented a system controlled via SMS commands through mobile phones, showcasing a practical approach to remote agricultural equipment management without the need for constant physical intervention. Similarly, in the “Controlled Environment Agriculture – Scoping Study,” the author explores high-intensity farming methods that rely heavily on precision monitoring and control technologies to optimize crop production within enclosed environments. This includes regulated lighting, temperature, humidity, and nutrient delivery, often controlled through automation and data-driven systems. Together, these works reflect the ongoing trend toward intelligent, responsive, and efficient agricultural and robotic systems that integrate sensor-based inputs with smart control mechanisms. The common thread across these studies is the use of minimal yet powerful computational hardware to enable real-time decision-making, environment interaction, and system scalability, making them relevant not just in research but also in practical, on-field deployments

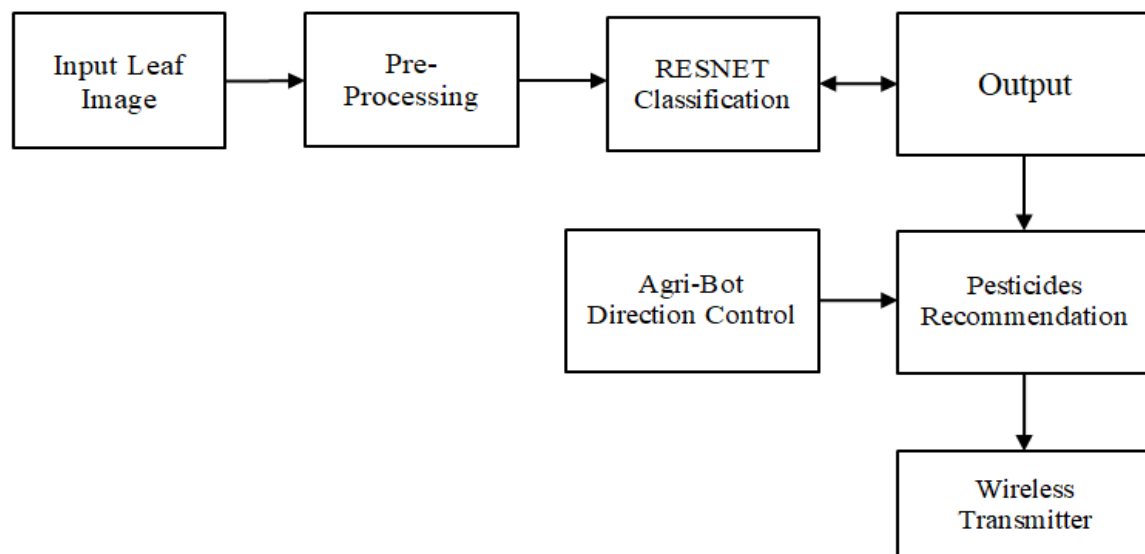


Fig 1: Proposed Block Diagram

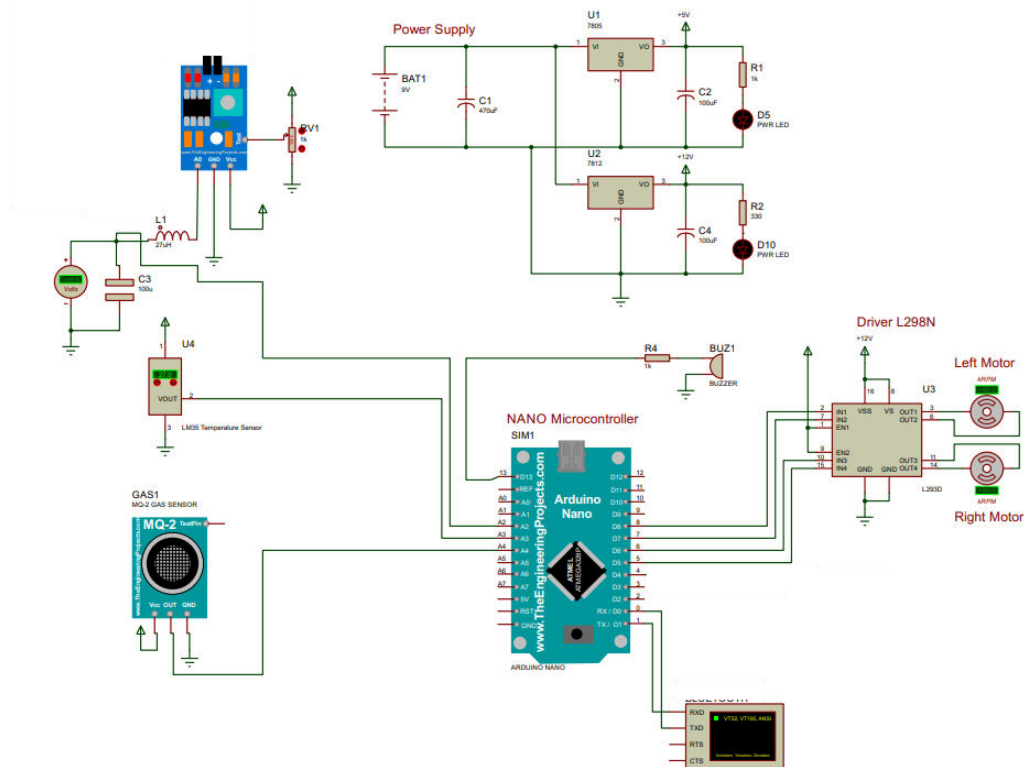
The proposed system utilizes a high-resolution camera for continuous plant image acquisition, capturing clear and detailed images of plant leaves. These images are then resized and normalized to standardize their resolution and pixel intensity, ensuring they are ready for processing. The preprocessed images are passed through a pre-trained ResNet model implemented in MATLAB for disease detection. ResNet, a deep learning-based model, identifies patterns and features in the plant images, accurately classifying diseases and determining the health status of the plants. Once a disease is detected, MATLAB communicates with an Arduino Nano microcontroller through HC-12 wireless modules, enabling seamless control of the autonomous robot's movement. The Arduino Nano triggers the pesticide sprayer, targeting the affected areas with precision. This integrated system allows for real-time plant disease detection and automatic pesticide application, optimizing crop management by minimizing human intervention, reducing labour costs, and ensuring the precise use of chemicals. The approach significantly improves the efficiency of agricultural practices, enabling sustainable farming by reducing overuse of pesticides and promoting environmental safety. By combining deep learning and robotics, this system provides an innovative solution to modern agricultural challenges, making it a valuable tool for precision agriculture and improving overall crop health management.

The robotic system is powered by a battery or solar panel, ensuring a sustainable energy source for all operations, including movement, sensors, and control units. The Arduino Nano serves as the central control unit, acting as the brain of the robot. It receives commands from the external MATLAB system via wireless communication through the HC-12 module and processes them to manage the robot's functions. The HC-12 module enables seamless data transfer between the MATLAB system and the robot, facilitating real-time disease detection and triggering necessary actions for crop management. The robot's movement is controlled by actuators connected to motors, allowing for precise navigation in the field. Additionally, the robot is equipped with a pesticide sprayer that can be activated through a solenoid valve or a peristaltic pump. When the system detects plant diseases, the Arduino Nano sends commands to activate the sprayer, targeting the affected areas for efficient and controlled pesticide application. This integration of power supply, control, wireless communication, and actuators ensures that the robotic system operates autonomously with minimal human intervention, offering an effective solution for precision agriculture and optimized pesticide usage.

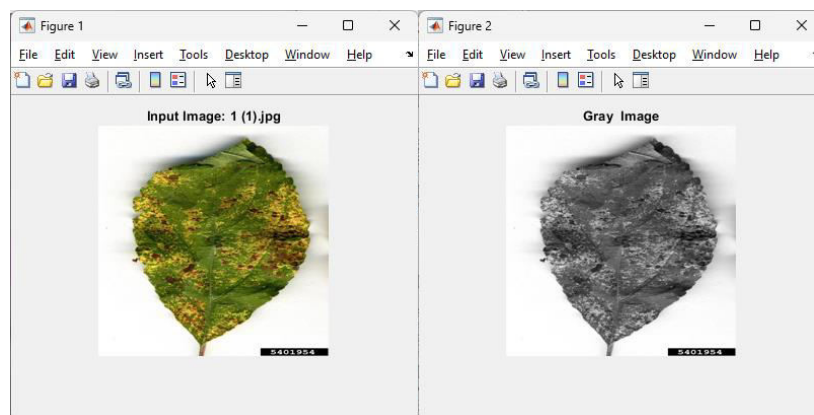
IV. IMPLEMENTATION AND RESULT

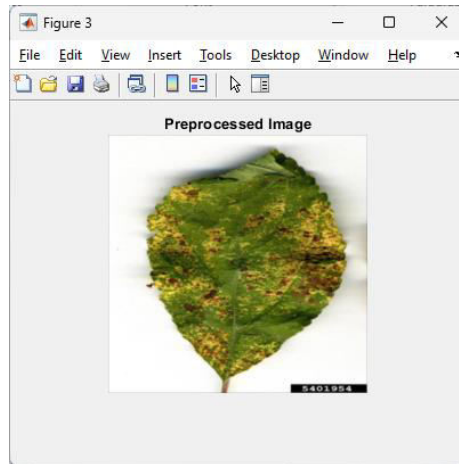
The integration of robotics into the design and implementation of IoT-enabled devices for real-time monitoring of greenhouse gas emissions and pressure in anaerobic reactors represents a significant advancement in environmental monitoring and waste management. Robotic systems enhance the precision, efficiency, and safety of data collection processes, particularly in challenging or hazardous environments associated with anaerobic digestion.

The robotic system is equipped with a suite of sensors, including pressure-controlled flow sensors, gas sensors for methane (CH_4), carbon dioxide (CO_2), and hydrogen sulfide (H_2S), as well as temperature and humidity sensors. These sensors are integrated into a mobile robotic platform capable of navigating the vicinity of anaerobic reactors. The robot utilizes microcontrollers, such as the ESP32, to process sensor data and transmit it wirelessly to a cloud-based platform for real-time monitoring and analysis. The mobility of the robot allows for comprehensive spatial data collection, enabling the detection of gas leaks and pressure anomalies at various points around the reactor. Additionally, the robotic system can be programmed to perform routine inspections, reducing the need for human intervention and enhancing safety.

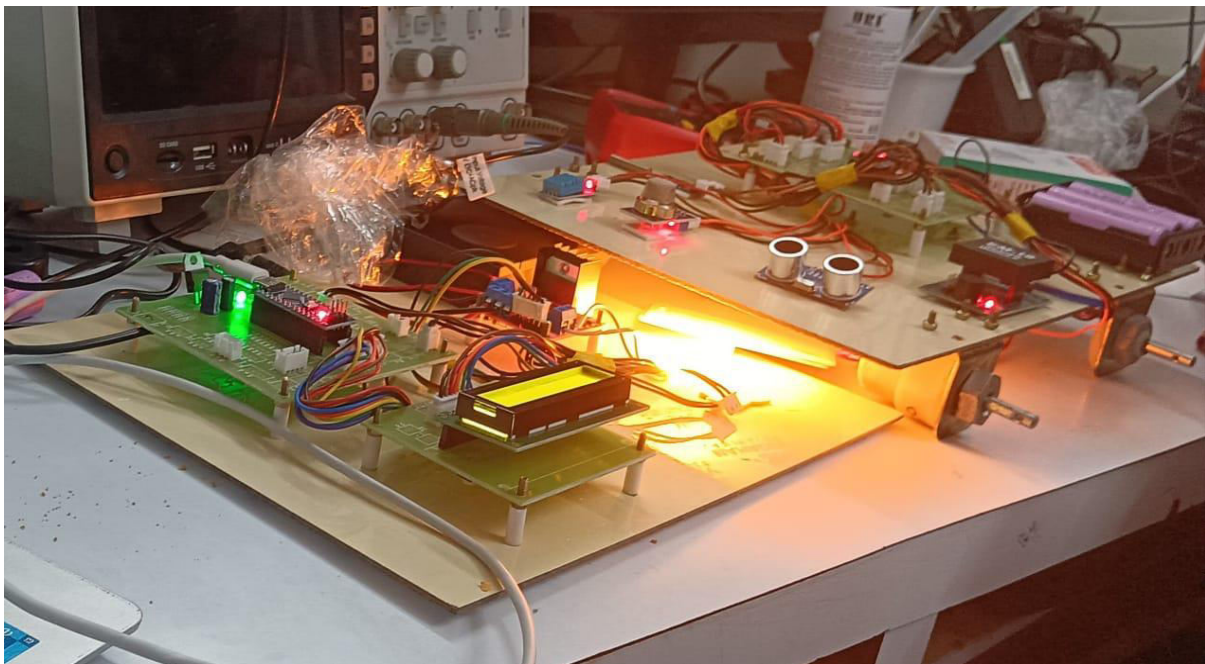


Experimental deployment of the robotic monitoring system demonstrated high accuracy in detecting and quantifying greenhouse gas emissions and pressure variations. The system achieved a correlation coefficient (R^2) of 0.997 and a Root Mean Square Error (RMSE) of 0.09 when comparing estimated gas production to actual measurements. The mobility of the robot allowed for the identification of localized emission hotspots and pressure irregularities, facilitating targeted maintenance and optimization of the anaerobic digestion process. The integration of robotics into the monitoring system not only improved data accuracy and spatial resolution but also enhanced operational safety by minimizing human exposure to potentially hazardous conditions.





.In conclusion, the incorporation of robotic systems into IoT-enabled monitoring devices for anaerobic reactors offers a robust and efficient approach to environmental monitoring. The enhanced data collection capabilities and operational safety provided by robotics contribute to more effective management of greenhouse gas emissions and pressure control in anaerobic digestion processes, supporting environmental sustainability and regulatory compliance.



V. CONCLUSION

In conclusion, the proposed system offers a smart, low-cost, and efficient solution for monitoring and controlling environmental conditions crucial for plant growth, particularly within greenhouse settings. By integrating temperature and humidity sensors with RFID technology, the system ensures precise regulation of climate parameters while enabling seamless plant identification and data tracking without physical contact. Its automated response mechanism enhances energy efficiency and reduces the need for constant human supervision, making it highly suitable for modern, scalable agricultural applications. With capabilities for real-time monitoring, automated alerts, and potential IoT integration, the project significantly advances sustainable farming practices, supporting both productivity and environmental responsibility.

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