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Autonomous Plant Health Monitoring and Climate Actuation using YOLOv8 and ESP32-based Mobile Rover

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Abstract: Maintaining plant health and ensuring suitable environmental conditions are essential aspects for modern agriculture. This work introduces an integrated system that combines artificial intelligence, mobile robotics, and Internet of Things (IoT) technologies to enable automated plant monitoring and greenhouse management. The proposed system employs a mobile robotic rover equipped with a vision unit to capture images of plant leaves. These images are processed using a YOLOv8-based deep learning algorithm to identify and classify plant diseases with high accuracy. In parallel, environmental parameters such as soil moisture, temperature, and humidity are continuously measured through embedded sensor modules via ESP32.The system adopts a distributed control framework using ESP32 microcontrollers, allowing seamless interaction between sensing components and actuators. When the soil moisture level falls below a predefined threshold, the system automatically activates a water pump to watering the plants. Along with, if the ambient temperature exceeds the desired limit, a cooling fan is triggered to lower the temperature. These automated control actions ensure that plants are consistently maintained under optimal growth conditions in disease free environment. Real-time data processing enables intelligent decision-making for irrigation and climate control. Furthermore, a mobile application interface allows users to remotely monitor system status, receive instant notifications, and make informed decisions based on collected data.
Keywords: Smart Agriculture, Deep Learning, IoT Systems, YOLOv8, Robotic Monitoring, Greenhouse Automation.

I. INTRODUCTION

Modern agricultural systems are increasingly required to adopt intelligent technologies to meet the growing demand for food production while minimizing resource consumption. Among the primary challenges are the timely detection of plant diseases and the maintenance of favourable environmental conditions within controlled cultivation environments such as greenhouses.

Conventional monitoring techniques depend largely on manual inspection, which introduces delays and inconsistencies. Such approaches are not scalable and often fail to detect diseases at an early stage, leading to significant yield loss [1] [2] [3]. However, many existing implementations lack mobility and integrated control capabilities.

To overcome the limitations of existing approaches, this work presents a mobile robotic system that integrates real-time disease detection, environmental monitoring, and automated response into a single unified platform. The primary objective is to improve operational efficiency, reduce reliance on manual intervention, and support data-driven agricultural practices.

In this work, a deep learning–based visual recognition model is employed to accurately detect plant diseases from images captured in real time. Simultaneously, an IoT-based sensor network continuously gathers environmental data, enabling precise monitoring of plant growth conditions. The proposed system is experimentally validated using a rover platform, demonstrating its practical applicability in real-field scenarios. By combining these technologies, the system enables early detection and timely response, ultimately improving plant health management and overall productivity.

II. LITERATURE REVIEW

Several studies have explored plant disease detection using image processing and deep learning techniques. Traditional approaches relied on manual feature extraction and classical machine learning classifiers, which showed limited accuracy under varying lighting and background conditions. Recent works have adopted convolutional neural networks (CNNs) trained on datasets such as Plant Village to improve disease classification performance [1], [2].

IoT-based greenhouse monitoring systems have been proposed to measure temperature, humidity, and soil moisture using static sensor nodes [3], [4].

While these systems provide continuous environmental data, they lack mobility and visual inspection capabilities. Robotic platforms have been introduced for agricultural monitoring; however, many are limited to navigation or basic sensing without intelligent disease diagnosis.

To the best of our knowledge, existing approaches have not fully integrated mobile robotics, deep learning–based vision, and automated actuation within a single cohesive framework. Most current solutions tend to focus on either plant disease detection or environmental monitoring and control, rather than addressing both aspects simultaneously [5]. This limitation reveals a clear research gap and emphasizes the need for a unified, intelligent, and autonomous system for greenhouse monitoring and management.

III.NOVELTY

1) AI-enabled mobile plant inspection: In contrast to fixed monitoring setups, this system integrates a YOLOv8-based deep learning model with a mobile robotic platform, allowing dynamic field coverage and real-time detection of plant diseases directly at the source.
2) Automated feedback-based climate regulation: The proposed solution incorporates a closed-loop control strategy in which environmental parameters such as soil moisture and temperature are continuously monitored and used to automatically activate irrigation and cooling systems, minimizing the need for manual intervention.
3) Decentralized IoT framework with ESP32 controllers: The architecture employs multiple ESP32 microcontrollers in a distributed manner to manage sensing, data exchange, and actuation tasks, resulting in improved system flexibility, faster response times, and enhanced operational reliability.
4) Integrated analysis of plant health and environmental conditions: The system combines image-based disease detection with real-time environmental sensing, enabling coordinated decision-making for both plant health management and climate control rather than addressing these aspects independently.
5) Remote monitoring with intelligent user support a mobile application interface is developed to provide continuous system monitoring, real-time alerts, and meaningful insights, assisting users in making informed decisions for efficient agricultural management.

IV. PROPOSED SYSTEM

The proposed system is designed as an integrated platform that combines mobile robotics, deep learning, and IoT-based sensing for efficient plant health monitoring and environmental control within a greenhouse environment. The overall architecture of the system is illustrated in the block diagram shown in Fig.1, which highlights the interaction between the rover, sensing units, processing module, and actuation system.

The system is built around a four-wheel robotic rover developed on a multi-wheel chassis and controlled using an ESP32 microcontroller. The rover navigates through the greenhouse to collect real-time data from different plant locations. An IP camera mounted on the rover continuously captures images of plant leaves, which are transmitted to a GPU-enabled server. A YOLOv8-based deep learning model processes these images to detect and classify plant diseases in real time [5], [6].

In addition to visual analysis, environmental monitoring is performed using a soil moisture sensor and a temperature–humidity (DHT) sensor mounted on the rover. The collected sensor data is continuously evaluated against predefined threshold values to assess plant growth conditions.

When the system detects deviations from optimal conditions, it initiates automated control actions. Control signals are sent via Wi-Fi to a secondary ESP32 controller, which operates a relay module connected to a water pump and a cooling fan. Based on these commands, the system performs automatic irrigation or temperature regulation as required.

All system outputs, including disease detection results and environmental status, are communicated to the user through a mobile application.

This enables remote monitoring and timely decision-making. Overall, the integration of sensing, analysis, and actuation ensures a responsive and autonomous solution for effective plant health management.

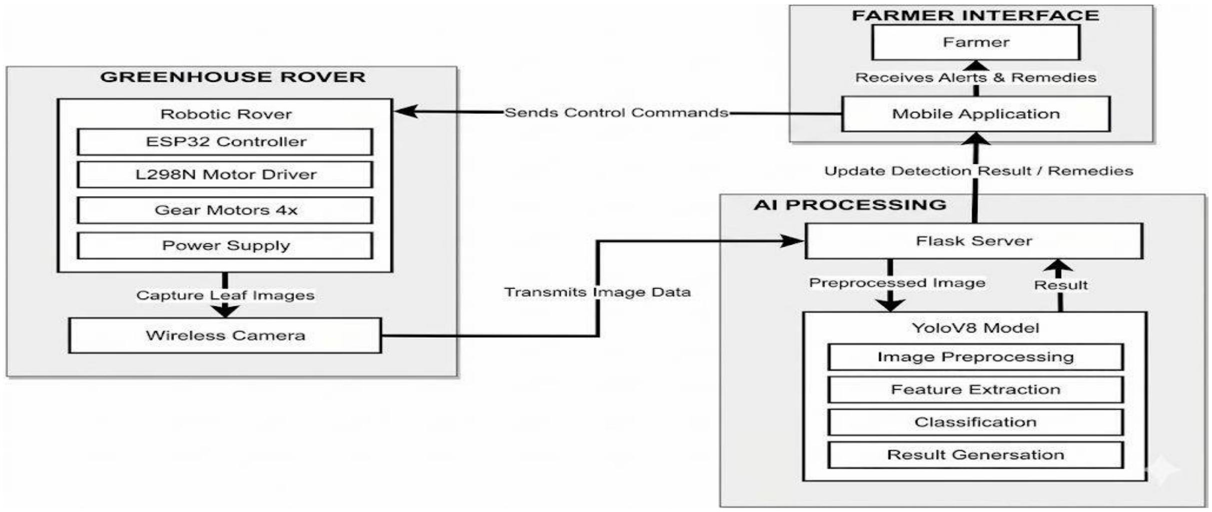

Figure 1: AI Model Block Diagram

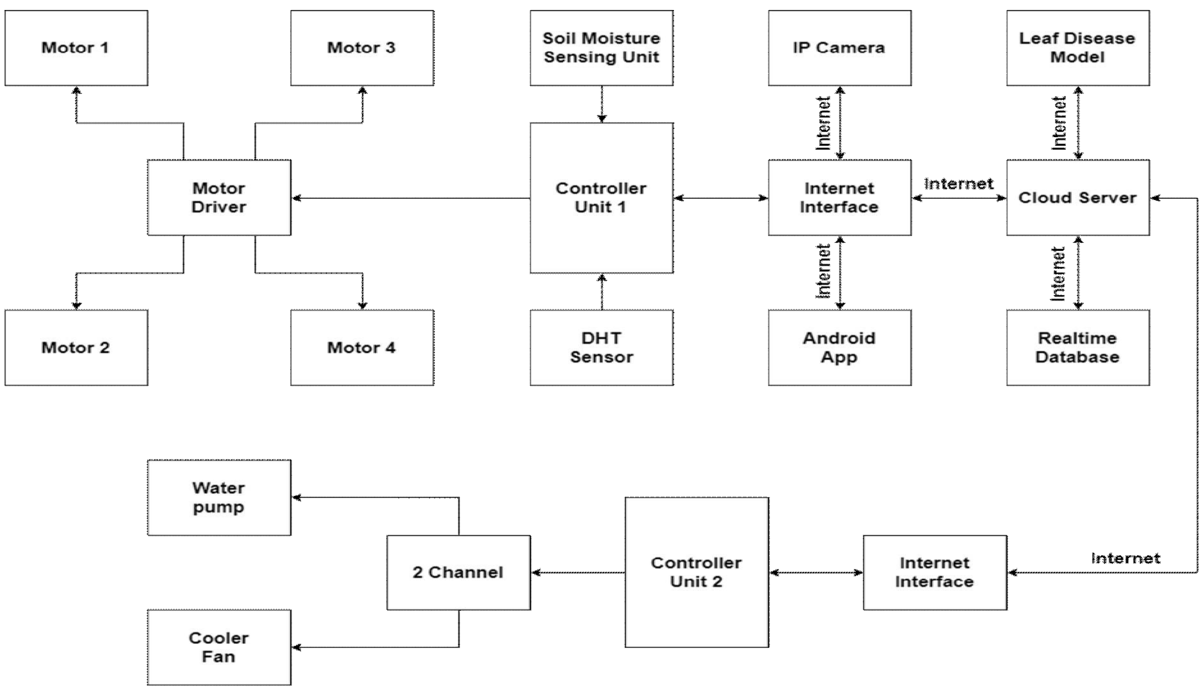

Figure 2: Robotic Rover Block Diagram

V. METHODOLOGY

A. *Visual Data Processing*

As the rover moves through the greenhouse, it continuously captures images of plant leaves from different locations. These images are sent in real time to a processing server, where a trained YOLOv8 deep learning model analyses them. The model identifies possible plant diseases and provides the corresponding class labels along with confidence scores. This process enables quick and reliable detection, helping to identify plant health issues at an early stage [5], [6].

B. *Environmental Monitoring*

Along with image-based analysis, the system keeps track of important environmental conditions that affect plant growth. Sensors mounted on the rover measure soil moisture, temperature, and humidity at regular intervals. The collected data is sent to the system and compared with predefined threshold values. This continuous monitoring helps in understanding whether the environment is suitable for healthy plant growth.

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C. Automated Decision Logic

Based on the sensor readings, the system makes automatic decisions to maintain optimal conditions. If the soil moisture level drops below the set limit, the system turns on the water pump to irrigate the plants. Similarly, when the temperature rises above the acceptable range, a cooling fan is activated to bring it down. Once the conditions return to normal, the system switches off the respective devices. This closed-loop operation ensures efficient control without requiring constant human involvement.

D. User Interface

A mobile application is used as the main interface for users to interact with the system. It provides real-time updates on plant health, environmental conditions, and system actions. The app also sends alerts whenever any abnormal condition is detected. This allows users to monitor and manage the system remotely, making it easier to take timely and informed decisions.

E. Hardware and Software Components

The system is composed of integrated hardware and software modules working together.

1) Hardware Components

- ESP32 Microcontroller
- L298N Motor Driver
- DC Motors with robotic chassis
- Camera module
- Soil moisture sensor
- Temperature and humidity sensor

2) Software Components

- Embedded C (Arduino IDE)
- Python for AI model implementation
- TensorFlow/CNN for disease detection

VI. EXPERIMENTAL RESULTS AND DISCUSSION

A. Deep Learning Model Performance

The YOLOv8-based disease detection model demonstrated high accuracy, achieving strong precision, recall, and mean Average Precision (mAP). The model was evaluated using standard performance metrics, which indicate consistent and reliable results across all classes. The confusion matrix shows good agreement between predicted and actual labels, confirming accurate classification with minimal class overlap. Furthermore, the training behaviour illustrates a steady reduction in loss values along with continuous improvement in performance metrics, indicating stable convergence of the model.

1) Model Performance Evaluation

The detection model is evaluated using standard metrics, including precision, recall, and mean Average Precision. The results indicate strong performance across all evaluated classes [5].

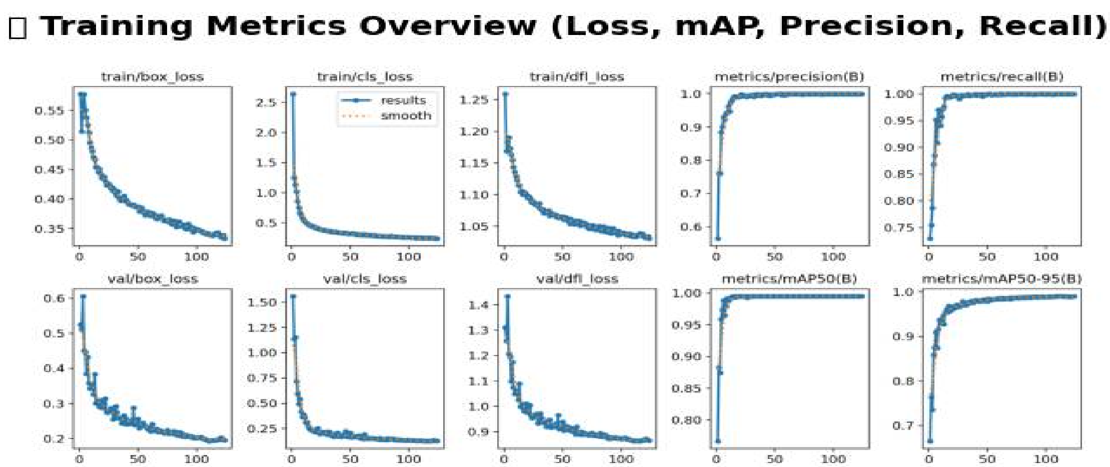

Figure 3: Training Metrics

2) Classification Analysis

The confusion matrix reveals that most predictions align with ground truth labels, indicating accurate classification and minimal overlap between classes.

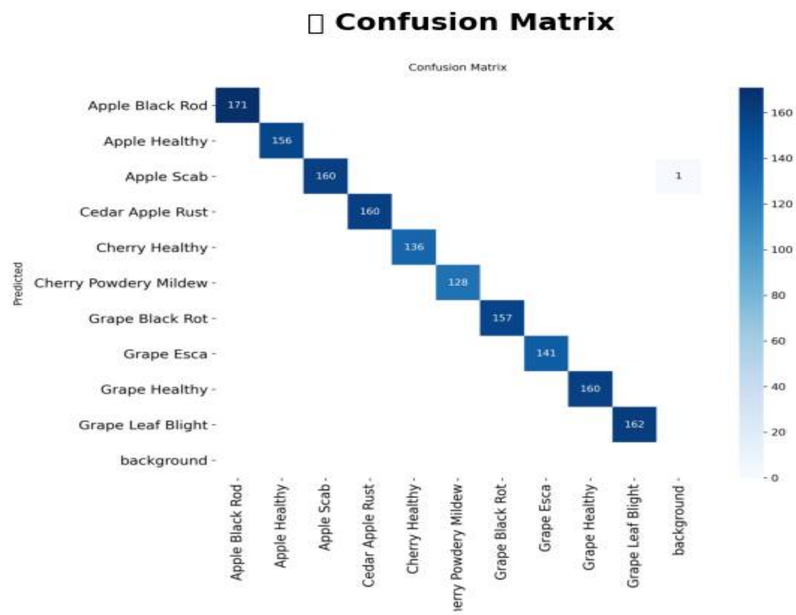

Figure 4: Confusion Matrix

Figure 5: Output of Plant Leaf Disease Detection by Robotic Rover

B. Rover and System Performance

The mobile rover operated reliably, capturing and transmitting plant images in real time. Environmental sensors provided consistent readings for soil moisture, temperature, and humidity, enabling continuous monitoring of plant conditions.

The system responded effectively to environmental changes by automatically activating the water pump and cooling fan based on predefined thresholds. Communication between ESP32 controllers remained stable, ensuring timely and accurate execution of control actions.

Figure 4: Leaf Medic APP Interface


Figure 5: Hardware Implementation

VII. CONCLUSION

This work presented a unified system for plant health monitoring and environmental control by integrating deep learning, IoT-based sensing, and a mobile robotic rover. The YOLOv8-based model enabled accurate and real-time detection of plant diseases, while the ESP32-driven sensor network ensured continuous monitoring of key environmental parameters. Automated actuation mechanisms, including irrigation and temperature control, were effectively triggered based on predefined thresholds.

Experimental evaluation demonstrated reliable performance in both disease detection and system operation. The rover platform facilitated real-time data acquisition, and the system consistently responded to environmental variations with timely control actions. The results highlight the potential of the proposed approach to improve efficiency and reduce manual intervention in greenhouse management.

Future work will focus on enhancing model robustness with larger datasets, expanding system scalability, and improving autonomous navigation for broader agricultural applications.

VIII. ACKNOWLEDGEMENT

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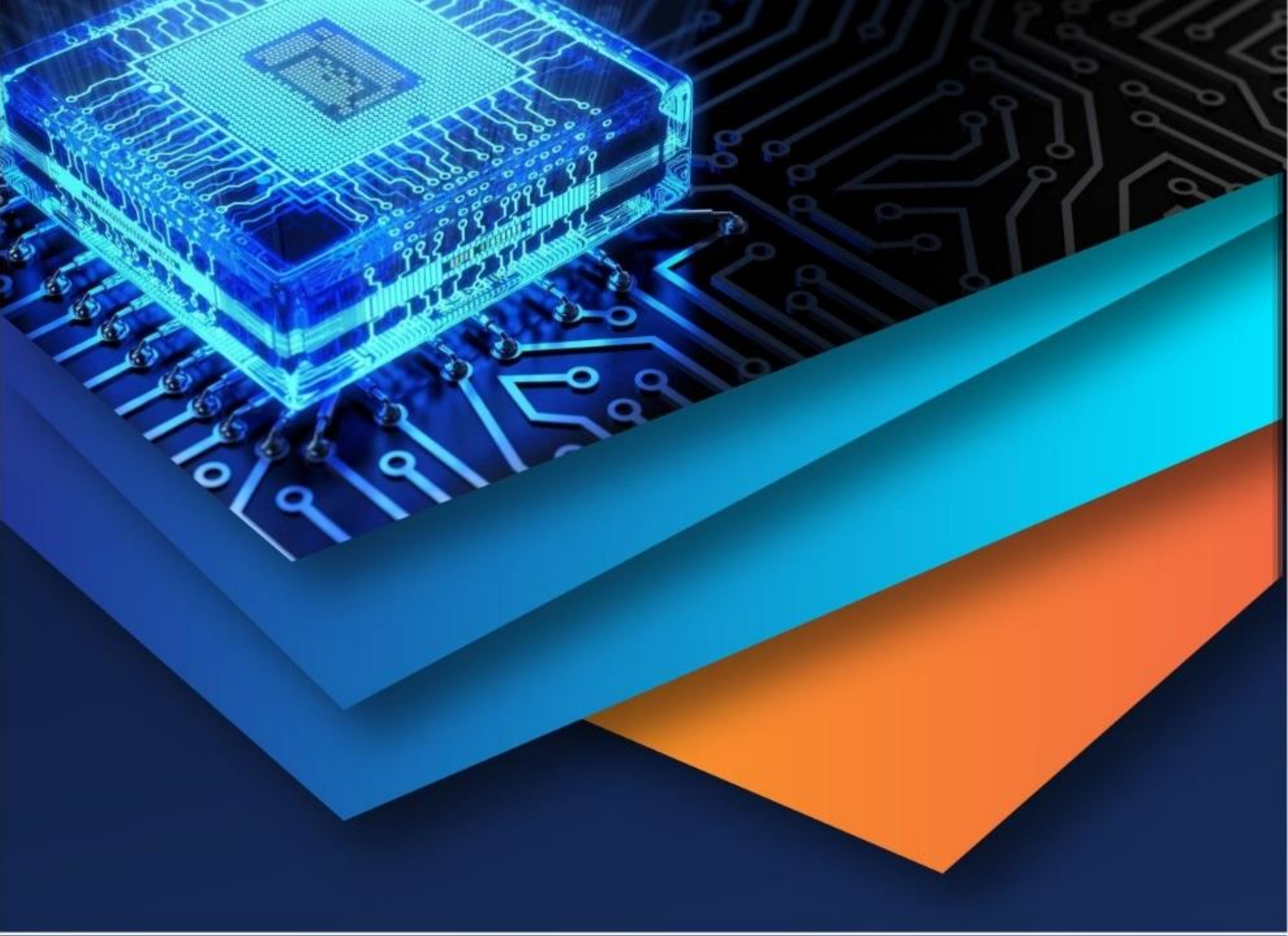

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