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An Integrated IoT-Based System for Automated Plant Disease Detection and Management

Prathibha KN[1]; Adithya D A[2]

[1,2] Assistant Professor, Department of CSE, Jyothy Institute of Technology

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Abstract: These days, a plant health examination is essential for guaranteeing food security and sustainable farming practices. This study introduces a novel integrated system that automates the detection and management of plant diseases by utilizing computer vision, machine learning, and Internet of Things (IoT) technology. The ESP32 microcontroller, at the heart of the system, manages the gathering of data from a camera module and several environmental sensors. Together, these elements are able to take readings and pictures of the crop environment in real time. The photos are processed by a Convolutional Neural Network (CNN) that has been trained to recognize the visual signs of common plant diseases. The system provides disease-specific insights and recommended mitigation measures to farmers immediately upon detection through a Telegram bot and a dedicated web dashboard. Although the prior works have shown the ability of CNNs for classification of plant disease and environmental monitoring via IoT network, many of the works lacked real-time communication ability or possessed complex configurations. The proposed solution corrects these limitations through the offer of a compact, low-cost, and scalable design, implementable in rural areas. Through the facilitation of the early detection of disease, the minimization of labor, and the support of environmentally responsible farming, the system attempts to empower the farmer with real-time, data-based decisions. The integration of AI-based analysis and smart communication tools makes the work herein a step further in the development of precision agriculture, particularly among resource-constrained groups of farmers.

Keywords: *Ethereum, Hyper ledger, Block chain, Electronic Health Care System, Survey.*

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I. INTRODUCTION

Agriculture continues to face significant challenges, particularly in ensuring plant health and productivity a midst changing climatic conditions and the growing global population. Among these challenges, the early detection and effective management of plant diseases remain crucial to prevent yield loss and improve crop quality. Traditional methods of disease detection often depend on manual inspection, which is time-consuming, labour-intensive, and prone to human mistake. Recent developments in artificial intelligence (AI) and the Internet of Things (IoT) have created new opportunities for automating agricultural management and monitoring.

By integrating IoT sensors with machine learning models, particularly Convolutional neural networks (CNN), it is possible to monitor crops continuously and detect diseases accurately. This paper proposes a comprehensive IoT based system that combines real-time data acquisition, intelligent disease detection, and user-friendly interfaces for efficient agricultural management.

II. LITERATURE REVIEW

The convergence of IoT technologies with deep learning models has significantly advanced precision agriculture. Real-time data collecting is made possible by IoT devices. while deep learning models, especially CNN, facilitate accurate disease classification based on image data. Dhaka. (2023) emphasized that IoT technologies enhance communication and automation, while CNN automatically extract relevant features from crop images to identify diseases effectively [1].

Ab ade et al. (2020) reviewed CNN applications in plant disease detection, noting their superiority in accuracy over traditional ML algorithms. Additionally, a comprehensive review in *Artificial Intelligence Review* analyzed over 160 studies and identified CNN like VGG Net, Res Net, and Dense Net as the most effective for agricultural image classification tasks[2].

The approach enhances early identification of plant diseases and demonstrates significant accuracy improvements over conventional detection methods. The data set used is diverse, comprising samples from various agricultural zones,

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which contributes to the model's robustness and practical applicability in precision farming [3].

Proposed a smart greenhouse monitoring system that uses IoT devices to collect environmental data, like soil moisture, temperature, and humidity. Machine learning algorithms then assess plant health and detect diseases. Their system not only sends automated alerts but also provides actionable suggestions to reduce crop losses, making it an efficient solution for adaptive greenhouse farming [4].

Introduced a framework that integrates wireless sensor networks with ML techniques for crop disease analysis. Their model captures real-time farm data and detects disease patterns, offering a scalable and accurate alternative to traditional visual inspections. This approach proves particularly effective for large agricultural fields [5].

III. PROPOSED SYSTEM METHODOLOGY

The proposed system offers an intelligent and automated approach to crop monitoring and disease detection by leveraging IoT technology and machine learning. Utilizing components such as the ESP32-CAM, soil moisture sensors, and relay modules, the system collects both environmental data and high-resolution images of plant leaves.

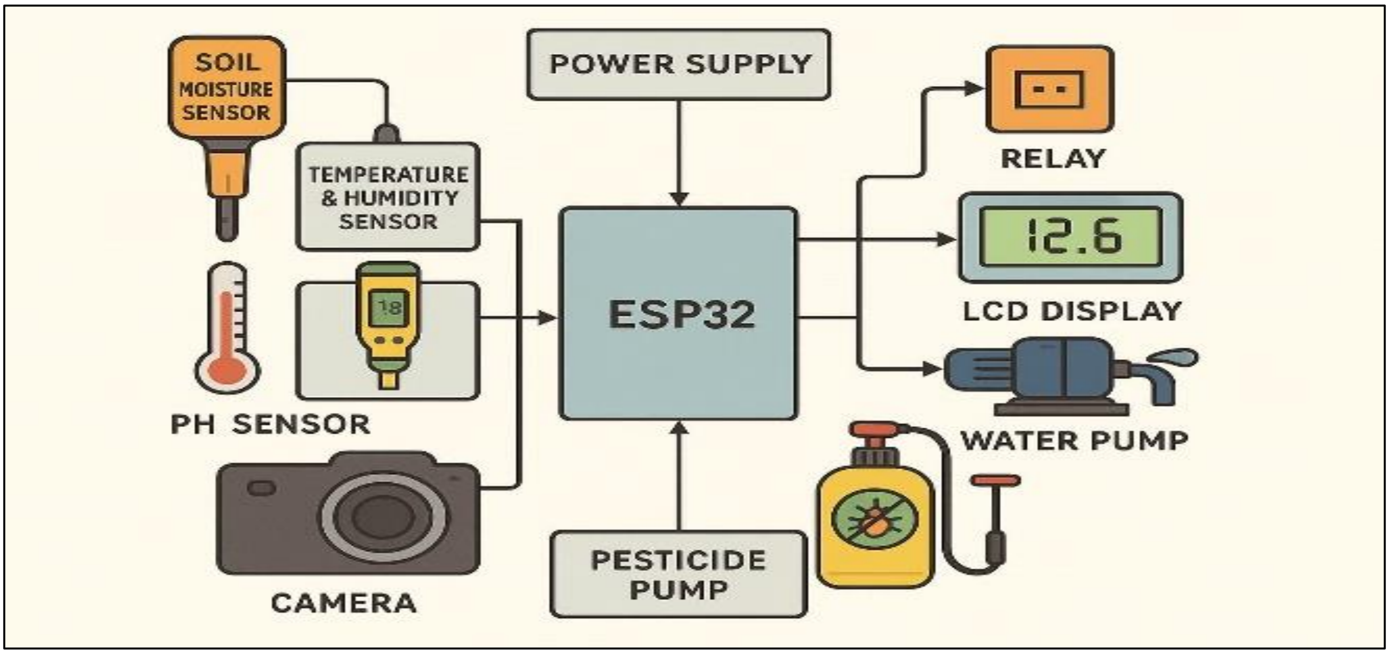

Fig 1 System Architecture of Automated Plant Disease Detection and Management

A. Hardware Setup

The ESP32 micro controller has built-in Wi-Fi, allowing real-time data transmission to the cloud platform for additional research and feedback. Additionally, it supports multiple sensor connections, making it scalable for different agricultural setups.

The ESP32-CAM captures crop images at regular intervals, which are then transmitted—along with sensor data like soil moisture and temperature—to the Thing Speak cloud platform. Thing Speak facilitates real-time data logging, processing, and visualization, allowing users to monitor field conditions remotely through an intuitive dashboard.

The system camera likely captures high-resolution images of plants to assess their health, detect diseases, or monitor growth patterns. The images can be processed by the system for further analysis. The soil's moisture content is determined using the soil moisture sensor. The water pump may be activated by the system to irrigate the plants if the soil becomes excessively dry.

Water Pump is responsible for triggering the irrigation to the plants when the soil moisture level is low. It's controlled by the ESP32 based on input from the soil moisture sensor. Pesticide Sprayer is triggered automatically when pests are detected or a certain threshold is met, the pesticide sprayer is activated to protect the plants.

The relay acts as an intermediary switch. The ESP32 can send signals to the relay to turn on/off devices like the water pump or pesticide sprayer based on sensor inputs. The LCD display displays data in real time, including soil moisture, levels, pH levels, or other system statuses, allowing users to monitor the system easily.

B. Software Setup

The software component of the proposed system acts as the intelligent core, integrating machine learning, data processing, and cloud technologies to enable real-time crop monitoring and automated decision-making. The process begins with **data collection and preprocessing** where environmental sensor data (such as soil moisture and temperature) and high-resolution images from the ESP32-CAM are collected at defined intervals. These images are re sized, normalized, and organized into structured datasets to ensure consistent input for model training and evaluation. pre processing also includes noise reduction and image

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enhancement techniques to improve the model's performance in diverse field conditions.

At the heart of the system lies a MobileNetV2-based **Convolutional Neural Network (CNN),** which is fine-tuned using a labelled data set of healthy and diseased plant leaves. MobileNetV2 is chosen for its lightweight architecture and high accuracy, making it ideal for deployment in resource-constrained environments like farms. The CNN is trained to recognize a wide range of disease symptoms such as leaf spots, blight, rust, and mildew. Once trained, the model can accurately classify incoming images from the field, enabling early and automated disease diagnosis.

All collected data—both from sensors and images—are uploaded to a cloud platform, such as Thing Speak. The cloud provides scalable storage for large volumes of sensor readings and image files and offers the necessary computing resources for running machine learning models in real-time.

A web-based dashboard provides real-time data visualization, including environmental data and disease predictions. Additionally, a Telegram bot delivers instant notifications about disease detection, severity levels, and possible interventions.

C. System Operation

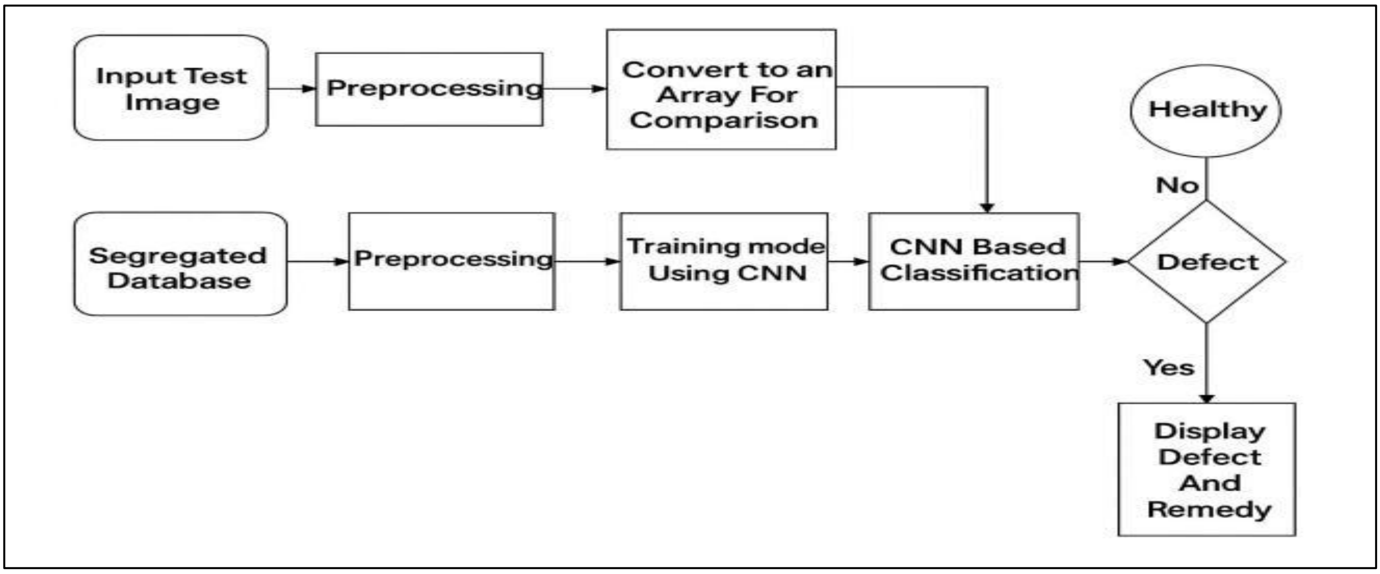

Fig 2 Data Flow Diagram of Disease Detection.

The process begins by acquiring the input test image, which is then preprocessed to ensure it is ready for comparison with the trained model. Preprocessing steps include resizing, normalizing, and converting the image into a numerical array that can be input into the model. The collection of data used to train the model is carefully segregated and preprocessed into separate folders based on disease types, ensuring that each image is appropriately categorized.

This organization is critical for effective model training. Once the data set is ready, To identify the characteristics and patterns in the photos, a Convolutional Neural Network (CNN) is trained,enabling it to recognize different plant diseases. The live can be detected using the system camera and the detected image can also be processed using the CNN Model.

After training, the model is used to compare the input test image with the learned patterns, and it generates a prediction indicating whether the plant is healthy or affected by a disease.

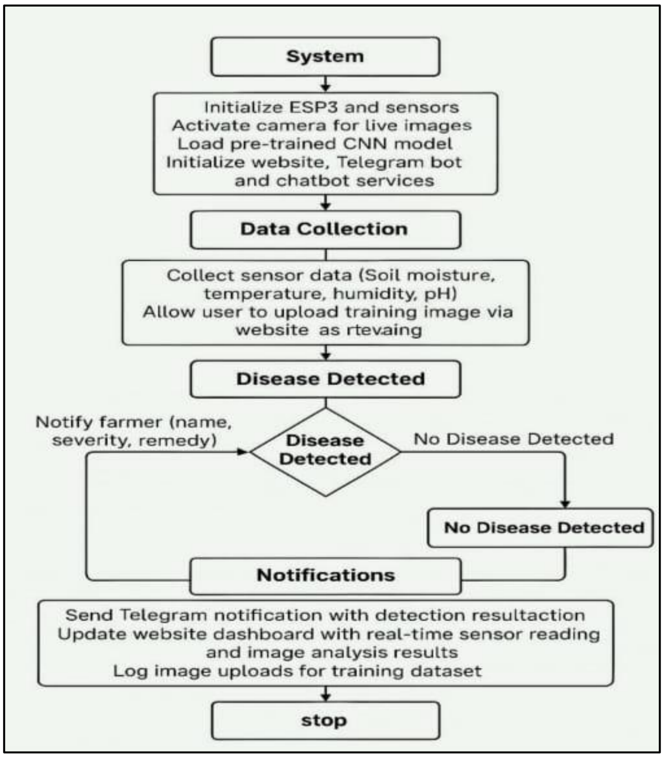

Fig 3 Flowchart of IOT Based Disease detection and monitoring.

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The flow diagram represents a structured overview of the system's operation, with a central focus on real-time plant disease detection and instant user notifications. The process begins with system initialization, where critical components such as the ESP32 micro controller, environmental sensors, and the camera module are activated. The pre-trained convolutional neural network (CNN) model is also loaded at this stage to enable immediate disease identification from captured crop images

Simultaneously, supporting services like the website dashboard, integrated chat bot, and Telegram bot are launched to ensure seamless user interaction. Once the system is live, it continuously collects real-time environmental data, including soil moisture, pH levels, and mineral content, through the sensors. The camera module captures images of the crops, and users also have the option to upload additional training images via the website to enhance the model's predictive performance over time.

As the data flows in, the CNN model analyses the crop images to detect signs of disease. If a disease is identified, the system not only classifies it by name but also assesses its severity and suggests appropriate remedies. These results are immediately communicated to the farmer through the Telegram bot, providing timely and actionable alerts. Additionally, all relevant sensor data and image analysis results are displayed in real-time on the website dashboard, offering users a comprehensive and accessible view of their crop health and field conditions.

IV. SYSTEM DESIGN

The system design integrates both hardware and software components to create a seamless and intelligent crop monitoring and disease detection solution. It is structured to collect real-time data from the agricultural environment, analyze it using advanced machine learning models, and communicate the results to farmers through an intuitive interface. At the core of the system is the ESP32 micro controller, which acts as the main processing unit. It coordinates data flow between connected sensors and modules.

To track important environmental factors like soil moisture, pH levels, and temperature, a variety of sensors are placed throughout the field. To guarantee thorough coverage and precise readings, these sensors are positioned thoughtfully throughout the crop area.

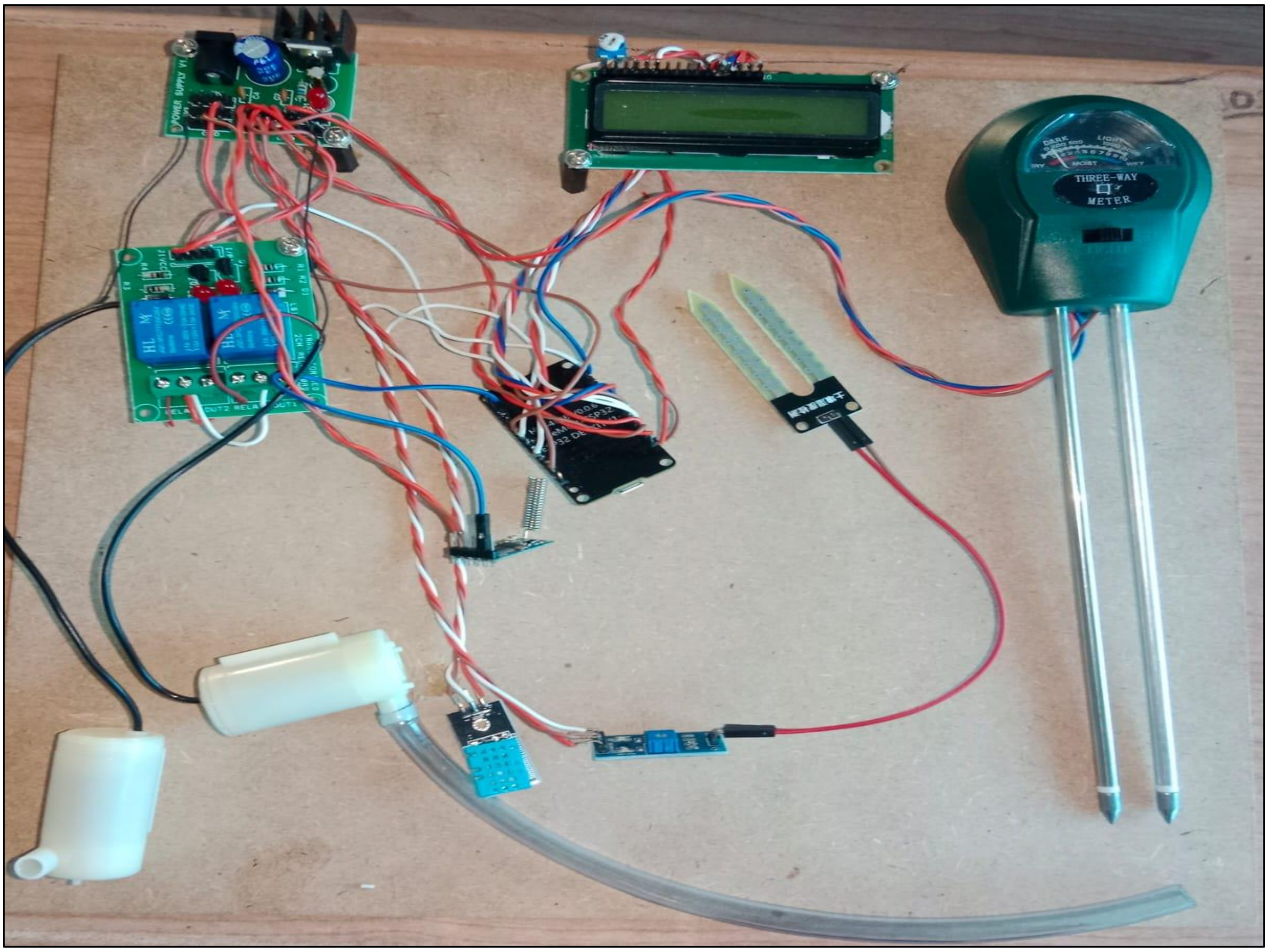


Fig 4 Hardware Implementation.

V. RESULT AND EVALUATION

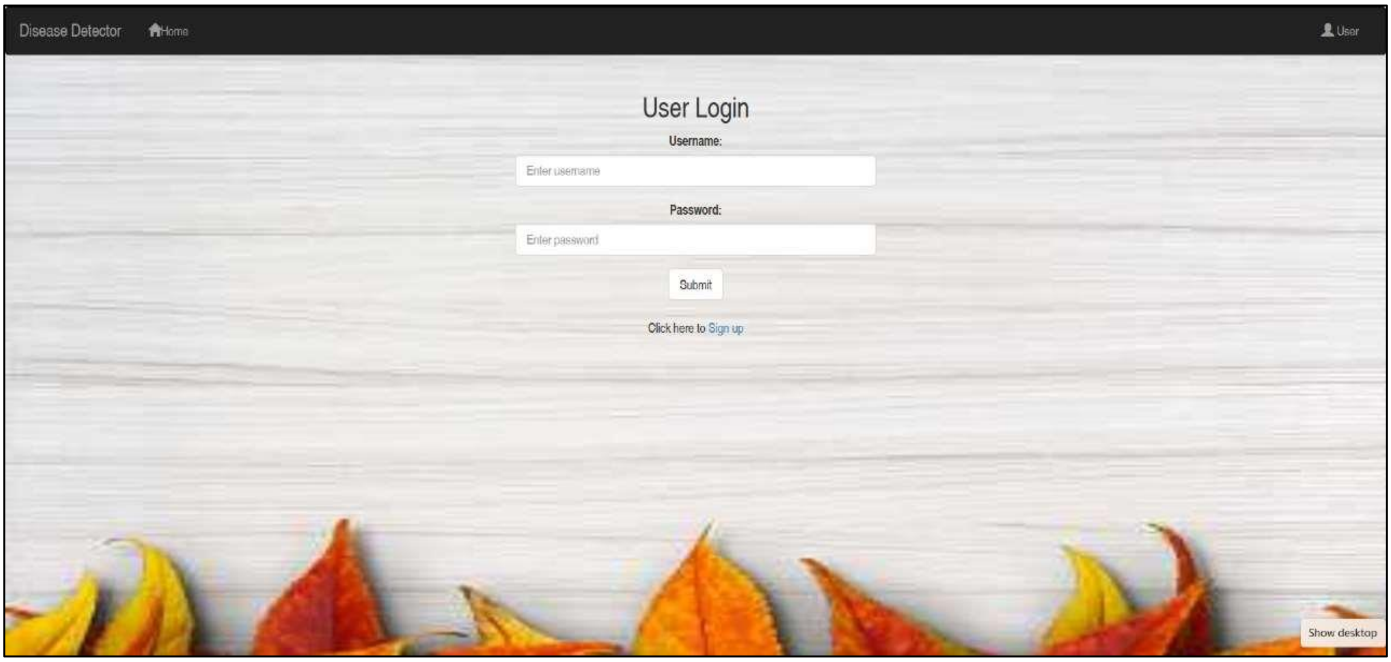


Fig 5 Login Page

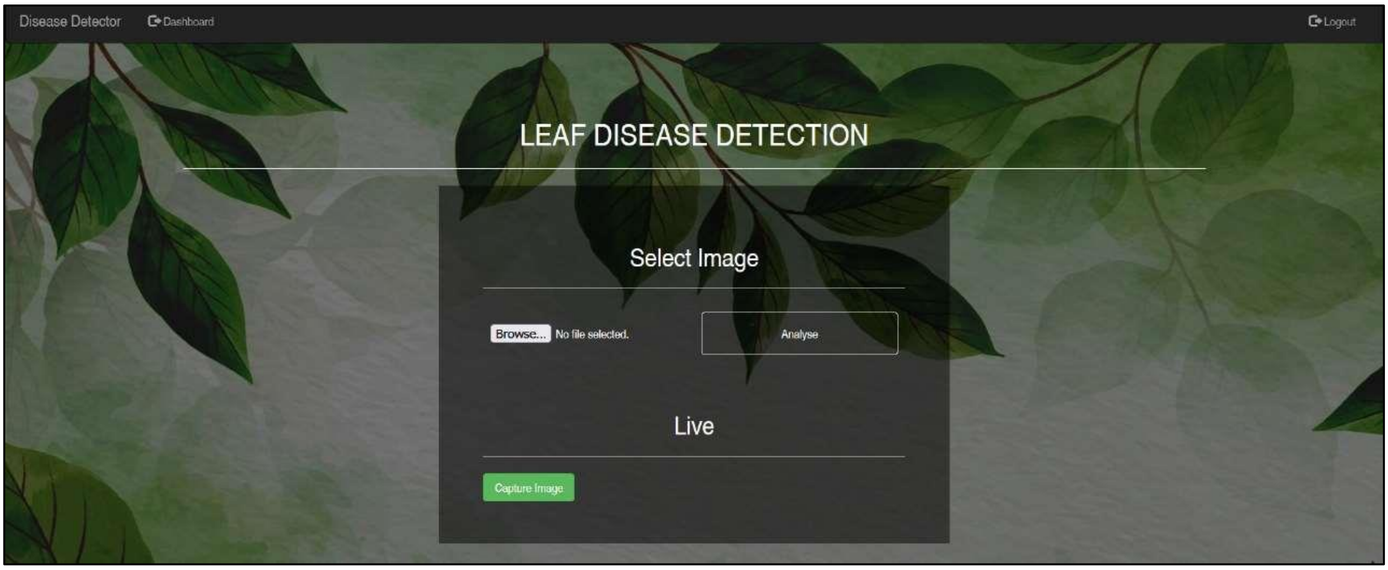


Fig 6 Dashboard

To capture images of the plants, the system uses an laptop camera, which takes high-resolution photos at regular intervals. These images are then uploaded to a cloud platform for processing. The images are analyzed using a Convolutional Neural Network (CNN) model, specifically a fine-tuned MobileNetV2, trained to identify and classify plant diseases. This model can recognize multiple crop diseases based on visual symptoms like leaf discoloration, spots, or lesions.

Farmers can directly interact with the Chat bot and it provides the required information in various languages.

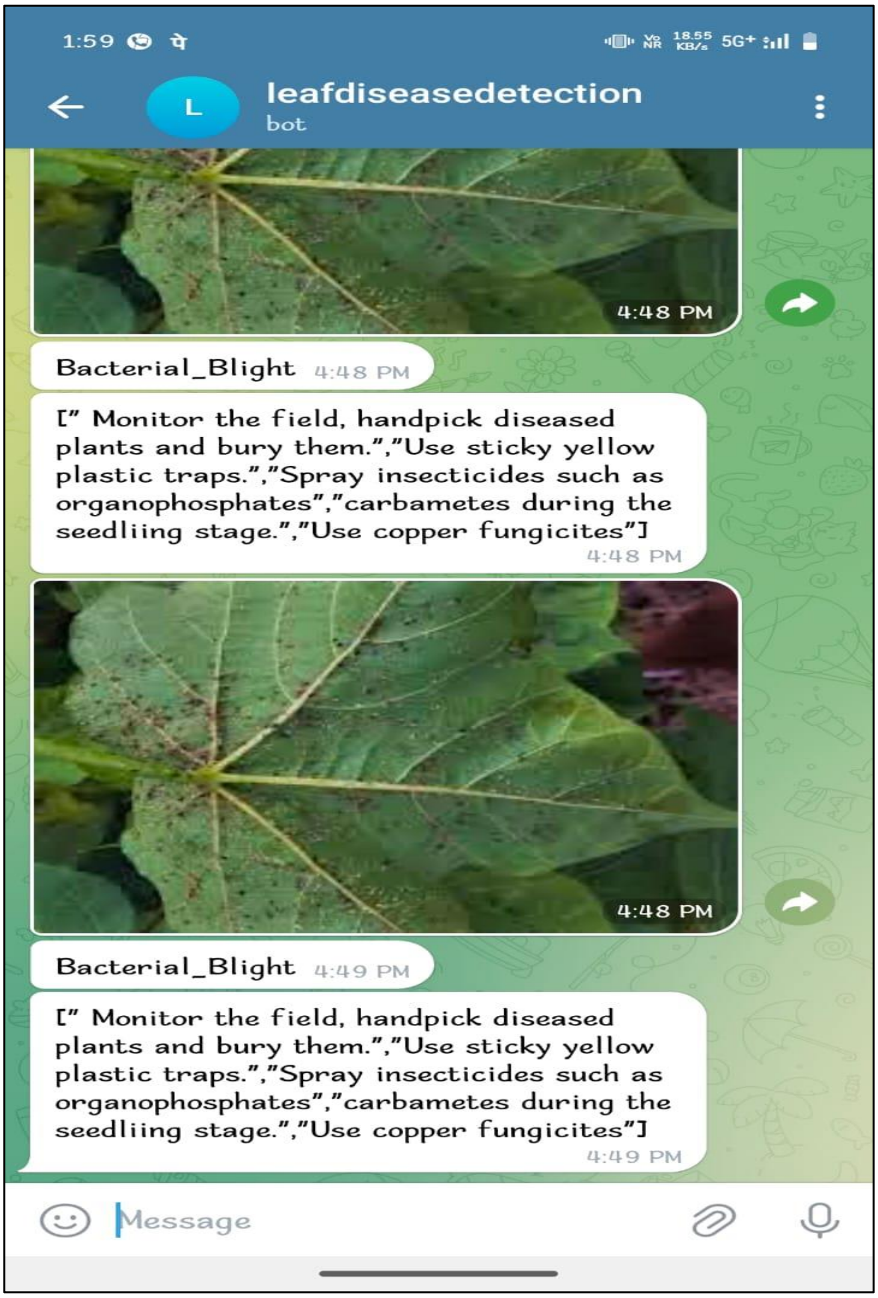
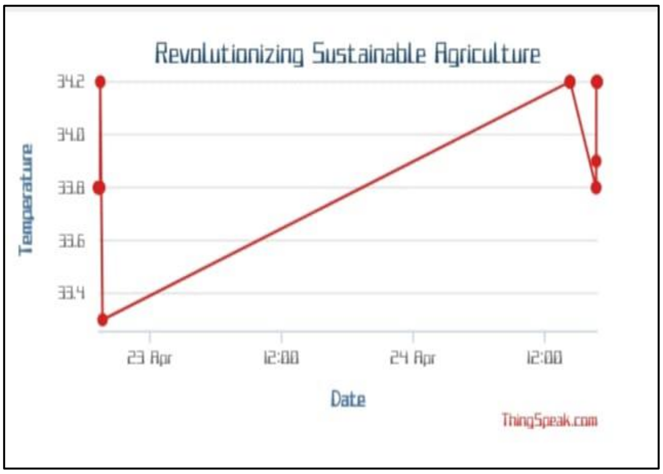


Fig 7 Telegram Alerts.

For user interaction and alerts, the system includes a Telegram bot, which sends instant notifications when a disease is detected, including its name, severity, and suggested countermeasures. Additionally, the system supports automated actions by triggering connected devices such as water pumps or pesticide sprayers based on the sensor input and disease detection results.

The cloud infrastructure such as Think Speak provides scalable storage and computing power for image analysis and data management. It also allows continuous model updates and real-time access to field data. All sensor readings and prediction results are visualized on a web-based dashboard, offering farmers an easy way to monitor crop health and field conditions.



(a)

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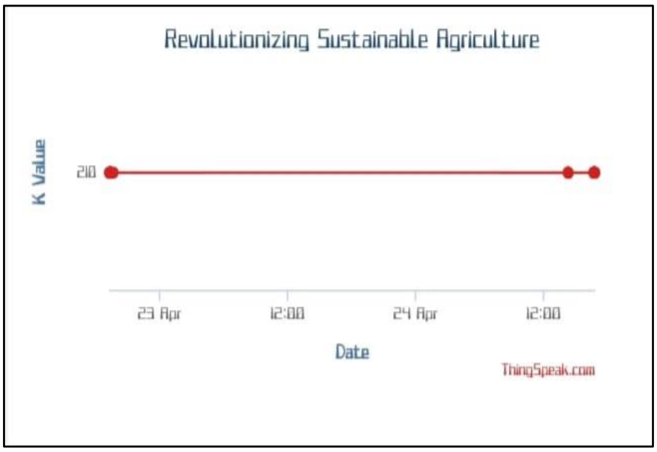

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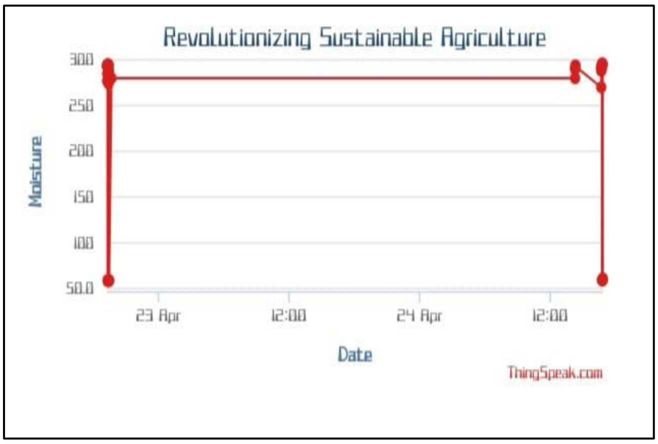

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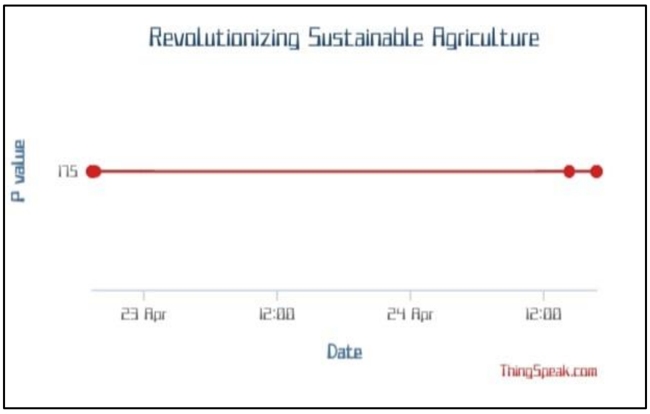

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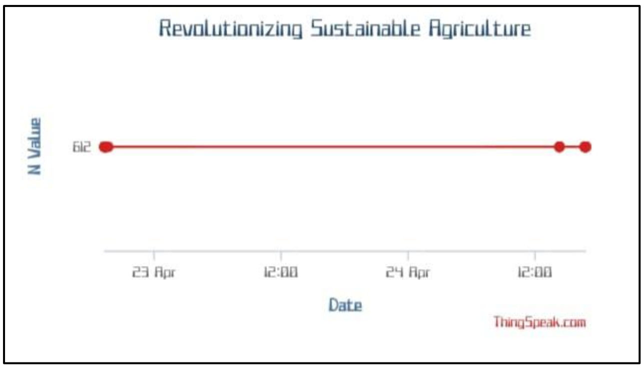

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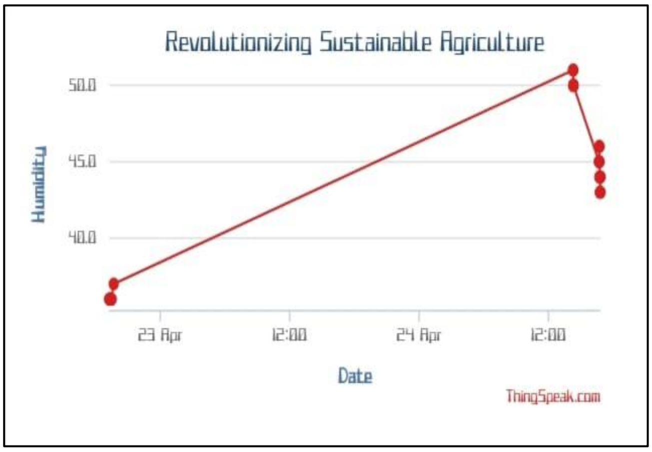

(f)

Fig 8 Temperature, Soil Moisture, pH Values

VI. CONCLUSION AND FUTURE WORK

The potential of an integrated Internet of Things-based system for the automated identification and control of plant diseases has been effectively illustrated by this study. The problems of managing plant diseases in agriculture can be effectively addressed by combining computer vision, deep learning, and real-time environmental monitoring. By utilizing IoT sensors to gather crucial environmental data and CNN models to process images and detect diseases, the system ensures early intervention, which can significantly reduce crop loss and improve yields. The implementation of a user-friendly web dashboard and Telegram alerts further enhances the system's accessibility and responsiveness, allowing farmers to act swiftly and effectively.

One of the major advantages of the proposed system is its scalability and adaptability. The use of edge computing devices like the ESP32 ensures that the system can function in remote, resource-limited agricultural environments without requiring continuous internet connectivity. The system's ability to deliver real-time predictions and alerts empowers farmers to take timely actions, minimizing the need for chemical interventions and promoting sustainable agricultural practices.

However, there are several areas for improvement and future development. One key aspect is the enhancement of the disease classification model. Currently, the system performs well with the diseases included in the dataset, but expanding the model to cover a broader range of diseases across different crops and regions would increase its utility. Furthermore, adding more advanced sensors (such as those measuring light intensity, soil nutrients, and CO_2 concentration) would provide a more comprehensive view of the crop environment, potentially leading to more accurate disease predictions and better-targeted interventions.

Using explainable AI (XAI) techniques to increase the model's decision-making process's transparency is an intriguing new research direction. This could help farmers

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understand why a particular disease is detected and gain trust in the system.

Finally, the system could benefit from incorporating **multi-modal data sources** such as satellite imagery and weather forecasts, which would further enhance its prediction capabilities. The use of such data could help predict disease outbreaks even before they are visually detectable on the crops, allowing for preemptive measures.

In conclusion, one of agriculture's most enduring problems can be solved practically and effectively with this integrated IoT-based disease detection that makes use of cutting-edge technologies like CNN, machine learning, and IoT.

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