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IoT-Driven Smart Crop Health Monitoring and Advisory System

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***Abstract:** Even in today's digital age, Indian agriculture still largely relies on traditional or outdated farming practices that have been passed down through generations, with limited integration of data-driven and intelligent solutions for efficient and sustainable farming. To overcome this limitation, we propose a Smart Agriculture System that integrates agriculture, IoT technologies, and Machine Learning. The smart system allows users to observe soil nutrients (NPK), temperature, humidity, and moisture levels using the IoT sensors in real-time and to capture and upload leaf images via the mobile application, which are then analysed to detect and diagnose leaf diseases with a confidence score. By combining these inputs, the system generates results such as overall soil condition status and fertilizer recommendations. These results are then showed in the mobile application, helping farmers make well-versed decisions, improve their resource usage, rise crop yields, and promote efficient, sustainable, and environment friendly farming practices.*

***Keywords:** Smart Agriculture, Machine Learning, Convolutional Neural Network (CNN), IoT, ESP32, NPK Sensors, Temperature, Humidity and Moisture Monitoring, Disease Detection, Soil Analysis, Firebase Realtime Database, Decision Support System, Crop Monitoring, Sustainable Agriculture.*

I. INTRODUCTION

The proposed project, titled IoT-Driven Crop Health Monitoring and Advisory System, is an IoT and mobile-based, cloud-integrated system that is developed to improve the efficiency, productivity, and sustainability of Indian farming practices. The system is made to integrate real-time soil monitoring with smart crop analysis, allowing users to make informed decisions through our platform.

The system combines multiple components, including an IoT-based sensor monitoring, image-based disease detection, and diagnosis. Through these components, users can monitor soil health, capture leaf images, analyze leaf health using the Machine Learning system, and receive recommendations related to fertilizer and irrigation. Finally, all of this is displayed on the user-friendly mobile interface.

The system is executed using modern technologies. The frontend is designed using Flutter for cross-platform mobile support. The backend is developed using Python for processing and integration, while Firebase Realtime Database is used for data storage and synchronization. Also, TensorFlow/Keras is used for CNN-based disease detection, and OpenCV supports image pre-processing. The IoT incorporation is done using the ESP32 microcontroller along with the other environmental sensors.

The main objective of this project is to create a smart farming solution that incorporates monitoring, analysis, and recommendations into a single platform. Unlike customary methods that rely on manual observation, this system provides automated, accurate, and real-time insights.

The importance of this project is its capability to show how AI, ML, and IoT can be successfully combined to address real-world farming challenges. By combining smart analysis with real-time data, the system encourages efficient and sustainable farming practices, improves crop yield, and improves efficient resource management.

II. OBJECTIVES

The main intentions of the proposed Smart Agriculture System using AI and IoT are as follows:

1) To develop an integrated smart farming system that combines leaf disease detection, soil monitoring, and a recommendation system within a single platform.
2) To provide an image-based disease detection module using machine learning to identify leaf-related diseases from the leaf images.
3) To implement an IoT-based monitoring system that collects real-time data on moisture, temperature, and soil nutrients (NPK).

4) To analyze environmental and soil conditions using sensor data to assess leaf health and growth.
5) To design a decision-making component that integrates image analysis and sensor data for generating accurate recommendations.
6) To enable real-time data synchronization and communication using a cloud-based database (Firebase).
7) To develop a user-friendly mobile application for capturing images, viewing results, and recommendations.
8) To improve crop productivity and reduce resource wastage through informed and data-driven decision-making.
9) To promote sustainable agricultural practices by optimizing fertilizer and water usage.
10) To create an accessible and cost-friendly system that is suitable for small and medium-scale farmers.
11) To allow tracking of past data and study of it for monitoring trends, which allows for long-term decision-making

III. METHODOLOGY

The proposed IoT-Driven Crop Health Monitoring and Advisory System is developed by integrating machine learning, IoT sensors, and cloud processing into a single platform. The platform is designed to support farmers through leaf image capturing, disease detection, real-time soil monitoring, data analysis, and recommendation generation. This method allows users to monitor soil conditions, assess crop health, and receive suggestions based on the conditions to improve the crop yield.

A. System Design Approach

The system has a multi-layer architecture involving a user interface layer, an application logic layer, a data storage layer, a machine learning layer, and an IoT layer. The front end enables user interaction through the mobile application for image-based disease detection and viewing of results. The backend manages data processing, integration, and API handling. The Firebase database stores image data, sensor readings, and predictions. The machine learning layer performs plant disease detection while the IoT layer uses soil sensors to collect sensor readings.

B. Development Process

The development process followed a phase-based iterative process. The major components identified were image acquisition, sensor data collection, disease detection, sensor data analysis, decision-making, and results visualization. The IoT hardware module was created first, followed by the development of backend processing logic and the integration of APIs. The database was connected to the backend, and the last phases of the development process were mobile application development and machine learning implementation. Each component was tested independently and later integrated to test and validate the complete system's working.

C. Frontend Methodology

The frontend was designed using Flutter for cross-platform mobile application development. Each module of the mobile application has its own separate screens. Reusable UI components and Firebase integration have been used to maintain consistency, ensure smooth navigation, and provide a user-friendly experience, making the application easy to access even for new users.

D. Backend Methodology

The backend was developed using Python to handle data processing, data integration, and system logic. A modular architecture has been adopted, in which different components handle image processing, sensor data analysis, and decision-making. The system retrieves leaf image from database, processes it using the machine learning model, and analyzes sensor data to measure soil and environmental conditions. The system is designed to ensure efficient data handling, reliable communication with the mobile application, and smooth integration with IoT devices. This system allows accurate processing, real-time updates, and seamless interaction between the system components

E. Database Design Methodology

Firebase Real-time Database is used for cloud-based storage and real-time data synchronization. The database stores image URLs, sensor readings (temperature, humidity, and NPK), and prediction results. The system is designed to support real-time updates, efficient and smooth data retrieval, and seamless communication among the mobile application, IoT sensors, and the database unit.
The system design allows continuous data flow and supports tracking of current and past predictions, allowing better examination and observation of the plant health and soil conditions.

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F. Model Training Methodology

The CNN model is trained using a labeled dataset of healthy and unhealthy leaf images. Data expansion techniques such as rotation, flipping, and scaling are applied to improve the model's simplification. The model is trained and validated to achieve optimal accuracy and prevent overfitting, ensuring reliable performance across different conditions.

G. Data Preprocessing Methodology

The system performs preprocessing techniques to improve the quality of the input data before analysis. Leaf images are resized, normalized, and improved using OpenCV to improve the accuracy of the CNN model. Sensor data is filtered and then validated to remove noise and inadequate readings. This preprocessing ensures the consistency of the input for both machine learning and decision-making processes.

H. External Integration Methodology

External integrations were added to improve the working of the system. Firebase Realtime Database is used for data storage and real-time data synchronization between the mobile application, backend, and IoT sensors. The ESP32 microcontroller is integrated to collect and transmit sensor data, such as moisture, temperature, humidity, and NPK levels.

These integrations will ensure continuous and smooth communication across system components and support real-time monitoring and decision-making. The system is designed to handle connectivity issues smoothly, ensuring basic functionality even during short-term network issues.

I. Testing and Validation Methodology

The system was validated through a combination of code checks, API testing, and complete workflow assessment. Front end validation comprised interface testing, and basic code checks, while backend testing guaranteed proper execution of processing logic and API responses. End-to- end testing was performed to verify the full system flow, including image upload, sensor data handling, disease detection, and recommendation generation.

Key functionalities such as data integration, real-time updates, and result presentation were tested to ensure accurate output and smooth interaction between components. This approach guaranteed that all components are working correctly both individually and as part of the complete system.

J. Documentation and Delivery Methodology

Project documentation was developed in a structured manner, covering system instructions, system overview, technical details, and execution methodologies. This ensured clear communication of the system’s design, functionality, and usage. The documentation was organized to be easily understood by both technical and non-technical users, supporting effective presentation, deployment, and future enhancements of the system.

K. Summary of Methodology

Overall, the methodology combines mobile application development, IoT-based data collection, machine learning, and cloud-based processing into a single smart agriculture system. The approach combines image-based disease detection with real-time sensor data analysis to generate accurate recommendations. The system is intended to support monitoring, analysis, and decision-making in a practical, efficient, and user-friendly manner, promoting sustainable and data-driven farming practices.

IV. RESULTS

The Smart Precision Agriculture System was successfully developed as a single platform that combines mobile application functionality, IoT-based sensing, machine learning, and cloud integration. The system demonstrates smooth and continuous coordination among the mobile interface, database processing, and the machine learning model, ensuring smooth data flow across all the modules.

The main features, such as image-based disease detection, real-time soil nutrient monitoring, and smart recommendation generation, worked effectively. The integration of multiple technologies enabled accurate analysis and timely insights, validating the system’s capability to handle complete workflows. Overall, the results showed that the system is consistent, efficient, and suitable for practical deployment in smart farming scenarios.

A. Overall Platform Result

The final system was implemented as a fully functional mobile-based platform that combines all the core modules within a single application. The main interface acts as the central access point, allowing users to perform key operations such as capturing leaf images, monitoring sensor data, viewing analysis results, and utilizing the chatbot.

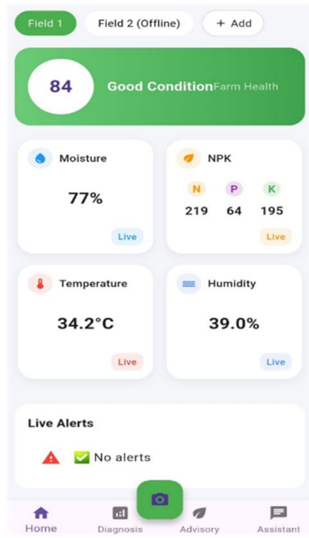


Figure 1: Home page of the IoT- Driven Crop Health Monitoring and Advisory System showing integrated access to Diagnosis, Advisory, and Assistant.

B. Diagnosis Module Result

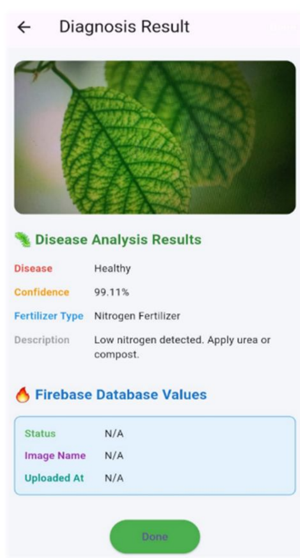


Figure 2: Diagnosis module interface displaying weekly trends and diagnosis based on leaf images.

The diagnosis module detects plant diseases from leaf images using a CNN-based machine learning model. Users can upload images through the mobile application, and the model analyzes features such as leaf color, texture, and patterns to identify diseases and generate predictions with confidence scores.

Also, apart from disease detection, the module also presents a weekly trend graph, which allows users to track changes in crop health and soil factors over time. This helps in monitoring, calculating, and understanding the effectiveness of treatments and the growth of the plant. The results are then stored in Firebase and displayed in the mobile application, allowing informed and timely decision-making.

C. Advisory Module Result

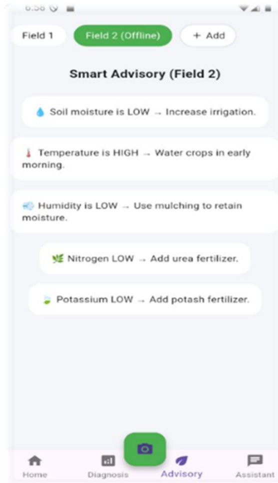


Figure 4: Advisory Module that provides insights and suggestions based on the soil conditions.

The advisory module provides actionable recommendations based on the results obtained from disease detection and sensor data analysis. It evaluates factors such as identified plant diseases, soil nutrient levels (NPK), temperature, and humidity to generate suitable suggestions.

The module offers guidance on fertilizer application, irrigation requirements, and preventive measures to improve crop health. These recommendations are tailored to the current conditions and are updated in real-time through Firebase. The results are displayed in the mobile application, helping users take timely and informed decisions for effective farm management.

D. Assistant Module Result

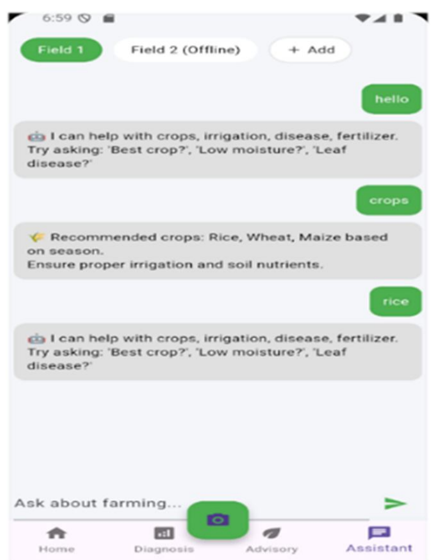
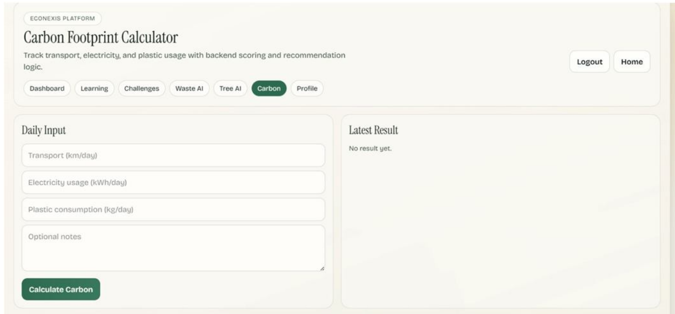


Figure 5: Assistant Module that can be used by the user to ask questions.

The assistant module acts as an interactive support feature within the system, helping users understand results and make informed decisions. It provides simple explanations for disease predictions, soil conditions, and recommendations generated by the system.

Users can access guidance on how to apply fertilizers, manage irrigation, and take preventive measures for crop health. The module presents information in an easy-to-understand format, making it especially useful for non-technical users. By offering quick assistance and clarifications, it enhances usability and ensures effective utilization of the system.



E. Historical Tracking and System Integration Result

The system successfully supports historical data tracking and seamless integration across all modules. Data related to crop images, disease predictions, sensor readings, and recommendations are continuously stored in Firebase, enabling users to review past records and monitor trends over time.

The integration between the mobile application, IoT sensors, backend processing, and machine learning components guarantees efficient data flow and real-time updates. This consistent interaction allows users to track crop health progression, analyze changes in environmental conditions, and make better long-term decisions. Overall, the system demonstrates effective synchronization and reliable performance across all integrated components.

F. Limitations and Summary of Results

The system demonstrates efficient performance in incorporating machine learning and IoT for smart agriculture, providing accurate disease detection and real-time recommendations. However, certain limitations exist. The accuracy of disease detection depends on the quality of input images, and sensor readings may vary due to environmental noise or calibration issues. Additionally, the system relies on internet connectivity for real-time data synchronization through Firebase, which may affect performance in remote areas.

Despite these limitations, the overall results confirm that the system is reliable, efficient, and capable of supporting data-driven farming decisions. It successfully integrates multiple components to deliver practical and actionable insights for improving agricultural productivity.

V. CONCLUSION

The IoT-Driven Smart Crop Health Monitoring and Advisory System combines machine learning and IoT to improve modern farming. It integrates image-based disease detection with real-time monitoring of temperature, humidity, and NPK levels to provide accurate suggestions. A CNN model identifies leaf diseases, while sensor data is processed to generate fertilizer and irrigation recommendations. With Firebase enabling real-time communication, the system enhances decision-making, reduces wastage of resources, and promotes efficient and sustainable agricultural practices.

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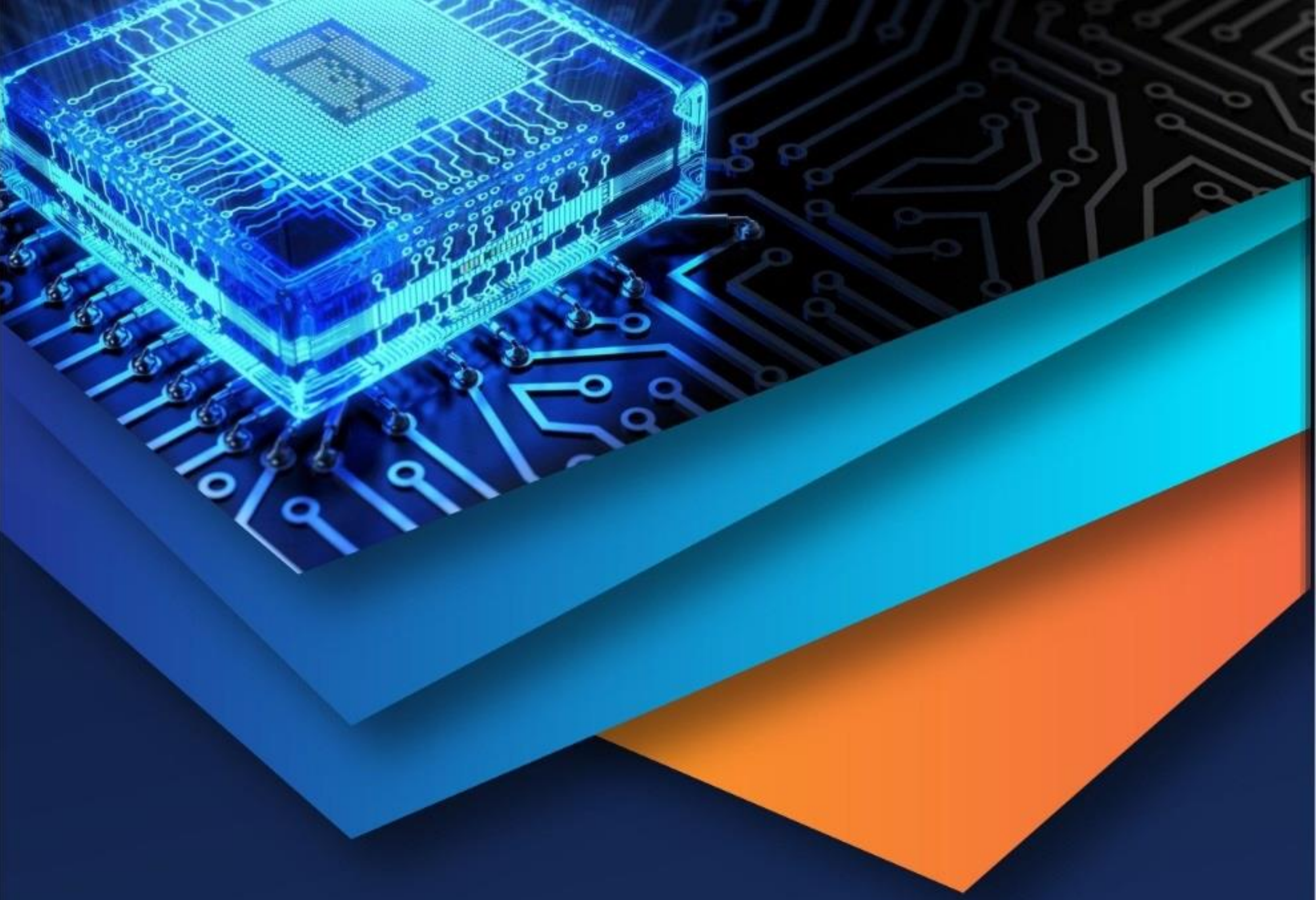

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