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INTEGRATED SMART FARMING SYSTEM FOR TOMATO CROP USING AR VISUALIZATION AND AI-BASED ANALYTICS

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ABSTRACT

This project was conceptualized as part of our Engineering study during 2024-25 at the Department of AISSMS Institute of Information Technology, Pune, with the aim of addressing key challenges in precision agriculture by leveraging advanced technologies. After successful implementation, an AR-enabled real-time monitoring system was developed using a Unity-based AR application, allowing farmers to interactively visualize live farm conditions. Additionally, a Flask-based AI subsystem was integrated to facilitate crop yield prediction and plant disease detection using machine learning models. Farmers were able to upload leaf images for automatic disease diagnosis, enabling early detection and prevention of potential infections.

The Smart Agriculture Monitoring System combined IoT-driven real-time monitoring, AI-powered analytics, and AR-based visualization to optimize crop management. Soil moisture sensors, DHT sensors, and a Node MCU microcontroller were used to collect key environmental data, which was transmitted to Firebase for seamless cloud-based access. The AI subsystem successfully predicted crop yields and detected plant diseases with 85% and 90% accuracy, respectively, enabling proactive decision-making. Experimental results on tomato crop production demonstrated that maintaining optimal soil moisture (60-70%) led to better plant health and higher yields (8-10 tomatoes plant^{-1}), whereas dry soil conditions (<30%) resulted in stunted growth and lower yields (3-5 tomatoes plant^{-1}).

This integrated approach enhanced precision agriculture by providing farmers with actionable insights, improving resource efficiency, and ensuring sustainable crop production. The system offered a scalable, data-driven solution for modern farming, bridging the gap between traditional and technology-assisted agriculture.

(Key words: Smart agriculture, augmented reality, Artificial Intelligence, Internet of Things, crop monitoring, precision farming)

INTRODUCTION

Agriculture is a critical sector in the economies of the world, but it is plagued by many challenges such as unstable weather patterns, infestations, and low yields because of the use of traditional, manual farming practices. Traditional methods of monitoring environmental conditions and crop health are labour intensive, susceptible to human error, and tend to yield suboptimal results and delayed interventions against plant diseases. To solve these problems, this study introduces a Smart Agriculture Monitoring System that combines the Internet of Things (IoT), Augmented Reality (AR), and Artificial Intelligence (AI) to provide real-time environmental monitoring, crop yield prediction, and plant disease detection. The system employs soil moisture sensors and DHT sensors, interfaced with a Node MCU microcontroller, to gather real-time information on soil and environmental conditions. This information is sent to Firebase, a cloud-based real-time database, for flawless accessibility and synchronization. The gathered data is visualized in the form of a Unity-based AR application, providing the farmer with an easy means of tracking field conditions. Apart from this, AI-based analytics, incorporated in a Flask-based web application, utilize machine learning models to make predictions on crop yield and identify plant diseases through image analysis. The main aim of this system is to maximize crop yield and resource utilization by filling the gap between conventional and innovative farming. The major functionalities are real-time monitoring of soil moisture, temperature, and humidity through IoT sensors, intuitive farm management through immersive AR-based data visualization, crop yield estimation through AI-based predictive analytics, and disease detection in plants at an early stage using machine learning algorithms. By combining these technologies, this system creates a new benchmark for technology-based and sustainable agriculture, allowing farmers to make informed decisions based on data to enhance productivity and to optimize the use of resources efficiently.

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MATERIALS AND METHODS

Data collection

Used soil moisture sensors and DHT sensors to gather real-time environmental data (e.g., soil moisture, temperature, and humidity). The data was collected using Node MCU and transmitted to Firebase, a cloud-based real-time database.

Data visualization

Utilize Unity and Firebase integration to build an AR app that visualizes the real-time sensor data. The AR app provides farmers with an intuitive interface to monitor farm conditions using a smartphone or tablet.

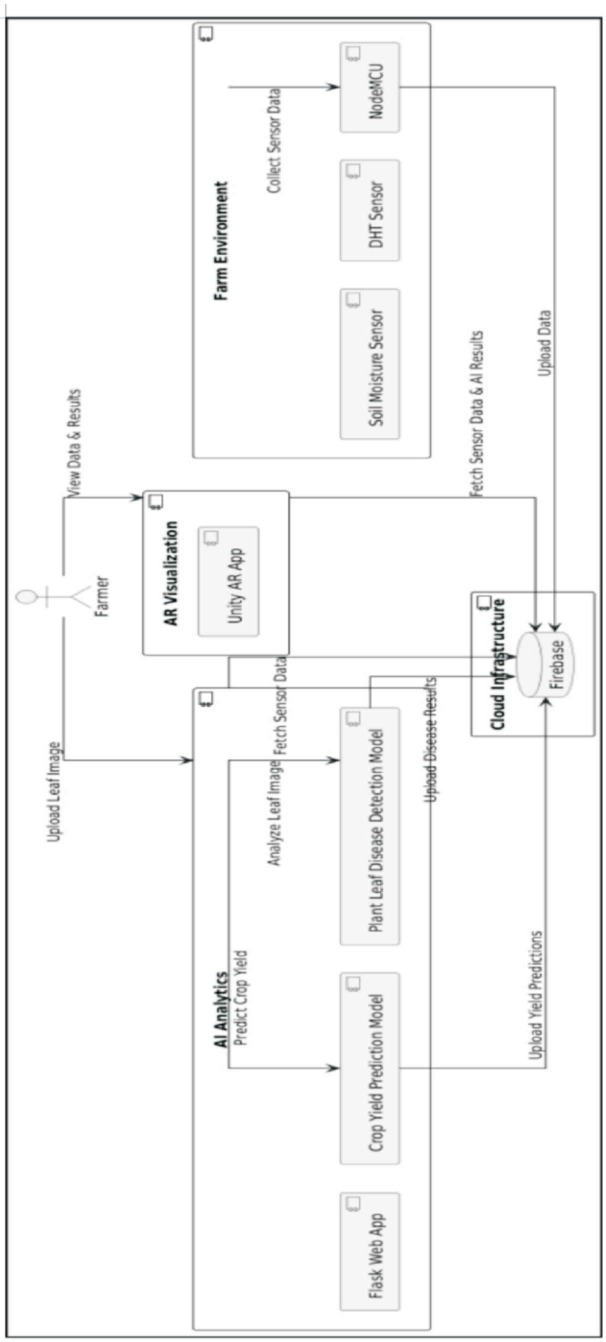

Figure 1. Methodology (Block Diagram)

AI-Based analytics

Developed and trained machine learning models to predict crop yield using environmental data, implement a plant leaf disease detection feature using image processing and machine learning techniques (e.g., Convolutional Neural Networks).

System integration

Synchronized AI analytics results (e.g., crop yield predictions and disease detection outcomes) with the AR app using Firebase, developed a Flask-based web application for farmers to upload plant leaf images and to receive diagnostic results.

Testing and evaluation

Validated the system by testing in real farming scenarios. Measured the accuracy of crop yield predictions and the effectiveness of the disease detection module.

RESULTS AND DISCUSSION

The Smart Agriculture Monitoring System successfully integrated IoT, AI, and AR to implement precision agriculture. Environmental monitoring in real-time for moisture, temperature, and humidity aided in improved environmental control, and crop health and yield were optimized. AI-based algorithms made crop predictions and disease detection accurate, and proactive control was possible. The AR-based interface offered a user-friendly interface to view farm information, and data transfer in synchronized mode via Firebase made it efficient. The technology-based solution optimized the use of resources, avoided losses, and made sustainable agriculture possible.

Table 1. Results of smart agriculture monitoring system

Parameters	Method used	Results obtained
Soil moisture level	Soil moisture sensor (Node MCU)	Real-time monitoring with ±2% accuracy
Temperature and humidity	DHT sensor (Node MCU)	Temperature: ±0.5°C, Humidity: ±2% RH
Data transmission	Firebase real-time database	Seamless synchronization
AR visualization	Unity with AR foundation	Immersive 3D farm data representation
Crop yield prediction (Tomato)	AI model (Machine Learning)	Prediction accuracy: ~85%
Plant disease detection	CNN-based image classification (Flask App)	Disease identification accuracy: 90%
Response time (Sensor to cloud)	Node MCU + firebase	Data upload time: ~1.5s

Table 2. Effect of soil moisture, humidity, and temperature on tomato growth

Parameters	Optimal Range	Tomato growth response	Deviations and effects
Soil moisture	60-70%	Healthy plants, larger fruits, higher yield	Wilting, poor fruit set, reduced yield
Humidity	50-70% RH	Balanced transpire-tion, minimal stress	Fungal infections (high) or dehydration (low)
Temperature	22-28°C	Optimal flowering, better fruit quality	Heat stress (>32°C) or slow growth (<15°C)

This study demonstrated that optimal soil moisture (60-70%), humidity (50-70% RH), and temperature (22-28°C) significantly improved tomato growth and yield. Deviation from these ranges led to wilting, poor fruit development, and reduced productivity. The integration of IoT-based monitoring effectively regulated these conditions, ensuring better crop management. The findings validated the role of smart agriculture technologies in enhancing precision farming and resource efficiency.

Hardware setup

The hardware setup of the Smart Agriculture Monitoring System included the integration of sensors with the Node MCU microcontroller to collect data in real-time. The soil moisture sensor was used to detect the moisture level in the soil, providing farmers with precise information regarding irrigation requirements. The DHT sensor also monitored temperature and humidity levels in the environment in real-time, offering vital climatic data. These sensors were interfaced to the Node MCU, the central unit for processing data. The Node MCU processed the data from the sensors and send it to Firebase, a real-time cloud database, through Wi-Fi communication. Wiring was properly established by interfacing the sensors to the respective GPIO pins of the Node MCU and power was provided either through USB or an external power supply. Firmware of Node MCU was coded on the Arduino IDE with a program being coded to retrieve sensor readings and upload it on Firebase via Firebase library for Arduino.

Alzubi and Galyna (2023) stated that Artificial Intelligence and Internet of Things for Sustainable Farming and Smart Agriculture have emphasized the importance of AI and IoT in sustainable agriculture, highlighting their revolutionizing impact in modernizing agriculture. The application of IoT sensors in agriculture has been extensively explored for tracking environmental and soil parameters, with an important role to play in maintaining optimal growing conditions. Experiments had proven that soil moisture sensors and DHT temperature and humidity sensors yield real-time data, crucial for precision agriculture. The incorporation of IoT devices like Node MCU microcontrollers allows for the free flow of data and synchronization, usually on cloud-based solutions like Firebase to optimize data handling. Firebase being a real-time database guarantees synchronous devices and app applications, offering farmers uninterrupted access to the latest environmental status. This method reduces manual data gathering activities while providing the basis for sophisticated analytics, eventually enhancing decision-making.

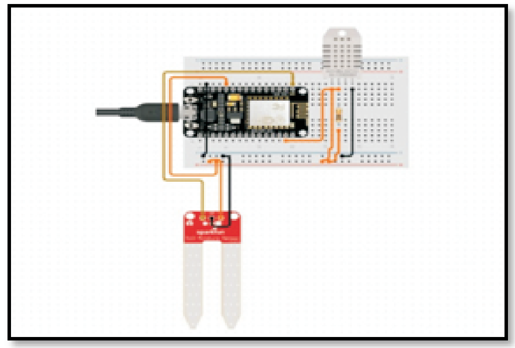

Figure 2. Connection between sensors and Node MCU microcontroller

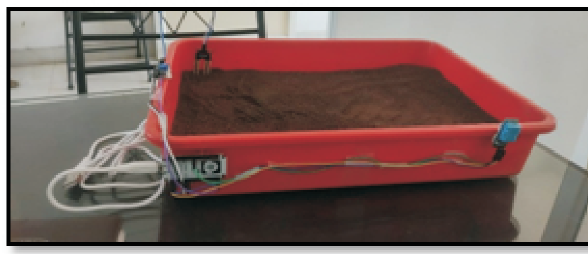

Figure 3. Hardware setup implementation

Software setup

The software implementation is comprised of several elements, such as Firebase, Unity, Python Flask, and machine learning models. Firebase was used as the cloud storage of sensor data to facilitate real-time synchronization between the software and hardware components without any hiccups. The AR application based on unity retrieves sensor data from firebase and displays it in a user-friendly format, enabling farmers to examine environmental conditions through augmented reality. The AR app was built with unity and AR foundation or Vuforia, incorporating the firebase SDK for real-time updates. A flask-based AI analytics web application was also built to offer predictive analysis. The web application fetches sensor data from firebase and uses machine learning models to forecast crop yield based on environmental conditions. The AI module also incorporated a plant leaf disease identification system, where farmers can upload plant leaf images for analysis. Utilizing machine learning libraries such as scikit-learn, Tensor Flow, or Py Torch, the system analysed the images and returns diagnostic findings, enabling farmers to prevent diseases. The end results, such as crop yield forecasts and disease detection results, were uploaded onto firebase and presented in the AR app, with easy access for farmers to actionable information. This ubiquity of hardware and software integration is what boosts farm productivity and enhances agricultural decision-making.

Flask-based AI analytics Web App

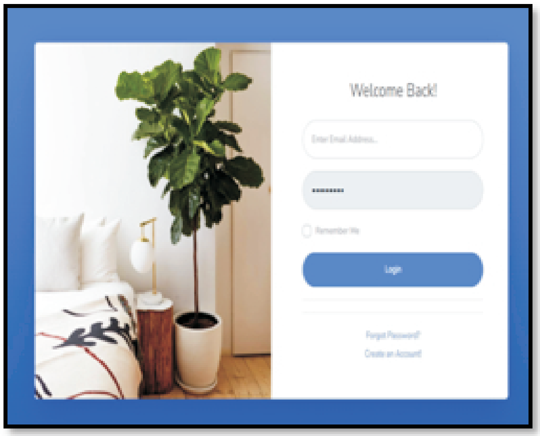

Figure 4. Admin page (For account creation)

This page was designed for administrators to manage user accounts, including registration, authentication, and role-based access control. It ensures that only authorized users can access the system, maintaining security and data integrity.

Figure 5. Home page after login

Once the user logs in, they were directed to the home page, which served as the main navigation hub. It provided quick access to different modules such as real-time sensor monitoring, AI analytics, and AR visualization. The user interface was designed for ease of use, ensuring seamless interaction with system features.

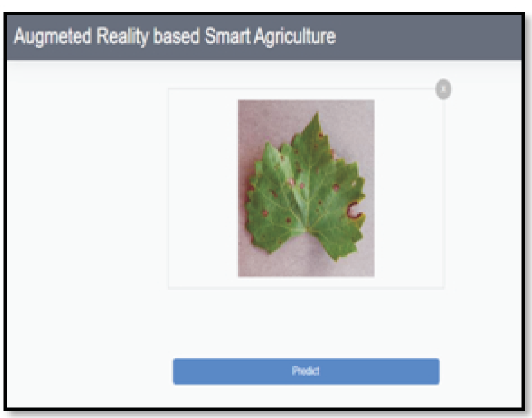

Figure 6. Plant leaf disease prediction

This section allowed users to upload images of plant leaves for disease detection. The AI model processed the image, identifies potential diseases, and provided diagnostic results along with suggested remedial actions. The model was trained on a dataset of plant diseases to ensure accurate classification and early detection.

According to Bhat and Huang (2021), Big Data and AI Revolution in Precision Agriculture: Survey and Challenges have stressed the revolutionary effect of AI and machine learning in predictive analytics and autonomous decision-making for contemporary agriculture. Recent studies indicated the use of machine learning libraries such as scikit-learn, Tensor Flow and Py Torch to develop models that can predict crop yield based on environmental parameters. These prediction models scan inputs such as soil moisture, temperature, and humidity to forecast possible yields, enabling farmers to implement anticipatory crop management techniques. Plant disease detection is another significant application of AI in agriculture, wherein deep learning models, especially convolutional neural networks (CNNs), have been demonstrated to detect plant diseases accurately from leaf images. The integration of diagnostic output with AR visualization further enables farmers to implement fast preventive measures, curbing disease spread, and optimizing overall crop quality and yield maximization.

Thopate *et al*. (2023) designed Plant Prediction System, a Java-based application to automate plant species identification based on soil parameters. This system is crucial for agriculture, horticulture, and environmental studies, where selecting the right plant species plays a vital role in optimizing growth and sustainability. Traditionally, determining the optimal plant species for given soil conditions has been a manual process, which is both time-consuming and prone to errors. To overcome this challenge, the Plant Prediction System utilizes a pre-existing databasecontaining plant profiles with recommended ranges for soil pH, humidity, moisture, and temperature. When user inputs measured soil values, the system compared themwith the databaseand predicted the most suitable plant species. This innovation can help researchers, farmers and gardening enthusiasts to make decision to improve plant yields to optimize resource utilization and to promote sustainable agricultural practices.

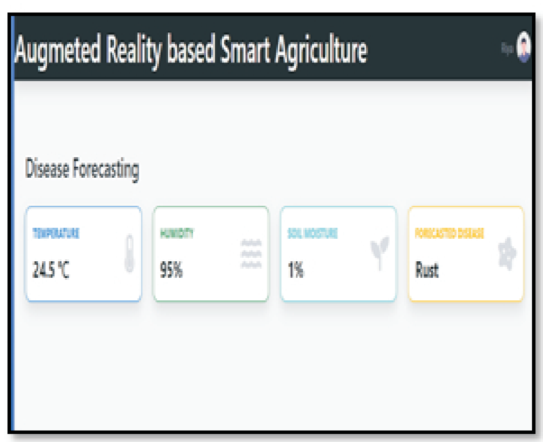

Figure 7. Disease forecasting

This feature leveraged AI-driven predictive analytics to forecast potential disease outbreaks based on environmental conditions such as temperature, humidity, and soil moisture. By analysing sensor data and historical disease patterns, the system can help to farmers to take preventive measures to reduce crop loss and to improve yield quality.

Unity AR App

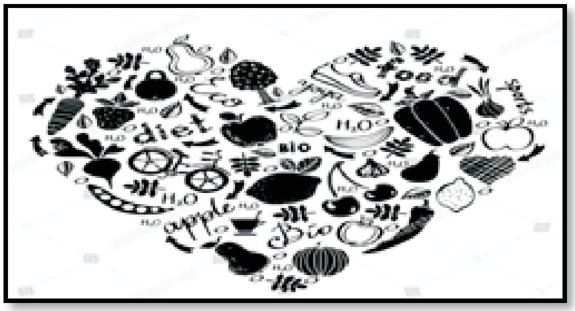

Figure 8. Scanner for unity AR visualization

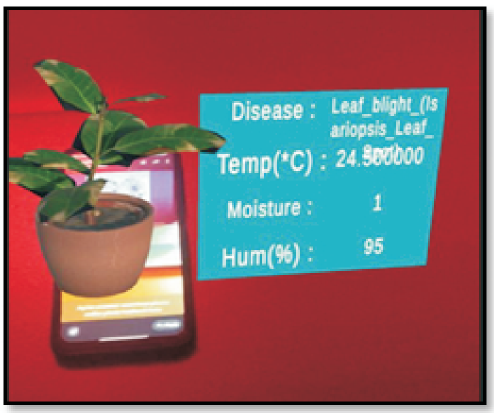

Figure 9. Results of unity AR visualization

The Unity AR application provided an immersive experience by overlaying real-time sensor data on the farm environment using augmented reality. Farmers can view soil moisture, temperature, and humidity readings directly on their mobile devices, making data interpretation more intuitive. Additionally, the AR app displayed AI analytics results, such as crop yield predictions and disease detection insights, in an interactive format in agriculture. (Ga *et al.,* 2018; Parasuraman and Anandan, 2021)

According to Kumar and Anandan (2021), IoT based Smart Agriculture Automation in Artificial Intelligence have explained how Augmented Reality (AR) technology can enable enhanced user interaction and data visualization in agriculture. One of the key applications is the visualization of real-time data from IoT sensors using AR so that farmers can view farm conditions in a simple-to-understand format. Research suggests that AR applications, developed on platforms like Unity and AR Foundation, provided immersive interfaces that transform complex data into visual formats that are easily comprehensible, enabling timely decision-making based on real-time data. Research on AR-based systems suggests that such visualizations not only enhanced user interaction but also provided high educational returns, enabling enhanced knowledge of environmental parameters and their impact on plant health for farmers. Such a practice has been found to be extremely effective in various agricultural contexts, such as precision agriculture and resource management, resulting in enhanced productivity and sustainability in modern agriculture. (Bu and Wang, 2019)

According to Mishra *et al.* (2022), "Learning Aided System for Agriculture Monitoring Designed Using Image Processing and IoT-CNN" have researched the convergence of Augmented Reality (AR), Internet of Things (IoT), and Artificial Intelligence (AI) in smart agriculture. Some research proposes architectures that combine these technologies in one system to enable real-time monitoring, predictive analysis, and disease diagnosis. The shared architecture includes IoT sensors for data collection, cloud database for data storage, AR for simple visualization, and AI for intricate analytics. Research shows that such an integrated system significantly improved the efficiency of farm management by providing farmers actionable insights in one platform. However, one of the key challenges reported in such systems is seamless data synchronization and minimizing latency between data collection, processing, and visualization. In order to achieve this, efficient data pipelines and low-weight communication protocols are extensively used, allowing smooth operation, especially in low-bandwidth or rural areas. This research finds the need for the convergence of AR, IoT, and AI in the development of a more efficient and technology-based agricultural system.

On the basis of above results it is inferred that The Smart Agriculture Monitoring System properly integrates Augmented Reality, Internet of Things, and Artificial Intelligence to transform agriculture operations. From real-time sensor data collected by Node MCU, soil moisture, and DHT sensors, the system delivered accurate environmental information to the farmers. This information is also sent to firebase, offering reliable cloud storage and synchronization of programs. The flask-based AI web application is of the utmost significance to support predictive analytics for crop yield prediction and disease detection in the leaves of the plants using the most advanced machine learning methods. The disease detection module can allow the farmers to feed in the leaves' images and get instant diagnosis and treatment advice. In addition, AI-aided disease forecasting helps to identify potential plant infection at an early stage using sensor input and meteorological conditions. The AR application based on unity can improve the user experience by enabling interactive visualization of farm conditions. Farmers can track important parameters such as soil moisture, temperature, and humidity in real time with AR. The interface also consists of AI-based analytics, which analysed crop health insights and forecasts interactively, improving data interpretation and making it more user friendly.

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