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FARM GUARD: An IoT-Based Smart Agricultural System For Automated Irrigation, Crop Recommendation, and Plant Disease Detection Using ESP32

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Abstract- *Agriculture faces several challenges, such as inefficient water management, improper crop selection, and delayed detection of plant diseases, which reduce crop yield and farmer income. To address these issues, this study presents an IoT-based smart agriculture system developed using the ESP32 web server platform. The proposed system integrates automated irrigation, crop recommendation based on predefined soil pH reference data, and image processing-based plant disease detection. Soil moisture is continuously monitored, and irrigation is automatically controlled to maintain optimal water conditions, thereby reducing water waste. Suitable crops were recommended using stored soil pH reference values. For plant health monitoring, leaf images collected from agricultural fields and uploaded into MATLAB were analyses using image processing techniques to identify early disease symptoms. All important system information, including sensor readings, irrigation status , crop recommendations and disease detection results, was displayed in real time through a web-based dashboard. The experimental results demonstrate that the proposed system improves resource utilization, supports precision farming, and assists farmers in making informed decision regarding sustainable agricultural practices.*

Keywords- Smart Agriculture, Inter of things, ESP32, Automated Irrigation, Crop Recommendation, Plant Disease Detection, Precision Farming.

I. Introduction

Agriculture plays a vital role in the economy of many developing countries and is essential for meeting the rapidly growing global demand for food. However, traditional farming practices still depend heavily on manual irrigation, farmers experience for crop selection, and visual inspection to identify plant disease. These conventional approaches are often time-consuming and less reliable, which may lead to excessive water usage, unsuitable crop cultivation, and delayed detection of plant diseases. As a result, farmers may experience reduced crop productivity and economic losses.With the advancement of the internet of Things (IoT) and embedded technologies, modern agriculture is gradually shifting towards smart and automated farming solutions. IoT-based systems use sensors, microcontroller, and communication technologies to monitor environmental conditions and automate agricultural processes. Among the available embedded platforms, the ESP32 microcontroller has become widely used sue to its built-in Wi-Fi capacity, low power consumption, and ability to support web-based monitoring applications.

This study presents a smart agriculture system that integrates automatic irrigation, crop recommendation using predefine soil pH reference data, and plant disease detection using image processing techniques. A soil moisture sensor is used to continuously monitor the moisture level in the soil. Based on the controlled data, the ESP32 microcontroller automatically controls the irrigation system, ensuring that crops receive an adequate amount of water. This helps in preventing both over-irrigation and under-irrigation, thereby improving water management in agricultural fields. For crop recommendation, instead of using a physical soil pH sensor, the system utilizes predefine soil pH reference data derived from standard agricultural guidelines. These reference values are analyzed to recommend crops that are suitable for specific pH ranges, helping frames select crop that are more compatible with soil conditions and improving the chances of better crop growth and yield.

In addition, plant disease detection is carried out using image processing techniques implements in MATLAB. Images of plant leaves are analyzed to identify visible symptoms of diseases at an early stage. Early detection allows farmers to take appropriate preventive actions, reducing the risk of crop damage and minimizing potential losses.

All system information, including soil moisture readings, irrigation status, crop recommendations, and disease detection results, is displayed through a web-based dashboard hosted on the ESP32 web-server. This enables farmers to remotely monitor field conditions using smartphones or computers. By combining automation, crop guidance, and disease monitoring, the proposed system supports efficient resource utilization and contributes to the development of sustainable and precision-based agricultural practices.

II. System Overview

The FARM GUARD system is a smart agriculture monitoring and automation platform developed using the ESP32 microcontroller. The main objective of this system is to improve irrigation efficiency, monitor environmental conditions, and support early detection of plant diseases, thereby reducing manual effort in farming operations. By integrating IoT-based sensing, automated control, and MATLAB-based image processing, the system promotes precision farming and sustainable agricultural practices.

The ESP32 acts as the central controller of the system. It continuously collects data from various sensors installed in the field, processes the information using predefined threshold values, and controls the connected actuators. Due to its built-in Wi-Fi capability, the ESP32 enables real-time monitoring through a web-based interface, allowing farmers to access field data remotely. Soil moisture is monitored using a soil moisture sensor placed in the cultivation area. When the moisture level falls below the required limit, the ESP32 automatically activates the irrigation system using a relay-controlled water pump. Once the soil reaches the desired moisture level, the pump is switched off automatically. This process ensures efficient water usage and prevents both over-irrigation and under-irrigation.Environmental conditions are monitored using a DHT11 sensor, which measures temperature and humidity. These parameters provide important information about climatic conditions that influence crop growth and irrigation requirements. In addition to irrigation automation, the system plant disease detection using MATLAB-based image processing techniques. Leaf images are collected separately and analyzed offline using MATLAB to identify visible disease symptoms. Image processing steps such as preprocessing, segmentation, and feature extraction are applied to evaluate leaf conditions, and the obtained results assist in crop health assessment.All essential system information, including soil moisture, temperature, humidity, irrigation status, and disease detection results, is displayed on both a local LCD screen and a web-based monitoring dashboard hosted on the ESP32 web server. This dual monitoring approach allows farmers to observe field conditions locally as well as remotely using smartphones or computers.

Overall, the FARM GUARD system provides an integrated and intelligent solution by combining automated irrigation, environmental monitoring, and disease analysis. It enhances farming efficiency, conserves water resources, reduces manual intervention, and supports sustainable agricultural practices.

III. Related Works

Many researchers have toured the adoption of Internet of Things (IoT) technologies to salvage modern-day agricultural activities. Kumar et al. industrialised an automatic water irrigation system which operates on soil moisture sensors to regulate the water supply and ensure that minimal expenditure is incurred. Nandhini and Balaji estimated a soil pH monitoring system that helps farmers on how to choose the right crops depending on the condition of the soil. Barbedo proposed the techniques of image dispensation in the detection of plant diseases through the inspection of the leaf images.

As Hossain et al. imagined, a web-based surveillance system was created in which the ESP32 microcontroller would be used to detect environmental conditions in real time. Similarly, in another research, Gondchawar and Kawitkar introduced an IoT-based system of agricultural monitoring that will be used to refine the overall crops management and surveillance of fields.

Though these studies have been able to articulate specific challenges in agriculture, a majority of the current system have concentrated on partial aspects like irrigation control or environmental monitoring. There are very few solutions where irrigation automation, crop suggestion, and plant disease identification are integrated into one platform. The proposed FARM GUARD system seeks to overcome this shortcoming by integrating automated irrigation, soil pH testing and MATLAB disease identification into a single system, providing a more holistic approach to the procedure of precision farming.

IV. Existing System

The current agricultural system is characterized by the use of traditional and manual farming activities in most of the farming activities. Irrigation is normally performed with constant time intervals or according to experience taken by farmers and does not involve actual soil moisture conditions. This mostly either leads to over-irrigation or under-irrigation. Irrigation, which causes wastage of water, low crop growth, and soil unfertilization. In traditional farming, crop choice is largely an experience or locality issue without the proper analysis of the soil pH levels. Consequently, farmers can produce crops that are incompatible with the soil status and this impacts negatively on crop production and leads to the use of more fertilizers and soil treatment. Detecting plant diseases in the current system is done manually by farmers or agricultural experts by visual checking the plant. Such as approach is time-consuming, involves professional expertise, and does not always reveal illnesses in its early phases. Failure to identify diseases early may mean that the diseases spread very fast and this will result in massive losses of crops. Also, the current system is not remote and automated. In order to monitor the state of soil, irrigation and plant health, farmers have to be on-site. The traditional farming is inefficient and labour-intensive because there is no centralized platform to observe various parameters in real time, making traditional farming inefficient and labor-intensive.

V. Proposed System

The proposed system introduces a smart agriculture solution that integrates automated irrigation, crop recommendation using predefined soil pH references data, and image processing-based plant disease detection through an ESP32 web server. The system aims to improve crop productivity, reduce water wastage, and assist farmers in making informed decisions.

Soil moisture sensors continuously monitor the water content in the soil. Based on the collected data, the ESP32 automatically controls the irrigation systems to ensure optimal water supply to crops. This prevents over-irrigation and under-irrigation and promotes efficient water management.Instead of using a physical soil pH sensor, the system utilizes predefined reference datasets based on standard agricultural guidelines. These references values are analyzed and suitable crops are recommended based on predefined pH ranges. This approach helps farmers select crops that are well suited to soil conditions, leading to improved growth and higher yield.

For plant health monitoring, the system supports disease identification using MATLAB-based image processing techniques. Leaf images are analyzed to detect visible disease symptoms at an early stage. Early identification enables timely preventive measures, thereby reducing crop damage and minimizing economic loss.

All sensor readings, irrigation status, crop recommendations, and disease detection results are displayed on web-based dashboard hosted on the ESP32. Farmers can remotely monitor field conditions using smartphones or computer. The proposed system enhances precision farming, supports sustainable agriculture, and reduces manual effort through automation and real-time monitoring.

VI. Methodology

1 Collection of soil and Environmental Data

The systems begin by continuously monitoring soil and environmental conditions using sensors installed in the agriculture field. A soil moisture sensor is used to measures the water content in the soil. Instead of using a physical pH reference data are used to determine whether the soil is acidic, neutral, or alkaline. These values are selected based on standard agriculture guidelines. The sensor outputs are transmitted to the ESP32 microcontroller, where the analog signals are converted into digital form for further processing.

2 Processing of Sensors Data Using ESP32

The ESP32 functions as the main processing unit of the system. It continuously receives data from the soil moisture sensor and predefined pH references datasets. This information in analyzed using predefined threshold values. By evaluating the moisture data, the system determines whether irrigation is required. Similarly, the references pH values are used to understand soil conditions and identify suitable crops. This real-time processing enables the system to respond quickly to changing field conditions.

3 Automatic Irrigation Control Mechanism

Based on the processed soil moisture values, the irrigation system operates automatically, When the moisture level drops below the set thresholds, the ESP32 activates the water pump through a relay module. Water is supplied to the crops until the optimal moisture level is achieved. Once sufficient moisture is reached, the pump is turned off automatically. This mechanism ensures efficient water usage, minimizes wastage, and maintains healthy soil conditions for crop growth.

4 Soil pH-Based Crop Recommendation

The system recommends suitable crops using predefined soil pH references values. These values are compared with standard pH ranges associated with different crops. Based on this comparison, crops that can grow effectively in the existing soil condition are suggested. This recommendation process helps farmers select appropriate crops, improves plant growth, reduces risk, and increase overall productivity.

5 Plant Disease Detection Using Image Processing

To monitor plant health, the system employs image processing techniques implemented in MATLAB. Images of plant leaves are captured and used as input for analysis. The images undergo preprocessing steps such as resizing, noise reduction, and color conversion to enhance quality. Important features related to disease symptoms are extracted and compared with trained datasets to identify possible diseases. Early detection enables farmers to take timely preventive measures and reduces crop damage.

6 Web-Based Monitoring and User Interface

An embedded web server running on the ESP32 displays system information through a user-friendly web dashboard shows real-time soil moisture data, irrigation status, crop recommendations, and disease detection results. Farmers can access the interface using smartphones or computers from any location, enabling convenient monitoring and management of agriculture fields.

7 Overall System Integration

All system components, including sensor monitoring, data processing, irrigation control, crop recommendation, disease detection, and web visualization, work together as a unified platform. This coordinated operation supports precision farming, promotes sustainable agriculture, and significantly reduces the need for manual intervention.

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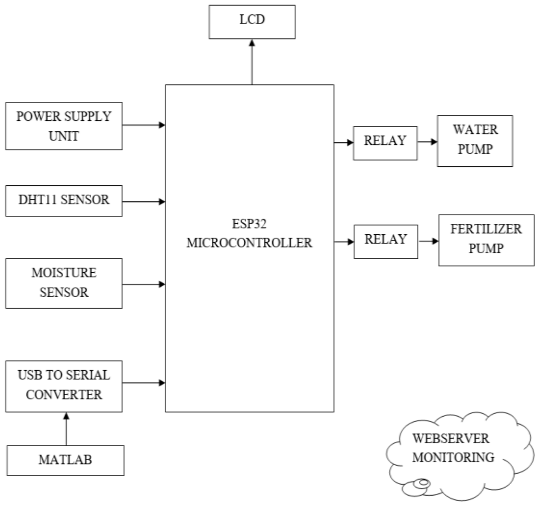

Fig 1. Block Diagram

VII. Experimental Result

The proposed FARM GUARD system was applied using an ESP32 microcontroller along with soil moisture, soil predefined pH reference data, and DHT11 sensors, a relay module, and a water pump. The system was tested in a small agricultural setup under real field conditions to evaluate its performance. The experiments were conducted for several days to observe the behaviour of the system under different environmental situations.

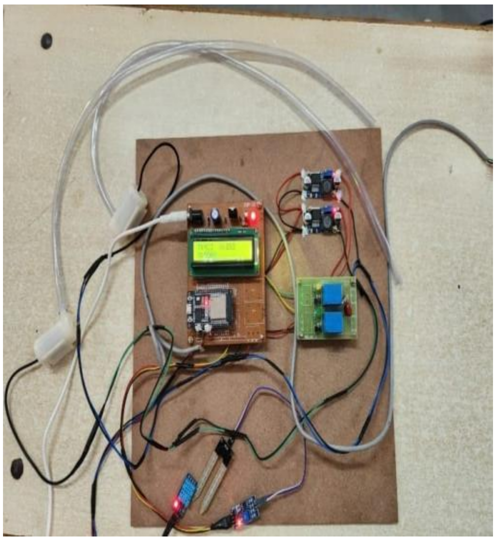

Fig 2 .Hardware setup of the proposed smart agriculture system using ESP32 sensors.

During testing, the soil moisture sensor continuously monitored the water content in the soil. When the moisture level dropped below the predefined threshold value, the irrigation system was automatically activated. Once the required moisture level was achieved, the water pump was switched Off. The automatic control mechanism helped in maintain optimal soil conditions and significantly reduced unnecessary water usage.

In this system, soil pH values were taken from predefined reference datasets instead of being measured using a physical sensor. These stored values were used to represent different soil conditions for testing and analysis. Based on the given pH inputs, the system generated suitable crop recommendations. When the pH value was between 6.0 and 6.5, crops such as rice, maize, and wheat were suggested. These results matched well with standard agricultural guidelines, showing that the crop recommendation module works effectively.

Crop	Ideal Soil pH	Target pH	Apply Lime Below	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)
Rice	5.5–6.5	6.5	6	100–150	40–60	40–60
Wheat	6.0–7.5	6.8	6.2	120–150	60	40
Maize	5.5–7.0	6.5	6	120–150	60	40
Cotton	5.8–7.5	6.5	6	100–120	50	50
Sugarcane	6.0–7.5	6.8	6.2	250–300	100	120
Groundnut	6.0–6.5	6.2	6	20–30	40–50	40–50
Potato	5.0–6.5	6.2	5.5	150–180	80–100	100–120
Tomato	5.5–7.0	6.5	6	100–120	60	60
Onion	6.0–7.0	6.5	6	100–120	50	50
Chilli	6.0–6.8	6.5	6	100	50	50
Banana	6.0–7.5	6.8	6.2	200	60	200
Pulses	6.0–7.0	6.5	6	20–25	40–50	20
Tea	4.5–5.5	5.2	4.8	120	60	60
Coffee	5.0–6.0	5.5	5	120	60	60

Fig 3. pH Table

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For plant health monitoring, the image processing module was evaluated using several leaf images collected from different plants. The images were processed using MATLAB, and disease symptoms were successfully identified at an early stage. The system achieved an average detection accuracy of approximately 85-90%, which shows its effectiveness in identifying common plant diseases.

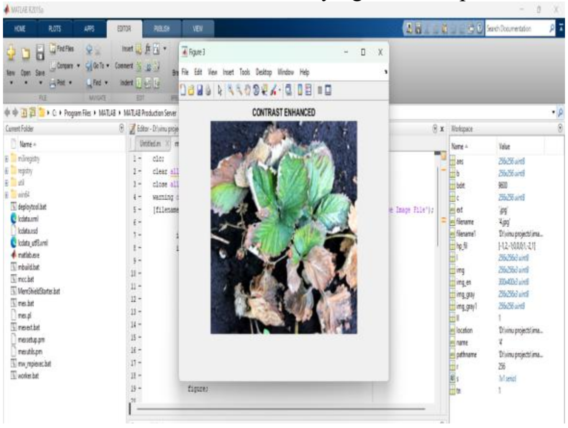

Fig.4. Processed leaf image highlighting disease-affected regions using contrast enhancement.

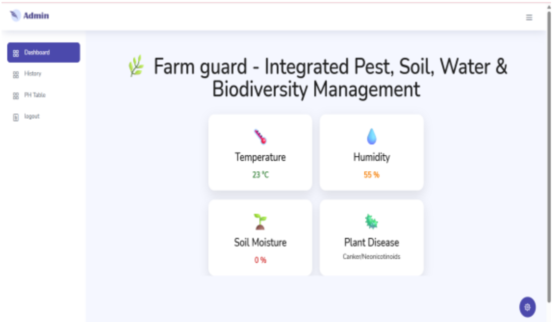

Fig.5. Web-based dashboard displaying real-time agriculture parameters of the proposed system.

The monitoring interface was online and run on the ESP32 to show real-time sensor data, irrigation condition, and detection of diseases. The dashboard was fast with the least lag time that users could easily check the conditions of the field even on their smartphones or computers. This aspect minimized the necessity of making physical visits to the field frequently and enhanced convenience.

All in all, the experimental findings show that the suggested system can work effectively even under the conditions of real-time. It is effective in controlling the irrigation process, giving precise crop advice, identifying diseases affecting plants at an early stage, and making it possible to monitor them remotely. The fundings affirm that FARM GUARD system is appropriate to practice precision farming and sustainable agriculture.

VII. Result

A smart agriculture system was proposed and the development and implementation of the system were done using the ESP32 web server platform. The system was constantly measured with the soil moisture content and the irrigation process was automatically controlled with the real-time information. This was a strategy of ensuring the best soil condition and it drastically reduced water wastage as a result of over-irrigation and under-irrigation. As a result, effective use of water resources was realized, ehich favored health development of crops. There was an effective use of predetermined soil pH reference data to come up with the correct crop recommendation. The system proposed the crops which were compatible with the available soil conditions based on the given pH values. These suggestions caused better crop choice, high productivity and minimization of low yield risk. Plant disease detection module which was implemented by applying image processing approached of MATLAB was able to process leaf images and identify visible disease symptoms at an early stage. Timely preventive action was taken through early detection thus limiting damage of crops and economic loss. The real time display of all the necessary system parameters such as the level of soil moisture, irrigation status, crop-specific recommendation based on pH, and the result of disease detection, was presented in a convenient web interface. This allows farmers to remotely check on the condition of the field with their smartphones or computers hence reducing the frequency with which they had to visit the field physically. The system was proven to perform reasonably well in permanent mode with little lag in the transmission and visualization of the data. On the whole, the experiments show that the given system is efficient and trustworthy and can be used in practice in the field of agriculture. Using the combination of automated irrigation, crop recommendation and disease monitoring in one platform, the system is efficient in farming, minimizes manual interaction and promotes precision agriculture through intelligent automation and real time control.

XI. Conclusion

This project manages to show the application of a Smart Agriculture System based on an ESP32 Web Server, which combines the automatic irrigation, the choice of crop, and the detection of plant diseases based on the image processing. The system is very effective in solving significant problems of conventional farming by automating irrigation, enhancing crop assortments , and facilitating early disease outbreaks. Real-time monitoring of soil moisture to automatically irrigate farmland aided in the efficient use of water also minimized the amount of water that was not necessary. The analysis of the soil pH was informative in determining the type of crop to be used, which is capable of enhancing the crop production and alleviating soil erosion. The plant disease detection module allowed early detection of the diseases so that preventative actions can be taken and losses on crop reduced. Monitoring system based on the web also enabled the farmers to remotely access real-time information saved them a lot of labor and brought them more convenience. In general, the proposed system boosts precision agriculture, sustainable farming activities, and productivity by automating and making smart decision. This project shows that the application of IoT and image processing in the agricultural sector can be of great help to farmers and be included in contemporary smart agriculture.

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