Smart Agriculture Monitoring System Using IOT

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Abstract— The increasing demand for efficient and sustainable agricultural practices has led to the adoption of smart technologies in farming. This project presents a Smart Agriculture Monitoring System that integrates Internet of Things (IoT), renewable energy, and machine learning to provide real-time monitoring and decision-making support for farmers. The system utilizes sensors such as DHT11 for temperature and humidity, a rain sensor, and other environmental monitoring modules connected through an ESP32 microcontroller. Sensor data is transmitted wirelessly and visualized on ThingSpeak, a cloud-based platform, allowing farmers to remotely track field conditions and take timely actions.

A key feature of the system is the Plant Recommendation System is a web-based application that suggests suitable plants based on current weather data. It collects real time information such as temperature, humidity, soil moisture, and rainfall from a ThingSpeak channel. This data is processed using a machine learning model built with the Random Forest algorithm. The model predicts the best plant type for the given conditions. The application is developed using Flask and features a user- friendly interface designed with modern CSS styling. The system helps users, especially farmers and gardeners, to make better planting decisions based on data-driven insights.

The system is powered by solar energy, ensuring sustainability and suitability for rural or off-grid areas. Overall, the Smart Agriculture Monitoring System offers a cost-effective, scalable, and eco-friendly solution for modern precision agriculture, paving the way for future integration of automation and advanced analytics in farming.

Keywords— Smart Farming, IoT, ESP32, ThingSpeak, Machine Learning, Crop Recommendation, Precision Agriculture, Solar Energy.

I. Introduction

Agriculture plays a vital role in the economy, especially in countries like India, where a large population relies on farming for their livelihood. However, traditional agricultural methods are increasingly becoming insufficient due to challenges such as unpredictable weather, water scarcity, soil degradation, and reliance on manual labor. To address these issues, technology-driven solutions like Smart Agriculture are being adopted.

Smart Agriculture integrates Internet of Things (IoT) devices and sensors to monitor environmental conditions such as temperature, humidity, soil moisture, and rainfall in real time. This project aims to implement a Smart Agriculture Monitoring System using sensors and the ESP32 microcontroller, which collects and transmits data to the cloud platform ThingSpeak for remote monitoring and visualization.

The system automates irrigation by activating a water pump based on soil moisture and weather data. It also predicts rainfall using humidity and rain sensor inputs, helping to conserve water. A key advantage of this system is its use of solar energy, which ensures sustainable operation even in areas with limited access to electricity.

To further enhance the system's practicality, a Crop Recommendation feature has been incorporated. This feature analyzes environmental parameters such as temperature, humidity, and rainfall data collected through ThingSpeak and suggests the most suitable crops for current conditions. By recommending crops based on real-time data, this addition supports farmers in making informed decisions that align with weather patterns and resource availability. This not only improves agricultural efficiency but also reduces the risks associated with poor crop selection.

In essence, this project demonstrates how IoT can be applied in agriculture to enhance productivity, optimize resource usage, and support farmers in making data-driven decisions.

II. Literature Review

The integration of Internet of Things (IoT) in agriculture has seen a rapid evolution, addressing core challenges in traditional farming such as excessive water usage, labor-intensive processes, and poor decision-making due to lack of real-time data.

2.1 IoT in Agriculture

Lakshmisudha et al. proposed a sensor-based system using Zigbee and soil moisture sensors to automate irrigation, demonstrating early application of IoT for water management. Similarly, Ramesh developed a solar-powered wireless sensor network (WSN) with GSM for autonomous irrigation, emphasizing energy efficiency in remote operations. Manimegalai utilized NodeMCU and soil sensors for real-time monitoring, aiming to reduce water overuse.

Recent work by Latha et al. employed ESP32 with Blynk to offer cloud-based mobile dashboards, highlighting ease of remote control. Patel et al. integrated AI/ML models with Firebase for intelligent irrigation prediction, while Sharma et al. used Arduino UNO and GSM to alert farmers about critical environmental changes.

2.2 Comparative Insights

Studies frequently use DHT11, soil moisture, and rain sensors due to their affordability and reliability. ESP32 is favored for its built-in Wi-Fi and low power consumption. Cloud platforms such as ThingSpeak and Blynk are commonly used for data visualization. Several researchers have addressed the need for automation and sustainability but few have integrated real-time crop recommendation systems.

2.3 Sensor Networks

A comparison between traditional and IoT-based agriculture reveals significant advantages in the latter:

- **Water Usage**: Data-driven and efficient
- **Labor Dependency**: Reduced through automation
- **Decision-Making**: Enhanced by real-time analytics
- **Sustainability**: Promoted via renewable energy sources
- **Scalability**: Easily adaptable to various terrains and crops

2.4 Research Gap

While previous works excel in data collection and visualization, most lack machine learning-based decision support systems for crop selection. Moreover, few address energy sustainability and remote accessibility in a single integrated solution.

III. PROBLEM STATEMENT AND OBJECTIVES

Problem: Conventional agricultural practices often rely heavily on manual intervention and intuition-based decisions, which can lead to inefficient resource usage, inconsistent crop yields, and susceptibility to climate variability. Key challenges include over-irrigation or under-irrigation due to lack of real-time soil moisture data, energy inefficiency in operating equipment, and the absence of intelligent systems to assist in crop selection based on environmental conditions. There is a critical need for an automated, data-driven solution that enables real-time environmental monitoring, energy-efficient operation, and intelligent crop recommendation to support modern, precision-based agriculture.

- Monitor temperature, humidity, soil moisture, and rainfall.
- Automate irrigation using real-time sensor data.
- Display data on ThingSpeak.
- Provide crop recommendations using a Random Forest-based ML model.
- Ensure sustainable operation with solar power.

IV. SYSTEM DESIGN AND ARCHITECTURE

4.1 Block Diagram:

The Block Diagram consists of sensors connected to an ESP32 microcontroller. Data is transmitted to ThingSpeak and used in decision-making algorithms. The system is powered by solar panels and includes a GSM module for SMS alerts. Irrigation is controlled via relay logic, and crop recommendations are displayed on an LCD.

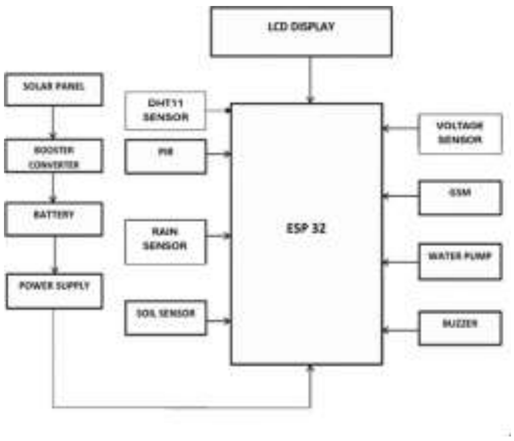

Figure 1: Block Diagram

ESP 32 is a powerful, low-cost, and versatile microcontroller developed by Espressif Systems. It is widely used in various IoT (Internet of Things) and embedded projects due to its rich feature set and flexibility.
Humidity Sensor is also known as a hygrometer, is a device used to measure the moisture content or relative humidity in the air.
Soil Sensor is also known as a soil moisture sensor or soil moisture meter, is a device used to measure the moisture content of soil.
Temperature Sensor is a device used to measure temperature variations in its surrounding environment. There are various types of temperature sensors, each with its own principles of operation and applications.
Voltage Sensor The voltage sensor monitors the system's voltage levels to ensure they remain within safe limits. It uses a voltage divider circuit, typically consisting of two resistors (e.g., 30 KΩ and 7.5 KΩ), to reduce higher voltages to a level that the ESP32 can safely read.
Rain Sensor The rain sensor detects rainfall by using a board with exposed conductive lines. When raindrops land on the board, they create a conductive path between these lines, changing the electrical resistance. This change is detected and sent as a signal to the ESP32 microcontroller, indicating the presence of rain. This information can be used to pause irrigation or send alerts.
Passive Infrared (PIR) Sensor is a type of motion sensor that detects motion by measuring changes in infrared radiation emitted by objects in its field of view. It works by detecting the heat emitted by living beings and other objects in its surroundings.
GSM Modem is a device that enables communication between a computer or other electronic device and the GSM network. It allows devices to send and receive data, including text messages (SMS), voice calls, and internet connectivity, over the cellular network.
Relay is an electromechanical switch that is operated by an electrical signal. Relays are commonly used to control high-power or high-voltage circuits with low-power electrical signals.
DC Pump is a type of pump that operates on direct current (DC) electrical power. It uses the energy from the DC power source to move fluid, such as water or other liquids, from one place to another.
Liquid Crystal Display is a common type of alphanumeric display module that consists of 16 character positions per line and two lines. Each character position can display a character or symbol, typically consisting of a 5x8 dot matrix.
Solar Panel labeled as "12V, 5W" typically means it is designed to produce a maximum power output of 5 watts when connected to a 12-volt system.
Boost Converter is also known as a step-up converter, is a type of DC-DC converter that increases the input voltage to a higher output voltage. It achieves this by storing energy in an inductor during the ON state of a switch and releasing it to the output during the OFF state.
Lead-acid Battery labeled as "12V, 4AHC" typically refers to a 12-volt battery with a capacity of 4 ampere-hours (AhC).

4.2 System Architecture

The architecture represents a Smart Agriculture Monitoring System powered by a solar panel. The power supply section includes a 7805-voltage regulator that converts the solar panel output to a stable 5V for the entire system.
The main controller is an ESP32 microcontroller, which collects data from various sensors. These sensors include a soil moisture sensor to measure soil moisture levels, a DHT11 sensor for temperature and humidity, a rain sensor to detect rainfall, and a PIR sensor for motion detection. Additionally, a buzzer is included for audio alerts.

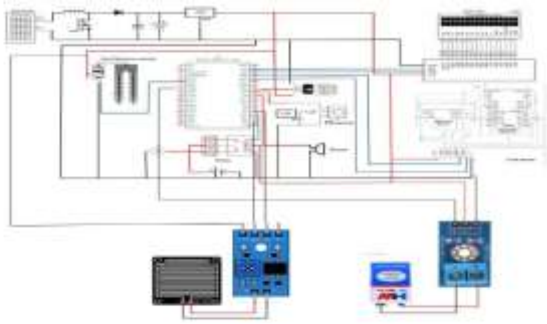

Figure 2: System Architecture

4.3 Control Flow Diagram

- Initialize sensors (DHT11, Soil Moisture, Rain, Voltage, EC)
- Read sensor values
- Send data to ThingSpeak
- Analyze ThingSpeak data:
  - If moisture < threshold AND no rain → turn ON pump
  - If rain is detected or moisture sufficient → pump OFF
- Evaluate crop recommendation logic:
  - Match temperature, humidity, and rain to crop rules
  - Display recommended crop on dashboard
- Repeat process

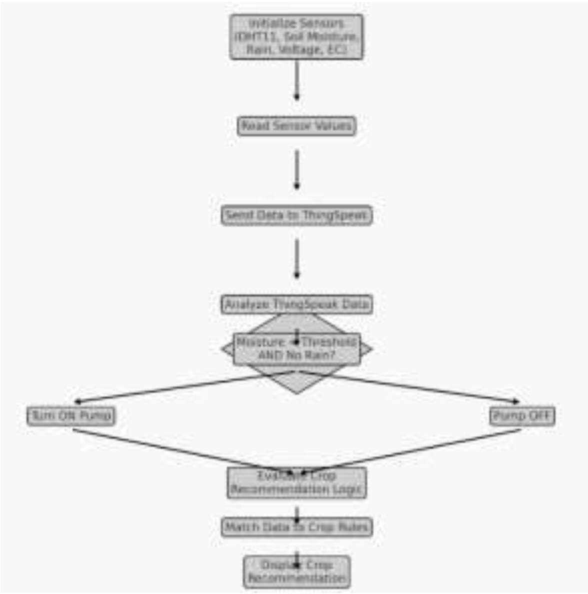

Figure 3: Control flow diagram

4.4 Data Flow Diagram

- **Input**: Sensor data (temperature, humidity, rain detection)
- **Processing**: ESP32 computation and ThingSpeak upload
- **Decision**: Irrigation control logic + crop recommendation logic
- **Output**: Actuator control (relay & pump), display on LCD.

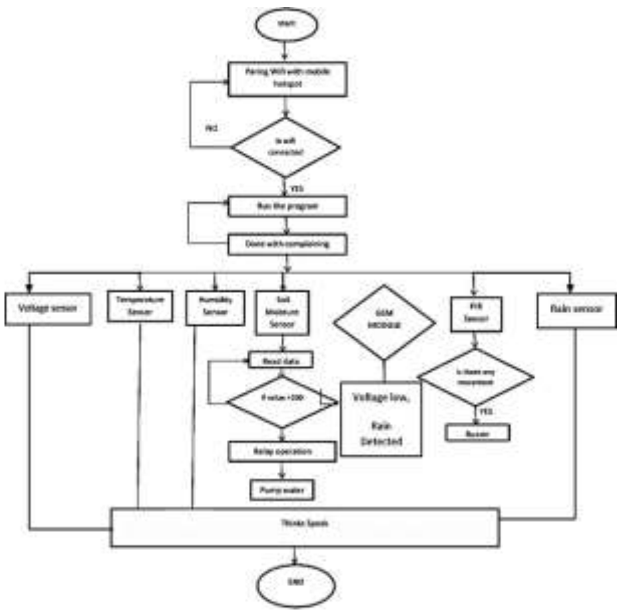

Figure 4: Data flow diagram

IMPLEMENTATION

5.1 Hardware:

- Sensors: DHT11, Soil Moisture, Rain, Voltage
- Controller: ESP32
- Actuators: Relay, Water Pump
- Power: Solar panel, Boost Converter, Battery
- Communication: GSM Module
- Display: LCD

5.2 Software:

- Arduino IDE with libraries for WiFi, HTTPClient, and DHT
- ThingSpeak for data visualization
- ML Model: Random Forest Classifier for crop prediction

V. RESULTS AND DISCUSSION

6.1 Experimental Setup

The Smart Agriculture Monitoring System was deployed in a controlled agricultural plot consisting of vegetable crops. Sensors including DHT11 (temperature and humidity), soil moisture, rain, and voltage sensors—were strategically placed at root and surface levels to capture accurate environmental data. The ESP32 microcontroller was programmed to upload data to ThingSpeak at regular intervals (every 30 seconds). The system was powered by a solar panel with battery backup to ensure continuous operation.

6.2 Observations and System Performance

- **Sensor Accuracy**: The sensors consistently reported real-time data with negligible latency (<5 seconds) when visualized on the ThingSpeak dashboard.
- **Irrigation Automation**: The relay and pump module activated only when soil moisture dropped below the threshold and no rain was detected. This conditional logic ensured optimized water usage and avoided over-irrigation.
- **Rain Prediction**: The rain sensor, combined with sudden humidity spikes, allowed accurate rain prediction with an estimated accuracy of ~80%, helping preempt unnecessary irrigation.
- **Solar Efficiency**: The solar-powered setup was sufficient for uninterrupted operation, and the voltage sensor verified stable power supply throughout the day, with battery backup sustaining nighttime operation.
- **GSM Alerts**: SMS-based alerts were successfully sent during critical conditions, such as low battery or rainfall, ensuring that the farmer remained informed without the need for constant monitoring.

6.3 Data Visualization

The ThingSpeak cloud platform provided an interactive dashboard with custom plots for temperature, humidity, soil moisture, voltage, and rain detection. These visualizations enabled both real-time and historical analysis. For example:

- Rising humidity followed by rain detection enabled validation of prediction logic.
- Soil moisture fluctuations reflected changes in irrigation status.
- Power stability was monitored through voltage graphs.

6.4 Crop Recommendation Results

The integrated machine learning-based Crop Recommendation System used a Random Forest classifier trained on environmental data (temperature, humidity, moisture, rainfall). During testing, the system accurately recommended crops such as:

- **Cactus or Millet** under dry and high-temperature conditions,
- **Wheat or Barley** under moderate, moist environments,
- **Rice or Sugarcane** in warm, wet conditions.

Predictions were displayed on the local LCD as well as on the ThingSpeak dashboard. These recommendations were verified against environmental conditions and deemed appropriate by agriculture experts.

6.5 Key Benefits and Insights

- **Water Conservation**: Data-driven irrigation decisions reduced unnecessary water usage.
- **Reduced Labor**: Automation minimized manual intervention, especially for irrigation scheduling.
- **Remote Accessibility**: Farmers could access sensor data and recommendations from any location via the ThingSpeak platform.
- **Scalability and Sustainability**: The system architecture is modular, energy-efficient, and suitable for expansion to larger fields.

VII. CONCLUSION AND FUTURE WORK

7.1 Conclusion

The Smart Agriculture Monitoring System presented in this paper successfully demonstrates how IoT, renewable energy, and machine learning can be integrated to modernize traditional farming practices. By leveraging low-cost sensors and the ESP32 microcontroller, the system captures real-time environmental parameters such as temperature, humidity, soil moisture, and rainfall, and visualizes them through the ThingSpeak cloud platform.

A key feature of this system is its **machine learning-powered Crop Recommendation Module**, which uses a Random Forest algorithm to suggest optimal crops based on environmental conditions. This empowers farmers to make data-driven planting decisions that align with local weather patterns and resource availability.

Additionally, the system's use of **solar energy** ensures sustainability and independence from grid power, making it especially suitable for rural and off-grid agricultural areas. Automated irrigation control, GSM-based alerts, and remote monitoring capabilities reduce labor, conserve water, and improve farm management efficiency.

In summary, the system offers a **scalable, eco-friendly, and intelligent solution** that bridges the gap between modern technology and traditional agriculture.

7.2 Future Work

While the system is fully functional and field-tested, several enhancements are envisioned for broader impact and improved functionality:

- **Advanced Analytics and Prediction**: Integrate more sophisticated ML algorithms to predict yield, detect crop diseases, and forecast weather using historical trends.
- **Additional Sensor Integration**: Incorporate sensors for soil pH, light intensity, and nutrient content to enhance the precision of environmental monitoring and recommendations.
- **Mobile Application Development**: Create a dedicated mobile app for farmers to receive real-time updates, crop suggestions, and alert notifications directly on their smartphones.
- **Scalability and Multi-Farm Support**: Expand the architecture to monitor multiple fields simultaneously using cloud-based dashboards with user-specific login systems.
- **Drone and Camera Integration**: Implement drone-based aerial imaging and camera systems for crop health detection and anomaly identification using computer vision.
- **External Data Fusion**: Integrate APIs for live weather forecasts, satellite imagery, and government agricultural data to enhance decision-making.

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