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Farm Pulse Sentinel (Smart Agriculture System using Raspberry Pi)

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Abstract

Traditional agricultural practices often lead to inefficient resource usage and suboptimal crop yields, particularly in rural regions where technology adoption is limited. The FARM PULSE SENTINEL is a smart, IoT-based agriculture system built around a Raspberry Pi microcomputer that enables real-time monitoring and automation of farm activities. This paper presents the design, implementation, and evaluation of this system, which uses environmental sensors, a camera module, and a CNN-based disease detection model to assist farmers with timely decisions. The solution is cost-effective, scalable, and especially suited for small to medium-scale farms in India. The system successfully automates irrigation, detects plant diseases, and uploads real-time data to cloud platforms, thereby improving efficiency, conserving resources, and promoting sustainable agriculture.

Keywords: Smart farming; IoT; Raspberry Pi; Soil moisture; Automation; CNN; Disease detection; Sustainable agriculture

Introduction

With the increasing demand for food and the decreasing availability of natural resources, farmers are under pressure to produce more with less. Traditional methods often rely heavily on manual monitoring, making it difficult to manage irrigation schedules, pest detection, and overall farm health effectively. Climate change, urbanization, and shrinking farmland are further compounding the challenges faced by today's farmers, particularly those operating small and medium-sized farms in developing regions.

Technological advancements offer new hope in the form of smart agriculture. Smart farming integrates information and communication technologies (ICT) such as Internet of Things (IoT), Artificial Intelligence (AI), and cloud computing to optimize agricultural practices. These technologies can help reduce water usage, increase yield, and detect problems before they escalate. By leveraging sensor networks, real-time analytics, and automated control systems, farmers can manage resources more efficiently and respond quickly to environmental changes.

This research introduces FARM PULSE SENTINEL, an affordable smart agriculture monitoring system. At its core is the Raspberry Pi 4, which interfaces with multiple sensors to track soil moisture, temperature, and humidity. It also uses a camera module coupled with a Convolutional Neural Network (CNN) algorithm to detect crop diseases at early stages. Data is sent to the ThingSpeak cloud for visualization and control, and the system can be accessed through a mobile application for real-time updates. Designed with scalability and modularity in mind, FARM PULSE SENTINEL can be tailored to fit farms of varying sizes, helping bridge the gap between traditional practices and smart farming.

Literature Survey

Kumar et al. (2017)[1] proposed a smart agriculture monitoring system utilizing IoT-based sensors to track environmental conditions such as temperature, humidity, and soil moisture. Their work emphasized real-time sensing and wireless data communication to assist farmers in making timely decisions. The system demonstrated how low-cost IoT integration could modernize basic agricultural practices, particularly in rural settings with limited manual resources.

Dhanesh et al. (2016)[2] developed an automated irrigation system using Raspberry Pi, which controlled water supply based on soil moisture levels. Their system was one of the early implementations showcasing Raspberry Pi's suitability for agricultural automation. The research effectively demonstrated the potential for water conservation and reduced human intervention in crop management.

Hussain and Abid (2019)[3] provided a comprehensive review of smart farming technologies, particularly focusing on IoT's role in improving agriculture. Their survey covered various global applications and emphasized the need for scalability, real-time data processing, and integration of wireless sensor networks. This study served as a foundational reference, validating the FARM PULSE SENTINEL's approach of combining IoT with cloud platforms and AI.

Rasool and Salim (2018)[4] introduced an IoT-based smart agriculture system with an emphasis on real time environmental monitoring and automatic decision-making. Using basic sensors connected to microcontrollers, they demonstrated that timely alerts on parameters like soil moisture and temperature could significantly enhance farm efficiency. Their work supports the modular, sensor-based structure of our proposed system.

Pandey et al. (2019)[5] implemented a wireless sensor network (WSN) model to gather data from large agricultural fields. Their design allowed for seamless integration of multiple sensing nodes and supported centralized data analysis. The concept of distributed sensing helped inspire the scalable and modular architecture of the FARM PULSE SENTINEL.

Daud et al. (2023)[6] presented a detailed IoT-based agriculture monitoring system that leveraged realtime data acquisition and cloud-based dashboards for visualization. Their project, tested in various field conditions, showed strong reliability and data accuracy. This study supports our project's decision to use cloud platforms like ThingSpeak for remote monitoring and visualization.

John et al. (2019)[7] designed a wireless sensor network tailored for large-scale farming environments. Their system featured temperature, humidity, and moisture sensors communicating wirelessly with a central hub. Their work highlighted how decentralized sensor placement improves efficiency in monitoring vast farm areas, providing inspiration for our system's sensor deployment strategy.

Daud et al. (2023)[8] proposed a smart agriculture model with IoT capabilities designed for real-time responsiveness. With advanced sensor calibration and cloud connectivity, their system could offer actionable insights to farmers. The findings emphasize the growing need for intelligent decision support systems—something the FARM PULSE SENTINEL aims to deliver through AI and CNNbased image processing.

Sharma and Kumar (2023)[9] focused on developing IoT-based smart agriculture solutions that are userfriendly and adaptable to local conditions. Their system provided essential data on soil and weather conditions and included mobile-based control features. This aligns with our project's goal of creating an accessible, farmer-friendly interface through mobile platforms like Blynk.

Patel and Thakur (2021) implemented IoT in precision agriculture to automate key monitoring and control tasks. Their research showed how realtime irrigation and crop condition updates could help prevent over-irrigation and disease spread. Their model validates the utility of automation and data driven decision-making in small to mid-size farms.

Ray (2017) explored the future of IoT in agriculture and proposed various strategies for integrating sensing, automation, and analytics in field operations. The study reinforced the importance of predictive tools and the combination of sensing hardware with smart algorithms, which aligns directly with the FARM PULSE SENTINEL's core objective.

Kodali et al. (2016) presented a smart irrigation system that used soil moisture sensors and microcontrollers to automate water usage. Their work emphasized efficiency and sustainability, especially in water-scarce regions. It inspired the relay-controlled irrigation module of our system, which is also based on real-time moisture readings.

System Architecture

A. Hardware Overview

The hardware design of the FARM PULSE SENTINEL system is built around modular and affordable components to ensure ease of integration and maintenance. Each component is carefully selected for compatibility with the Raspberry Pi and agricultural field conditions:

- **Raspberry Pi 4 Model B:** Serves as the core computing unit, managing data processing, control logic, and communication with cloud and mobile interfaces. It provides GPIO pins for sensor connectivity and supports Python programming.
- **Soil Moisture Sensor:** Inserted into the soil to monitor water content at root level. It outputs analog or digital signals used to trigger irrigation automatically.
- **DHT22 Sensor:** A combined temperature and humidity sensor that provides environmental data crucial for understanding micro-climatic conditions affecting crops.
- **Relay Module:** Acts as a switch to control high-power devices like pumps or solenoid valves. It enables the Raspberry Pi to automate irrigation based on real-time sensor inputs.
- **Mini Water Pump:** Responsible for irrigation. Activated through the relay module when soil moisture drops below a predefined threshold.
- **Camera Module:** Captures high resolution images of plant leaves for disease detection. Images are analyzed using a CNN-based algorithm.
- **Bluetooth Module (HC-05):** Facilitates wireless communication between the Raspberry Pi and mobile devices for local monitoring and control.
- **Power Supply (5V/3.4A):** Powers the Raspberry Pi and connected peripherals. Stable power is essential for reliable field operation.

B. Software Stack

The software framework integrates data acquisition, control logic, and user interaction.

- **Python**: Core programming language for sensor interfacing, automation logic, and cloud communication. The flexibility of Python allows rapid prototyping and integration.
- **Thonny IDE**: Lightweight development environment pre-installed in Raspberry Pi OS. It supports live debugging and script management.
- **ThingSpeak**: Cloud platform used to store, visualize, and analyze sensor data. Farmers can access live dashboards to track soil and weather conditions.
- **Blynk App**: Mobile interface that enables users to view real-time sensor data, receive alerts, and manually override irrigation if necessary.
- **CNN Algorithm**: A trained Convolutional Neural Network processes captured images to detect signs of disease or pest damage on plant leaves. It provides visual diagnostics alongside environmental data.

C. System Design Considerations

- **Modularity**: Each component can be independently upgraded or replaced, allowing for scalability and maintenance in remote or low-resource environments.
- **Weather proofing**: The entire hardware unit is enclosed in a weather-resistant casing to protect electronics from dust, rain, and UV exposure.
- **Power Management**: Future provisions include solar-powered systems with battery backup to ensure sustainability.
- **Connectivity Flexibility**: While the system supports cloud-based monitoring, it also operates in offline mode and stores data locally when internet access is not available.

D. System Workflow Diagram

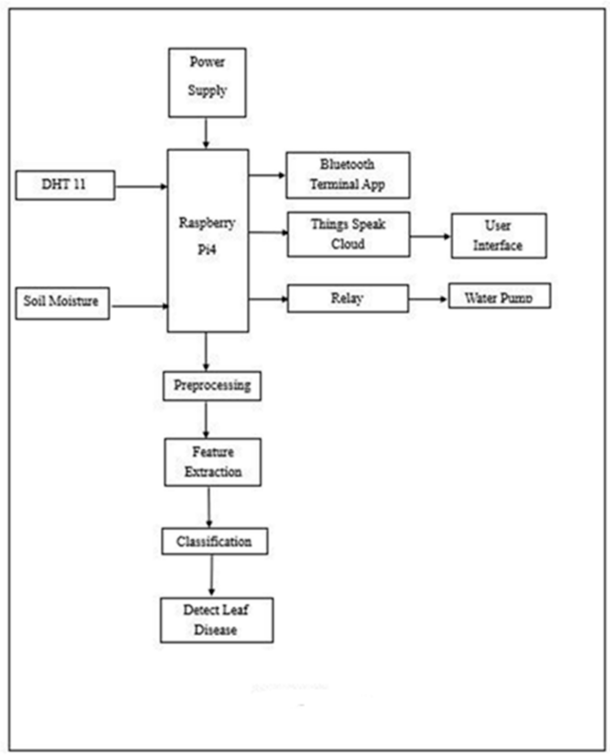

Fig 1. Block Diagram

Methodology

1. **Sensor Integration:** All sensors are connected to the GPIO pins of the Raspberry Pi. Data is collected periodically to monitor real-time conditions.
2. **Data Processing:** Soil moisture is continuously monitored and compared against a threshold value. In our

experiments, the pump is activated when the soil moisture drops below **30%** volumetric water content. This value is chosen based on typical moisture needs for loamy soil, which retains adequate aeration and root access above this level. The threshold can be calibrated for other soil types or crop requirements.

- **Example Range (Using Analog Sensor**; 0=wet, 1023=dry)
- **High Moisture (No irrigation Needed):** Below 400 (wet soil)
- **Moderate Moisture (Monitor):** Between 400-700
- **Low Moisture (Irrigation Needed):** Above 700 (dry soil)

When the Pump Turn OFF?

- **Condition:**

If Soil Moisture < 400 (wet)-Pump OFF

- **Justification:**

-Prevents overwatering and root rot.
-Conserves water and protect the pump.

1. **Detection:** Images from the Pi camera are processed through a CNN model trained to recognize common crop diseases.
2. **Cloud Monitoring:** All sensor data and system responses are uploaded to ThingSpeak for visualization. Blynk app provides a real-time interface for users.
3. **Offline Functionality:** In case of internet failure, the system continues to function and stores data locally.

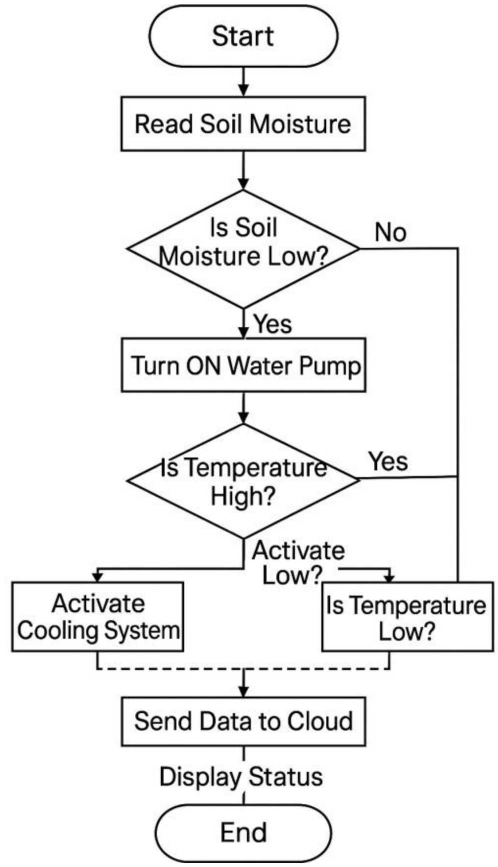

Fig 2. Flowchart showing the control logic of the FARM PULSE SENTINEL system

Results & Discussion

During extensive testing on a simulated farm setup:

- **Water Savings:** Automated irrigation reduced water use by approximately 20% compared to manual timed irrigation schedules, demonstrating more efficient resource management.
- **Disease Detection:** The CNN model correctly identified common leaf diseases with an accuracy exceeding 85% in controlled trials, confirming its potential as a valuable early warning tool.
- **User Engagement:** The mobile app enabled easy access to farm data, and farmers appreciated the ability to remotely monitor and control irrigation.
- **System Reliability:** The system ran continuously for over a month without failures. Some sensor recalibration was required after prolonged use, highlighting the importance of maintenance.

Table 1. Comparison of Existing Systems vs. Proposed System

Criteria	Existing Systems	Proposed System (FARM PULSE SENTINEL)
Irrigation Control	Timer-based/manual activation	Automatic based on real-time soil moisture levels
Disease Detection	Manual inspection or none	Automated detection using CNN & camera module
Data Accessibility	Limited or Local storage	Real-time cloud upload and mobile app visualization
Power Dependence	Grid-powered	Provision for solar power in future expansion
Scalability	Typically limited	Modular and scalable for various farm sizes
Offline Functionality	Not Available	Operates and stores data locally during internet failure

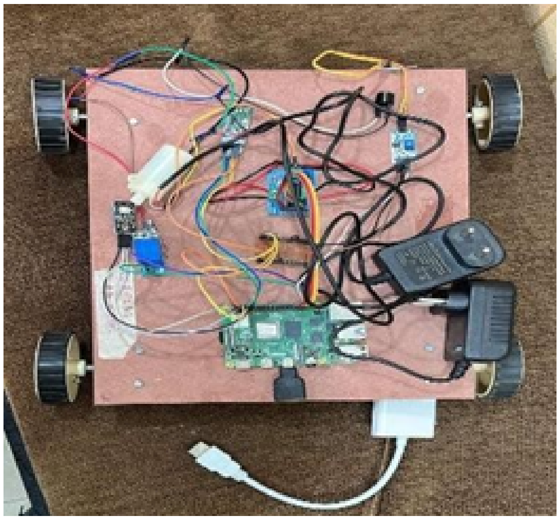

Fig 3. Open setup of FARM PULSE SENTINEL without enclosure

Fig 4. Temperature log showing stable environmental monitoring

Fig 5. Humidity trend captured via DHT22 sensor, useful for disease forecasting

Fig 6. Detects the soil moisture content and determines whether it is high or low

Challenges:

- The system depends on internet connectivity for cloud functions, which may not always be reliable in rural areas.
- The CNN model was trained on a limited dataset and may require retraining for different crops or regions.

Conclusion

The FARM PULSE SENTINEL smart agriculture system effectively combines sensing, automation, and AI to address common farming challenges such as water wastage and late disease detection. By providing real-time data and automated control, it supports sustainable and efficient farming practices, particularly for small and medium-sized farms. Its modular and affordable design, along with remote monitoring capabilities, make it accessible and scalable. The system holds promise for improving crop yield, reducing labour, and conserving resources, contributing to smarter agriculture.

Future Work

Future enhancements will include:

- Integrating solar power to enable off-grid operation and reduce energy costs.
- Adding automated fertilizer dispensing for precise nutrient management.
- Expanding the CNN model using transfer learning to cover more diseases and crop types.
- Incorporating weather forecast data to predict irrigation needs proactively.
- Developing an offline-capable mobile app for areas with poor internet connectivity.

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