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A SCALABLE REAL-TIME IOT AGRICULTURAL FARM SENSOR-BASED APPLICATION MONITORING SYSTEM

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The persistent attacks on farmers by herdsmen, bandits, and unknown gunmen worldwide have significantly disrupted agricultural production and endangered farmers. This paper presents a scalable real-time IoT agricultural farm sensor-based application monitoring system aimed at enhancing agricultural productivity and improving farmer surveillance. Agriculture remains a critical economic driver for many countries. Leveraging the Internet of Things (IoT), this system seeks to boost farm efficiency and yield while minimizing losses and waste. The proposed system comprehensively monitors agricultural farms using smart devices, including sensors, cameras, and internet-enabled technologies. The application was developed using object-oriented languages such as C-Sharp, Python, and Django, integrating data from soil moisture, temperature, and humidity sensors connected to an Arduino microcontroller. Additionally, Django facilitated the development of a crop monitoring system employing sensor data and machine learning algorithms to detect crop diseases and pests. The deployment of this system enhances farmers' confidence by providing real-time monitoring and control of agricultural farms from any location. The application delivers accurate and actionable information to users, particularly farmers, for effective farm management.

Keywords: IoT, Agricultural Monitoring, Sensors, Real-time, Smart Farming

Introduction

The imperative to enhance agricultural production has become critical in today's world. The global population and food consumption have surged, while environmental changes challenge sustainable food security (Kiran et al., 2023). The development of an agricultural nation increasingly relies on the integration of the Internet of Things (IoT) in agriculture (Durgesh et al., 2021; Othmane et al., 2021; Vu et al., 2022). Persistent agriculture-related issues hinder a country's progress, affecting both the quality and quantity of food and crop products. Inadequate agricultural practices also impair livestock health, compromising the quality of meat and dairy products available for consumption (Mathushika et al., 2022; Shashi et al., 2022; Panelprem et al., 2023). Modernizing traditional agricultural practices is essential to address these challenges (Afroj et al., 2022).

The escalating insecurity in various regions, driven by threats such as unknown gunmen, ISWAP, and Boko Haram, has significantly disrupted farming activities (Odikwa et al., 2024). Farmers, increasingly vulnerable to these threats, face risks that curtail food production, particularly in Nigeria. Consequently, ensuring a sustainable food supply is vital to support the rapidly growing global population and bolster national economies.

Adopting cutting-edge technologies, specifically the Internet of Things (IoT), is crucial for enhancing productivity, efficiency, and mitigating the challenges farmers face. IoT enables farmers to access the latest technological advancements and modern farming techniques (Douglas et al., 2023; Matthew et al., 2021).

This research aims to implement an IoT-based farming system to automate farm activities, including security monitoring to deter invaders, weeds and crop monitoring, irrigation scheduling, and the management of temperature and humidity using sensors.

Materials and Methods

This section outlines the methods used to achieve the research objectives. It includes the research methodology, data gathering techniques, the sample population, and the general architecture of the automated system.

Research Methodology

The research methodology combines qualitative and quantitative approaches. Qualitative methods include observations, document reviews, and in-depth interviews, though less common methods for gathering qualitative data exist. Quantitative methods involve numerically generated and computed data. These approaches ensure a comprehensive understanding of user (farmer) needs and system functionality.

Data Gathering Techniques

Primary Data Collection Methods: Primary data were collected directly from farmers regarding their farming activities and challenges, particularly related to insecurity. Two methods were employed:

(1) **Questionnaire:** A questionnaire was designed and distributed to 100 farmers. The questions addressed farming challenges, and responses were analyzed to inform this research.
(2) **Interviews:** In-depth interviews were conducted with farmers, who shared insights on current farming operations and daily insecurities. Farmers consistently noted that insecurity hampers agricultural production and highlighted the lack of modern techniques for monitoring farmlands as a significant barrier to food production.

Population of the Study

The study involved 100 farmers, both peasant and mechanized, from the South-East and South-South geopolitical zones of Nigeria. These farmers were interviewed, and their responses on recent farming experiences in Nigeria were recorded.

Architecture of IoT Farm Application Monitoring System

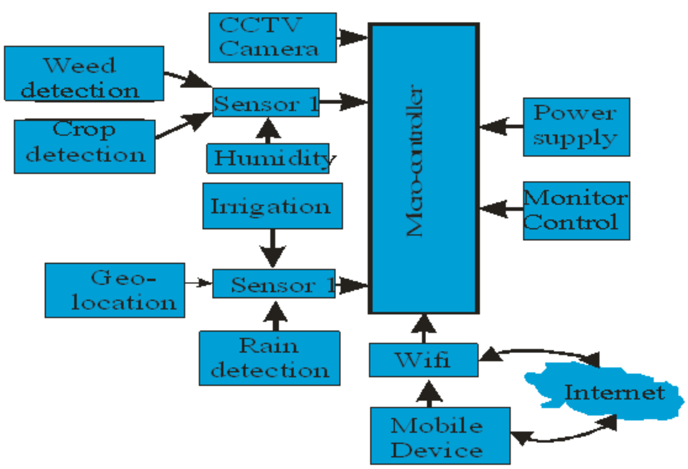

Figure 1 Architecture of IoT Farm Application Monitoring System

The system architecture comprises the following modules:

- **Rain Detection:** This module, linked to meteorological weather forecasts, predicts rainfall.
- **Temperature:** The temperature detection module measures the degree of coldness or hotness of the farmland.
- **Location Module:** Equipped with CCTV cameras, this module identifies the farmland's location and monitors for intruders.
- **Soil Moisture:** This module measures the water content on the farmland's surface.
- **Micro-controller:** An Arduino-based embedded system integrates all IoT equipment, enabling automation, sensor operations, and other appliances for farmland monitoring.
- **Weed/Crop Detection Module:** Enabled by CCTV cameras, this module monitors weed and crop growth levels on the farmland.
- **Monitor Control Module:** This central module oversees all monitoring activities, providing users with comprehensive information on farmland operations.
- **Power Supply:** This module supplies electricity to the system, with a standard capacity of 12 volts. =enditemize sectionResults and Discussion

This section presents the results of experiments conducted with the IoT sensor-based agricultural application monitoring system. The system, designed as illustrated in Figure 1, was deployed on an agricultural farmland.

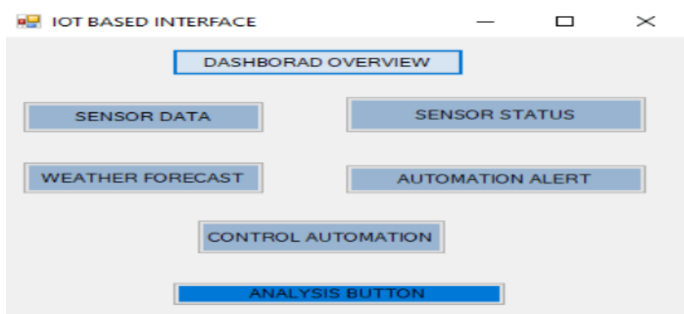

Figure 2 IoT-based Agricultural Farm Monitoring Interface

Figure 2 illustrates the farmer's user interface for monitoring agricultural farmland. It includes modules to interact with sensor statuses and data, providing real-time analysis of farmland conditions. The interface integrates weather forecasts to inform farmers of weather conditions. Additionally, control automation embedded in the interface manages processes such as irrigation, weeding, and soil humidity. The interface in Figure 2 generates sub-interfaces shown in Figures 3, 4, 5, and 6.

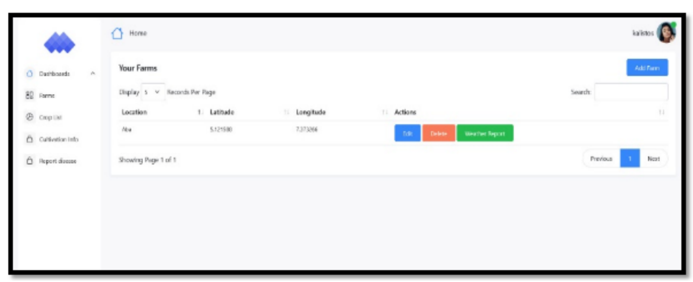

Figure 3 Output Query Result of the System Showing the Farm Page

Figure 3, a sub-interface of Figure 2, displays the output query result of the monitoring system. It shows the farm's location, latitude, longitude, and recommended actions. The system, integrated with CCTV cameras, reports the number of crops planted and alerts farmers to plant diseases, such as cassava mosaic disease or stunted growth, prompting insecticide application.

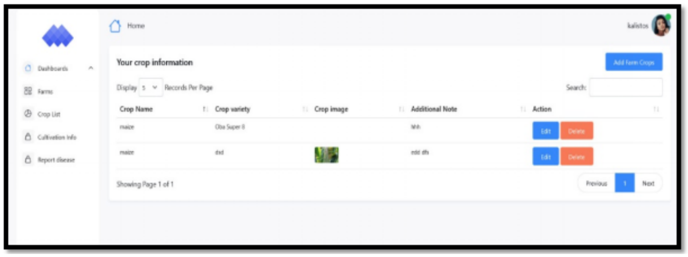

Figure 4 Output Query Result of the System Showing Crop Information

Figure 4 presents crop information and images as part of the farm monitoring system. It displays the variety of crops and weed growth images on the farmland.

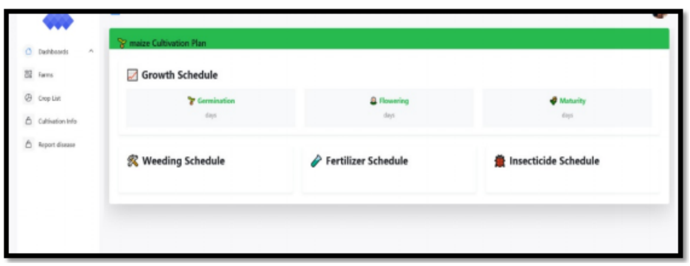

Figure 5 Output Query Result of the System Showing Growth Schedule

Figure 5 depicts the system's report for monitoring crop growth from planting. Farmers use this dashboard to track crop development, determine fertilizer application timing, and monitor weed growth via IoT sensors. The system indicates optimal weeding times, improving on previous systems that only monitored temperature, humidity, and soil moisture for irrigation. The schedule page includes germination days, flowering days, maturity days, weeding, fertilizer, and insecticide schedules.

Figure 6, a sub-interface accessed via the analysis button in Figure 2, enables farmers to monitor crops during cultivation, track product sales, and assess revenue. This robust IoT platform monitors all farm activities, including crop and weed growth, and informs farmers when to apply fertilizers or insecticides. The system reduces the need for frequent farm visits, mitigating insecurity risks. The analytics dashboard displays the number of crops cultivated, farm locations monitored, and cultivation records.

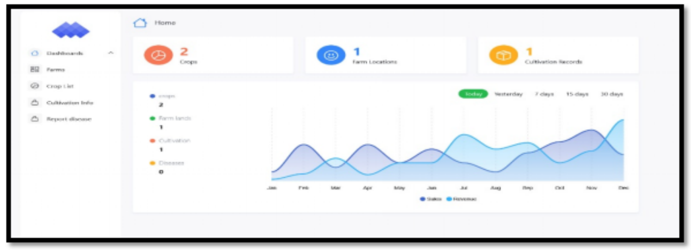

Figure 6 Output Query Result of the System Showing Farmer Analytics Dashboard

Table 1 Test Case 1: Temperature Sensor Reading

Test Case	Expected Result	Actual Result	Pass/Fail
Temperature Sensor Reading	25°C	25°C	Pass

Table 2 Test Case 2: Humidity Sensor Reading

Test Case	Expected Result	Actual Result	Pass/Fail
Humidity Sensor Reading	60%	58%	Fail

Table 3 Test Case 3: Soil Moisture Sensor Reading

Test Case	Expected Result	Actual Result	Pass/Fail
Soil Moisture Sensor Reading	30%	33%	Pass

Table 4 Test Case 4: Alert and Notification

Test Case	Expected Result	Actual Result	Pass/Fail
Alert and notification for temperature threshold breach	Send alert and notification to the user	Alert and notification sent to the user	Pass

Table 5 Test Summary

Test Case	Pass/Fail
Temperature Sensor Reading	Pass
Humidity Sensor Reading	Fail
Soil Moisture Sensor Reading	Pass
Alert and Notification	Pass

Table 6 Defect Report

Defect ID	Test Case	Description	Severity
DEF-001	Humidity Sensor Reading	Humidity sensor reading is 2% lower than expected	Medium

Tables 1 and 2 present the temperature and humidity sensor readings from the pilot farm. The temperature reading met the expected 25°C, suitable for farming, passing the test. However, the humidity reading of 58% fell below the expected 60%, failing the test. Table 3 shows a soil moisture reading of 33% against an expected 30%, within the favorable range of 29%–45% for crop planting, passing the test. Table 4 confirms that alerts for temperature threshold breaches were successfully sent, passing the test. Table 5 summarizes the test results, with only the humidity sensor failing. Table 6 details the humidity sensor defect, noting a 2% lower reading with medium severity.

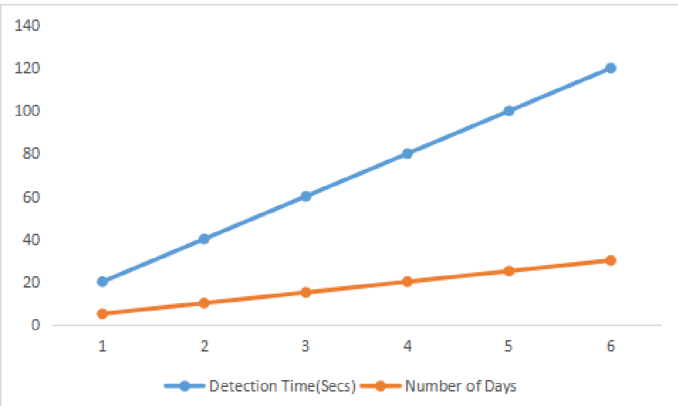

Figure 7 Accuracy of Weed Detection by the IoT-based Farm Monitoring System

Figure 7 compares weed detection time (in seconds) over the test period on the pilot farm. The system detected weeds within 20 seconds in one application, demonstrating high accuracy of the IoT monitoring system.

Conclusion

The application of the Internet of Things (IoT) in Nigerian agriculture offers significant benefits. Compared to existing agricultural practices in the country, the designed IoT-based system is more practical, technically advanced, and efficient in monitoring farmlands. This scalable, real-time monitoring system enhances the cultivation of high-quality and high-quantity farm produce. The application saves time, reduces the need for manual labor, provides accurate real-time information to farmers from any location without requiring their physical presence, and, most importantly, mitigates security risks faced by farmers.

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