IoT-based Weather Monitoring System for Ghanaian Farmers

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ABSTRACT
The changing climate patterns have significantly impacted farmers' ability to effectively plan their agricultural activities, particularly in timing the application of fertilizers, weedicides, pesticides, and other inputs. Unforeseen heavy rainfall shortly after applying fertilizers can lead to the loss of these inputs, preventing the crops from reaping their intended benefits, especially when using water-soluble granulated formulas. This study introduces the design and development of a personalized IoT-based weather monitoring system to empower farmers to accurately monitor atmospheric pressure, relative humidity, and temperature, enabling them to predict the weather for their specific location. The system includes temperature and humidity sensors to measure the atmospheric conditions in a specific farm location, a photo sensor to measure sunlight intensity, and a Wi-Fi module to transmit the data to a cloud data repository for analysis. A prototype IoT-based Weather Monitoring System was created and tested in real-world conditions. The proposed system proved capable of electronically alerting farmers on their mobile devices with real-time weather updates, thereby informing their farm planning and management practices like fertilizer and pesticide applications.

General Terms
Application of IoT, Smart Farming, Information Technology

Keywords
Internet of Things, Weather Monitoring System, Farming Activities, Decision Support System for Farming

1. INTRODUCTION
Most people in Ghana are engaged in agriculture and heavily rely on the weather patterns and annual rainy seasons to irrigate their farms [1]. The weather patterns have become increasingly unpredictable due to the impacts of global warming resulting from bad human environmental activities, rapid urbanization, and industrialization [2],[3],[4]. Due to climate change, farmers are facing challenges in the effective planning of their farming activities, including the timing of applying fertilizers, weedicides, pesticides, and other agricultural inputs. Unpredictable excessive rainfalls following the application of fertilizers can result in the washing away of these inputs, preventing the crops from receiving their intended benefits, particularly when using water-soluble granulated formulas. Heavy rainfalls can wash solid fertilizers away or dilute them too much thus causing nutrient leaching in the soil [5],[6]. The loss of expensive fertilizers due to leaching would affect the overall production cost of the farmers since they may have to reapply at another time incurring extra costs.

In addressing these challenges, personalized IoT-based weather monitoring systems could be considered a vital solution to support farmers' decision-making concerning weather forecasts and the planning of farming activities. This system is designed to update the farmer with accurate weather forecasts twice a day to help farmers make informed decisions on which activities to carry out without wasting resources. The application of this technology addresses farming business processes and activities planning related to the weather and aligns with the main objective of the implementation of an inexpensive, sustainable, and efficient IoT-based weather monitoring system for farmers. The proposed system would use multiple sensors which would be integrated and carefully installed on a farm to monitor atmospheric pressure, relative humidity and temperature that would help predict the accurate weather for a specific location. This proposed system enables real-time data transmission into a cloud storage system to facilitate remote administration and assessment of weather data by cell phones.

In a study conducted by Holovatyy (2021) [7], on the development of an IoT weather monitoring system based on Arduino and ESP8266 Wi-Fi Module, the researcher successfully developed and tested a prototype weather monitoring system and stressed the importance of developing such systems to monitor localized weather.
Mondol *et al.* [8] in a study on the application of IoT in a poultry farm argued that real-time weather monitoring in a poultry farm is one of the most important challenges of poultry farms. This involves monitoring the status of the temperature and humidity on the farm which directly impacts the health condition of the birds and food management. The proposed system could send alert messages to a user’s smartphone and signals to a buzzer that enables the farmer to monitor the poultry farm remotely.

A similar study by [9] developed an IoT-based system for monitoring and notification of weather conditions in greenhouses. The proposed system developed and tested in the study effectively monitored the temperature, humidity, light, and air pressure at predefined regular intervals. Then, the collected data was uploaded to an IBM Watson Cloud platform. The IoT-based weather monitoring system developed was able to effectively inform the greenhouse managers via e-mail whenever there are major changes in the parameters of the weather.
An IoT-based weather monitoring system, linked to a data analytics subsystem and developed with weather monitoring sensors controlled by Raspberry Pi, was proposed and developed by [10]. The system proved to be efficient for providing data that was used in analyzing weather parameters in any geographical location. It was concluded that an IoT-Based Weather Monitoring System with Raspberry Pi as the controller is the most compact unit for measuring weather parameters [10].

The need to use a cost-effective IoT platform and open-source technologies to develop and deploy a weather monitoring system was argued and justified by [11]. In an explorative study by [11], NodeMCU ESP 8266, Raspberry Pi Zero W, and suitable sensors to measure temperature, humidity, atmospheric pressure, and dust particles were used to develop a demonstrational real-time weather monitoring system. The researchers concluded that it is feasible to develop and deploy a scalable weather station from scratch using open-source technologies to cut the cost of development.

According to [12], IoT and Arduino-based Weather Monitoring Systems are considered innovative technologies that have transformed the way weather data is gathered, examined, and utilized to advance our understanding of weather patterns and support the decision-making of various industries such as agriculture, disaster management, military and civil aviation. It was further argued by [12] that there is a need to factor cost implications in the development and deployment of IoT-based weather monitoring systems which are consistent with the works of [11],[13],[14] on low-cost weather monitoring systems.

Even though various studies have justified and demonstrated with working prototype systems the need to adopt innovative IoT applications into farm environments, only a few studies have considered specific tailored IoT-based weather monitoring systems to support farmers in the rural areas of Ghana. Therefore, this study is designed to focus on the design, development and deployment of a low-cost, IoT-based weather monitoring system for farmers in Ghana. The proposed system can update the farmer with accurate weather forecasts twice a day to help farmers make informed decisions on which activities to carry out without wasting resources. The application of this technology addresses farming business processes and activities planning related to the weather.

2. MATERIALS AND METHODS USED

The development of the proposed IoT-based weather monitoring system involved the integration of several sensors and components to provide accurate and real-time weather data. This section gives a detailed account of how each component was utilized:

2.1 ESP32 Dev Kit

The ESP32 Dev Kit shown in Figure 1 was chosen as the main microcontroller for its powerful processing capabilities and built-in Wi-Fi. It served as the central hub for the system, managing data collection, processing, and transmission. The controller was programmed to interface with all connected sensors. It collected data from sensors, processed it, and transmitted it to the cloud via Wi-Fi. It was also used to ensure real-time data updates to the Blynk platform and SMS notifications through Twilio.

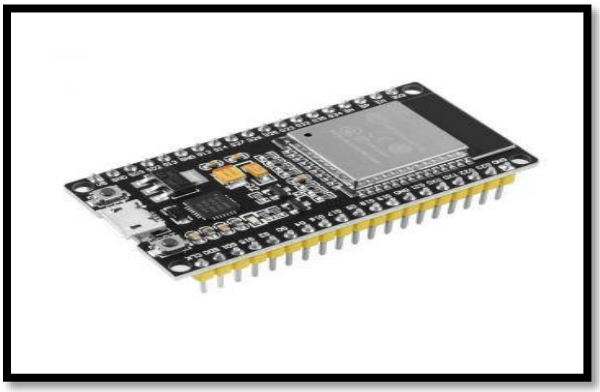

Figure 1: ESP32 Dev Kit

2.2 Raindrop Sensor

This sensor was crucial for measuring rainfall. It was mounted in an open area to collect raindrops and provide data on the intensity and occurrence of rain. The raindrop sensor detected and measured the amount of rainfall, and the data was subsequently sent to the ESP32 for transmission to the cloud for real-time monitoring. This system proved helpful in determining the optimal times for fertilizer application by indicating upcoming or current rainfall, ultimately preventing the loss of fertilizers due to runoff. The raindrop sensor is shown in Figure 2.

Figure 2: Raindrop Sensor

2.3 DHT11 Sensor

The DHT11 sensor shown in Figure 3 provided vital information about temperature and humidity. It was installed in a sheltered yet open spot to accurately measure ambient conditions without direct exposure to sunlight. The sensor measured the temperature and humidity levels, and the data was continuously sent to the ESP32 for processing. This system enabled farmers to understand microclimatic conditions, aiding in decisions related to fertilizer application.

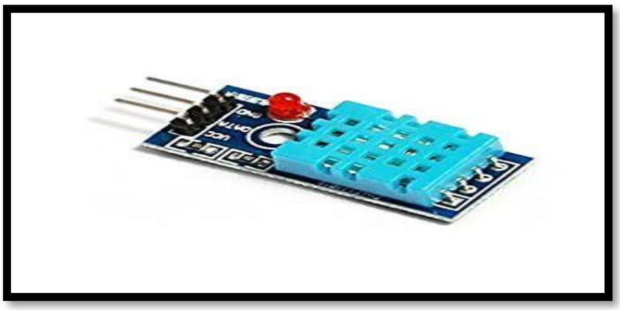

Figure 3: DHT11 Sensor

2.4 Photoresistor (Photo Sensor)

A photoresistor shown in Figure 4 was used to measure sunlight intensity, crucial for understanding daylight exposure on the farm. The photoresistor was installed in a position with unobstructed access to sunlight, and it measured light intensity, sending the data to the ESP32 to help farmers determine the best times to apply fertilizer.

Figure 4: Photoresistor (Photo Sensor)

2.5 BMP180 Sensor

The BMP180 sensor was employed to measure atmospheric pressure, providing data crucial for weather forecasting. The BMP180 sensor was installed and integrated into the system to capture precise atmospheric pressure readings. The collected data was then relayed to the ESP32 and seamlessly transmitted to the cloud for analysis. The information acquired from the sensor significantly improved the precision of weather forecasts by providing atmospheric pressure trend data. The BMP180 sensor used for the proposed system is shown in Figure 5.

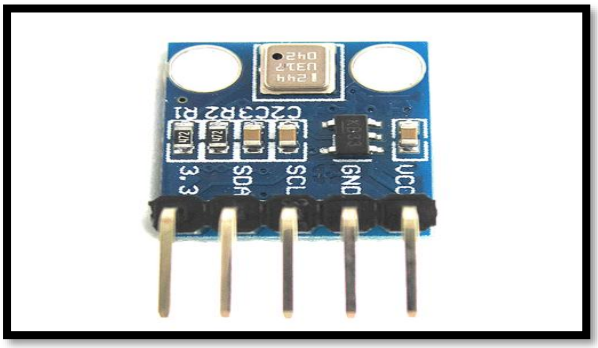

Figure 5: BMP180 Sensor

2.6 LCD Display (20x4)

The LCD component shown in Figure 6 provided a straightforward way for farmers to view real-time weather data directly on-site. The LCD was integrated into the system to show real-time readings from the raindrop sensor, DHT11, photoresistor, and BMP180, allowing farmers to quickly assess weather conditions without the need for a smartphone or computer.

Figure 6: LCD Display

2.7 Solar Panel

A solar panel was used to power the entire setup to ensure the system was sustainable and could operate in remote areas. The Solar Panel was successfully installed and integrated into the system to provide renewable energy to power the ESP32 and connected sensors. This ensured continuous operation, especially as the farm did not have access to electricity. The solar panel used for the proposed system is shown in Figure 7.

Figure 7: Solar Panel

2.8 Blynk IoT Cloud Platform

Blynk was chosen for its easy-to-use interface and ability to visualize data in real-time. It hosted weather data collected by the ESP32 and offered a customizable dashboard for farmers to monitor current weather conditions using their smartphones. It also allowed for remote monitoring and access to data from any location with internet connectivity.

2.9 Twilio API real-time

Twilio's API was integrated into the system to send SMS updates, ensuring that farmers received timely weather information. It was set up to send daily weather updates via SMS to registered phone numbers on the system, enabling farmers without internet access to still receive vital weather data. This improvement led to better decision-making by offering reliable and timely weather alerts.

2.10 Open Weather API

The Open Weather API was used to complement local sensor data, particularly for wind speed information, which was not directly captured by our hardware sensors. The Open Weather API was seamlessly integrated into the proposed system to retrieve wind speed data from the Open Weather platform, merging it with local sensor data to offer comprehensive weather updates. The wind speed information was incorporated into the data transmitted to the Blynk platform and used for SMS updates.

3. SYSTEM DESIGN, ANALYSIS AND IMPLEMENTATION

3.1 System Design and Analysis

The proposed IoT-based weather monitoring system's logical design with the sensors deployment, data processing unit, Wi-Fi module, and LCD are illustrated with a Block diagram in Figure 8.

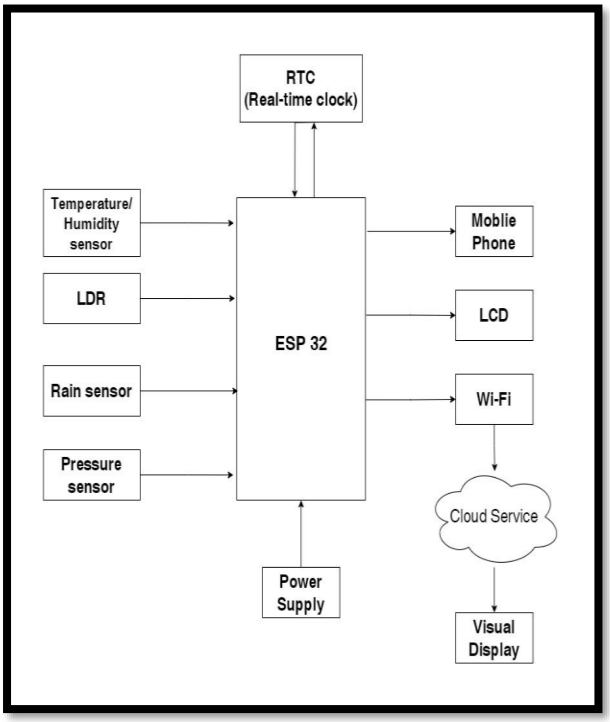

Figure 8: Block diagram of the proposed IoT-based Weather Monitoring System

A sequence diagram of the IoT-based weather monitoring system, which shows the objects, procedures, and interactions that must occur for the system to function is shown in Figure 9.

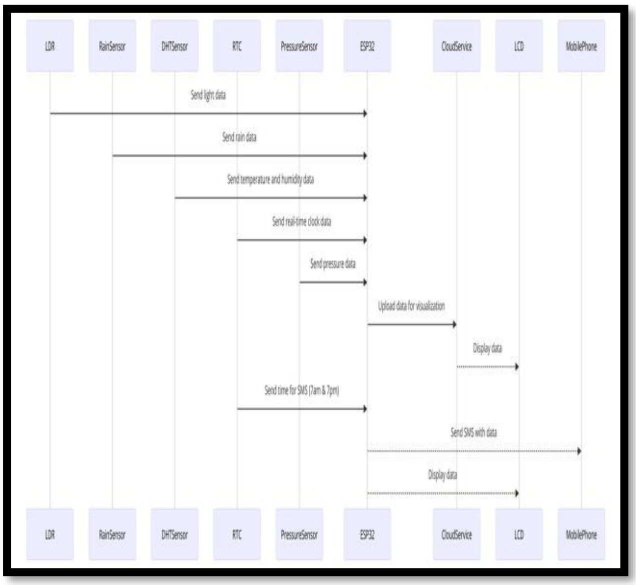

Figure 9: Sequence diagram of the proposed IoT-based Weather Monitoring System

The flowchart of the IoT-based Weather Monitoring System is depicted in Figure 10.

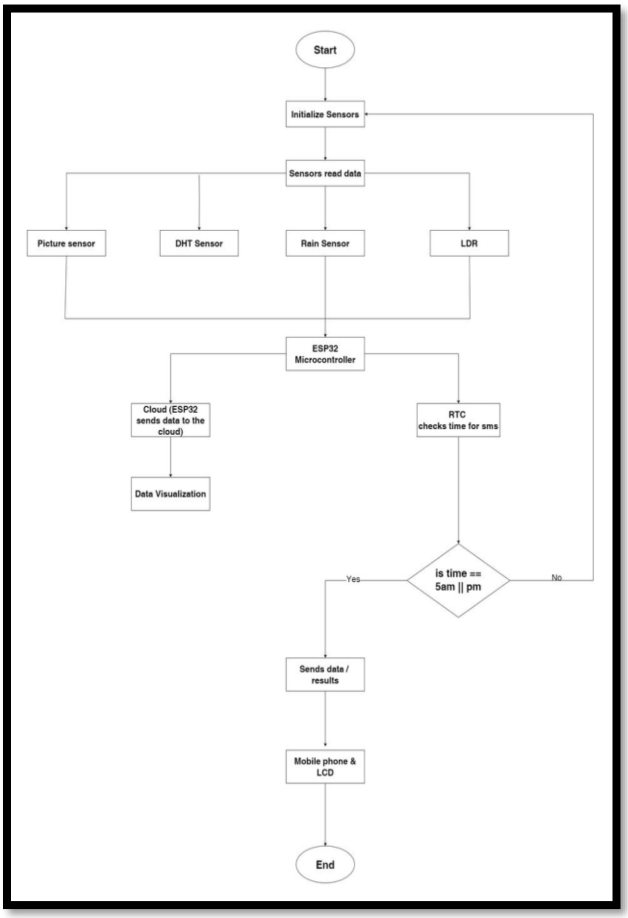

Figure 10: Flowchart of the proposed IoT-based Weather Monitoring System

Figure 11 depicts the layout and logic of the proposed IoT-based weather monitoring system's circuit architecture. The proposed circuit diagram structure was carefully customized to meet the specific weather data requirements of the farms that were selected for the research.

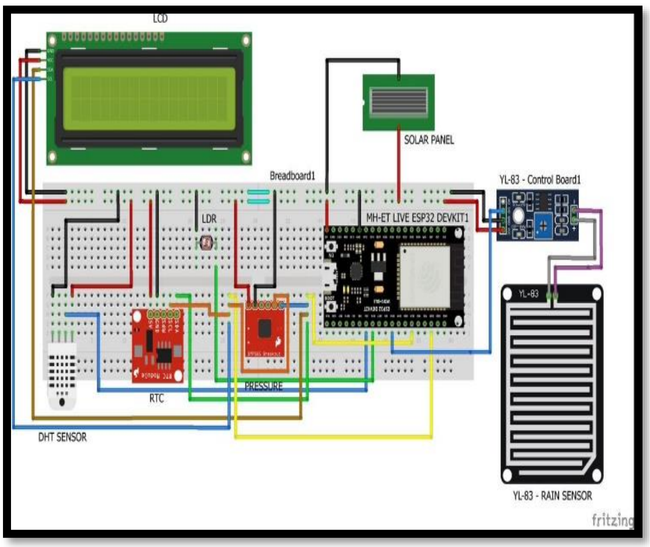

Figure 11: Circuit Diagram of the IoT-based Weather Monitoring System

3.2 System Implementation

The proposed system was designed, developed and well-packaged in a waterproof container to protect the components from the weather. The packaged system was tested for 5 weeks on an open field near a selected farm as shown in Figure 12. All the weather sensors and auxiliary components were put together in one unit. The system was powered by small-sized solar panels to capture sunlight and convert it into energy. This ensured continuous operation, especially as the farm did not have access to the main electricity lines. The web-based interface was accessible remotely through either a smartphone or a standard computer to allow real-time monitoring of weather data. The LCD integrated into the system can also display instant real-time data on the field.

Figure 12: IoT-Based Weather Monitoring System

4. RESULTS AND DISCUSSIONS

The IoT-based Weather Monitoring System was designed and developed to offer farmers real-time weather information and precise guidance on optimal timing for fertilizer applications through SMS notifications. The system effectively utilized sensor data to provide actionable weather updates. On a demonstration farm, the installed system was able to send out SMS notifications twice daily, delivering specific weather conditions and fertilizer application recommendations to farmers. These notifications were generated based on real-time sensor data, as depicted in Figure 13, collected from various sensors and processed by the ESP32 Dev Kit.

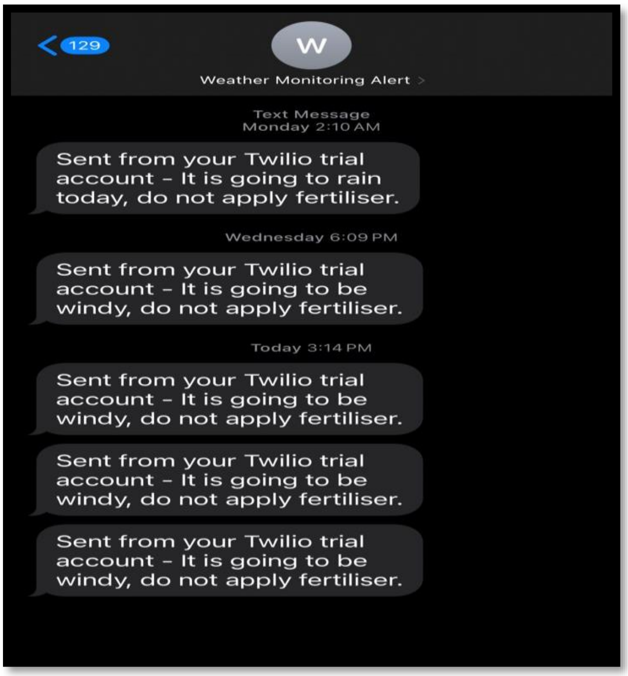

Figure 13: SMS Notifications

With the aid of the Blynk IoT cloud platform, the system continuously recorded and updated weather parameters every two seconds. This real-time monitoring allowed farmers to have constant access to the latest weather data via a customized dashboard on their smartphones or computers. The key parameters monitored were rainfall intensity, atmospheric pressure, temperature, humidity, and wind speed. The raindrop sensor detected rainfall and measured its intensity. The data from the raindrop sensor was used to predict wet periods which informed the farmers to avoid fertilizer application during heavy rains. The interface of the Blynk IoT cloud platform is shown in Figure 14 with the specific readings from the various sensors.

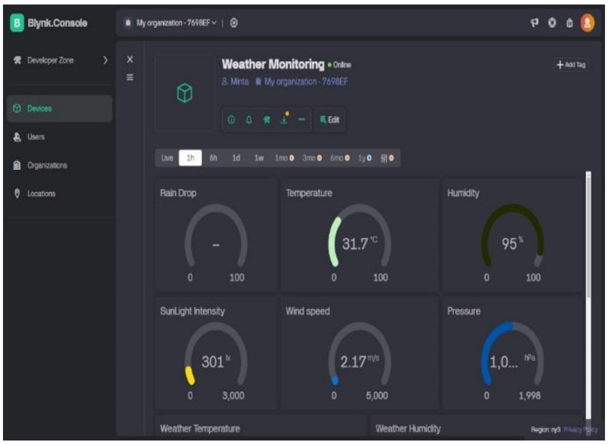

Figure 14: Dashboard of the Blynk APP

The photoresistor was able to measure sunlight intensity and the data assisted in determining the best times for fertilizer application based on optimal sunlight exposure. The installed BMP180 sensor recorded changes in atmospheric pressure, providing valuable data for predicting upcoming weather conditions. Simultaneously, the DHT11 sensor continuously monitored the temperature and humidity, offering insights into atmospheric moisture levels and ambient conditions to ensure optimal fertilizer application. Additionally, wind speed data from the Open Weather API integrated with the local sensor readings successfully provided comprehensive wind speed for predicting weather updates which informed the farmers on the times to avoid application of fertilizers during high wind periods. All the data received from the various sensors can also be conveniently visualized using the mobile app seamlessly integrated into the proposed system, as illustrated in Figure 15.

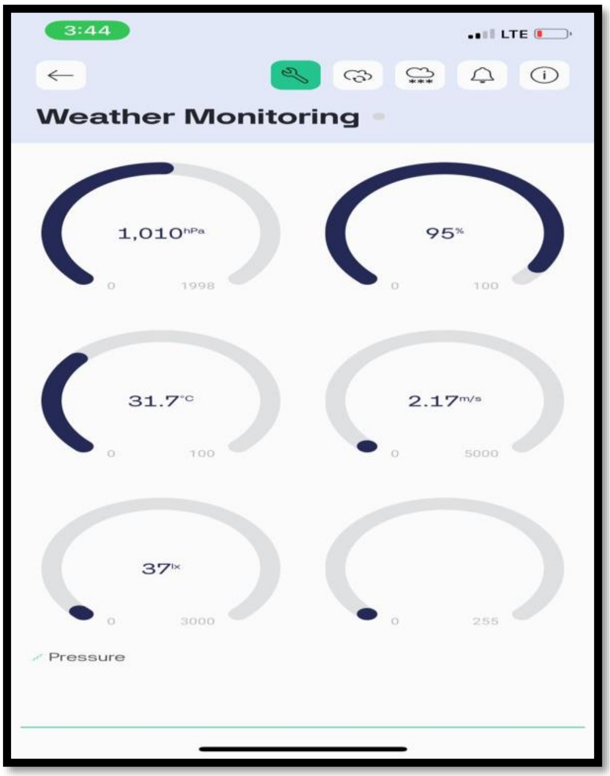

Figure 15: Dashboard of the Mobile App

Analysis of the data collected over 5 weeks demonstrated the system's effectiveness in providing actionable weather information. The major specific findings were a reduction in fertilizer wastage, improved crop yields, favorable user feedback, accurate temperature and humidity trends, and understandable data visualizations. These findings were consistent with those of [10] and [11] who were able to develop and test a cost-effective IoT-based weather monitoring system. The implementation of the proposed IoT-based weather monitoring system for agriculture in Ghana aimed to address the challenges posed by unpredictable weather patterns due to climate change was a success. The system was designed to provide farmers with real-time weather data and actionable insights, particularly focusing on the optimal timing for fertilizer application. The results obtained from the deployment and testing of the system demonstrate its effectiveness and highlight several critical points of discussion.

The system's ability to provide accurate and reliable weather data was crucial for its success. By integrating multiple sensors (raindrop sensor, DHT11, photoresistor, BMP180) and leveraging cloud-based platforms (Blynk and Open Weather API), the system ensured real-time monitoring and updates. The data collected was accurate enough to make informed decisions, as evidenced by the significant reduction in fertilizer waste reported by farmers. The twice-daily SMS notifications further reinforced the system's reliability by delivering precise weather information and actionable advice.

One of the primary objectives of the system was to optimize fertilizer application by preventing losses due to weather conditions. The system effectively informed farmers about when to apply or avoid applying fertilizers. This targeted approach helped farmers avoid unnecessary expenses and improve the efficiency of fertilizer use, leading to better crop yields and reduced negative environmental impact.

The user feedback indicated that farmers found the system easy to use and highly beneficial. The integration of SMS notifications was particularly effective in reaching farmers who might not have constant access to internet services. The clear, concise messages provided actionable guidance without requiring extensive technical knowledge. Additionally, the real-time data access through the Blynk platform allowed more tech-savvy users to monitor weather conditions and make timely decisions remotely.

The use of a solar panel to power the system ensured sustainability, especially in remote areas in Ghana with limited access to electricity. This feature made the system viable for widespread deployment across various farming regions in Ghana. Based on the ESP32 Dev Kit, the modular design allows for easy scaling and customization according to specific needs and available resources. Future iterations of the system could include additional sensors or functionalities, such as soil moisture sensors or automated irrigation controls, to further enhance its utility.

The successful implementation of the proposed IoT-based weather monitoring system in Ghana has broader implications for agricultural practices in other regions facing similar climate challenges. The system serves as a model for leveraging technology to enhance agricultural productivity and sustainability. Providing farmers with the tools to make data-driven decisions, can help mitigate the adverse effects of climate change on agriculture, improve food security, and promote sustainable farming practices globally.

5. CONCLUSION

The IoT-based Weather Monitoring System developed and tested in this research provided significant benefits to the farms that were used for the demonstration of the system in Ghana. By delivering accurate, real-time weather data and specific guidance on fertilizer application, the system helped optimize resource use, reduce waste, and improve crop yields. The positive feedback from farmers underscores the system's practicality and effectiveness. Future enhancements and broader implementation of such systems hold the potential to further transform agricultural practices and enhance resilience to climate change.

While the system demonstrated substantial benefits, there were a few areas in the system that could be improved. The calibration of sensors has to be done regularly to maintain accuracy over time. An automated calibration method could be explored to reduce maintenance efforts. Another critical area that could be improved is the incorporation of extended weather forecasts to provide farmers with more advanced warnings and planning capabilities. And lastly, the expansion of the system to include data on other critical agricultural practices, such as pest control and crop rotation could be done to provide a more comprehensive decision-support tool.

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