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Smart Monitoring System for Vegetable Greenhouse

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ABSTRACT

Food security has become a growing global concern, with population growth, urbanization, and climate change presenting significant challenges to sustainable agriculture. Small-scale farmers in Nigeria face numerous challenges that hinder their ability to produce crops sustainably, including limited access to water, unpredictable weather patterns, and high energy costs. To address these challenges, there is a need for innovative solutions that leverage technology to optimize crop growth and reduce waste. Greenhouse technology offers the potential to increase crop yields and make agriculture more efficient, provided that environmental conditions are effectively regulated. Global agriculture is changing as a result of the convergence of many developing technologies being fueled by the Fourth Industrial Revolution. There are significant prospects to improve greenhouse farming by using the Internet of Things (IoT). The system is designed to keep track of and regulate greenhouse-related variables, such as temperature, humidity, and soil moisture. A cloud-based platform receives the sensor data and processes it for analysis. The system consists of an Arduino IDE-programmable Node-Micro controller with DHT11 and soil moisture sensors attached to it. Remote monitoring is made possible by the real-time transmission of sensor data through the ThingSpeak platform and ThingView application. The effectiveness of the system was tested in the Taraba greenhouse, where it regulated conditions that exceeded certain levels and notified farmers via Twitter. The validation of the system's effectiveness was achieved by comparing actual data with observed data, with the mean absolute percentage error (MAPE) being less than 10%. The system has the potential to enhance agriculture by increasing crop quality and efficiency, leading to higher profits, and contributing to the global Sustainable Development Goals, such as ending world hunger. This implementation can be further stretched for other applications to optimize agricultural production while addressing the challenges of the 21st century.

General Terms

Smart Agriculture, Food security, Cloud-based platform, Fourth Industrial Revolution, Sustainable Development Goals (SDGs)

Keywords

Internet of Things (IoT), Greenhouse technology, ThingSpeak platform

1. INTRODUCTION

Food security is a global concern due to population growth, urbanization, and climate change. Sustainable food production is crucial for ensuring food security [1]. The Fourth Industrial Revolution, driven by technologies like IoT, AI, and big data analytics, is transforming the agricultural sector. IoT has the potential to improve agricultural practices and increase productivity. The agriculture sector contributes significantly to the global economy, and smart agriculture offers potential for increased production [2].

Traditional agricultural practices are insufficient to meet the growing demand for food, necessitating the adoption of new technologies. Greenhouse farming can be time-consuming and labor-intensive, but IoT-based systems can effectively manage workflow and improve productivity [3].

The use of greenhouse technology in Nigeria to counter the negative effects of climate change on food production is increasing. However, challenges such as manual monitoring and a shortage of qualified personnel hinder the effectiveness of greenhouses [4]. Additionally, continuous monitoring and management of environmental parameters require extensive data collection and analysis.

1.1 Statement of the Problem

The adoption of smart farming in greenhouses also faces obstacles related to cost, design limitations, and a lack of understanding. The use of IoT in agriculture, particularly in remote areas, presents additional challenges such as hardware failures, limited internet access, high costs, and concerns about security and privacy [5]. The research aims to address these limitations by developing a cost-effective and adaptable framework for real-time monitoring in greenhouses.

Several studies have developed systems for monitoring and controlling greenhouse environments, but their effectiveness requires further evaluation. The literature shows significant interest in greenhouse environment management, but challenges exist at the hardware and network layers [6]. IoT-based greenhouse monitoring systems have the potential to improve efficiency and productivity in agriculture.

Adoption of IoT in agriculture faces obstacles such as cost, literacy, privacy, and security concerns. Widespread implementation requires trust-building measures and privacy legislation [7]. IoT has been successful in large-scale commercial farms but needs more real-world applications in smallholder agriculture. Security is a significant challenge, and current efforts are in the prototype phase with limited knowledge about addressing security concerns [8]; [9].

However, further research and development are needed for IoT-based systems in the greenhouse. Challenges in implementing greenhouse technology include manual monitoring, lack of qualified employees, and managing environmental parameters. A smart monitoring system using environmental sensors can overcome these challenges.

2. LITERATURE REVIEW

The concept of IoT, its components, and its application in various industries are elaborated in this section. It centers on the challenges posed by climate change, food security, urbanization, and their impact on agriculture. The Fourth Industrial Revolution, also referred to as Industry 4.0 or 4IR, is introduced as a term coined by Klaus Schwab in 2016, which encompasses emerging technology domains such as artificial intelligence and machine learning, cybersecurity, augmented reality, big data analytics, autonomous robots, drones, device-to-device and mobile communications, three-dimensional (3D) printing, cloud computing, and the IoT.

The rise in sea levels due to climate change is anticipated to reduce agricultural land globally, which is already affected by floods and droughts. The search for agricultural labor is compounded by urbanization and aging populations [4]. The Paris Agreement aims to limit global temperature rise; however, effectively addressing rising temperatures may prove challenging. Pollution and transportation issues affect food supply and costs. The food supply chain has been disrupted by the Ukrainian-Russian conflict and the COVID-19 pandemic [10]. Automatic greenhouse microclimate (GMMC) systems that employ sensors and wireless networks can assist farmers in dealing with climate change and urbanization challenges [11]. To ensure optimal plant development in greenhouses, various factors such as temperature, humidity, water supply, light, and ventilation must be monitored. The Internet of Things (IoT) has been successfully used in agriculture for monitoring, control, and precision farming.

The present section provides an empirical review of research on the development of Internet of Things (IoT)-based systems for monitoring interior climate variables in greenhouses.

In their studies, [12]. focused on enhancing food production technology to meet the increasing food demand. The researchers emphasized the integration of sensors and actuators in greenhouses to monitor and manage environmental conditions.

The greenhouse control system developed by [13]. employs algorithms to evaluate current conditions and establish thresholds based on plant requirements. Farmers are notified via IoT if parameters exceed or fall below limit values, and they make control decisions that are sent to the system. The system then controls the parameters and triggers the appropriate actuators.

[14]. proposed a technique for dynamically monitoring the greenhouse environment with Wi-Fi, which allows remote monitoring of humidity, temperature, and light intensity with a sensor and server software. A cloud-based solution that can be utilized as a virtual sensor in real-time or as a research simulator was proposed.

Moreover, [15]. proposed a fuzzy logic controller (FLC) for regulating greenhouse climate, and a greenhouse control system was developed with algorithms to adjust temperature, humidity, light, and soil moisture within threshold ranges. Sensors collect data, and a microprocessor controls actuators in the system. Data is stored for analysis and allows remote monitoring. Nevertheless, the number of rules required to enhance reliability can grow exponentially, and a comprehensive understanding of the system's operating states is necessary. Fuzzy logic controllers are often precise and cost-effective, making them suitable for greenhouse applications [16].

[17] developed a "soft sensor" for greenhouse tomato crops by simulating biological and physical processes with dynamic models and incorporating external weather forecasts to evaluate plant growth. [18]. demonstrated that web applications can be used to adaptively design greenhouse management and monitoring parameters.

[6]. proposed an automated greenhouse farming system that employs machine learning and artificial intelligence to detect early-stage diseases and make decisions in real-time. The technology also employs neural networks to monitor the health and maturity of plants. The application of IoT technology, information communication technology, and wireless sensor networks enables agriculture to handle technological, economic, and environmental concerns.

The application of a variety of sensor devices and systems in greenhouse monitoring is identified as a challenging task, and the selection of sensor devices capable of withstanding greenhouse humidity is critical. Wi-Fi and mobile technology are frequently utilized in greenhouses and agriculture to monitor land and water resources, but connecting a large number of devices and the lack of technical knowledge among farmers are impediments to implementing IoT systems. The current centralized architecture for supporting IoT systems is also underdeveloped, limiting network and system expansion.

3. METHODOLOGY

This section introduces the approach that has been implemented in the development of a smart greenhouse system. The process of creating the system is delineated, encompassing the definition of requirements, the design of the hardware and software, and the execution of testing. The aim of this system is to establish a smart greenhouse that is both efficient and productive. The hardware design phase entails the selection of an appropriate transducer, taking into consideration factors such as accuracy and performance. The central component of the system is determined to be the Node MCU microcontroller.

The proposed architecture for the monitoring system is partitioned into three layers: perception, networking, and application. The perception layer collects environmental data from the greenhouse through the utilization of temperature, humidity, and soil moisture sensors. This data is then transmitted to the data processing layer for further analysis. The data acquisition layer plays a crucial role in furnishing the requisite raw data for comprehending and optimizing greenhouse conditions.

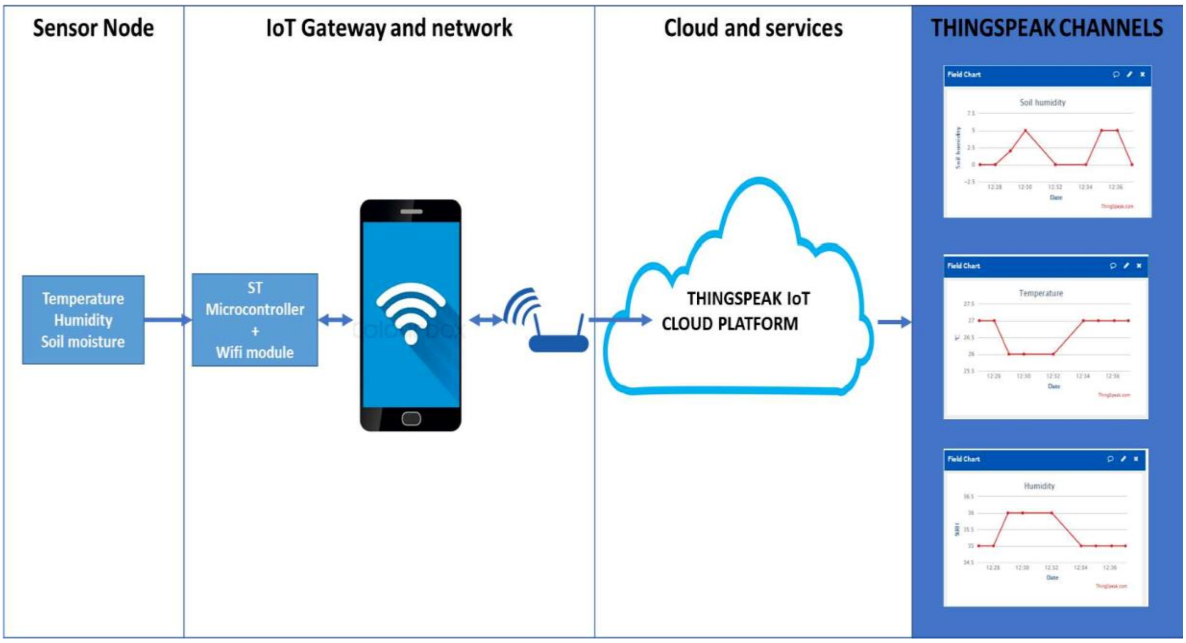

Figure 1: System Architecture

The system combines data garnered from temperature, humidity, and soil moisture sensors through the process of sensor fusion. In cases where there exist deviations from the normal environmental parameters, notifications are dispatched to the farmer by means of a Node MCU microcontroller. The data is subsequently stored in the cloud to ensure optimal storage conditions. The system design encompasses Internet of Things (IoT) devices, Wi-Fi communication, and cloud servers. Users are endowed with the capability to access and oversee the greenhouse conditions via a web interface. This particular section also places significant emphasis on the importance of selecting the appropriate technology and elucidates on the process of selecting the controller and sensors. The decision to opt for the NodeMCU microcontroller was predicated on its seamless integration with Wi-Fi and its cost-effectiveness. The development of the software was executed using the Arduino Integrated Development Environment (IDE) and the C/C++ programming language. The cloud platform selected for monitoring environmental data was ThingSpeak, owing to its efficient application programming interface (API) caching and its security features. This section further elaborates on the security measures that have been implemented, including the utilization of Advanced Encryption Standard (AES) encryption and API key protection.

Furthermore, statistical parameters are utilized to assess the performance and efficiency of the system. MATLAB was employed for statistical analyses with the purpose of studying the relationship between variables. A multitude of metrics were computed, including Mean Absolute Percentage Error (MAPE) to ascertain the discrepancy between actual and measured data, the Pearson correlation coefficient (R) to evaluate the correlation, R-squared (R2) to indicate the strength of said correlation, Root Mean Square Error (RMSE) to compare measured values, and the Index of Agreement (IOA) to describe the error ratio.

4. RESULTS AND DISCUSSION

The Taraba greenhouse functioned as a site for experimentation for the system, an innovative project situated in the North East region of Nigeria. This pioneering initiative stands as the most prominent greenhouse enterprise in the country, paving the way for groundbreaking advancements across the entire area. Within the confines of this exceptional greenhouse, a wide variety of crops, including tomatoes, peppers, lettuce, and cucumbers, thrive and prosper. It is worth highlighting that this impressive facility boasts an annual yield of 250 tons of vegetables.

The inclusion of the Node microcontroller is an essential component vital to the success of this endeavor. This exceptional technological marvel equips farmers with the ability to directly collect highly accurate data from their farms. This invaluable information encompasses crucial measurements such as temperature, humidity, and soil moisture, seamlessly transmitted to the ThingSpeak IoT analytics platform. The user-friendly ThingView app further simplifies the process of exporting and analyzing this data, whether in Excel format or accessible on mobile devices.

Figure 2 presents a visual representation of the data acquired from the greenhouse's sensor systems on the cloud platform. This captivating illustration serves as evidence of the greenhouse's unwavering ability to maintain an ideal environment for plant growth. Real-time sensor readings can be easily accessed through the utilization of an API key on www.thingspeak.com. The meticulous recording of sensor data plays a crucial role in ensuring the effectiveness and integrity of the prototype system. Acting as the receiver, the web server collects the accurately calibrated data provided by the sensors, with the DHT11 sensor seamlessly transmitting this invaluable information to www.thingspeak.com via the WiFi module. This data can be conveniently accessed through smartphones or computers and effortlessly downloaded in either CSV or Excel format. This remarkable technological advancement represents a significant leap forward in the design of greenhouse systems, guaranteeing the utmost accuracy of environmental data in this era of rapid progress in sensor technology.

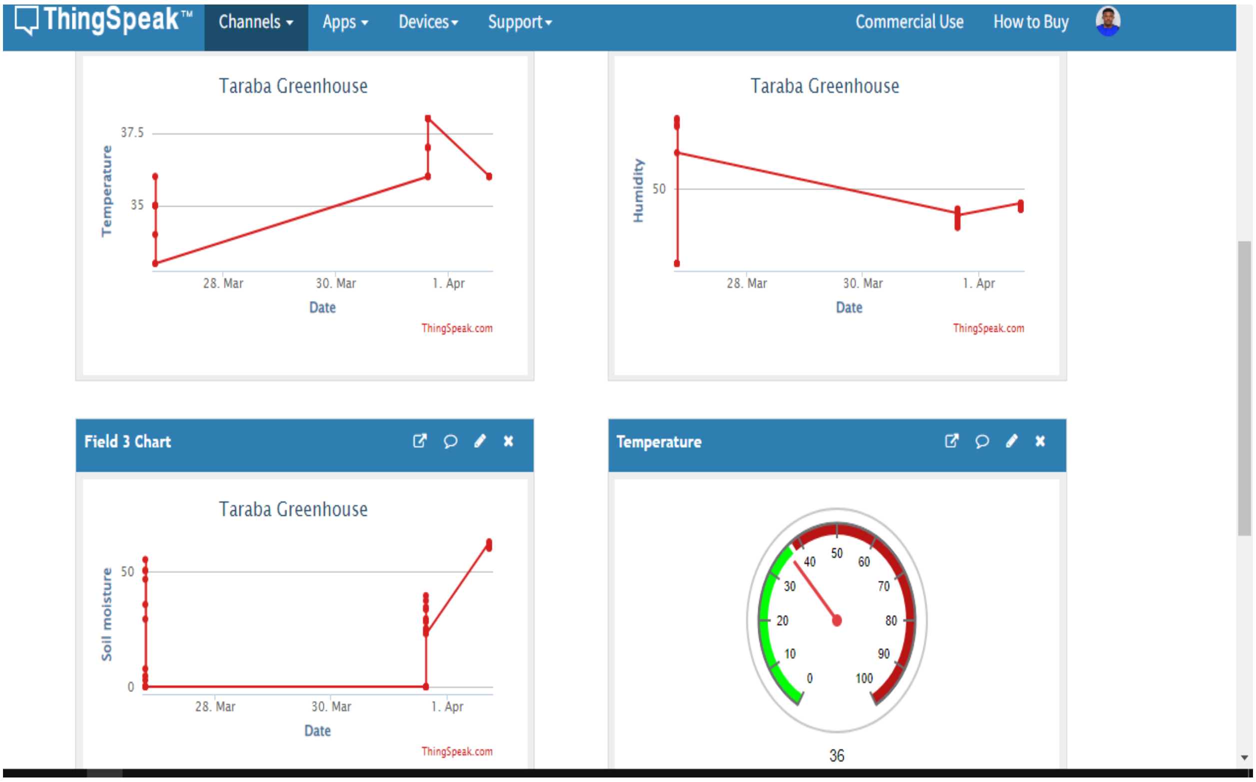

Figure 2: **Visual representation of the data on ThingSpeak**

4.1 Results of Calibrated sensor Testing

The precision of the sensor directly affects both the performance of the system's transmission and the stability of its applications. To ensure the validation of the air temperature, humidity, and soil moisture readings in the greenhouse, the testing process was conducted. Throughout the evaluation, the gathering of temperature, humidity, and soil moisture values was carried out on fifteen distinct occasions. The resulting data can be observed in Figures 3, 4, and 5. The examination of the temperature unveiled an average deviation of 0.26°C from the actual values, with the maximum absolute percentage error reaching 2.58% and the minimum error recorded at 0.42%.

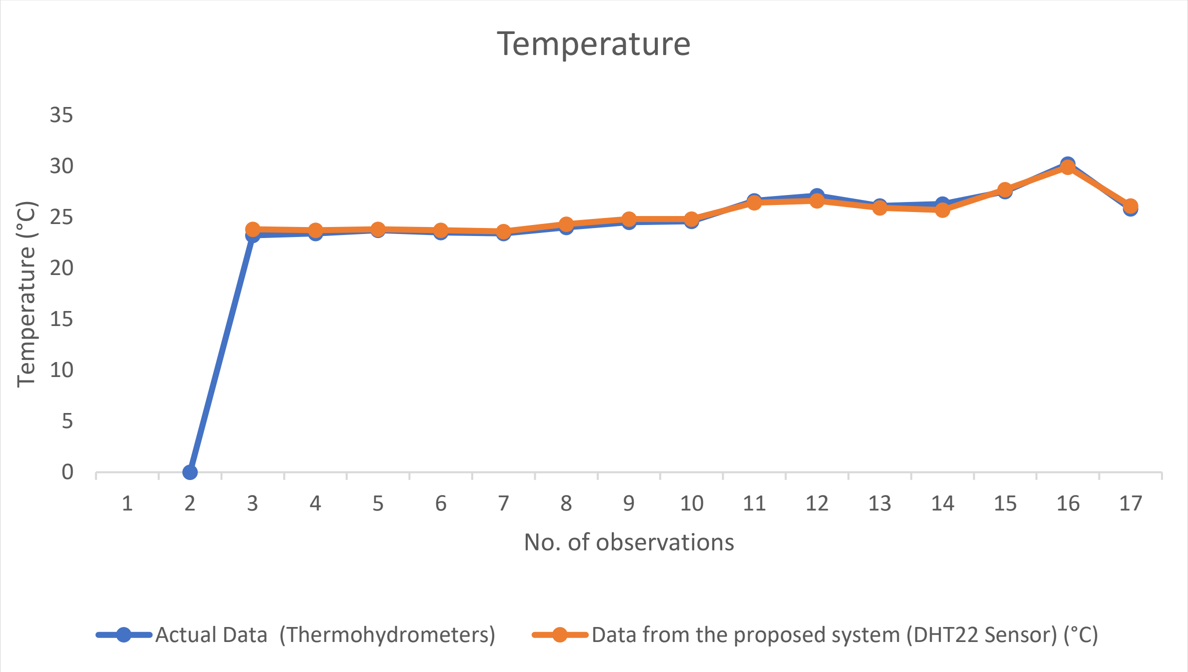

Figure 3: The Deviation of Actual Data and Observed Data for Temperature

The humidity evaluation revealed an average absolute error of 2.2%, with a maximum error of 8.0% and a minimal error of 1.12% as shown in Figure 4

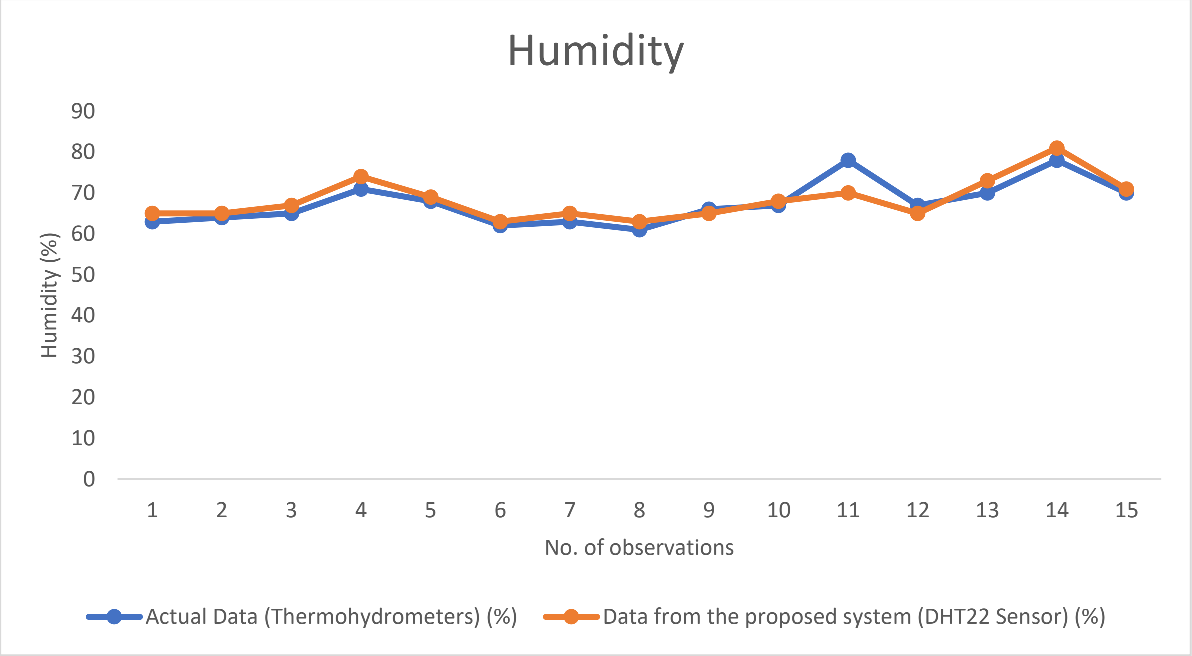

Figure 4: The deviation of actual data and observed data for humidity

An average absolute error of 1.33% was found in the soil moisture assessment, with a minimum error of 0.5% and a minimum percentage error of 0.7 percent as shown in Figure 5

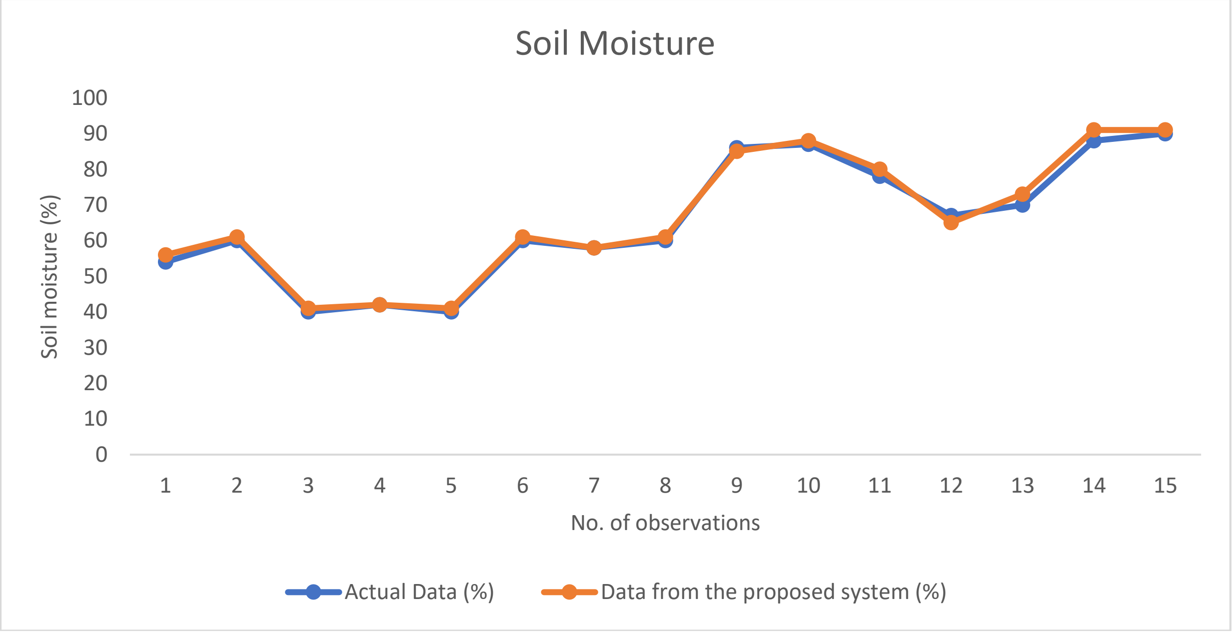

Figure 5: The Deviation of Actual Data and Observed Data for Soil Moisture

The assessment of the accuracy of calibration was carried out employing a range of statistical indicators, such as Pearson correlation, determination coefficient, root mean square error, and agreement index. Significantly, the calibration effectively achieved the intended level of precision within the specified parameters. The accuracy of temperature and humidity measurements obtained from the esteemed DHT11 sensor, in conjunction with the performance of the soil moisture sensor under various conditions, was comprehensively verified and found to be remarkably accurate.

Table 1. Measured values of temperature, humidity, and soil moisture sensors are compared with reference values

Parameters	**Statistical Metrics**			
	R	**R2**	**RMSE**	**IOA**
Temperature	0.989	0.979	2.323	0.621
Humidity	0.849	0.722	0.516	0.388
Soil moisture	0.993	0.986	0.316	0.930

The reliability of the data system is ensured through a deliberate design approach that minimizes errors and guarantees uninterrupted data flow. Randomized experiments assess the system's reliability by measuring accuracy and time delay. The smart monitoring system incorporates a proactive notification system using tweets to inform users promptly as shown in Figure 6. The system continuously monitors the greenhouse environment, allowing users to make informed decisions. A graphical representationaids users in interpreting real-time information. The reliability of the data system is a result of a well-thought-out design that includes rigorous testing, proactive notifications, and continuous monitoring

Taraba Greenhouse System ...
Attention!!! Temperature is greater than 38° C please turn on fans

Taraba Greenhouse System ...
thingspeak.com/channels/16349...

Figure 6: Tweet Notification

5. SUMMARY

This research explores the benefits of implementing an intelligent monitoring system, with a specific focus on the potential increase in agricultural production rates, higher crop yields, and the reduction of data-related burdens. The continuous connection of the system to the ThingSpeak platform enables the storage of data in the cloud, allowing for the utilization of advanced data mining techniques to reveal intricate patterns and relationships among variables. This analytical capability empowers users to develop predictive models to support informed decision-making. Furthermore, the adaptable hardware and software components of the system facilitate seamless customization and integration of sensors. Ultimately, the widespread adoption of this system has the potential to significantly enhance farmers' financial prospects by improving crop yields.

5.1 Suggestions for Further Work

This section underscores the need for further research into the use of artificial intelligence (AI) in modeling diseases in greenhouse farming. It emphasizes the necessity of developing data analytics algorithms that can efficiently process large volumes of greenhouse farm data, taking into account the complexity and scale of the information. Moreover, the section suggests prioritizing the improvement of greenhouse systems' Internet of Things (IoT) security measures, such as intrusion detection systems, and the use of Field-Programmable Gate Array (FPGA) and System-on-a-Chip (SoC) architectures, and Python programming for better monitoring and management. Lastly, the research emphasizes the importance of energy efficiency in the deployment of IoT-enabled sensors and devices in greenhouses, calling for research on ways to reduce energy consumption while still ensuring effective data collection and transmission over long distances.

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