Implementation of an IoT-Based Field Monitoring for Smart Agriculture System

Muhammad Daffa Ramadhan[1], Kurniawan D. Irianto[2]
[1,2]Department of Informatics, Universitas Islam Indonesia, Yogyakarta, Indonesia
Email: [1]22523024@students.uii.ac.id, [2]k.d.irianto@uii.ac.id

Abstract

Agricultural land monitoring is essential for supporting effective farming activities, particularly in rice cultivation where environmental conditions directly affect crop productivity. In practice, field conditions are still commonly monitored manually, which requires frequent field visits and may lead to delayed responses to environmental changes. This study presents an IoT-based agricultural field monitoring system designed to provide real-time and practical environmental information. The system integrates an ESP32 microcontroller with soil moisture, temperature-humidity, and light intensity sensors, and transmits data wirelessly to a cloud-based Firebase Realtime Database for remote access through a mobile application. The system was developed and evaluated through iterative implementation and functional testing under real field conditions. In addition to real-time monitoring, a simple forecasting feature based on historical data was incorporated to support early decision-making. Experimental results show that the system operates reliably and is positively accepted by farmers, indicating its potential to support practical and scalable agricultural land monitoring.

Keywords:
Internet of Things, Smart Farming, ESP32, Field Monitoring, Precision Agriculture, Firebase

1. Introduction

Agriculture remains one of the most important sectors in supporting food security, especially in regions where rice is the main staple crop [1]. Rice farming is highly influenced by environmental conditions, including soil moisture, air temperature, humidity, and light intensity. These parameters affect irrigation needs, plant growth, and overall crop productivity [2]. In practice, farmers usually monitor these conditions by directly visiting their fields and relying on experience passed down over time. While this approach has been used for decades, it often lacks accuracy and does not provide continuous information about changing field conditions.

One common challenge faced by farmers is the difficulty of monitoring agricultural land consistently throughout the day [3]. Field conditions can change quickly due to weather, water availability, or sunlight exposure. To ensure that crops remain in good condition, farmers may need to visit their fields multiple times, which can be time-consuming and physically demanding. This situation becomes even more difficult when fields are located far from residential areas or when farmers manage more than one plot of land. As a result, important changes such as excessive soil moisture or increasing temperature may not be detected early.

The development of Internet of Things (IoT) technology provides a practical alternative to conventional monitoring methods. IoT allows physical devices equipped with sensors, microcontrollers, and communication modules to collect data automatically and transmit it through the internet. In agricultural applications, IoT-based monitoring systems enable real-time observation of field conditions without requiring farmers to be physically present in the field. Data collected from sensors can be stored in cloud platforms and accessed through mobile or web applications, making monitoring more flexible and efficient [4].

Several previous studies have implemented IoT-based systems for agricultural land monitoring. Most of these studies focus on real-time data acquisition and visualization, demonstrating that environmental parameters can be measured and transmitted successfully [5]. However, many existing implementations emphasize technical deployment rather than practical use in daily farming activities. Predictive features based on historical data are often not included, and user evaluation is sometimes limited to laboratory testing or short demonstrations, without involving farmers directly in real field environments.

In real agricultural practice, the success of an IoT system is not determined only by its technical performance, but also by how useful and practical it is for farmers. Information provided by the system must be relevant to daily decision-making, such as determining irrigation needs or understanding soil conditions. Without considering farmer acceptance and field practicality, even technically functional systems may not be adopted in the long term. Therefore, evaluating IoT systems directly with farmers in real agricultural settings is an important aspect that should not be overlooked.

Based on these considerations, this study implements an IoT-based field monitoring system designed for agricultural land, particularly rice fields. The proposed system uses an ESP32 microcontroller integrated with soil moisture, temperature-humidity, and light intensity sensors to collect environmental data [6]. Sensor data are transmitted to a cloud-based Firebase Realtime Database and accessed through a mobile application in real time [7]. In addition to real-time monitoring, a simple forecasting feature based on historical data is included to provide early predictive information. The system is evaluated through functional testing and user evaluation involving farmers, with the aim of assessing both technical performance and practical acceptance in real field conditions. The system was developed using a prototype-based approach, allowing iterative design, implementation, and refinement based on testing results and real field conditions.

2. Related Works

Various studies have explored the application of IoT technology in agricultural land monitoring. Most early implementations focus on collecting environmental data such as soil moisture, temperature, and humidity using microcontrollers connected to sensors [2]. The collected data are usually transmitted to cloud platforms, allowing farmers or stakeholders to monitor field conditions remotely. These studies demonstrate that IoT can effectively replace manual observation and provide more consistent monitoring compared to conventional methods [8].

Several researchers have specifically investigated soil moisture monitoring systems, as soil condition is considered one of the most critical factors in crop cultivation [3]. IoT-based soil monitoring systems are commonly used to support irrigation management by indicating whether the soil is dry or excessively wet. While these systems are effective in measuring soil conditions, many of them focus on a single parameter and do not integrate additional environmental factors such as light intensity or air temperature, which also influence plant growth.

Other studies have proposed more comprehensive IoT-based agricultural monitoring systems by integrating multiple sensors and mobile or web-based visualization platforms [8]. These systems allow users to view real-time data through dashboards or applications, improving accessibility and convenience. However, in many cases, the evaluation of such systems is limited to technical testing, such as sensor accuracy or data transmission reliability [6] [10]. User evaluation involving farmers is often minimal or conducted only in controlled environments, making it difficult to assess the system's practicality in real farming activities.

In addition, predictive features based on historical data are not commonly included in existing IoT agricultural monitoring systems. Most implementations focus on real-time data presentation without providing early warnings or simple forecasts that could support decision-making. Furthermore, the lack of direct user involvement means that system adoption and long-term usability are not always addressed. Based on these observations, there is a need for an IoT-based agricultural monitoring system that not only provides real-time environmental data but also incorporates basic forecasting and evaluates practical acceptance through direct farmer involvement in real field conditions. This research aims to address these gaps.

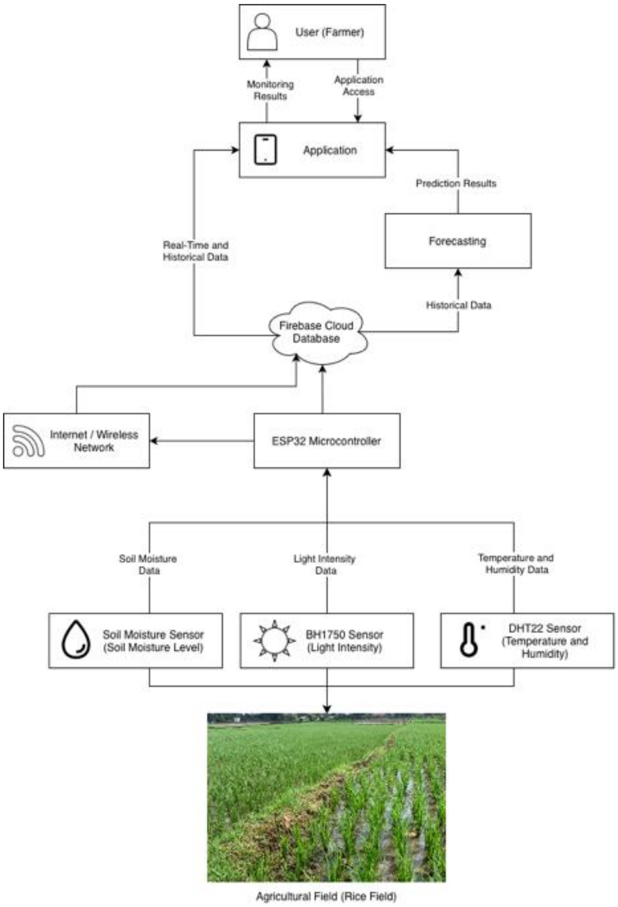

Figure 1. System Architecture Diagram

3. Proposed Method

The development of the proposed system follows a prototype-based methodology [9] [12]. An initial prototype was designed to validate core system functionality, including sensor integration and data transmission. The system was then refined iteratively based on testing outcomes and user feedback to ensure suitability for real agricultural field conditions. This section explains the proposed IoT-based field monitoring system, including the overall system architecture, data acquisition process, data transmission mechanism, and the forecasting approach. The system is designed to support agricultural land monitoring by providing real-time and predictive information while maintaining simplicity and practicality for field deployment.

3.1 System Architecture

The proposed system consists of four main components: sensing units, a processing and communication unit, a cloud-based database, and a user interface. The sensing units are responsible for collecting environmental data from the agricultural field, including soil moisture, air temperature, humidity, and light intensity. These parameters were selected based on their relevance to daily farming activities, particularly in rice cultivation.

An ESP32 microcontroller is used as the core processing and communication unit. The ESP32 reads data from the connected sensors, processes the readings, and transmits the data wirelessly via Wi-Fi. The choice of ESP32 is motivated by its built-in Wi-Fi capability, low power consumption, and suitability for IoT applications in outdoor environments.

Collected sensor data are sent to a Firebase Realtime Database, which serves as the cloud storage and synchronization platform. Firebase allows data to be updated and accessed in real time, ensuring that the latest field conditions are always available. A mobile application retrieves data from Firebase and presents it to users in a simple and readable format, enabling farmers to monitor their fields remotely without the need for constant physical presence.

The overall system architecture is illustrated in Fig. 1, showing the data flow from sensors to the ESP32 device, through the Wi-Fi network, to the cloud database, and finally to the mobile application.

3.2 Data Acquisition and Transmission

Sensor data acquisition is performed at fixed intervals of 60 seconds. This interval is selected to balance data freshness and power efficiency, ensuring that environmental changes can be detected without excessive energy consumption. At each interval, the ESP32 reads values from the soil moisture sensor, the DHT22 temperature-humidity sensor, and the BH1750 light intensity sensor.

After data acquisition, the ESP32 formats the sensor readings and transmits them to the Firebase Realtime Database. To maintain system reliability, an automatic reconnection mechanism is implemented. If the Wi-Fi connection is temporarily lost, the system attempts to reconnect automatically and resumes data transmission once the connection is restored. This approach ensures continuous monitoring even under unstable network conditions.

In addition to storing historical data, the system maintains a set of the most recent sensor readings in the database. This allows the mobile application to display up-to-date field conditions immediately when accessed by the user.

3.3 Forecasting Process

In addition to real-time monitoring, the proposed system includes a simple forecasting feature to support early decision-making. The forecasting process is based on historical sensor data stored in the cloud database. Instead of performing forecasting calculations directly on the embedded device, the forecasting module is implemented as a separate process outside the ESP32.

This design choice reduces computational load on the IoT device and prevents interference with real-time monitoring tasks. Historical data are retrieved from the Firebase database, processed to generate predicted values, and then sent back to the database as forecast results. These predicted values can be accessed by the mobile application alongside real-time data.

The forecasting feature is intended as a decision-support tool rather than a high-precision prediction model. Its primary purpose is to provide users with an early indication of potential changes in field conditions based on existing trends, thereby enhancing the usefulness of the monitoring system without increasing system complexity.

3.4 System Workflow

The overall workflow of the proposed system can be summarized as follows. First, sensors continuously collect environmental data from the agricultural field. Second, the ESP32 processes and transmits the data to the cloud database at regular intervals. Third, the mobile application retrieves and displays the data in real time for user monitoring. Finally, historical data stored in the database are used by the forecasting module to generate predictive information, which is then returned to the system and made available to users.

This workflow ensures that the system provides both real-time and predictive information while remaining simple, scalable, and suitable for practical deployment in agricultural environments.

Figure 2. System Workflow Diagram

4. Experimental Setup

This section describes the experimental environment, testing procedures, and evaluation methods used to assess the proposed IoT-based agricultural monitoring system. The experimental setup is designed to evaluate system functionality, reliability, and practicality in conditions that represent real agricultural environments.

4.1 Testing Environment

The system was tested in an outdoor agricultural environment that represents typical rice field conditions. The IoT device was placed directly in the field to allow sensors to interact with actual environmental conditions, including soil moisture variation, temperature changes, and different levels of light intensity. This setup ensures that sensor readings reflect real-world conditions rather than controlled laboratory scenarios.

The ESP32-based device was powered continuously during the testing period and connected to a local Wi-Fi network to enable real-time data transmission. Sensor data were collected at fixed intervals of 60 seconds to balance data accuracy and power efficiency. All collected data were transmitted to a Firebase Realtime Database and accessed through a mobile application for monitoring purposes.

4.2 Testing Method

A black box testing approach was used to evaluate system functionality. This method focuses on verifying system behaviour based on input and output responses without considering internal implementation details. Each main system function was tested according to expected operational scenarios, including sensor readings, Wi-Fi connectivity, data transmission, forecasting, and data visualization. All testing activities were conducted iteratively as part of the prototype development process to validate system functionality at each refinement stage.

The testing scenarios include variations in soil condition, environmental temperature, and light intensity to observe sensor responsiveness. Network reliability was also tested by temporarily disconnecting and reconnecting the Wi-Fi network to evaluate the system's automatic reconnection capability. In addition, data transmission to the cloud database and data synchronization with the mobile application were monitored to ensure real-time updates.

Forecasting functionality was evaluated functionally by verifying that historical data could be retrieved from the database, processed successfully, and returned as forecast results. The evaluation focused on system integration and data flow rather than prediction accuracy.

Table 1. Black Box Testing Results

No	Tested Function	Test Scenario	Input/ Condition	Expected Output	Result
1	Soil Moisture Reading	Evaluate sensor response under different soil conditions	Dry soil to wet soil	Soil moisture value changes significantly according to soil condition	Passed
2	Temperature and Humidity Reading (DHT22)	Observe sensor response to environmental changes	Shaded area to hot area	Temperature increases and humidity changes according to conditions	Passed
3	Light Intensity Reading (BH1750)	Measure sensor response to light variation	Dim light to bright sunlight	Lux value increases with higher light intensity	Passed
4	Wi-Fi Connectivity	Test automatic reconnection mechanism	Router turned off and turned on again	ESP32 reconnects automatically and resumes data transmission	Passed
5	Data Transmission to Firebase	Verify real-time data delivery during sensor operation	New sensor readings generated	Firebase database updates data in real-time	Passed
6	Data Synchronization on Mobile Application	Check application data update mechanism	Firebase receives new data	Mobile application displays the same updated values as Firebase	Passed
7	System Stability	Evaluate system performance over continuous operation	Device runs for several hours	System remains stable without error or freeze	Passed

8	Data Forecasting Process	Validate forecasting process using historical data	Historical sensor data available in Firebase	System successfully generates predicted values	Passed
9	Forecast Data Transmission to Firebase	Verify forecast data delivery to cloud database	Forecasting process completed	Forecast data stored in Firebase and accessible by the application	Passed

4.3 User Evaluation Setup

User evaluation was conducted through direct interviews and system demonstrations involving farmers with different ages and farming experience. The evaluation focused on practical acceptance of the IoT system rather than interface usability. Farmers were shown how the system operates and how sensor data can be accessed remotely.

4.4 Evaluation Metrics

System evaluation in this study focuses on three main aspects. First, functional performance is assessed through black box testing to verify correct system operation under various conditions. Second, system reliability is evaluated based on the stability of data transmission and continuous operation over time. Third, user acceptance is assessed based on farmer feedback regarding system usefulness and practicality in real field conditions.

By combining technical testing and user-centered evaluation, the experimental setup provides a comprehensive assessment of both system performance and real-world applicability.

5. Result and Analysis

This section presents the results obtained from system testing and analyzes the performance of the proposed IoT-based agricultural monitoring system. The analysis focuses on sensor performance, system functionality, data transmission reliability, forecasting integration, and user acceptance in real field conditions.

5.1 Sensor Performance Evaluation

Sensor performance was evaluated by observing the system’s response to changes in environmental conditions during field testing. The soil moisture sensor was tested under varying soil conditions ranging from dry to wet soil. The results show that the sensor was able to differentiate soil conditions consistently, with values changing in accordance with actual field conditions. This confirms that the soil moisture sensor is suitable for monitoring irrigation-related parameters in agricultural land.

Temperature and humidity readings were obtained using the DHT22 sensor. During the testing period, variations in ambient temperature were successfully captured, reflecting changes in environmental exposure. Humidity readings also responded accordingly to surrounding conditions. These results indicate that the DHT22 sensor provides stable and reliable measurements for monitoring air conditions in the field.

Light intensity measurements obtained from the BH1750 sensor showed clear variations corresponding to different lighting conditions. Significant differences were observed between shaded and direct sunlight conditions, demonstrating the sensor’s ability to accurately reflect changes in environmental illumination. Overall, the sensor readings confirm that the selected sensors are capable of capturing key environmental parameters required for agricultural monitoring.

The results of sensor data visualization over time are presented in Fig. 3, Fig. 4, and Fig. 5, which illustrate soil moisture, temperature, and light intensity variations, respectively.

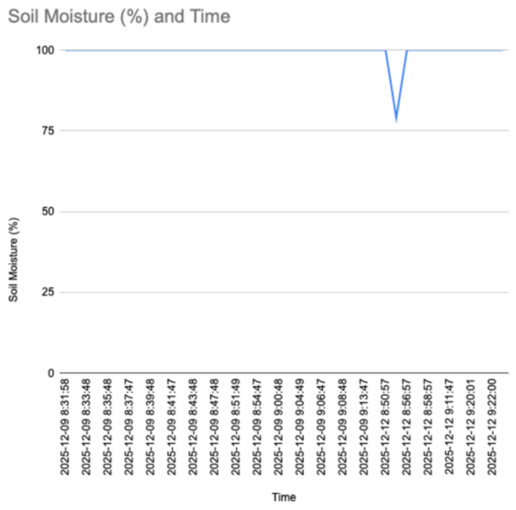

Figure 3. Soil Moisture Readings

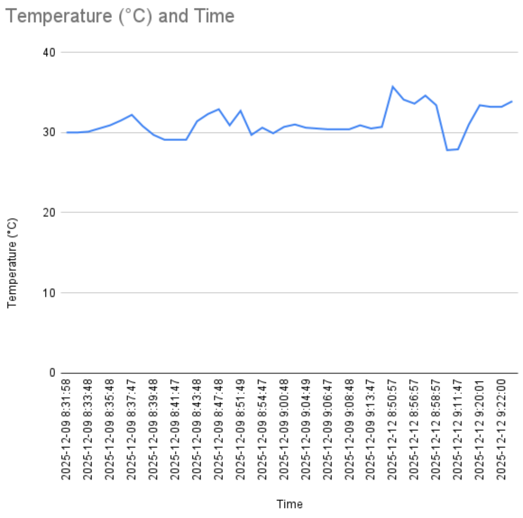

Figure 4. Temperature and Humidity Readings

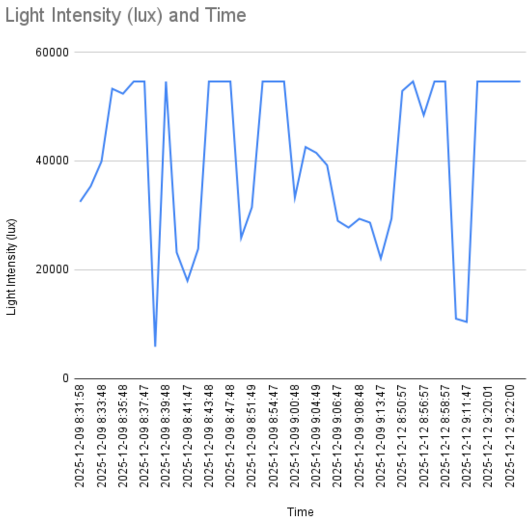

Figure 5. Light Intensity Variation

5.2 System Functionality and Data Transmission

System functionality was evaluated using a black box testing approach, focusing on expected input-output behaviour. The testing scenarios included sensor data acquisition, Wi-Fi connectivity, data transmission to Firebase, forecasting processes, and data synchronization with the mobile application. The detailed results of black box testing are summarized in Table 1.

During testing, the ESP32 device successfully transmitted sensor data to the Firebase Realtime Database at fixed intervals of 60 seconds. The system maintained stable operation under normal network conditions. When the Wi-Fi connection was temporarily disconnected, the automatic reconnection mechanism functioned as expected, allowing the system to resume data transmission once the connection was restored.

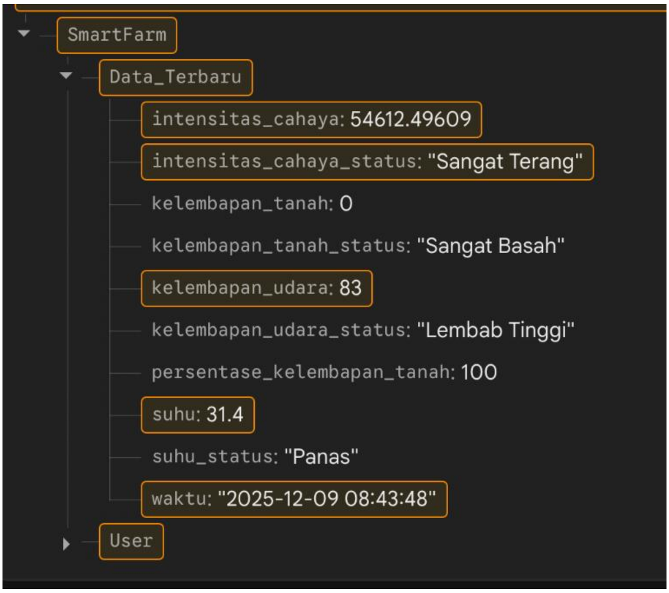
SmartFarm
Data_Terbaru
intensitas_cahaya: 54612.49609
intensitas_cahaya_status: "Sangat Terang"
kelembapan_tanah: 0
kelembapan_tanah_status: "Sangat Basah"
kelembapan_udara: 83
kelembapan_udara_status: "Lembab Tinggi"
persentase_kelembapan_tanah: 100
suhu: 31.4
suhu_status: "Panas"
waktu: "2025-12-09 08:43:48"
User

Figure 6. Screenshot of Real-Time Data Displayed on The Firebase

Real-time data updates were observed on the Firebase Realtime Database without noticeable delay. The mobile application consistently displayed the latest sensor readings retrieved from Firebase, confirming reliable data synchronization between the field device, cloud database, and user interface. A screenshot of real-time sensor data displayed on the Firebase Realtime Database is shown in Fig. 6.

5.3 Forecasting Integration Analysis

The forecasting feature was evaluated functionally to verify its integration within the overall system. Historical sensor data stored in Firebase were successfully retrieved and processed to generate predicted values. The forecasting results were then transmitted back to the database and made available for access by the mobile application.

The evaluation of forecasting focused on system workflow and data flow reliability rather than prediction accuracy. The results demonstrate that the forecasting module can operate without disrupting real-time monitoring processes. By implementing forecasting as an external process, the system avoids additional computational load on the embedded device while still providing predictive information to support early decision-making.

These findings indicate that the forecasting feature effectively complements the real-time monitoring system and enhances its functionality as a decision-support tool for agricultural land management.

5.4 User Evaluation and Practical Acceptance

User evaluation was conducted through direct interviews and system demonstrations involving farmers with varying ages and farming experience. The evaluation focused on practical acceptance and usefulness of the IoT system in real agricultural environments rather than interface usability.

Most respondents indicated that soil moisture information was the most important parameter for daily farming decisions. Farmers reported that real-time access to environmental data reduced the need for frequent field visits, particularly for those managing multiple plots of land. The system was perceived as helpful in monitoring field conditions remotely and supporting irrigation-related decisions.

Although some older farmers required initial guidance to understand system operation, overall acceptance of the IoT system was positive. Most respondents expressed willingness to use the system in the long term, provided that the device continues to operate reliably. A summary of user evaluation results is presented in Table 2.

Table 2. Summary of User Evaluation Results

No	Evaluation Aspect	Description	Overall Response
1	Sensor Data Relevance	Relevance of measured parameters (soil moisture, temperature, light intensity) for farming activities	Very Positive
2	Sensor Data Reliability	Consistency of sensor readings compared to actual field conditions	Positive
3	Real-Time Capability	Ability of the IoT system to provide update field condition information	Very Positive
4	Reduction of Manual Field Monitoring	Impact of the IoT system on reducing the need for frequent field visits	Very Positive

5	System Practically in the Field	Ease of deploying and operating the IoT device in rice field	Positive
6	Connectivity and Data Avaibility	Reliability of data transmission from field device to cloud (Firebase)	Positive
7	Overall Usefulness of the IoT System	Perceived benefit of the IoT-based monitoring system for daily decision-making	Very Positive

6. Conclusion

This study presented the design and implementation of an IoT-based agricultural field monitoring system aimed at supporting real-time and practical decision-making in agricultural land management. The proposed system integrates multiple environmental sensors with an ESP32 microcontroller to monitor soil moisture, temperature, humidity, and light intensity. Sensor data are transmitted in real time to a cloud-based database and accessed remotely through a mobile application, enabling continuous monitoring without requiring frequent field visits.

Experimental results show that the system operates reliably under real field conditions. Sensor readings responded appropriately to environmental changes, and data transmission to the cloud database remained stable through the implemented automatic reconnection mechanism. Functional testing using a black box approach confirmed that all system components, including data acquisition, cloud synchronization, and forecasting integration, functioned as expected.

In addition to real-time monitoring, a simple forecasting feature was successfully integrated into the system using historical sensor data. Although forecasting accuracy was not the primary focus of this study, the results demonstrate that predictive information can be generated and incorporated without affecting the performance of the embedded system. This feature enhances the system's role as a decision-support tool rather than a standalone monitoring device.

User evaluation conducted with farmers in real agricultural environments indicates positive acceptance of the proposed IoT system. Farmers highlighted soil moisture information as the most critical parameter for daily farming decisions and reported that the system helped reduce the need for frequent manual field inspections. Overall, the findings suggest that the proposed system is not only technically feasible but also practically acceptable for long-term use in agricultural field monitoring.

Future work may focus on evaluating forecasting accuracy using longer-term data and exploring additional parameters or automation features, such as irrigation control, to further enhance system functionality and impact.

References

[1] Y. Natalia and T. Sutabri, "Rancangan Sistem Pemantauan Lingkungan Berbasis IoT untuk Pertanian Padi," *Jurnal Sains dan Teknologi Informasi,* vol. 2, 2024.

[2] A. Amir, U. Suwardoyo and I. N. P. Irwan, "Sistem Pengukuran dan Pemantauan Parameter Lingkungan Tanah Pertanian berbasis Internet of Things," *Jambura Journal of Electrical and Electronics Engineering,* vol. 7, 2024.

[3] B. Sugandi and R. F. Hasibuan, "Monitoring Suhu, pH dan Kelembapan Untuk Aplikasi Smart Farming Berbasis Internet Of Things," *Electrician : Jurnal Rekayasa dan Teknologi Elektro,* vol. 19, 2025.

[4] A. Kumar and A. Jain, "Smart Agriculture Monitoring System using IoT," *International Journal for Research in Applied Science & Engineering Technology ,* vol. 8, no. VII, 2020.

[5] A. Pangestu, U. Latifa and L. Nurpulaela, "PERANCANGAN SISTEM MONITORING JARAK JAUH PADA SMART AGRICULTURE SYSTEM," *Aisyah Journal of Informatics and Electrical Engineering,* vol. 5, no. 1.

[6] I. L. Laksono, D. P. Kynta, M. Fadli, V. Wijaya and D. Hermanto, "Pemantauan Kelembaban tanah Berbasis IoT Menggunakan Sensor Soil Moisture," *Jurnal Algoritme,* vol. 5, 2024.

[7] H. Juanto, B. Nugroho and Nurfiana, "Pengembangan Model Aplikasi Smart Farming Berbasis Internet Of Things (Iot)," *JURNAL OTOMASI DAN INTERNET OF THINGS (JOINT).*

[8] M. Y. Saputra, Nurchim and J. Maulindar, "Design And Development of An Automated Watering System for Curly Red Chili Plants Based on Internet of Things," *Journal of Artificial Intelligence and Software Engineering,* vol. 5, 2025.

[9] R. S. Pressman, Software Engineering: A Practitioner's Approach, Seventh Edition, New York: McGraw-Hill, 2010.

[10] F. Albar, I. V. Paputungan and K. D. Irianto, "Sistem Pemantauan Nutrisi Air Pada Tanaman Hidroponik Model Rakit Apung," *Journal of Information System Research (JOSH),* vol. 3, 2022.

[11] K. D. Irianto, "Design of Smart Farm Irrigation Monitoring System Using IoT and LoRA," *JURNAL RESTI (Rekayasa Sistem dan Teknologi Informasi),* vol. 6, 2022.

[12] K. D. Irianto, "Performance evaluation of LoRa in farm irrigation system with internet of things," *Kinetik: Game Technology, Information System, Computer Network, Computing, Electronics, and Control Kinetik: Game Technology, Information System, Computer Network, Computing, Electronics, and Control Journal,* vol. 7, 2022.

[13] S. Wahyu, M. Syafaat, A. Yuliana and R. Meliyani, "Aplikasi Sensor BH1750 untuk Sistem Monitoring Pertumbuhan Tanaman Cabai Menggunakan Arduino Bertenaga Surya Terintegrasi Internet of Things (IoT)," *Jurnal Teori dan Aplikasi Fisika,* vol. 09, 2021.