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Web-Based Information System for Monitoring Soil Conditions (Moisture and Temperature) Integrated with IoT

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***Abstract*— Indonesia's agricultural sector faces challenges due to climate change and limited access to accurate, real-time information on soil conditions. Traditional methods relying on visual observation are inefficient and prone to error, which can reduce crop productivity. This research aims to develop a web-based information system integrated with the Internet of Things (IoT) for real-time monitoring of soil moisture and temperature. The system was developed using a Research and Development (R&D) approach with prototyping methodology. The hardware components include an ESP32 microcontroller, a capacitive soil moisture sensor v1.2, and a DS18B20 digital temperature sensor. Sensor data is transmitted to Firebase Realtime Database and displayed via a web interface built with HTML, CSS, and JavaScript. Field trials conducted in Talang Padang village (OKU Selatan) over 7 days demonstrated the system's ability to provide accurate, real-time monitoring. The system includes real-time gauge visualizations, historical graphs, notification features, and exportable sensor logs. Positive responses from farmers indicate the system's potential to support better agricultural decision-making. However, internet dependency and the need for sensor recalibration remain as limitations.**

***Index Terms*— IoT; soil monitoring; moisture sensor; temperature sensor; web application; precision agriculture.**

I. INTRODUCTION

Agriculture remains one of the most strategic sectors in Indonesia, with approximately 26.15% of its 144.64 million workforce engaged in agricultural, forestry, and fisheries activities, equating to around 37.81 million workers, according to the Central Bureau of Statistics (BPS) as of August 2024. However, the sector faces significant challenges, particularly in optimizing productivity amid climate change, land degradation, and limited access to accurate and real-time information regarding soil conditions. Soil plays a crucial role in agriculture as it serves as the primary medium for plant growth and provides essential nutrients such as nitrogen, phosphorus, potassium, and other microelements. Optimal soil conditions—especially in terms of moisture and temperature—are essential to support healthy and productive crop development. In practice, most farmers still rely on subjective visual observation and traditional methods to assess soil conditions, which are often inefficient and prone to inaccuracy. These limitations can lead to poor decision-making regarding irrigation and fertilization, potentially resulting in reduced crop yields.[1]

To address these problems, technological advancements in information and communication have opened new opportunities for the agricultural sector. One promising innovation is the Internet of Things (IoT), which enables the use of interconnected sensors and devices for real-time data collection and transmission. IoT allows for continuous monitoring of soil conditions, thus supporting precise, data-driven decision-making in agricultural management. This research aims to develop a web-based information system integrated with IoT to monitor soil moisture and temperature in real-time. By leveraging sensor data transmitted through cloud-based services, farmers will be able to access accurate information from anywhere, facilitating more effective and efficient land management.[2]

The research was conducted using a Research and Development (R&D) approach with a prototyping methodology. The development stages included problem identification, data collection through literature review, interviews, and field observations, followed by system design, prototyping, system testing, and final refinement.[3] The system utilizes an ESP32 microcontroller, a capacitive soil moisture sensor (v1.2), and a DS18B20 digital temperature sensor, all connected to Firebase Realtime Database for cloud-based data storage. The web interface, developed using HTML, CSS, and JavaScript, displays real-time soil condition data with graphical visualization and notification features. The system was tested in Talang Padang Village, OKU Selatan, over seven days. Black-box testing confirmed that all system components functioned correctly. Field trial results and user feedback indicated that the system effectively helped farmers monitor soil conditions and provided valuable decision-making support, despite some limitations such as dependence on internet connectivity and the need for future sensor calibration.

II. LITERATURE REVIEW

A. *Internet of Things (IoT) in Agriculture*

The agricultural sector in Indonesia is strategic, employing a significant portion of the workforce. However, it faces challenges like climate change and limited access to accurate soil data. Traditionally, farmers rely on visual observation, which is often inefficient and inaccurate, potentially harming crop yields. The Internet of Things (IoT) offers a transformative solution by enabling interconnected sensors to collect and transmit data in real-time. This technology supports precision agriculture by providing continuous, data-driven insights into soil conditions, thereby facilitating more effective land management.[4]

B. *Soil Monitoring Systems with Microcontrollers*

Previous research has extensively used microcontrollers for soil monitoring. Many systems focused on automated irrigation based on soil moisture. For instance, a system by P. Ariyanto, et al.[5] used an ESP8266 microcontroller to control water flow automatically, demonstrating improved water efficiency. Similarly, R. Sarwansah, et al.[6] developed an automated watering system using a NodeMCU ESP8266 and the Blynk application, but it was limited to monitoring only soil moisture. Other research by J. L. Gaol, et al.[7] resulted in a comprehensive Android-based application called SISMOLA for monitoring multiple farm parameters. However, its reliance on a native mobile application requires installation and lacks the accessibility of a web-based platform. While these studies were foundational, they were often limited by their focus on a single parameter, platform dependency, or a lack of an integrated, user-friendly interface for data analysis.

C. *Cloud-Based Data Storage with Firebase*

Firebase has emerged as a popular solution for real-time data storage in IoT applications due to its cloud-based nature and fast synchronization capabilities.[8]

D. *Connectivity Challenges and Scalable Architectures in Rural Areas*

Although many IoT-based agricultural systems have been successfully developed, a primary challenge often arises during implementation in rural areas with limited internet connectivity. To address this issue, Ahmed, et al.[9] proposed a scalable network architecture using a Wi-Fi-based Long Distance (WiLD) network to extend the connectivity range. Furthermore, they integrated the concept of fog computing, where sensor data is processed locally at fog nodes to reduce latency and network load before the aggregated data is sent to the cloud.

E. *Research Contribution*

While previous studies have addressed various components such as hardware, connectivity, and basic visualization, they often lacked integration of these components into a single cohesive system. This research proposes a complete solution that includes ESP32-based sensing, real-time Firebase data storage, a responsive web interface, dynamic charts (Chart.js), and automatic alerts for critical soil conditions, contributing a more holistic and scalable model for smart farming, particularly suited for rural Indonesian agriculture

III. METHOD

This research uses a Research and Development (R&D) approach with the prototyping model to build a functional web-based soil monitoring system. The system was developed through several phases, namely: requirements analysis, system architecture design, component integration, interface development, and field testing.[10]

The stages in the Research and Development (R&D) model can be adapted based on the needs and context of the system being developed. In this study, the system development process follows seven main stages, which are combined with a prototyping approach. The stages of this research process are illustrated in Fig. 1.

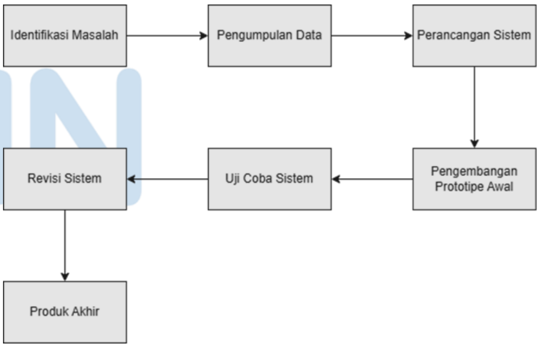


Fig. 1. Research stages

A. *Problem Identification*

This stage involved observing the farming practices in Talang Padang Village to identify challenges in monitoring soil conditions. Interviews and field visits revealed that farmers relied on manual observations, which were inefficient and often inaccurate. The need for a digital monitoring solution was confirmed through these findings.

B. *Data Collection*

Literature reviews and scientific references were collected to strengthen the theoretical foundation of the system design. The review focused on concepts such as IoT, soil sensors, microcontroller integration, Firebase cloud platforms, and web-based interfaces. Previous studies were also examined to identify best practices and limitations in related research.

C. System Design

To support a clear understanding of the IoT-based web system for monitoring soil moisture and temperature, this stage focused on technical design using Unified Modeling Language (UML).[11] The design process involved collaboration between programmers and analysts to visualize system workflows and user interactions. Some of the diagrams used include use case diagrams, activity diagram and block diagrams were developed to illustrate system architecture, data flow from sensors to Firebase, and the web interface for real-time data visualization:

The Use Case Diagram is used to illustrate the functional interactions between the user (Actor) and the core features provided by the system. The actor can perform several actions, including logging in, monitoring real-time soil moisture and temperature data, viewing charts and historical data, exporting data to Excel or PDF, and receiving visual and audio notifications.[12]

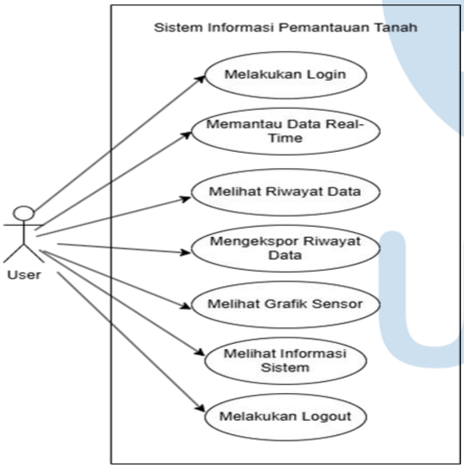


Fig. 2. Use Case Diagram

In addition to the use case diagram, an activity diagram is designed to illustrate the sequential workflow of the proposed system. The activity diagram describes the operational flow starting from sensor data acquisition, data processing by the ESP32 microcontroller, transmission to the Firebase Realtime Database, real-time data visualization on the web interface, and alert generation when predefined threshold values are exceeded. This diagram clarifies system behavior, decision points, and interactions between hardware, cloud services, and users during system operation.

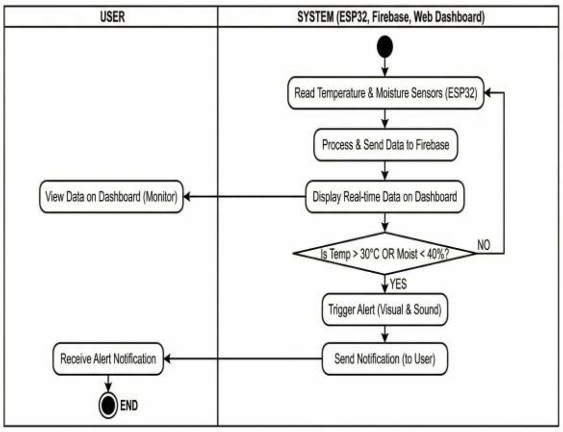


Fig. 3. Activity Diagram

The Block Diagram illustrates the overall system architecture.[13]showing the key hardware components, including the DS18B20 temperature sensor and capacitive soil moisture sensor v1.2, whose data are processed by the ESP32 microcontroller. The processed data are then transmitted via a Wi-Fi network to a cloud-based backend, namely the Firebase Realtime Database, and finally displayed to users through a web application.

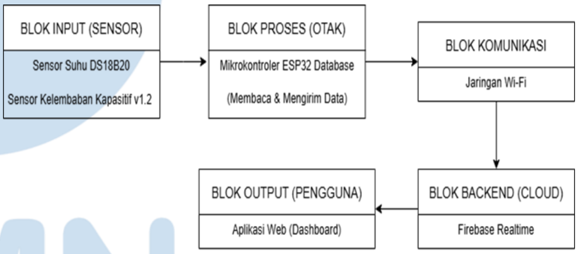


Fig. 4. System Block Diagram

A simple prototype of the IoT-integrated web-based monitoring system was developed, covering hardware, software, and user interface aspects to ensure real-time operation and accessibility, particularly for farmers.[14] Before building the system, a thorough analysis of hardware and software requirements was conducted.

1. Hardware Requirements Analysis

The hardware components required include:

a. ESP32 microcontroller (AI Thinker, Shenzhen, China) – functions as the control center and data transmitter.

b. Capacitive soil moisture sensor v1.2 (DFRobot, Shanghai, China) – measures soil moisture levels.

c. DS18B20 waterproof temperature sensor (Maxim Integrated, San Jose, CA, USA) – measures soil temperature.

d. Wi-Fi communication module (integrated with ESP32).

e. Breadboard, jumper wires, and a power supply (power bank or adapter).

2. *Software Requirements Analysis*

The software was designed to operate and manage the system as follows:

a. Firmware for ESP32, developed using Arduino IDE v1.8.19 (Arduino, Somerville, MA, USA), programmed to read sensor data and send it to Firebase.

b. Firebase Realtime Database (Google LLC, Mountain View, CA, USA; https://firebase.google.com) – serves as a cloud database for storing real-time temperature and moisture data.

c. Web interface developed using HTML5, CSS3, JavaScript, used to display sensor data in readable table and chart formats.

3. *Database Development*

Firebase Realtime Database was selected for continuous storage of soil moisture and temperature data. It supports real-time communication between the hardware (ESP32) and the web interface, and is easily integrated with microcontroller systems.

4. *Web-Based User Interface Design*

The interface was designed to be responsive and accessible via mobile devices and laptops. It focuses on simplicity and readability, allowing users (especially farmers) to easily interpret soil condition data. Key metrics such as temperature and moisture levels are presented in both numeric and graphical formats.

D. *Initial Prototype Development*

This stage involved implementing the planned system using selected hardware components: ESP32, DS18B20 sensor, and capacitive soil moisture sensor. The system was connected to Firebase for cloud storage and integrated with a responsive web dashboard built using HTML, CSS, and JavaScript.

E. *System Testing*

The prototype was tested in a real agricultural setting to evaluate its functionality. Testing criteria included sensor accuracy, data transmission stability, and user interaction with the web interface. The testing was conducted for seven consecutive days to assess the reliability of both hardware and software components under field conditions.

F. *System Revision*

Based on feedback from the field tests and technical analysis, the prototype was refined. Revisions focused on improving system stability, optimizing data refresh intervals, enhancing user interface elements, and ensuring robust cloud synchronization.

G. *Final Product*

The final output is a stable and accurate web-based IoT monitoring system for soil temperature and moisture. The product includes a complete set of features: real-time monitoring, graphical displays, exportable data logs, and notification alerts. Technical documentation was also prepared to support future maintenance and scalability.

IV. RESULT AND DISCUSSIONS

At this stage, the researcher presents the system interface through several web pages representing the core features, including Login, Dashboard, Real-Time Monitoring, History, and Profile. These pages allow secure access, display live and historical soil data, support data export (Excel/PDF), and show user information. Additional features include graphical charts, real-time alerts (visual/audio), and a logout function for session security.

System testing was conducted using the black-box method to validate the functionality of each feature against expected outputs, without analyzing internal program logic. Furthermore, a User Acceptance Test (UAT) was carried out with target users (local farmers) to assess system usability, readability of the interface.[15] and the reliability of sensor data presentation. The following section provides detailed explanations of each interface feature developed in the system.

A. *Login Page*

The system provides a login page where users enter their email and password, which are securely authenticated using Firebase Authentication. This ensures that only authorized users can access the system and its monitoring features.

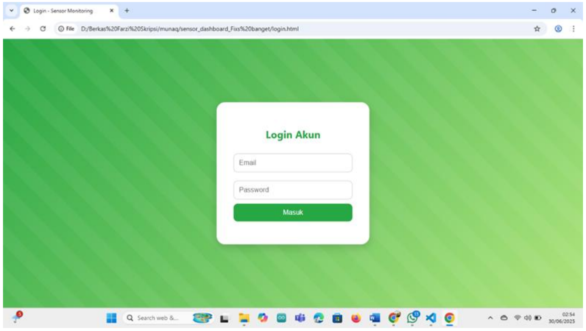
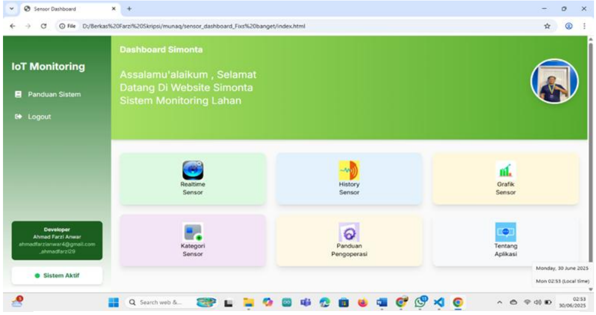


Fig. 5. Login Page

B. Dashboard Page

After a successful login, users are directed to the dashboard, which displays a summary of the latest soil temperature and moisture data. It also provides quick navigation links to other pages such as real-time monitoring, historical data, and profile settings.

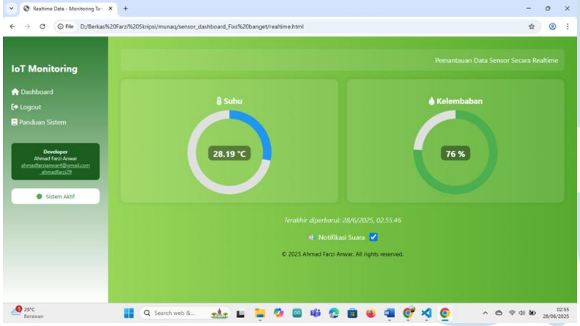


Assalamu'alaikum , Selamat Datang Di Website Simonta Sistem Monitoring Lahan

Fig. 6. Dashboard Page

C. Real-Time Monitoring Page

This page displays live sensor data that is updated every 10 seconds, including current temperature and soil moisture readings. It also includes graphical charts (using Chart.js) that visualize fluctuations over time. When sensor values exceed defined thresholds, the system triggers real-time alerts, both visual (on-screen pop-ups) and audio notifications.



Suhu: 28.19 °C

Kelembaban: 76 %

Terakhir diperbarui: 28/6/2025, 02.55.46

Notifikasi Suara ☑

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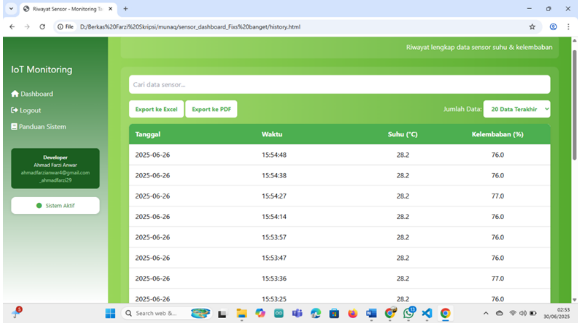
Fig. 7. Real-Time Monitoring Page

D. History Page

The history page provides a comprehensive table of previously recorded soil temperature and moisture data. Users can search and filter the information by date and time, making it easier to review specific entries and analyze environmental trends over time. To support data preservation and reporting needs, the system also offers export functionality, allowing users to download the historical data in both Excel (.xlsx) and PDF formats. These features enable farmers and agricultural practitioners to store sensor records offline, share them with relevant stakeholders, and utilize the data for planning, documentation, and decision-making purposes.



Jumlah Data: 20 Data Terakhir

Tanggal	Waktu	Suhu (°C)	Kelembaban (%)
2025-06-26	15:54:48	28.2	76.0
2025-06-26	15:54:38	28.2	76.0
2025-06-26	15:54:27	28.2	77.0
2025-06-26	15:54:14	28.2	76.0
2025-06-26	15:53:57	28.2	76.0
2025-06-26	15:53:47	28.2	76.0
2025-06-26	15:53:36	28.2	77.0
2025-06-26	15:53:25	28.2	76.0

Fig. 8. History Page

E. Sensor Data Visualization

Interactive graphs are integrated into the real-time and history pages using Chart.js to visually represent sensor data. These graphs help users identify environmental trends and fluctuations in soil conditions.

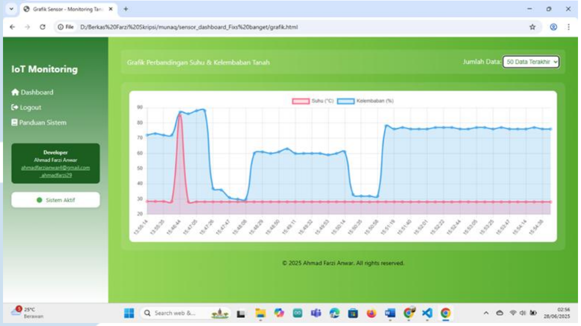
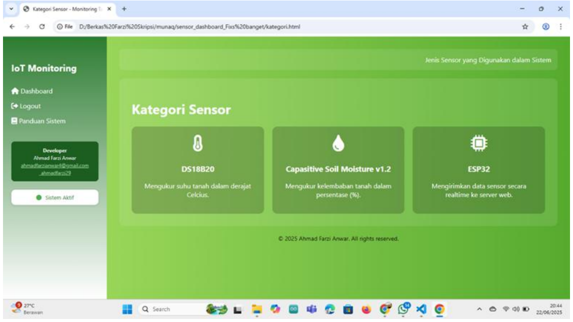


Fig. 9. Sensor Data Visualization

F. Sensor Categories

Sensor values are categorized into clear labels such as “Normal,” “Dry,” or “Hot” to aid user interpretation. This classification enhances decision-making by giving immediate insight into the condition of the soil.



Kategori Sensor

DS18B20
Mengukur suhu tanah dalam derajat Celcius.

Capasitive Soil Moisture v1.2
Mengukur kelembaban tanah dalam persentase (%).

ESP32
Mengirimkan data sensor secara realtime ke server web.

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Fig. 10. Sensor Categories

G. User Guide Section

An embedded guide provides instructions on how to use the system, including how to log in, read real-time data, respond to alerts, and export information. This ensures accessibility for first-time users, especially farmers.

Panduan Pengguna

Ikuti langkah-langkah berikut untuk menggunakan sistem monitoring tanah berbasis IoT:

1. **Login:** Masuk ke sistem menggunakan akun yang telah terdaftar.
2. **Dashboard:** Lihat ringkasan suhu dan kelembaban terkini.
3. **Realtime:** Pantau data sensor secara langsung.
4. **Riwayat:** Lihat histori data suhu dan kelembaban.
5. **Grafik:** Analisis tren data dalam bentuk grafik.
6. **Export:** Unduh data riwayat dalam bentuk Excel atau PDF.
7. **Logout:** Keluar dari sistem saat selesai.

Pastikan perangkat IoT tetap terhubung dengan internet untuk memastikan data dapat dipantau secara real-time.

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Fig. 11. User Guide Section

H. About Application Page

This page outlines the background and objectives of the system. It explains how the system was developed, its core functions, and its intended benefits for agricultural monitoring in rural areas.

Tentang Sistem

Sistem ini dikembangkan untuk memantau kondisi tanah secara real-time menggunakan sensor kelembaban dan suhu yang terintegrasi dengan modul IoT (seperti ESP32). Data yang diperoleh akan ditampilkan secara langsung melalui dashboard ini, serta dapat dilihat dalam bentuk riwayat dan grafik.

Tujuan dari sistem ini adalah untuk membantu petani, peneliti, dan pihak terkait dalam mengetahui kondisi tanah secara akurat sehingga pengambilan keputusan menjadi lebih efektif dan efisien.

Fitur utama sistem:

- Monitoring suhu & kelembaban tanah secara realtime
- Riwayat data yang tersimpan otomatis
- Grafik visualisasi data untuk analisis
- Integrasi data dengan cuaca Bandar Lampung (via OpenWeatherMap)

Pengembangan sistem oleh: **Ahmad Farzi Anwar** - Universitas Islam Negeri Raden Intan Lampung

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Fig. 12. About Application Page

I. Profile Page

The profile page displays basic user information, including name, email, Instagram handle, and contact number. This feature personalizes the system and verifies user identity.

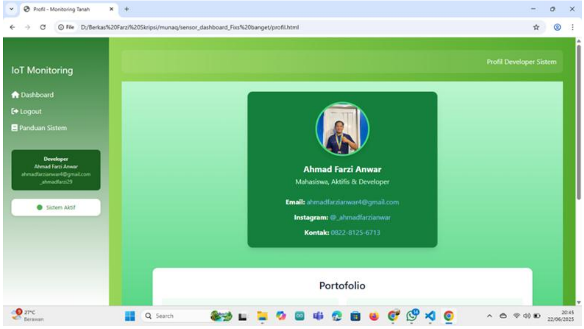

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Fig. 13. Profile Page

J. Field Testing and User Evaluation

TABLE I User Acceptance Testing Results

No.	Test Item	Success Criteria	Test Outcome	Notes
1	Login Functionality	User Successfully Logs in Via Firebase	✓ Passed	All Users Authenticated Without Errors
2	Real-Time Data Display	Data Updates Every 10 Seconds	✓ Passed	Sensor Values Shown Live on Web Interface
3	Notification System	Alerts Triggered If Threshold Exceeded	✓ Passed	Both Visual and Sound Alerts Functioned
4	History Viewing	Users Can Access and Scroll Through Past Records	✓ Passed	Date-Based Filtering Works Correctly
5	Export Feature	Data Export to Excel and PDF Without Error	✓ Passed	Output Files Readable and Properly Formatted
6	Graph Visualization	Users Can View Data Charts Clearly	✓ Passed	Charts Interpreted Easily by All Users
7	PROFILE PAGE	Displays Full User Identity	✓ Passed	Profile Info Accurate and Complete
8	Logout Functionality	Ends Session and Returns to Login Page	✓ Passed	Logout Process Secure and Functional
9	Ease Of Use (Usability)	Non-Tech Users Complete Task Without Assistance	✓ Passed	Interface Considered User-Friendly
10	Overall Satisfaction	User Finds System Useful and Practical	✓ Passed	Viewed As Beneficial for Agriculture

Table 1 summarizes the results of User Acceptance Testing (UAT) based on 10 main criteria. Each test was evaluated by participants during a 7-day trial. All system features—login, real-time monitoring, alerts, history view, data export, and profile access—met the success criteria. Users highly appreciate the intuitive interface and timely notifications that support farming decision making.

K. Sensor Testing Results

Table 2 presents representative sensor readings obtained during field testing using an ESP32 microcontroller, a DS18B20 temperature sensor, and a capacitive soil moisture sensor. The system effectively detected environmental changes and reliably triggered alerts whenever the temperature exceeded 30°C and/or the soil moisture level dropped below 40%. These findings demonstrate both the accuracy and responsiveness of the sensors and validate the overall effectiveness and reliability of the system under actual agricultural field conditions. Such performance confirms the system's potential to support real-time soil monitoring and informed decision-making in precision farming.

TABLE II Soil Sensor Testing Results

No.	**Timestamp**	**Sensor Data**	**Environmental Condition**	**Alert Status**
		Temperature (°C)	**Moisture (%)**	
1	2025-06-15 08:00:00	29.5	37	Dry and Hot
2	2025-06-15 08:00:10	30.0	35	Dry and Hot
3	2025-06-15 08:00:20	31.2	33	Dry and Hot
4	2025-06-15 08:00:30	28.7	42	Normal
5	2025-06-15 08:00:40	27.5	49	Normal
6	2025-06-15 08:00:50	29.1	70	Wet but Normal

L. System Evaluation

The system evaluation demonstrates that the IoT-based soil monitoring system functions effectively in real-time conditions. It accurately collects and transmits soil temperature and moisture data every 10 seconds using ESP32, DS18B20, and capacitive sensors, with the data stored in Firebase and displayed through a responsive web interface. User Acceptance Testing confirmed that all core features such as real-time monitoring, historical data access, alert notifications, data export, and user authenticationworked as expected and were well received by users. The system was stable during field trials, easy to use, and provided timely alerts, although it remains limited to a small-scale test area and single-node deployment. Overall, the system meets its functional goals and shows strong potential for supporting precision agriculture.

M. Limitations of the Study

Although the proposed IoT-based soil monitoring system demonstrated reliable performance during field implementation, this study has several limitations. The system testing was conducted over a relatively short period of seven days and was limited to a single agricultural location in Talang Padang Village, OKU Selatan. As a result, the evaluation may not fully represent the system’s long-term stability and performance under diverse environmental conditions. Factors such as seasonal climate variations, different soil characteristics, and extended operational duration were not comprehensively assessed. Therefore, the findings should be interpreted within the scope of short-term and single-location deployment

V. CONCLUSIONS

This research concludes that a web-based soil condition monitoring system integrated with IoT technology has been successfully developed and implemented. The system utilizes an ESP32 microcontroller along with a DS18B20 temperature sensor and a capacitive soil moisture sensor v1.2 to collect data every 10 seconds, which is automatically transmitted to Firebase Realtime Database. The front-end application, developed using HTML, CSS, JavaScript, and PHP, is capable of displaying real-time data, storing historical records, and providing essential features such as graphical visualization, export to Excel and PDF, user profile display, and secure login/logout. The system also includes a notification mechanism that triggers alerts when temperature exceeds 30°C or soil moisture drops below 40%, allowing timely responses to adverse conditions. User Acceptance Testing (UAT) confirmed that all functionalities operated as expected and were well received by end users, including farmers and field observers, who found the interface easy to use and the information provided both accurate and useful. The sensor testing further validated the accuracy and reliability of the system, demonstrating its potential as an effective digital solution to support real-time agricultural decision-making.

For future work, it is recommended to conduct long-term testing over extended periods and deploy the system in multiple agricultural locations with different soil types and climate conditions to further evaluate system stability and scalability. Future enhancements may include the integration of additional environmental sensors, implementation of adaptive sensor calibration techniques, and optimization of data processing for larger-scale deployments. These improvements are expected to enhance system reliability and strengthen its applicability for precision agriculture and sustainable farming practices.

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