Pertanika J. Sci. & Technol. 32 (6): 2575 - 2589 (2024)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Design an Agricultural Soil and Environment Monitoring System Based on IoT

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ABSTRACT

One of the problems farmers face is the inability to make complete, real-time, and accurate observations of their farmland. The system proposed in this paper helps farmers to know the condition of farmland from anywhere and anytime by using a web-based application. The main objective of this prototype is to reduce the failure of the growth process of farming commodities by knowing the conditions inside and outside the soil with a total of 14 parameters. Internet of Things (IoT) technology is used to implement the prototype, which consists of Sensor Panels, Controllers, Message Broker, and Backend Service. All obtained data, created and tested in real-time, are displayed on the application. In addition to real-time data display, the system also includes monitoring history, alerts, and site location management.

Keywords: Agricultural, environment, Internet of Things, monitoring system, soil

INTRODUCTION

Soil and environmental monitoring in agriculture is essential to improve the effectiveness of agriculture itself (Huang & Hartemink, 2020; Tahat et al., 2020). By understanding soil conditions such as fertility levels, soil texture, and water availability, farmers can plan for more efficient planting and fertilisation. Monitoring also helps farmers identify problems such as eroded or terraced soils to take timely corrective actions to improve crop productivity (Hilali et al., 2023; Segarra et al., 2020). In addition, environmental monitoring helps anticipate the negative impacts of weather and climate changes so farmers can better adapt their

ARTICLE INFO

Article history:
Received: 13 December 2023
Accepted: 09 May 2024
Published: 25 October 2024

DOI: https://doi.org/10.47836/pjst.32.6.09

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ISSN: 0128-7680
e-ISSN: 2231-8526

farming practices, reduce the risk of crop failure, and increase the effectiveness of agricultural production (Ahmad & Pothuganti, 2020; Huang & Hartemink, 2020; Popescu et al., 2020).

In traditional agriculture, farmers often face obstacles in monitoring the condition of their farmland. Farmers only conduct limited visual monitoring of their land (Sahbeni et al., 2023). Limited visual observations can hinder early identification of changes that may occur in the farm environment. The inability to obtain accurate and up-to-date information on parameters such as temperature, soil moisture, nutrient availability, and other environmental factors often makes it difficult for farmers to manage their land effectively (Sudharson et al., 2023).

If these conditions continue, it can lead to failure in the growth process of farming commodities and even result in crop failure. In addition, agricultural yields will not be maximised. Therefore, there is an urgent need to develop solutions that allow farmers to monitor and manage their farms more effectively and efficiently. Internet of Things (IoT) technology is emerging as a promising solution to help address this challenge (Ahlawat & Rana, 2021; Boddu et al., 2023; Rehman et al., 2022). By utilising sensors embedded in the fields, data can be collected continuously. Sensors can accurately record agricultural parameters (Billa et al., 2023). The data will then be processed and displayed on a digital platform for easy understanding. Farmers can access the sensors' data remotely through the digital platform. Thus, problems in monitoring agricultural land will be resolved.

The main contribution of this research is to present the design and development of a monitoring system that uses a soil data and environmental data approach. The developed approach can collect and display data in real-time. The hardware component includes a control box that connects and acquires soil data such as NPK levels, acidity, temperature, moisture, conductivity, salinity, and TDS, and environmental data such as wind speed, rainfall, temperature, humidity, and brightness. It allows farmers to respond quickly to changes in soil and environmental conditions and take necessary measures. The system also stores historical data. It allows farmers to track changes in conditions over time, identify patterns, and make decisions based on long-term trends.

RELATED WORKS

IoT in agriculture uses sensors for field monitoring and control to learn about the agricultural sector (Rifat et al., 2022). According to Dhal et al. (2023), the application of various IoT platforms, wireless sensor networks, and other related technologies, including remote sensing, cloud computing, and big data analytics in digital agriculture. Shafira et al. (2023) have designed a simple monitoring tool and made automatic irrigation systems that measure soil moisture, temperature, and water distance in reservoirs in urban agriculture. It used an Internet of Things (IoT)-based design developed using the Solar Cell as an energy source and could be monitored with a smartphone/PC. According to Shafique et al. (2020), IoT technology is from a top-down perspective, outlining its statistical and architectural trends, application cases, difficulties, and hopes for the future. The report also provides a comprehensive and in-depth assessment of the new 5G-IoT situation. Cellular networks of the fifth generation (5G) offer essential enabling technologies for the widespread adoption of IoT technology. However, findings and analysis revealed that the Basic IoT system is reasonably priced for agricultural farms; however, the cost is greatly increased by incorporating specific features in the smart sensors. Additionally, the internet connectivity in farms and communities is subpar, hindering information exchange between farmers and agricultural professionals (Kumhar et al., 2022). As stated in the research of Yang et al. (2021), one implementation of the IoT system is NB-IoT, which is utilised in creating a monitoring system for the greenhouse environment (Narrowband Internet of Things). The system can wirelessly communicate data to the OneNET cloud platform and monitor the greenhouse's air temperature, relative humidity, light intensity, and carbon dioxide concentration. Additionally, the device can measure the greenhouse's air temperature. Growers may access the website and obtain information on the conditions in the greenhouse using a mobile phone or any portable device of their choosing.

The soil's moisture has a direct bearing on the growth and yield of the crop, which is an essential component of plant life. The soil's moisture is an important aspect of the plant that directly impacts how it develops and how much harvest it produces (Sankar et al., 2023). In addition to monitoring the environmental parameters such as Temperature, Humidity, Soil Moisture, Rain level and Light Intensity to monitor the conditions of agricultural farmland (Babu et al., 2023). Hossain et al. (2023) proposed an effective Internet of Things (IoT)-based soil nutrient monitoring and machine learning-based crop recommendation system. This system is intended to assist farmers by providing crop-related details and recommendations for crops based on various soil and weather attributes. The machine learning approach will recommend what kinds of crops have the greatest production potential for this land by monitoring N, P, K, temperature, pH, humidity, and rainfall values and analysing the permanent and temporary behaviour of the soil N, P, K, temperature, pH, humidity, and rainfall values. They studied how the Internet of Things (IoT), machine learning, and other sensor-based improvements have made environmental monitoring smart (Pal et al., 2023). Nalendra et al. (2022) developed IoT-Agri to assist farmers in monitoring soil, water, and environment data. IoT-Agri comprises several components, including sensors, applications, network elements, and other electronic devices. IoT-based soil nutrient monitoring and analysis systems employ Arduino and ESP8266 (Gomathi et al., 2022).

MATERIALS AND METHODS

Hardware Design

The hardware used in the research includes soil sensors and sensor stations. The main function of these sensors is to monitor the progress of the crops grown in the area, as well as to capture relevant data. The sensor system installed on the farm is designed to ensure efficient monitoring and surveillance of the crops. The devices installed in the farm area include various components, as shown in Figure 1. This system of sensors is capable of optimising agriculture and can accurately monitor and regulate the environmental conditions of the farm.

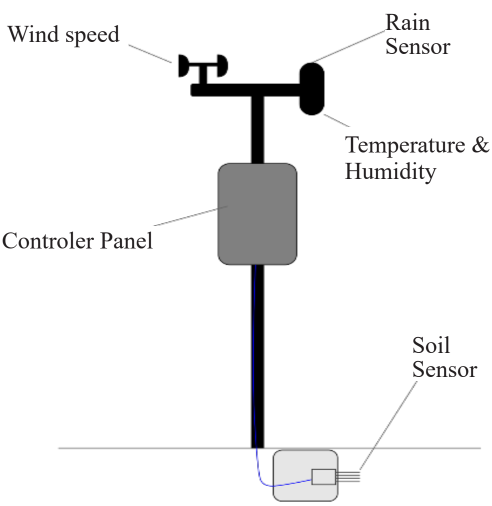

Figure 1. Controller and sensor panel

Table 1 shows the parameters and units related to data collection based on the sensor installation results.

Software Design

The software design of the proposed IoT-based farmland information system can be seen in Figure 2. First, each sensor collects data from the physical environment or monitored device, such as temperature, humidity, pressure, and other devices. This data is transmitted via the RS485 Modbus connection. Second, the controller acts as an interface between the sensor and the message broker. It collects data from various sensors connected using the RS485 Modbus

Table 1
Farmland data collection parameters

No	Parameters	Unit	Symbol
1	Environmental humidity	Per cent	%
2	Environmental temperature	Degree Celsius	ºC
3	Rainfall	Millimetres	mm
4	Brightness	Lux	lx
5	Wind speed	Meter/Second	m/s
6	Soil Moisture	Prosen	%
7	Soil Temperature	Degree Celsius	°C
8	Conductivity	Micro siemens per centimetre	us/cm
9	Soil acidity	Part per million	ppm
10	N content	Part per million	ppm

Table 1 *(Continue)*

No	Parameters	Unit	Symbol
11	P content	Part per million	ppm
12	Potassium Content	Part per million	ppm
13	Salinity	Milligrams per Liter	mg/L
14	TDS (soluble solids)	Part per million	ppm

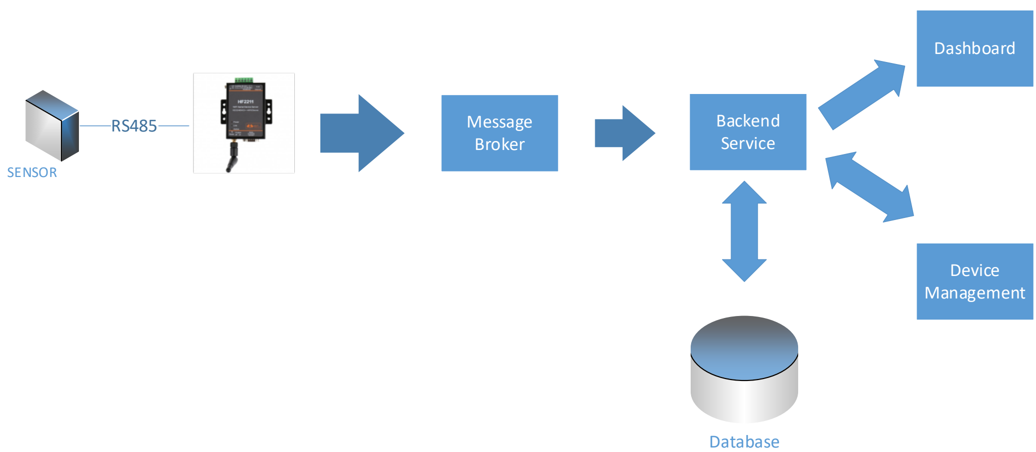

Figure 2. Data flow architecture

protocol and sends it to the message broker. This controller can also organise sensors and apply simple logic before sending data. Third, the message broker is responsible for receiving and distributing the data sent by the controller. The message broker is an intermediary between the controller and the backend service. When data is received from the controller, the message broker will send it to the backend service. Finally, the backend service is the core of the IoT application. Here, data from the message broker is received and processed. The backend service contains the business logic and algorithms required to process sensor data and generate useful information. Some of the main tasks of the backend service include:

a. Database Management

The backend service will store the accumulated data in the database. The stored data includes raw data from sensors as well as processed data.

b. Device Management

The backend service is also responsible for organising and managing IoT devices with device management.

c. Dashboard

The backend service will apply the appropriate algorithms and logic to process the data received from the sensors or database. The results of this processing will be displayed on the dashboard. Users can view the data in visualisations such as graphs and tables.

RESULTS AND DISCUSSION

Results in Proposed System

The prototype of the proposed IoT-based farmland information system can be seen in Figure 3. It is a web-based application designed for farmers who want real-time information about farmland conditions. The application will display information about soil conditions and its environment, such as soil temperature, temperature, moisture, humidity, rainfall, light, wind speed, soil acidity, conductivity, N content, P content, K content, TDS, and salinity. The proposed system includes a sensor panel, controller, message broker, and backend service.

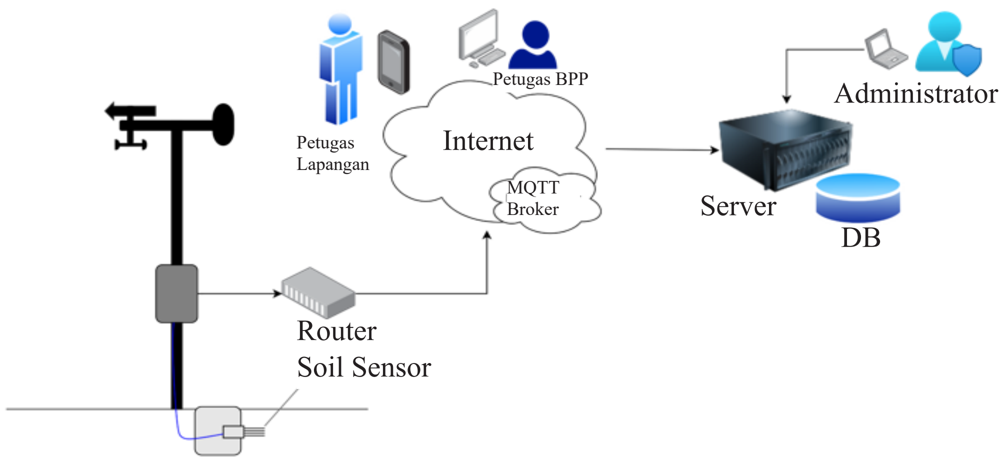

Figure 3. Prototype of farmland information system architecture

The installed sensors consist of two parts (Figure 3). The lower part contains soil sensors embedded in the ground to monitor conditions in the soil. In contrast, the upper part contains rain sensors, wind speed, and temperature and humidity sensors to measure environmental conditions above ground. All these sensors will be connected to the router via the Internet. Internet from the sensors will be collected and directed to one controller, and then from the controller, the data will be sent via the Internet to the router stage. After that, the data will go through the Internet and be received by the server, which is then stored in the database and displayed on websites or mobile phones. The MQTT Broker mechanism is used in this study to transmit the data on the Internet of Things (IoT). MQTT is a lightweight protocol, so it is suitable for IoT, which uses limited power.

In addition, the data from the database is accessed using SSH (secure shell). The SSH allows backend services to connect securely to the database. The backend is required to enter the appropriate SSH server IP address and password to connect. Furthermore, enter the appropriate information to connect to the database.

d. Soil Sensor

Soil sensors embedded in the farming area measure the soil conditions around the plants. The sensor can retrieve seven important parameters about the soil, such as moisture level, pH, and nutrient level. The system can use the data to regulate crop fertilisation appropriately and prevent soil quality problems.

e. Sensor Station

Sensor stations are important in capturing information about wind speed, rainfall, and air temperature and humidity around the plantation area. Data from various sensors, including soil sensors and controllers, will be sent through the internet router network.

f. Router

Data from sensor stations and controllers are collected and routed to one controller. The controller sends the data over the Internet to the stage. Next, the data passes through the Internet to the server, which is stored in the database.

g. Internet

The Internet is a medium for transmitting data from each stage installed on the sensor. It ensures the creation of accurate data, which will be stored in the DB Server.

h. MQTT Broker

The MQTT Broker mechanism is used to transmit data on the Internet of Things (IoT), but other messaging mechanisms can also be used.

i. DB Server

The DB Server is responsible for storing all farm-related data. The administrator can access this server database to monitor soil and crop conditions efficiently.

j. Admin

Administrators can monitor soil conditions on farmland through the database server. With the right information, farm officers can optimise crop growth and accurately manage farm environmental conditions for better results.

Implementation of the Proposed System

The implementation of the proposed system in this research is shown in Figure 4. The prototype is installed in one farming area, and the Internet is provided to monitor the soil and environmental conditions of the farming area using the Internet of Things. As an observation location, this research was conducted in 110 square meters of rainfed land in Garut district, West Java, Indonesia. The agricultural commodity observed is the Balinese Shallots. The duration of observations was carried out during two planting cycles. The first planting cycle was carried out from May to July 2023, while the second was carried out from August to October 2023.

Figure 4. Implementation of the prototype on limited land

Soil sensors and sensor stations are installed to collect and record data from when the seeds are planted until harvest time. This information is sent via the Internet to the server and the application. Figures 5 to 8 show the results displayed in the end-user application for the IoT-based farmland information system.

Real-time Monitoring

Real-time monitoring directly monitors the condition of the agricultural environment and related elements. The sensors that have been installed will generate data or information about soil temperature, ambient temperature, soil moisture, ambient humidity, rainfall, light, and wind speed, and then the data is retrieved and displayed instantly. So that farmers and agricultural administrators can access the latest information and make decisions based on accurate data. Overall, real-time monitoring provides accurate data to improve agricultural production and management while helping to reduce risks and increase efficiency.

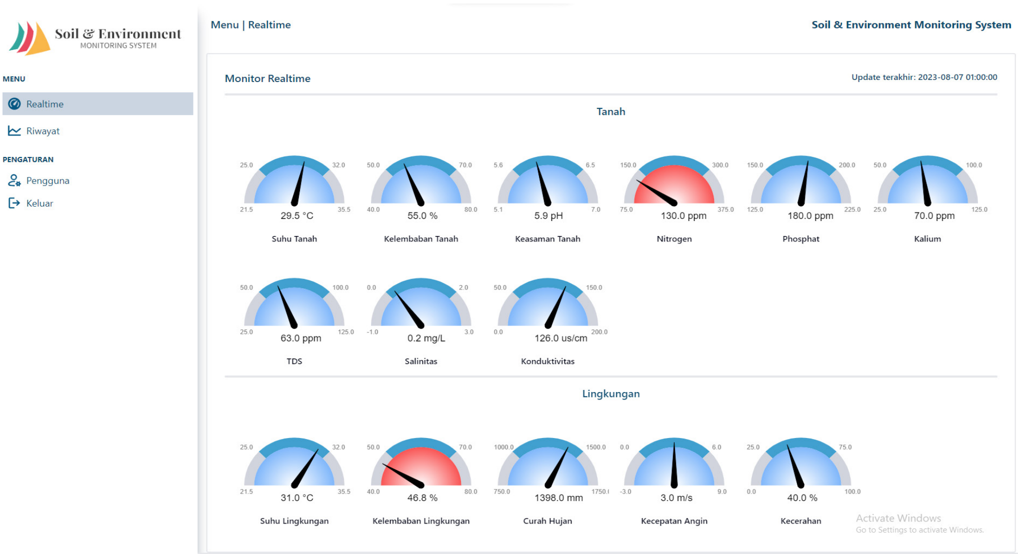

Figure 5. Application for real-time monitoring

Monitoring History

History monitoring has the function of storing historical data and information collected from monitoring processes in agricultural areas. It involves recording and storing data relating to environmental conditions, crop development, and other factors that affect the farm over time. This monitoring history describes the data obtained from the sensors that have been installed. The user is then given the option to activate specific sensors to compare parameters, which provides flexibility in making comparisons. The information displayed includes the date, hour, minute, and second when the data was collected. Users also can set the time and change the day and time as needed.

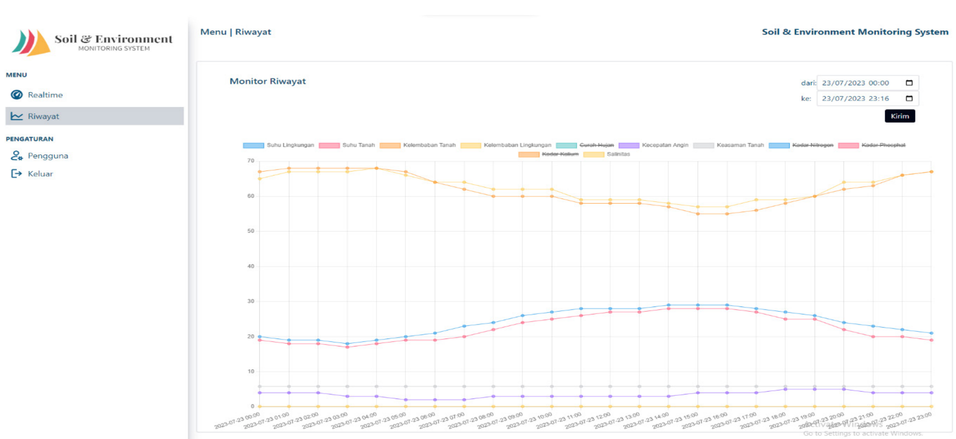

Figure 6. Application for monitoring history

Notifications

The notification function here is to provide information to the administrator regarding sensor values that do not meet the standards or exceed normal limits. This notification is important in ensuring a quick and responsive response to situations affecting the farm environment. In addition, notifications can also monitor weather temperature, soil moisture, and the condition of the farm environment area. Overall, notifications in agricultural monitoring provide the ability to adapt to changing environmental conditions in real-time, ultimately enabling a faster and more efficient response to situations that impact agricultural yields.

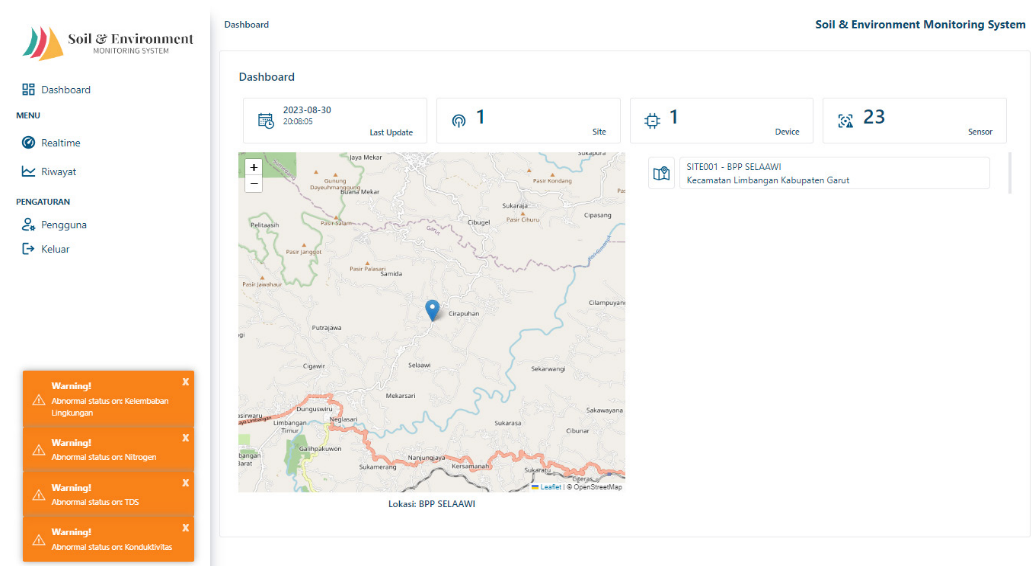

Figure 7. Application for notification

This dashboard shows the last update on the date, month, year, and time to second. It also shows the number of locations, devices, and sensors. In the bottom left corner are notifications indicating any sensor values that are out of standard or over normal limits.

Site Location

Site location plays an important role in displaying sensor positions and server locations. Furthermore, it enables the selection of the most optimal place to set up a facility or carry out agricultural activities. This process involves in-depth study and analysis of various factors that affect agricultural productivity and sustainability.

The location details page provides complete information about the location ID, location name, and address and contains a highly accurate location map.

In sum, the IoT-based land monitoring system that we have proposed has several advantages compared to other IoT-based agricultural monitoring options, including three

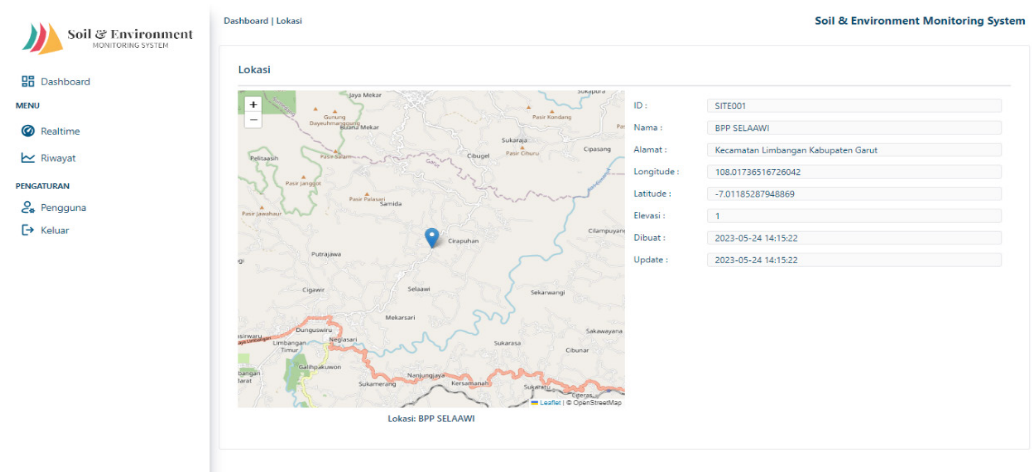

Figure 8. Application for site location

main features: (1) real-time monitoring of various parameters, (2) historical monitoring that stores data from the monitoring process, and (3) warnings about sensor values that do not meet standards or exceed normal limits. Scalability is also a key focus, possibly adding additional sensors or integrating new technology in agricultural recommendation systems. The significance of attributes like adaptable sensor integration, expandable system capabilities, and effortless setup was underscored when selecting a monitoring solution that aligns with the agricultural sector's demands. We compare the results of this study to assess the benefits of the suggested system within the larger framework of the advancement of Internet of Things-based agricultural monitoring technologies.

User Perception and Feedback

The prototype was demonstrated and tested by the relevant Agricultural Extension officers. This prototype has received very positive reviews during testing. The staff were enthusiastic during the test and were actively involved in the question-and-answer session. One thing we learned during the trial was that the staff said that this system would help monitor agricultural land conditions effectively and help make better decisions to ensure crop productivity was as planned. Also, the intuitive system design allows decision-makers to quickly understand how to use the system without experiencing difficulties in the form of colour on the real-time monitoring feature, which states that red indicates that sensor parameters do not meet standards or exceed normal limits.

CONCLUSION

This research proposes a prototype farmland information system designed and implemented using IoT technology. The system features real-time monitoring. Through sensors connected to the IoT network, data on soil and environmental conditions can be collected and displayed in real-time. It allows farmers to respond quickly to environmental changes and take necessary measures. Furthermore, the system has a Historical data Monitoring feature. The system also stores historical data on land and environmental conditions. This feature allows farmers to track changes in conditions over time, identify patterns, and make decisions based on long-term trends. In addition, the system has a Dashboard page. The Dashboard page displays a summary of data from the system, a map of sensor locations, and a list of monitored locations. It provides a visual understanding of where each sensor is located and the area covered by each device, allowing farmers to understand the geographical distribution of data. The Dashboard page can also display notifications to anticipate unusual or abnormal situations. When the data collected from the sensors shows values outside the normal limits, the system will notify the farmer. It allows for quick action to address any issues that may arise.

In conclusion, this system will help them reduce crop failures by providing farmers with the necessary information about their crops' growth. The system is practical and accurate for transmitting data using Wi-Fi. Further studies can focus on analysing the data collected using Machine Learning, such as farmland classification and recommendations. In addition, other parameters, such as special crop treatments, could be included for further study.

Data incompatibility is one of the problems or constraints that can occur during system setup or field use. To address this issue, ensure that there is an accessible tool for data transformation so that data from different sources can be converted into a format that the system can understand. If possible, standardise the form of data. Security vulnerabilities and system performance bottlenecks are additional challenges that need to be addressed. To find hardware or system code bottlenecks, use profiling tools. If necessary, fix the hardware or optimise the code. If possible, consider scalable cloud-based solutions. Conduct regular security audits to find and fix vulnerabilities. Implement strict access control and security measures. Keep up to date with the latest security risks.

ACKNOWLEDGEMENTS

This research activity is supported through RIIM Kompetisi funding from the Indonesia Endowment Fund for Education Agency, the Ministry of Finance of the Republic of Indonesia, and the National Research and Innovation Agency of Indonesia (BRIN) according to contract numbers 128/IV/KS/11/2022 and 374/SAM4/PPM/2022. We also thank Telkom University, Indonesia and UPT Pertanian Wilayah 5 Kabupaten Garut, Indonesia for supporting this research activity.

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