Design and Development of an IoT-Based Soil Moisture Monitoring System with Real-Time Web Dashboard Visualization

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Abstract

Manual soil moisture measurement is often inaccurate and inefficient, potentially hindering the optimization of plant growth. This study aims to design and develop an *Internet of Things* (IoT)based soil moisture monitoring system with real-time web dashboard visualization. The system integrates a soil moisture sensor with an ESP32 microcontroller as the main processing unit. Data is transmitted via the HTTP protocol to a MySQL real-time database. Sensor readings are then visualized on a web dashboard in the form of dynamic charts to facilitate remote soil condition monitoring. The system features multiple interfaces including a public web monitoring page displaying current soil moisture and pH levels, a monitoring page with live sensor status, and an admin dashboard providing aggregated statistics such as total records, daily records, average moisture values, and a 7-day moisture trend chart. Based on testing results, the system is capable of updating data on the dashboard with an average delay of 3000 ms. Sensor testing shows a precision level of 40% compared to conventional measuring instruments. This system is expected to serve as a foundation for the development of a more efficient automatic irrigation system.

Keywords: *Internet of Things (IoT), Soil Moisture, Web Dashboard, Real-Time Monitoring, ESP32.*

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2nd International Conference on Islamic Community Studies (ICICS)
Theme: History of Malay Civilisation and Islamic Human Capacity and Halal Hub in the Globalization Era
https://proceeding.pancabudi.ac.id/index.php/ICIE/index

Introduction

Agriculture plays a critical role in sustaining food security, particularly in tropical regions where soil moisture levels directly affect crop productivity. Soil moisture is defined as the volumetric ratio of water in the soil to the total soil volume, and its accurate measurement is essential for effective irrigation management [1]. However, conventional manual measurement methods are frequently inaccurate and time-consuming, hampering the ability of farmers and researchers to respond promptly to changing soil conditions [2].

The rapid advancement of the *Internet of Things* (IoT) technology has opened new possibilities for agricultural monitoring systems. IoT enables physical devices to collect and exchange data through the internet, facilitating automation and remote monitoring without direct human intervention [3]. In the agricultural context, IoT-based systems can continuously and automatically record soil conditions, reducing reliance on manual labor while improving data accuracy and timeliness [4].

Previous research has explored various approaches to soil moisture monitoring. Josephson et al. [5] proposed a hybrid approach using in-ground backscatter tags combined with above-ground commodity radars, achieving accuracy comparable to commercial capacitive sensors. Maghuna et al. [6] designed an Android-based capacitive soil moisture measurement tool with 99.83% calibration accuracy. Wijaya et al. [7] developed an IoT-based monitoring and automatic irrigation system for corn plants using NodeMCU ESP8266 and the Blynk application. Ronaldo et al. [8] implemented a microcontroller-based peanut plant watering system using Raspberry Pi and fuzzy logic algorithms. Despite these contributions, there remains a need for an integrated, web-accessible dashboard system that provides comprehensive visualization of soil moisture data for non-specialist users.

This research addresses that gap by designing and developing an IoT-based soil moisture monitoring system that integrates an ESP32 microcontroller with a web-based dashboard featuring real-time data visualization. The system transmits sensor data via HTTP to a MySQL database and presents it through a multi-page web interface accessible on desktop and laptop computers. The novelty of this work lies in the combination of a public-facing monitoring web page and a dedicated admin dashboard providing statistical summaries and trend analysis, making the system suitable for educational and small-scale agricultural monitoring purposes.

Literature Review

Soil moisture, or Volumetric Water Content (VWC), is a fundamental parameter in agriculture and environmental science. It influences plant growth, irrigation scheduling, and hydrological modeling [1]. Accurate and timely measurement of soil moisture is therefore vital for optimizing water use efficiency.

Capacitive soil moisture sensors measure the dielectric permittivity of soil, which correlates with water content. Compared to resistive sensors, capacitive sensors offer greater durability and accuracy, as they are less susceptible to corrosion caused by electrolysis [6]. The ESP32 microcontroller, equipped with built-in Wi-Fi and Bluetooth modules, has emerged as a preferred platform for IoT applications due to its dual-core architecture, efficient power consumption, and ability to support real-time data transmission [7].

Web-based dashboards have been widely adopted for IoT data visualization. Effendi et al. [9] demonstrated the use of the Blynk platform for real-time monitoring of soil moisture via smartphone applications. Saputra and Suryono [10] implemented a drip irrigation system using ESP32 with an LCD display for local moisture percentage visualization. The integration of MySQL databases for persistent data storage and dynamic chart rendering on web pages represents an advancement in making IoT sensor data accessible to a broader audience, including farmers and educators who may not have access to proprietary IoT platforms [7][8].

Research Methodology

This research employs a prototype development methodology, which involves iterative design, implementation, and evaluation phases to produce a functional system before full-scale deployment [7]. The development process consists of four main stages: requirements analysis, system design, prototype construction, and testing and evaluation.

3.1 System Architecture

The overall system architecture consists of three layers: (1) the hardware layer comprising the soil moisture sensor and ESP32 microcontroller; (2) the data transmission layer using the HTTP protocol over Wi-Fi; and (3) the application layer comprising the MySQL database server and web-based dashboard. The ESP32 reads analog values from the soil moisture sensor, converts them to percentage values, and periodically transmits the data to the web server via HTTP POST requests. The server stores incoming data in a MySQL database and makes it available for real-time visualization. ***3.2 Hardware Components***

The hardware components used in this research are listed in Table 1.

Table 1. Hardware Components of the IoT-Based Soil Moisture Monitoring System

No.	Component	Function
1	ESP32 Microcontroller	Main processing unit; Wi-Fi data transmission via HTTP
2	Capacitive Soil Moisture Sensor	Measures volumetric soil moisture level (0–100%)
3	MySQL Database Server	Persistent storage of sensor readings with timestamps
4	Web Server (PHP/Apache)	Hosts the web dashboard and processes HTTP API requests
5	Laptop / Desktop Computer	End-user monitoring interface via web browser

3.3 Web Dashboard Design

The web dashboard was developed using PHP and JavaScript with a dark-themed user interface to provide clear visual contrast for data readability. The system comprises three main pages accessible to different user roles. The public-facing homepage (Beranda) displays current temperature, soil moisture percentage, and pH level in a hero-style layout. The Monitoring page provides live sensor status and record statistics. The admin panel, accessible via a secure login interface, presents aggregated data including total records, daily records, average moisture value, sensor online/offline status, a 7-day moisture trend chart, and the most recent sensor data entries.

Results

The developed system successfully integrates hardware and software components into a functional IoT-based soil moisture monitoring platform. The following subsections present the system's interface components and performance evaluation results.

4.1 System Interface

Figure 1 shows the admin login page of the Web Monitoring Kelembaban system. The login interface employs a dark-themed design with username and password fields, restricting dashboard access to authorized administrators.

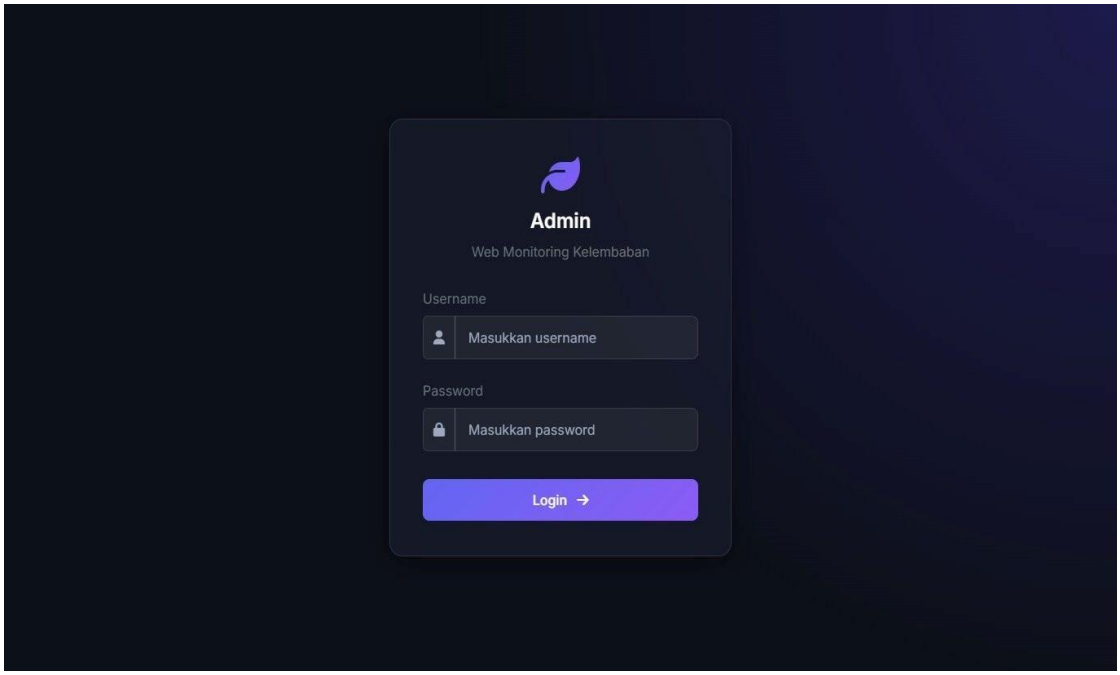


Figure 1. Admin Login Page of the Web Monitoring System

Figure 2 shows the homepage (Beranda) of the web monitoring system. The page displays current soil conditions including temperature in Celsius, soil moisture percentage, and pH level (7.6). The system identifier "SISKOM 2023" and soil type label are also displayed as contextual information.

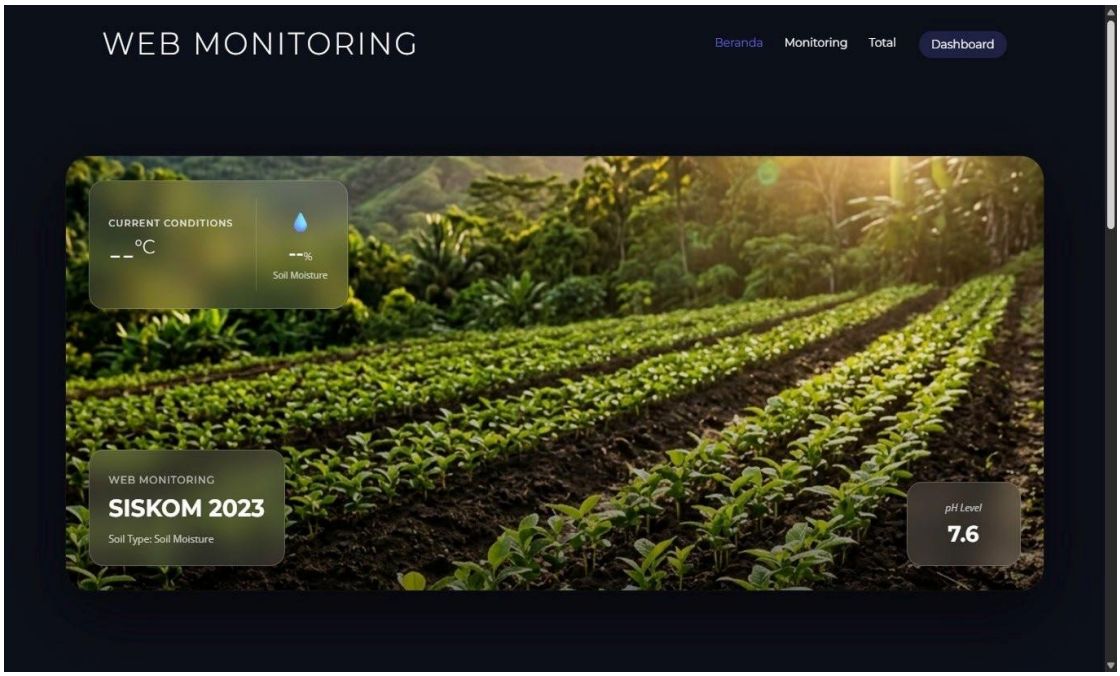


Figure 2. Homepage (Beranda) of the Web Monitoring System

Figure 3 displays the admin dashboard interface (Admin IoT), which presents key monitoring statistics including total records, daily records, average moisture (Avg Kelembaban), and sensor online/offline status. A dynamic line chart visualizes the 7-day moisture trend, while the most recent sensor data entries are listed in the Data Terbaru panel.

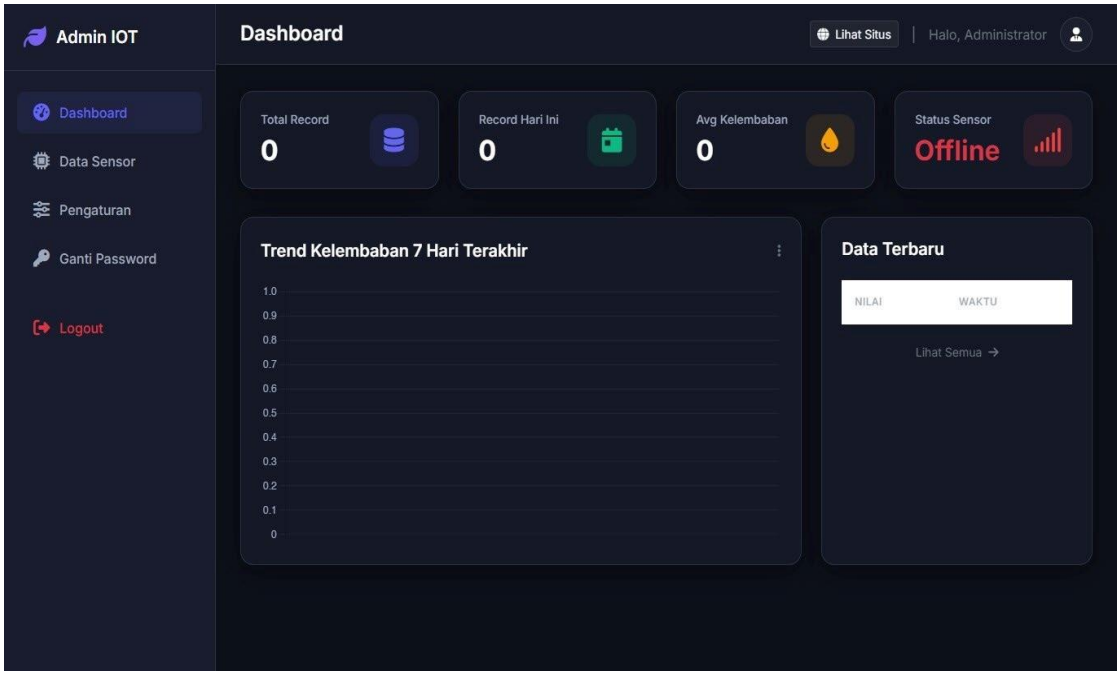


Figure 3. Admin Dashboard Displaying Moisture Statistics and 7-Day Trend Chart

Figure 4 presents the Monitoring page of the public web interface. This page displays the current sensor status and provides statistics on the number of records transmitted by the sensor for the current date as well as the total records stored in the database server.



Figure 4. Monitoring Page Displaying Sensor Status and Record Statistics

Figure 5 illustrates the additional information section (Informasi Lainnya) on the public web page, which provides a summary of the daily and total record counts stored in the database.



Figure 5. Additional Information Section of the Public Web Page

4.2 System Performance Evaluation

Table 2 summarizes the performance evaluation results of the system based on testing conducted with the ESP32 microcontroller and the soil moisture sensor.

Table 2. System Performance Evaluation Results

No.	Parameter	Result
1	Average data update delay (dashboard)	3000 ms
2	Sensor precision (vs. conventional instrument)	40%
3	Data transmission protocol	HTTP (POST request)
4	Database used	MySQL
5	Web interface accessibility	Desktop / Laptop browser
6	Sensor status detection	Online / Offline

The system demonstrated a consistent dashboard update delay of 3000 ms, which is acceptable for agricultural monitoring applications where near-real-time data is sufficient. The sensor precision of 40% compared to conventional instruments indicates room for improvement, particularly in calibration and sensor placement procedures. These results are consistent with findings from similar low-cost capacitive sensor-based systems, where sensor accuracy can be improved through soil-specific calibration [6].

Conclusion

This research successfully designed and developed an IoT-based soil moisture monitoring system with real-time web dashboard visualization. The system integrates a capacitive soil moisture sensor with an ESP32 microcontroller, transmits data via HTTP to a MySQL database, and presents the information through a multi-page web interface accessible on desktop and laptop computers. The web dashboard provides both a public-facing monitoring

page and a secured admin panel featuring a 7-day moisture trend chart, daily and total record statistics, and sensor online/offline status indicators.

Testing results indicate that the system achieves an average dashboard update delay of 3000 ms and a sensor precision of 40% relative to conventional instruments. While the precision level requires further improvement through sensor calibration, the system demonstrates functional viability as a prototype for educational and small-scale agricultural monitoring purposes. Future development should focus on improving sensor accuracy through soil-specific calibration, expanding the system to support multiple sensor nodes, and integrating automated irrigation control based on moisture threshold values.

This system is expected to serve as a foundational platform for the development of a more comprehensive smart agriculture system, contributing to improved water use efficiency and crop yield optimization in future applications.

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