Design of an IoT-Based Automatic Irrigation System for Chili Plants

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Abstract: Manual watering of chili plants makes it difficult for farmers to monitor soil moisture levels and ensure consistent, periodic watering. This study aims to design an Internet of Things (IoT)-based automatic irrigation system capable of real-time soil moisture monitoring and automated watering based on soil conditions. The prototyping method was employed, comprising the stages of communication, quick planning, quick design modeling, prototype construction, and deployment and feedback. The system was built using a soil moisture sensor, ESP32, relay, water pump, Firebase Realtime Database, and an Android application. Black Box Testing was conducted to verify that the system functions according to requirements. The results demonstrate that the system can read soil moisture levels, automatically control the water pump based on predefined thresholds, and transmit and display data in real-time via Firebase and the Android application. Testing also confirmed that all core system functions—including sensor readings, pump control, data transmission, and monitoring—operated correctly as designed. Thus, the developed IoT-based automatic irrigation system can assist in monitoring soil conditions and watering chili plants.

Keywords – Internet of Things; ESP32; automatic irrigation; soil moisture; chili plants.

1. INTRODUCTION

Chili plants are a high-value horticultural commodity widely cultivated in Indonesia. Successful chili cultivation depends on various factors, one of which is the availability of sufficient water to meet the plants' needs. Failure to maintain proper soil moisture can hinder plant growth, reduce productivity, and even lead to crop failure. Therefore, effective irrigation management is crucial for maintaining soil moisture levels suitable for chili plant growth [1], [2].

Based on observations and interviews with chili farmers in the Pakem area of Sleman, it was found that the watering process is still carried out manually. This method requires significant time and effort and carries the risk of imprecise irrigation, as the timing and volume of watering rely on the farmers' experience. Furthermore, soil moisture levels can only be assessed through direct on-site observation, rendering the monitoring process less effective—particularly when farmers are not present at the cultivation site.

Advancements in Internet of Things (IoT) technology offer opportunities to develop automated irrigation systems capable of real-time device monitoring and control. In such systems, soil moisture sensors can be utilized to detect soil conditions and provide data that serves as the basis for irrigation decisions. Integrating these sensors with a microcontroller and the internet enables automated watering and facilitates remote monitoring of field conditions [3], [4].

Several studies have developed IoT-based automated watering systems for chili plants. Nalendra and Mujiono [5] developed a chili plant irrigation system that can be monitored via mobile devices. Another study by Syahri and Ulansari [2] utilized a NodeMCU and soil moisture sensors to automate watering based on soil conditions. Meanwhile, Murtado and Suharjo [3] developed an IoT-based smart irrigation system capable of real-time plant condition monitoring. These studies demonstrate that the application of IoT technology can enhance irrigation effectiveness and simplify the monitoring of plant conditions.

Furthermore, the application of technology in the agricultural sector is considered capable of assisting farmers by utilizing systems that are more effective than conventional methods. Leveraging agricultural technology facilitates cultivation activities by reducing manual labor and streamlining land management processes. With these technological advancements, the implementation of Internet of Things (IoT)-based systems in agriculture offers an alternative for easier and more integrated monitoring and control [6].

Although various studies have developed IoT-based automatic watering systems for chili plants, there remains a need for a system that utilizes soil moisture levels as the primary parameter for automated watering decisions and allows for real-time monitoring. Therefore, this study aims to design an automatic irrigation system capable of watering chili plants in real-time based on soil moisture conditions. The developed system utilizes a soil moisture sensor as the primary data source to control the automatic watering process, thereby helping to maintain soil moisture levels in accordance with the needs of the chili plants.

2. RESEARCH METHODS

This study employs the prototyping method proposed by Roger S. Pressman. This method was selected because it enables incremental system development through the creation of prototypes that can be evaluated and refined until they meet the established requirements. The stages of the prototyping method consist of communication, quick plan, modeling quick design, construction of prototype, and deployment.

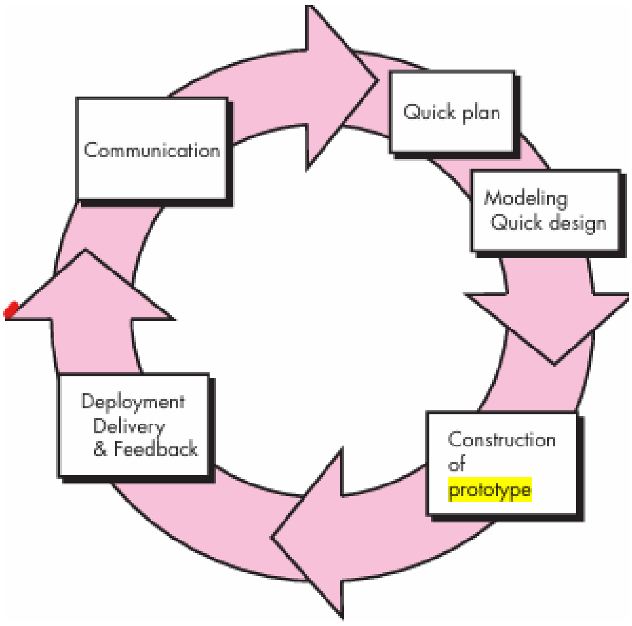

Figure 1. Prototyping Method

The prototyping method employed in this study consists of five stages: communication, quick plan, modeling/quick design, construction of the prototype, and deployment and feedback. The communication stage is conducted to identify system requirements based on observations and interviews. Subsequently, the quick plan and modeling/quick design stages are used to design the system to be developed. The construction of the prototype stage involves realizing the design through the implementation of hardware and software. The final stage, deployment and feedback, is carried out by testing the system using the Black Box Testing method to ensure that all functions operate in accordance with the established requirements.

2.1. Communication

The communication phase was conducted to identify system problems and requirements. Data collection involved observing and interviewing chili farmers in the Pakem area of Sleman. The findings revealed that the watering process was still performed manually, requiring significant time and effort. Additionally, farmers faced difficulties in periodically monitoring soil moisture levels. Based on these results, the system was designed to perform automatic watering based on soil moisture conditions and to provide real-time monitoring capabilities.

Table 1. System Requirements Analysis

No	System Requirements	Description
1	Soil moisture monitoring	Displays real-time moisture levels
2	Automatic watering	Pump activates when the soil is dry
3	Remote monitoring	Accessible via an Android app
4	Data storage	Data is stored on Firebase

2.2. Quick Plan and Modeling Quick Design

This stage involves system planning and design, encompassing both hardware and software components. The system utilizes a soil moisture sensor as the primary input to detect soil conditions. Data acquired by the sensor is processed by an ESP32 to determine the watering status based on the measured moisture level. Subsequently, the data is transmitted to Firebase, enabling real-time display on an Android application.

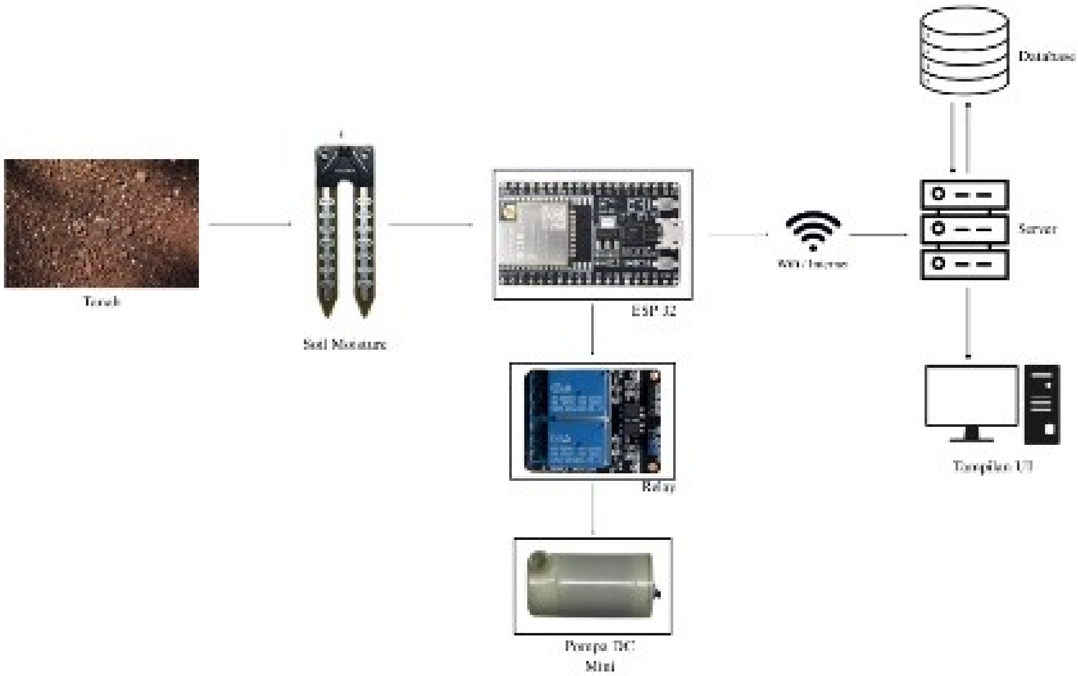

Figure 2. System Architecture

2.3. Construction of Prototype

During the prototype construction phase, the system design was realized as a prototype comprising a soil moisture sensor, an ESP32, a relay, a water pump, an OLED display, the Firebase Realtime Database, and an Android application. The system is designed to periodically measure soil moisture and automatically control the water pump based on predetermined threshold values.

The soil moisture threshold values were determined based on the moisture requirements of chili plants. The optimal soil moisture range for chili plant growth is 60%–80% [1], [7]. Based on these references, the system classifies soil conditions into three categories: dry, moist, and wet. This classification serves as the basis for decision-making during the automatic watering process, ensuring that soil moisture levels are maintained according to the plants' needs.

Table 2. Threshold Value

No	Soil Condition	Humidity Value
1	Dry	<60%
2	Moist	60-80 %
3	Wet	>80%

2.4. Deployment and Feedback

The deployment and feedback phase involved system testing using the Black Box Testing method. The testing aimed to ensure that all system functions operated according to the design. The aspects tested included soil moisture sensor readings, water pump control, data transmission to Firebase, and data monitoring via an Android application. The test results served as a basis for evaluation to ensure the automated irrigation system operated according to the established requirements.

3. RESULT AND DISCUSSION

3.1. System Implementation

The automatic irrigation system designed in this study has been successfully implemented as a prototype comprising a soil moisture sensor, an ESP32 microcontroller, a relay, a water pump, an OLED display, the Firebase Realtime Database, and an Android application. The soil moisture sensor detects the condition of the soil in the chili planting medium and transmits the readings to the ESP32 for processing. Based on the obtained moisture levels, the ESP32 determines the soil condition and automatically controls the water pump according to pre-set threshold values.

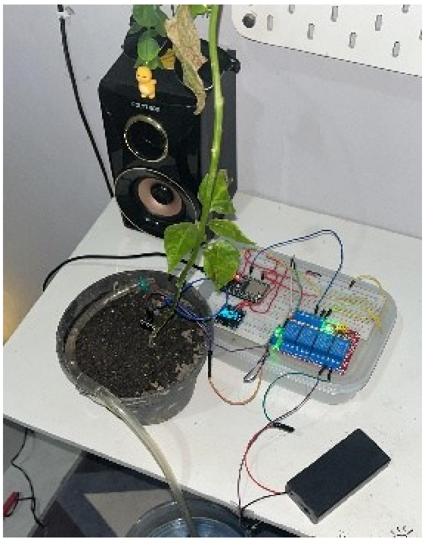

Figure 3. Comparison chart

As shown in Figure 4, the system prototype consists of a chili plant pot equipped with a soil moisture sensor, an ESP32 circuit acting as the main controller, a relay module serving as the interface between the microcontroller and the water pump, and a water reservoir that acts as the water source. In addition to displaying information on an OLED screen, the ESP32 transmits soil moisture data via the internet to Firebase, enabling real-time monitoring of soil conditions through an Android application.

During operation, the soil moisture sensor periodically monitors soil conditions. If the moisture level falls below a predefined threshold, the ESP32 activates the relay, turning on the water pump to deliver water to the growing medium via a watering hose. Once the soil moisture reaches the appropriate range, the pump automatically stops. This mechanism allows the watering process to occur without user intervention, ensuring that soil moisture is maintained according to the chili plants' needs.

3.2. Implementation of Monitoring

To support remote system monitoring, this study implements Firebase Realtime Database for data storage and synchronization. Firebase Realtime Database is a cloud-based database service that enables real-time data storage and updates, allowing connected devices to receive data changes instantly without requiring manual refresh processes [8]. In previous research, Firebase was also utilized to store sensor readings transmitted by an ESP32, making them directly accessible via an Android application for remote monitoring purposes [8]. Data from the soil moisture sensor is transmitted by the ESP32 to Firebase over the internet, enabling real-time access through the Android application. In addition to soil moisture data, the system stores information regarding watering status, watering history, notifications, and system configurations. Through this mechanism, users can obtain real-time information on the system's status and perform remote monitoring via the Android application.

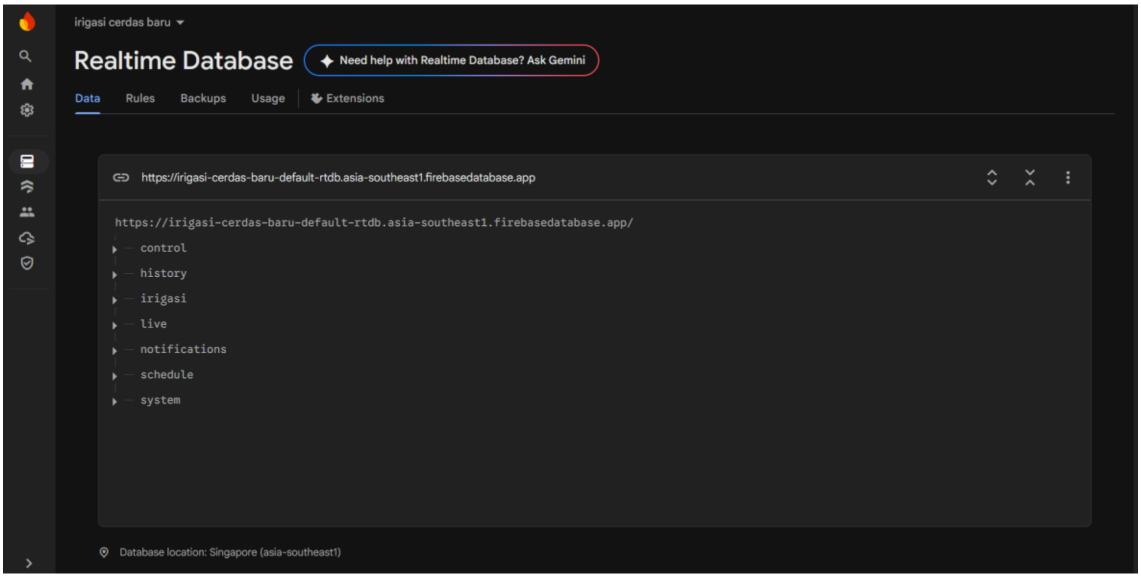

Figure 4. Firebase Realtime Database

As shown in Figure 4, the Firebase Realtime Database serves as the medium for data storage and exchange between the ESP32 device and the Android application. This database stores various data generated by the system—such as irrigation data, watering history, notifications, watering schedules, and soil moisture levels—along with other system data required for monitoring and control operations. The use of Firebase enables real-time data synchronization, ensuring that any data changes transmitted by the ESP32 are immediately received and displayed on the Android application without the need for manual updates.

In addition to data storage, the system includes an Android application that serves as the interface for user interaction. Through this application, users can remotely monitor soil moisture levels, check the status of the soil, and view the watering activities performed by the system. Users can also utilize the stored watering history to track changes in the condition of the growing medium over a specific period.

The integration of the ESP32, Firebase Realtime Database, and the Android application creates a connected system that simplifies monitoring and control tasks. This mechanism eliminates the need for users to physically inspect the soil, as the necessary information is available on the application in real time.

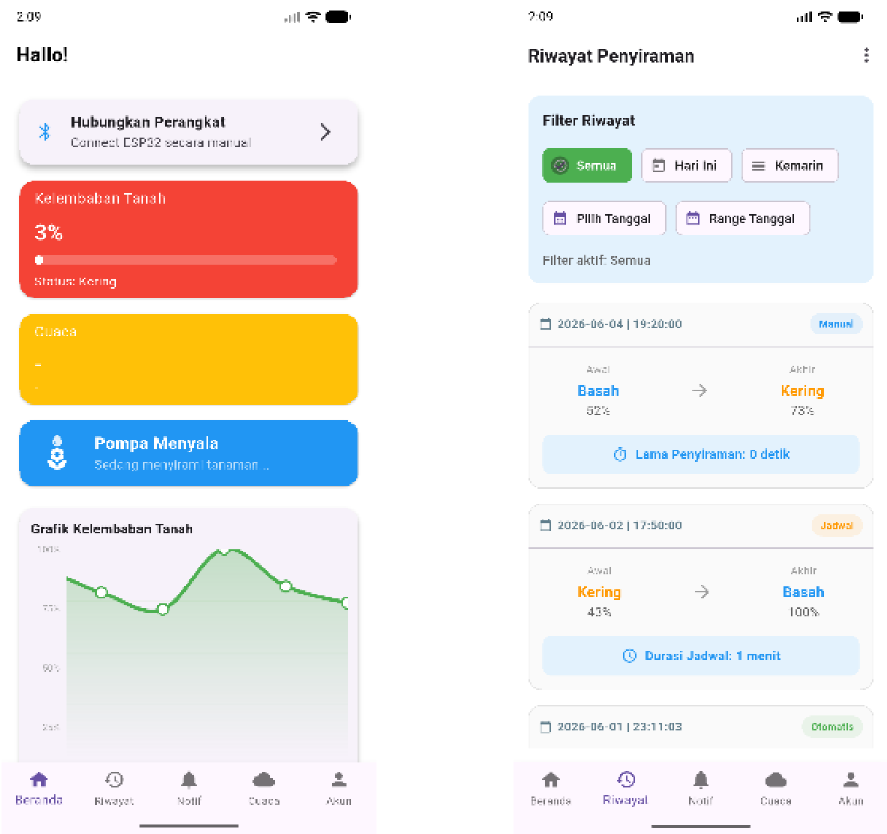

Figure 5. Application Humidity and Watering History

As shown in Figure 5, the Android application displays a watering history that includes the watering date, watering type, initial and final soil moisture levels, and watering duration. A filtering feature is also provided to allow users to easily search for data based on specific dates or desired date ranges. With this feature, users can monitor watering activities and changes in soil moisture conditions in a more convenient and structured manner.

3.3. Auto-save Results

Automatic watering tests were conducted to assess the system's ability to autonomously control the watering process based on soil moisture readings from the sensor. In this test, a soil moisture sensor monitored the growing medium in real-time, transmitting data to an ESP32 microcontroller for processing. The system compared the measured moisture level against a predefined threshold to determine whether watering was required. If the soil moisture fell below the minimum limit, the system activated a relay, turning on the water pump to begin automatic watering.

Throughout the watering process, the system continuously monitored soil moisture levels to track changes in the growing medium. Once the moisture level reached the optimal range for chili plant growth—specifically between 60% and 80%—the system automatically deactivated the pump, halting the watering process. This mechanism ensured that watering aligned with the plants' needs while preventing the soil from becoming excessively dry or waterlogged.

In addition to observing soil moisture fluctuations before and after watering, the test evaluated whether the decision-making and pump control functions operated according to the system design. The test results served as the basis for evaluating the system's performance in maintaining soil moisture levels throughout the testing period.

Table 3. Watering History

No	Date	Time	Initial Value (%)	Final Score (%)
1	May 29, 2026	14:53	52%	74%
2	May 30, 2026	02:13	68%	72%
3	May 31, 2026	12:46	62%	71%
4	June 1, 2026	06:24	58%	88%
5	June 2, 2026	06:00	43%	100%

Based on the test results in Table 3, the system is capable of increasing soil moisture levels following the watering process. When the sensor detects that the soil is in a dry state, the ESP32 activates the relay, turning on the water pump to supply water to the growing medium. Once the soil moisture reaches the predetermined level, the system automatically halts the watering process.

The test results demonstrate that the automatic watering mechanism operates according to the designed logic. The soil moisture sensor serves as the primary parameter for watering decisions, enabling the water supply process to function automatically without user intervention. Consequently, the system helps maintain soil moisture within the optimal range for chili plant growth.

The results indicate that the system effectively raises soil moisture levels to the specified range during the watering process. This watering mechanism, driven by soil moisture sensor readings, aligns with the research conducted by [9], which implemented an IoT-based automatic watering system using soil moisture sensors as the basis for watering decisions. In that study, the system periodically monitored soil conditions, transmitted data to a monitoring platform in real-time, and automatically activated the pump based on the state of the growing medium to maintain soil moisture within the desired range. Thus, the findings of this study demonstrate that a soil moisture-based watering approach can be successfully applied to automatically maintain the condition of the growing medium.

3.4. Black Box Testing

Black-box testing was conducted to ensure that every function of the system operates according to the established requirements [10]. The testing focused on the system's primary functions: soil moisture sensor reading, water pump control, data transmission to Firebase, and data monitoring via an Android application.

Table 4. Blackbox Testing

No	Testing Scenarios	Expected Results	Status
1	Soil moisture sensor reading	Soil moisture readings are displayed on the OLED screen and the app.	Successful
2	Automatic watering when soil is dry	The relay and pump activate automatically when moisture is <70%.	Successful
3	Stopping the watering process	The relay deactivates and the pump stops when moisture is >70%.	
4	Data transmission to Firebase	Moisture data is stored in Firebase when the ESP32 is	Successful

		connected to the internet.	
5	Application-based monitoring	Moisture data and pump status are displayed on the app.	Successful
6	Storage of watering history	Historical data is stored within the app.	Successful

4. CONCLUSION

Berdasarkan hasil perancangan, implementasi, dan pengujian yang telah dilakukan, sistem An Internet of Things (IoT)-based automatic irrigation system for chili plants has been successfully developed, meeting the requirements established during the analysis phase. The system utilizes a soil moisture sensor as the primary data source to monitor the condition of the growing medium in real-time. The acquired data is processed by an ESP32 microcontroller to automatically determine watering actions based on the measured soil moisture levels. Furthermore, the integration of the ESP32, Firebase Realtime Database, and an Android application enables remote monitoring of soil conditions and watering activities via the internet. With this system, users can obtain real-time information on soil moisture levels without needing to physically inspect the plants on-site.

Implementation results demonstrate that the system effectively performs integrated monitoring and control functions. The soil moisture sensor accurately reads the condition of the growing medium, while the ESP32 successfully processes data and controls the relay and water pump according to the designed watering logic. Sensor readings are successfully transmitted to and stored in the Firebase Realtime Database, allowing for real-time display on the Android application. Testing indicates that the system successfully increases soil moisture levels following the watering process and maintains moisture within the optimal range for chili plant growth. Consequently, the developed system offers an alternative solution for more effective plant watering and monitoring compared to manual methods.

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