Design and Implementation of an IoT-Based Automatic Irrigation System Using Soil Moisture Sensors and Automated Water Gate Control

David JM Sembiring[1], Junaidi[1*], Roberto Kaban[1], Asprina Br Surbakti[2], Ita Margaretta Br Tarigan[1]

[1]Faculty of Science and Technology, Informatics Engineering Study Program, Indonesian Institute of Technology and Business, Medan, Indonesia
[2]Faculty of Science and Technology, Information Technology Study Program, Indonesian Institute of Technology and Business, Medan, Indonesia
Email: [1]davidjmsembiring@gmail.com, [2,*]Ijun070900@gmail.com, [3]roberto.kaban@yahoo.com, [4]Asprina.surbakti28@gmail.com, [5]itamargaretta1997@gmail.com
(* : coressponding author)

Abstrak

This research, titled "Design and Construction of an IoT-Based Automatic Irrigation System Using Soil Moisture Sensors and Automatic Air Control," addresses the ineffectiveness of traditional irrigation methods, which cause air waste or freeze plants, due to their lack of real-time adaptation to environmental conditions.This research aims to implement an Internet of Things (IoT)-based automatic irrigation system by integrating soil moisture sensors and automatic air gate controls to manage air in real time based on plant needs and environmental conditions. This system utilizes an ESP32 microcontroller with Wi-Fi connectivity for remote monitoring and control via mobile devices or computers. This technological integration increases agricultural productivity, reduces air consumption, and maintains optimal soil moisture levels, contributing to sustainable air resource management amidst the challenges of climate change.

Keywords: Internet of Things (IoT); Automatic Irrigation System; Soil Moisture Sensor; ESP32; Automatic Water Flow Control; Remote Monitoring and Control

1. INTRODUCTION

Agriculture plays a vital role in meeting Indonesia's food needs, yet irrigation efficiency remains a major challenge particularly in the face of climate change and limited water resources. One of the key issues with traditional irrigation systems is their inability to adapt to changing environmental conditions, especially soil moisture levels. In most cases, watering is carried out based on fixed schedules or farmers' subjective estimates, rather than actual data on crop water requirements. This often leads to two problems: water waste, when irrigation is applied while the soil is still sufficiently moist, causing excess water to be lost through percolation or surface runoff; and water shortages, when irrigation is delayed or insufficient, leaving plants under water stress. Such stress reduces growth, lowers yields, and diminishes production quality. These challenges are further exacerbated by climate change, which disrupts rainfall patterns and makes water availability unpredictable. Without the ability to respond to real-time soil moisture conditions, traditional irrigation systems remain a significant barrier to achieving efficient and sustainable agriculture.

The development of Internet of Things (IoT) technology offers a promising solution to these challenges. By integrating soil moisture sensors with automated control systems, irrigation can be adjusted in real time according to the actual needs of crops, ensuring more efficient water use, reducing waste, and maintaining soil moisture at an optimal level for healthy plant growth. Devices such as the ESP32 microcontroller, which supports both Wi-Fi and Bluetooth connectivity, make this possible. Through remote monitoring and control via smartphones or computers, farmers can make timely irrigation decisions even when they are not physically present in the field. This integration of technology not only enhances agricultural productivity but also supports sustainable water resource management in the face of climate change.

Previous studies have shown that implementing IoT-based automatic irrigation systems can improve water-use efficiency by up to half compared to conventional methods. The use of microcontrollers such as the ESP32, combined with IoT capabilities for remote monitoring and control, has proven effective in optimizing irrigation management and reducing water waste. (Pradana et al., 2025)

According to research by (Purnama et al., 2024) an irrigation system was designed using the ESP32 microcontroller to support sustainable agriculture with remote monitoring and control capabilities. By integrating soil moisture sensors with the ESP32 microcontroller, the system was able to optimize greenhouse irrigation, reducing water usage by up to 30% while also improving irrigation efficiency in terms of time management. In addition, a soil moisture monitoring system was developed using a combination of Soil Moisture, Ultrasonic, and DHT11 sensors connected to IoT, which proved effective in supporting automatic irrigation decision-making.

According to research by (Feri et al., 2024) a Wireless Sensor Network (WSN) based on LoRa was utilized to manage cassava irrigation adaptively through both drip and rainfed systems, with data stored in the cloud for easier monitoring via web and mobile applications. These findings, along with previous studies, strengthen the evidence that integrating IoT, soil moisture sensors, and automated control technologies can provide more efficient, water-saving, and crop-specific adaptive solutions compared to conventional irrigation methods.

According to research by (Strata et al., 2021) IoT-based irrigation systems can reduce water usage by up to half compared to traditional methods while also improving farmers' work efficiency. With control accessible through smartphones or web applications, farmers are able to monitor and manage their fields remotely, even from home.

Based on this, the author intends to design a practical, efficient automatic irrigation gate that is easy to carry and move. The device will be built around the ESP32 microcontroller — a successor to the ESP8266 from Espressif Systems that combines Wi-Fi and Bluetooth Low Energy on a single chip. The ESP32's programmability and the wide availability of libraries and documentation make it convenient to program and customize.

The device will take input from a soil moisture sensor and a water-level sensor. The soil moisture sensor measures the moisture content of the soil, while the water-level sensor monitors the height of the water. Using command buttons on a keypad, the user can request measurements, and the readings will be shown on an LCD screen.

2. RESEARCH METHODE

2.1 Internet of Things (IoT)

The Internet of Things (IoT) is a technological concept that connects various physical devices to the internet, enabling them to communicate with one another, exchange data, and be controlled remotely. IoT allows for real-time data collection from the surrounding environment, information processing, and the execution of automated actions or decision-making without the need for direct human intervention.

According to (Selay et al., 2022) the Internet of Things (IoT) is a technological concept that enables physical devices such as sensors, actuators, microcontrollers, vehicles, and household appliances to connect to the internet, allowing them to communicate, transmit data, and operate automatically without direct human intervention. This marks a major shift in the use of technology, as devices that once functioned independently can now be integrated into a smarter digital ecosystem. In agriculture, the application of IoT provides farmers with the opportunity to remotely monitor field conditions and reduce human error in resource management. IoT is therefore regarded as a vital foundation for developing systems that are efficient, adaptive, and oriented toward long-term sustainability.

2.2 Mikrokontroler ESP 32

The ESP32 microcontroller, developed by Espressif Systems, is equipped with integrated Wi-Fi and Bluetooth modules, making it widely used in Internet of Things (IoT) projects. It offers relatively fast processing capability, low power consumption, and support for multiple interfaces such as GPIO, ADC, DAC, SPI, I^2C, and UART.

According to (Imran, 2020) the ESP32 is an upgraded version of the ESP8266, with advantages including a dual-core processor, larger memory, and built-in Wi-Fi and Bluetooth modules. It also allows system monitoring and control directly over the internet without requiring additional hardware, thereby improving power efficiency and supporting more complex system integration.

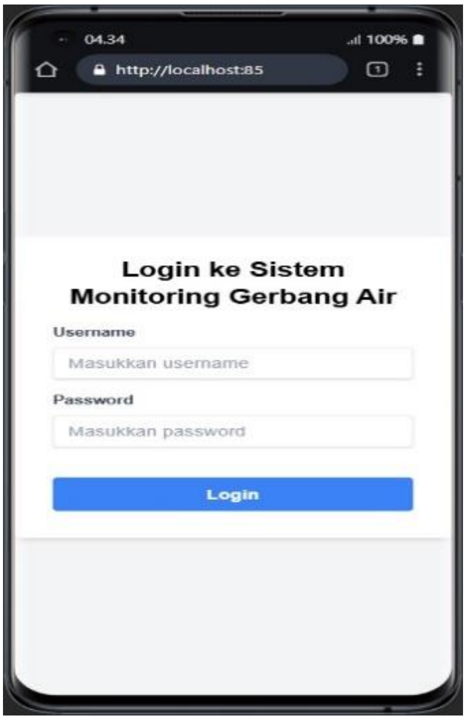
The ESP32 is a low-power microcontroller well-suited for IoT system development. With a large number of input/output (I/O) pins, it provides flexibility for connecting sensors and actuators as needed. It also supports multiple communication protocols such as I^2C, SPI, and UART, enabling it to function as a central controller in systems requiring device integration. Moreover, the ESP32 can be programmed using platforms like Arduino IDE, PlatformIO, and MicroPython, making it highly accessible to both researchers and practitioners. As highlighted by (Hercog et al., 2023) the ESP32 is not just a piece of hardware but part of a broader development ecosystem that fosters creativity, innovation, and the advancement of more complex and well-structured IoT systems.

3. RESULT AND DISCUSSION

3.1 Result

The presentation of results is an essential part of any research or system design, serving as a visual and descriptive representation of the implemented system, both in terms of hardware and software. This section provides concrete evidence of the system's success, illustrates the connection between the initial design and the final realization, and helps readers understand the workflow, functionality, and role of each component or feature developed. By including elements such as user interfaces, system diagrams, device photographs, simulations, or testing outcomes, this section demonstrates how the system has been fully implemented and whether it aligns with the predetermined specifications.

The software interface represents the visual aspect of a program displayed on a computer screen or other device, functioning as the bridge between users and the system. This interface typically consists of menus, icons, buttons, text, and graphics, all designed to make the system more user-friendly by simplifying command execution, data processing, and information retrieval. A simple, clear, and intuitive interface design improves user comfort and efficiency in operating the software. In this project, the login page of the Water Gate Monitoring System web application accessible via mobile devices serves as the authentication gateway before users can enter the main dashboard.



Login ke Sistem Monitoring Gerbang Air

Username

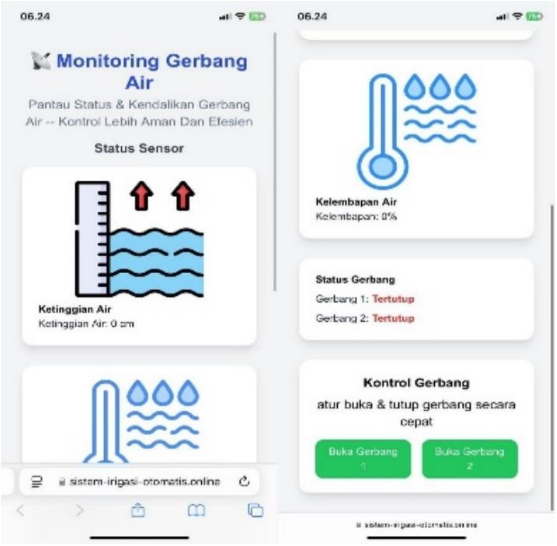
Masukkan username

Password

Masukkan password

Figure 1. Login Page

This page provides an authentication mechanism requiring users to enter their credentials in the form of a username and password for identification and verification. The system ensures that only authorized users with valid access rights can enter the dashboard area. The login page can be accessed through the address sistem-irigasi-otomatis.online, indicating that the system is already hosted online and accessible via the internet. The dashboard interface of the Water Gate Monitoring System, when accessed on a mobile device, displays key information such as sensor status, water level, temperature, and both automatic and manual controls for opening and closing the water gate. This interface enables users to monitor and manage the irrigation system efficiently, anytime and anywhere.



Monitoring Gerbang Air

Pantau Status & Kendalikan Gerbang Air -- Kontrol Lebih Aman Dan Efesien

Status Sensor

Ketinggian Air

Ketinggian Air: 0 cm

Kelembapan Air

Kelembapan: 0%

Status Gerbang

Gerbang 1: Tertutup

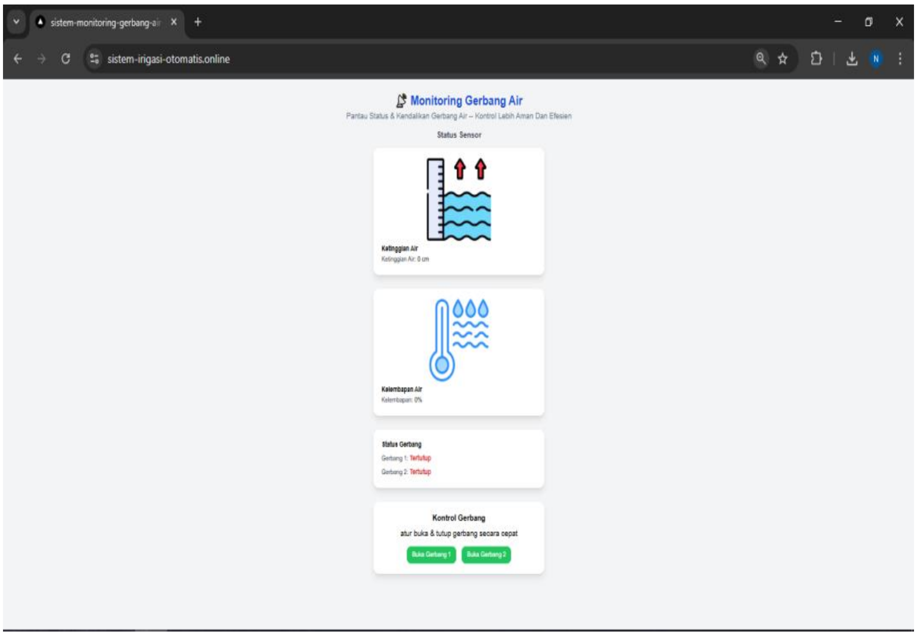
Gerbang 2: Tertutup

Kontrol Gerbang

atur buka & tutup gerbang secara cepat

Figure 2. Monitoring Dashboard Website on Mobile Devices

The dashboard interface of the Water Gate Monitoring System, when accessed via a computer, displays real-time information such as water level sensor readings, temperature, gate status, and both automatic and manual controls for opening and closing the water gate. This view allows users to easily monitor system performance and manage irrigation operations directly through the website, ensuring more efficient and responsive water management.



Monitoring Gerbang Air

Pantau Status & Kendalikan Gerbang Air – Kontrol Lebih Aman Dan Efesien

Status Sensor

Ketinggian Air
Ketinggian Air: 0 cm

Kelembapan Air
Kelembapan: 0%

Status Gerbang
Gerbang 1: Tertutup
Gerbang 2: Tertutup

Kontrol Gerbang
atur buka & tutup gerbang secara cepat

Figure 3. Monitoring Dashboard Website on Laptop

The device shown in the figure below represents the prototype of an IoT-based automatic irrigation system, which utilizes soil moisture sensors and an automated water gate. This system is designed to support efficient crop growth by ensuring precise water distribution, reducing waste, and enabling real-time monitoring and control through an online dashboard.

Figure 4. Hardware Display

The hardware setup consists of a circuit box containing the ESP32 microcontroller board as the central control unit, connected to various electronic components such as servos, sensors, and a battery. Cables and connectors are used to link the sensors, servos, and power module. LED indicators (red and green) serve as operational status markers—for example, showing when the system is powered on, when irrigation is in progress, or when the system is in standby mode. An LCD screen functions as a visual output, displaying real-time soil moisture levels detected by the sensors to indicate irrigation status, as well as the water level in the tank or container.

The prototype also includes a planting medium with growing rice plants. Soil moisture sensors are embedded in the medium to continuously monitor water content. Servo motors are installed at the top and bottom of the container to control the water gate or the automatic opening and closing mechanism of the irrigation channel. Connecting cables between the electronic control unit and the planting area ensure that sensor data is transmitted to the microcontroller, and that servos operate according to programmed logic. Integrated with IoT and web-based monitoring, the system enables users to remotely observe and control the entire irrigation process.

3.2 Discussion

The IoT-based automatic irrigation system using soil moisture sensors and automated water gate control operates under three main conditions related to the status of water flow gates. The first condition occurs when the input gate is open while the output gate is closed, allowing water to enter the system without being released to the irrigation area. The second condition takes place when both the input and output gates are closed, indicating that no water flows in or out because the irrigation requirements have already been met. The third condition occurs when the input gate is closed and the output gate is open, meaning that the system is distributing water to the irrigation area through the output channel while stopping water intake from the input source, as sufficient water is already available. All data generated from each condition—including water level, soil moisture status, and gate positions—are stored and transmitted to the server for real-time monitoring and analysis. The prototype displays soil moisture data and irrigation status on the LCD screen, while the green LED indicator signals that the input gate is open and the output gate is closed.

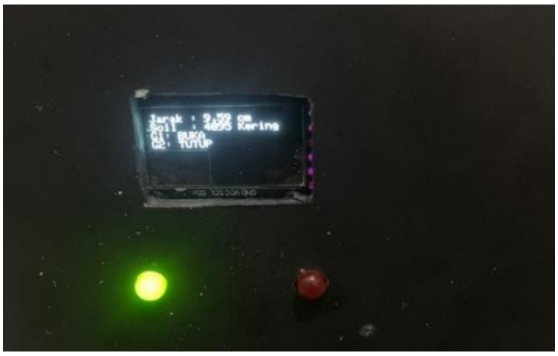


Figure 5. LCD Display with Input Gate Open and Output Gate Closed

The LCD display in Figure 5 shows the condition where the input gate is open and the output gate is closed. It functions as a visual interface that presents real-time information from sensor readings and actuator status. The data displayed is also transmitted to the server for monitoring and further analysis.

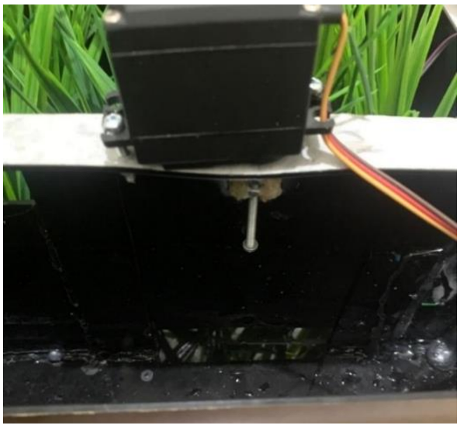


Figure 6. Input Gate Open Display

In Figure 6, the system shows the condition where the input gate is open, allowing water from the input irrigation channel to flow into the planting area.

Figure 7. Output Gate Closed Display

In Figure 7, the system shows the condition where the output gate is closed, allowing water to remain in the planting area so that the soil can absorb sufficient moisture.

Table 1. Results of Input Gate Open and Output Gate Closed

	Parameter	Displayed Data	Status
Testing Time 08:15:00 WIB	Water Level	9.59 cm	Active
	Soil Moisture	4095 (Dry)	Active
	Input Gate	Open	Active
	Output Gate	Closed	Active

In Table 1, the recorded water level shows a value of 9.59 cm, indicating the position of the water surface inside the container. Under active conditions, this ensures that the system can verify water availability before initiating the irrigation flow. The soil moisture reading displays a value of 1405, classified as dry, which means the soil requires additional water. The Input Gate status is shown as open, meaning water is flowing through the primary irrigation channel, while the Output Gate status is closed to allow water to fully fill the planting area. The prototype, as illustrated in Figure 8, displays soil moisture data and irrigation status on the LCD screen, with the red LED indicator signaling that both the input and output gates are closed.

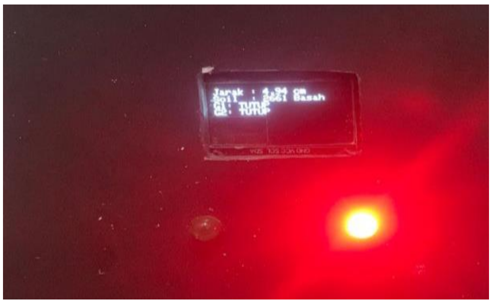


Figure 8. LCD Display with Input Gate Closed and Output Gate Closed

The LCD interface in Figure 8 shows the condition where both the input and output gates are closed. It functions as a real-time visual display of sensor readings and actuator status, with all data transmitted to the server for monitoring.

Figure 9 Input and Output Gates Closed Display

In Figure 9, the condition shown is when both the input and output gates are fully closed. This ensures that no water leaves the irrigation container since the stored water level is already sufficient.

Table 2 Results of Input Gate Closed and Output Gate Closed

	Parameter	Displayed Data	Status
Testing Time 08:20:00 WIB	Water Level	4,94 cm	Active
	Soil Moisture	**2661(Wet)**	Active
	Input Gate	Closed	Active
	Output Gate	Closed	Active

In Table 2 shows a recorded water level of 5.92 cm in active status, indicating that the water level sensor is functioning properly and the reservoir still contains water. The soil moisture value is 1122, categorized as *wet* and active, meaning the plants already have sufficient water. Both the Input Gate and Output Gate are in a *closed* and *active* state, confirming that no irrigation flow is being supplied since the reservoir is already adequately filled. The prototype in Figure 10 displays soil moisture data and irrigation status on the LCD screen, while the red LED indicator signals that the Input Gate is closed and the Output Gate is open.

Figure 10 LCD Display of Closed Input Gate and Open Output Gate

The LCD display in Figure IV.10 shows the condition where the Input Gate is closed and the Output Gate is open. It functions as a visual interface that presents real-time information from the sensor readings and actuator status. The data displayed on the screen is also transmitted to the server for monitoring and analysis.

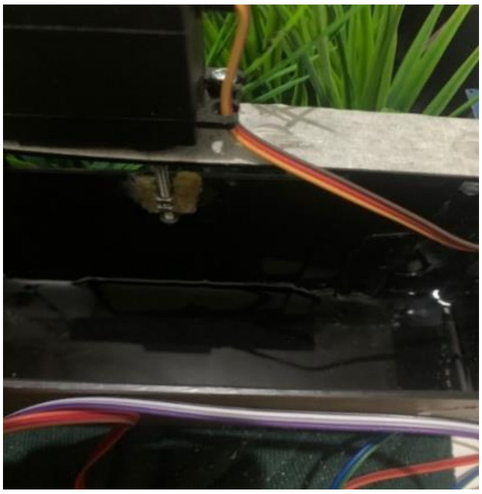


Figure 11 Input Gate in Closed Position

Figure 11 illustrates the condition where the input gate is fully closed, ensuring that no water flows out from the irrigation reservoir.

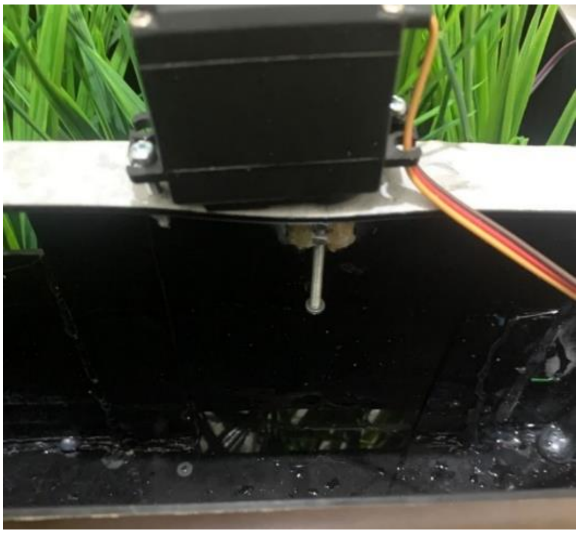


Figure 12 Output Gate in Open Position

Figure 12 shows the output gate in an open state, indicating that the water level in the reservoir has exceeded the predefined threshold, allowing excess water to be released.

Table 3 Results of Closed Input Gate – Open Output Gate Condition

	Parameter	Displayed Data	Status
Testing Time 08:25:00 WIB	Water Level	5,92 cm	Active
	Soil Moisture	**2630(Wet)**	Active
	Input Gate	Closed	Active
	Output Gate	Open	Active

Table 3 presents water level data of 5.92 cm in active condition, indicating that the water level sensor is functioning properly and the reservoir still contains water. The soil moisture value is recorded at 2630, with a status of *wet*, which suggests that the plants already have excess water. In this scenario, the input gate is closed while the output gate is open, meaning the system is releasing water through the output channel while stopping water inflow from the input channel, as the reservoir already has sufficient water.

Based on the experimental results conducted under three different gate conditions, it can be concluded that the automated irrigation system is capable of regulating water flow according to plant needs through a coordinated mechanism of opening and closing the input and output gates. In the first condition, the input gate is open and the output gate is closed to allow water from the reservoir to irrigate dry soil and restore adequate moisture. In the second condition, both gates remain closed because the soil moisture level is sufficient, and no additional water flow is required. In the third condition, the input gate is closed while the output gate is open to release excess water from the reservoir through the output channel, functioning as a drainage or water volume regulation mechanism. All these processes occur in real-time, with sensor data and actuator status continuously stored and transmitted to the server, supporting accurate monitoring and efficient decision-making

4. CONCLUSION

Based on the design, implementation, and testing of the IoT-based automatic irrigation system, the developed system is capable of regulating water distribution automatically in real time using data from water level and soil moisture sensors. The system can control the opening and closing of input and output gates as needed while transmitting monitoring data to a server for storage and analysis, thereby reducing reliance on manual irrigation. Testing under three different conditions demonstrated that the system was able to respond effectively to crop irrigation requirements while maintaining balanced water levels in the reservoir. Each test condition showed the system's ability to regulate water flow accurately, ensure water availability in the planting area, and optimize the use of water resources according to field conditions. The system has functioned as intended, though some limitations remain, such as its dependence on stable internet connectivity and the need for periodic sensor calibration to ensure accuracy. Future developments are expected to expand the application of this system, making it more widely adopted and optimized for agricultural use.

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