

Prototype of an Internet of Things-Based Irrigation System Using Soil Moisture Sensors for Monitoring Rice Field Drought in Lape Village

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ABSTRAK

Pengelolaan air pada lahan persawahan masih menjadi tantangan, terutama pada kondisi kekeringan akibat sistem irigasi manual yang kurang optimal. Ketidaktepatan waktu dan volume air menyebabkan tanaman tidak mendapatkan pasokan air yang cukup. Penelitian ini bertujuan untuk mengembangkan prototipe sistem irigasi otomatis berbasis Internet of Things (IoT) menggunakan ESP32 dengan metode logika fuzzy untuk mengurangi risiko kekeringan pada lahan pertanian. Sistem ini memantau kondisi lahan dan mengendalikan proses irigasi secara otomatis melalui platform berbasis web dengan memanfaatkan sensor kelembaban tanah dan sensor ultrasonik. Metode penelitian yang digunakan adalah pendekatan kuantitatif eksperimen melalui perancangan dan pengujian sistem. Hasil penelitian menunjukkan bahwa sistem mampu mengontrol pintu air dan pompa secara otomatis berdasarkan keluaran logika fuzzy sehingga menghasilkan irigasi yang lebih presisi. Berdasarkan hasil pengujian, sistem menghasilkan nilai logika fuzzy pada rentang 0,0–1,0 sesuai kondisi kelembaban tanah dan ketersediaan air. Sistem mampu mengaktifkan pintu irigasi secara otomatis pada sudut bukaan 45° dan 90°, serta mengaktifkan pompa air ketika sumber air utama tidak mencukupi kebutuhan irigasi. Sistem ini diharapkan dapat meningkatkan efisiensi penggunaan air pada lahan persawahan.

ABSTRACT

Water management in rice fields remains a challenge, especially during drought conditions caused by suboptimal manual irrigation systems. Inaccurate timing and water volume often lead to insufficient water supply for crops. This study aimed to develop a prototype of an automatic irrigation system based on the Internet of Things (IoT) using ESP32 and a fuzzy logic

method to reduce the risk of drought in agricultural land. The system monitors field conditions and controls irrigation automatically through a web-based platform utilizing soil moisture sensors and ultrasonic sensors. The research employed a quantitative experimental approach through system design and testing. The results showed that the system was capable of automatically controlling water gates and pumps based on fuzzy logic outputs, enabling more precise irrigation. Experimental testing indicated that the system generated fuzzy logic values ranging from 0.0 to 1.0 according to soil moisture and water availability conditions. The system was able to automatically operate irrigation gates at opening angles of 45° and 90°, and activate the water pump when the primary water source was insufficient. This system is expected to improve water use efficiency in rice fields.

1. INTRODUCTION

Irrigation in rice fields is a crucial activity to fulfill the water requirements of rice crops, which generally depend on irrigation systems as the primary water source. Adequate and stable water availability plays an important role in determining plant growth processes and harvest yields. However, during the dry season, many agricultural areas experience limited water supply, reducing irrigation effectiveness. This condition is worsened by suboptimal irrigation management systems, which often cause uneven water distribution and make it difficult to meet crop water requirements at specific growth stages [1].

Lape Village is one of the agricultural areas where the majority of the population works as rice farmers. In rice

cultivation activities, irrigation management is an important factor that greatly affects the quality and quantity of harvest yields. However, the regulation of irrigation timing and volume in the field still faces various constraints. Farmers generally rely on visual observation to assess soil conditions, so irrigation decisions are often inconsistent with the actual needs of the plants. As a result, water use becomes less efficient and rice productivity may decrease [2].

Irrigation problems in Lape Village become more severe during the dry season when irrigation water discharge decreases. Several rice field plots connected to a single main channel must take turns receiving water according to a predetermined irrigation schedule. In this rotational irrigation system, upstream plots tend to receive water

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earlier and in larger quantities, while middle and downstream plots often receive only the remaining water, which is insufficient for crop needs. In addition, the lack of coordination in shared water use causes unauthorized water withdrawal, potentially leading to conflicts among farmers [3].

The limited time available for farmers to continuously monitor field conditions is also a challenge. The process of opening and closing irrigation channels is still performed manually and often experiences delays, causing irrigation schedules not to run as planned. This condition leads to an imbalance in water distribution among rice field plots and reduces the overall effectiveness of the irrigation system [4].

Along with the development of information technology, the application of the Internet of Things (IoT) in agriculture offers a potential solution to these irrigation problems. The use of soil moisture sensors and water level sensors integrated with automatic control systems enables real-time and more accurate monitoring and irrigation management. Several previous studies have shown that IoT-based irrigation systems can improve water use efficiency and support better decision-making in agricultural water resource management [5], [6].

Fuzzy logic was selected in this study because irrigation decision-making involves uncertain and dynamic environmental conditions, particularly variations in soil moisture and water availability. Conventional decision-making methods based on fixed threshold values or simple if-else rules often produce rigid responses and are less capable of representing gradual changes in field conditions. In contrast, fuzzy logic enables the system to process input data using linguistic variables such as dry, moist, and wet, resulting in more flexible and adaptive irrigation decisions that better reflect actual agricultural conditions.

Several previous studies have developed irrigation and agricultural monitoring systems based on the Internet of Things using various approaches and technologies. Kurniawan et al. developed an IoT-based automatic irrigation system using soil moisture sensors and ultrasonic sensors to control water pumps automatically, but the system did not implement a fuzzy logic algorithm and was not integrated with a website monitoring platform [7]. Asmara et al. designed an irrigation monitoring and control system using Arduino Uno that was capable of automatically regulating rice field water levels, but it was not IoT-based and did not use fuzzy logic [8].

Other research conducted by Sihotang developed an irrigation monitoring system based on NodeMCU ESP8266 with real-time data displayed through the Blynk application, but the system only focused on monitoring without automatic irrigation control [4]. Aldiansyah et al. implemented an IoT-based soil moisture monitoring system with a fuzzy logic algorithm in a greenhouse environment and successfully improved water use efficiency, but the application had not been implemented in open rice fields and did not integrate irrigation water level measurement [10]. Meanwhile, Collins et al. developed an IoT-based soil quality monitoring system for rice fields using temperature and soil moisture sensors, but it was not equipped with an automatic irrigation system [11].

Based on the review of previous studies, it can be concluded that most developed systems still have limitations, such as focusing only on monitoring or

automatic watering, not being integrated with a website monitoring platform, and being mostly applied in greenhouse environments or laboratory-scale settings. In addition, some studies have not implemented decision-making that simultaneously considers soil moisture conditions and water availability.

Therefore, this study aims to design and implement a prototype of an automatic rice field irrigation system based on the Internet of Things (IoT) applied directly to rice fields in Lape Village. This system utilizes soil moisture sensors and ultrasonic sensors processed using fuzzy logic theory to control water pumps and irrigation gate servos automatically, and is equipped with a website monitoring platform to display real-time field conditions. The developed system is expected.

2. METHOD

2.1. Materials

This study uses various hardware and software components integrated into an automatic irrigation system based on the Internet of Things (IoT). IoT is a technological concept that connects physical devices, sensors, and computing systems through the internet network to collect and exchange data automatically [1], [12], [13]. In agriculture, IoT is used to support smart farming, including continuous monitoring of soil, crop, and environmental conditions, as well as irrigation automation to improve water use efficiency [1], [2].

The soil moisture sensor is used to measure the water content in the soil based on changes in the sensor's resistance or capacitance. Soil moisture data are classified into three categories in the fuzzification process, namely dry (0–30%), moist (31–60%), and wet (61–100%), which are then used for staged irrigation decision-making [2], [14], [15].

The ultrasonic sensor works based on reflected sound waves to measure water levels in irrigation channels or reservoirs. Water levels are categorized into high (0–3 cm), medium (4–6 cm), and low (7–10 cm), serving as inputs for fuzzy logic [5], [6], [16]. Fuzzy logic is used to process sensor data into irrigation control decisions. This process includes fuzzification, inference, and defuzzification to determine irrigation gate opening angles and pump status (ON/OFF), allowing the system to adjust irrigation according to soil conditions and water availability in real time [9], [10], [17], [18].

ESP32 functions as the main microcontroller that controls the entire system, reads sensors, processes fuzzy logic, and regulates actuators, including the SG90 servo motor for controlling irrigation gate openings and the 12 V DC water pump for automatic water flow [21], [22].

The electrical power system uses a 60 W solar panel that stores energy in a 12 V battery through a Solar Charge Controller (SCC) to maintain charging stability, while the voltage is reduced using an LM2596 step-down module according to system requirements [23], [24].

The website monitoring platform is developed using the Laravel framework and MySQL database, enabling real-time monitoring of soil moisture, water levels, and pump

and servo status through a browser, thereby supporting efficient and integrated system performance evaluation [19], [20].

2.2. Research Method

This study employs a quantitative experimental method, which is a planned and systematic experimental approach that includes tool design, component procurement, monitoring, system development, and device testing.

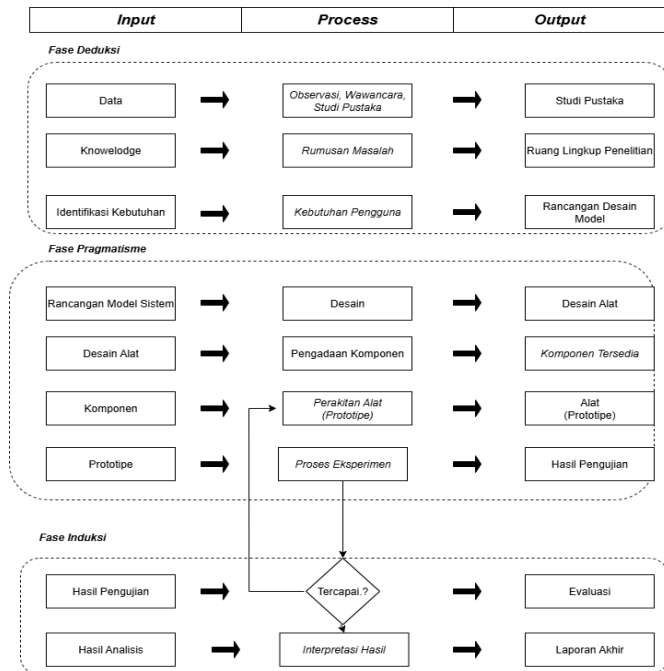


Fig. 1. Research Flowchart

2.3. Data Collection

Data collection in this study uses a mixed methods approach, combining quantitative and qualitative methods. This approach is chosen to obtain comprehensive data through several techniques, including observation, interviews, documentation studies, and literature review.

2.3.1 Observation

Observation was conducted directly in rice fields in Lape Village to obtain factual data regarding soil moisture conditions, water levels in irrigation channels, drought conditions in the field, and manual irrigation management patterns used by farmers. The observation results were used as the basis for determining system requirements and sensor placement in the prototype.

2.3.2. Interview

Interviews were conducted with local farmers to gather information related to irrigation problems, drought frequency, watering needs, and expectations regarding the implementation of an IoT-based irrigation system. The interview data were used to support the design of an automatic system suitable for field conditions.

2.3.3. Documentation Study and Literature Review

Documentation study and literature review were conducted by examining various references such as scientific journals, books, and articles related to IoT-based

automatic irrigation systems, ESP32 implementation, soil moisture sensors, ultrasonic sensors, and fuzzy logic methods. This stage aimed to strengthen the theoretical foundation and support the design of the developed system.

2.4. Requirement Identification

After the data collection stage, requirement identification was carried out to determine the hardware, software, and supporting resources needed in designing the prototype irrigation and drought monitoring system for rice fields. This stage ensures that the developed system can function according to the research objectives.

2.5. System Model Design

The system model design consists of three main parts: tool design, block diagram, and control system design.

2.5.1. Tool Design

Based on the results of requirement identification, the next stage is tool design, which includes designing the system architecture and integration among the main components so that the irrigation and monitoring system can operate optimally.

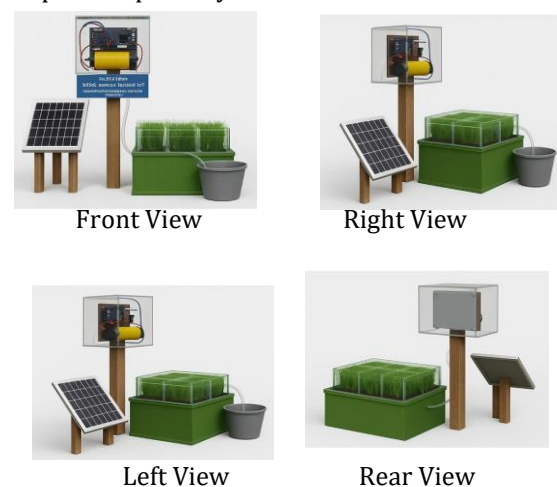


Fig. 2. Tool Design

2.5.2 Block Diagram

The block diagram provides an illustration of the main structure of each component. down module according to system requirements. ESP32 acts as the control center that

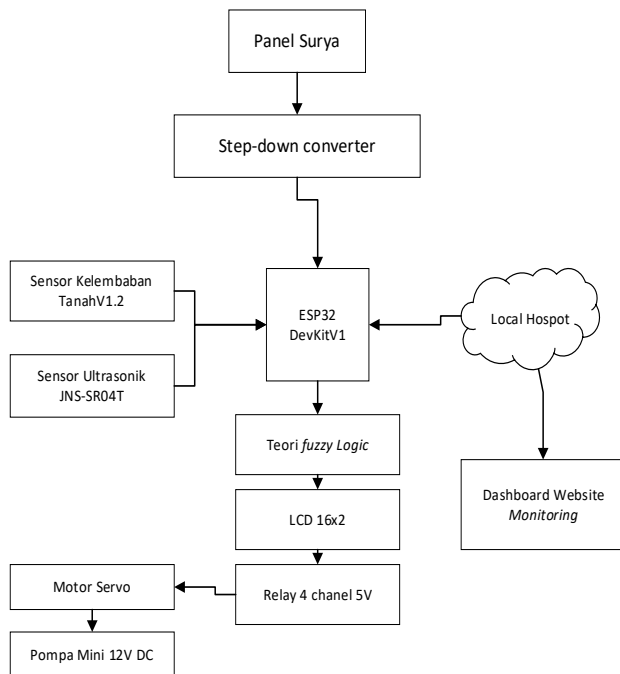


Fig. 3. Block diagram of the system

2.5.3 Control System

The control system stage involves arranging logic and connections more specifically to ensure that each component can function and connect properly.

Overall, the irrigation control system utilizes renewable energy from a 60 W solar panel stored in a 12 V battery through a Solar Charge Controller (SCC). The battery voltage is reduced using an LM2596 step-

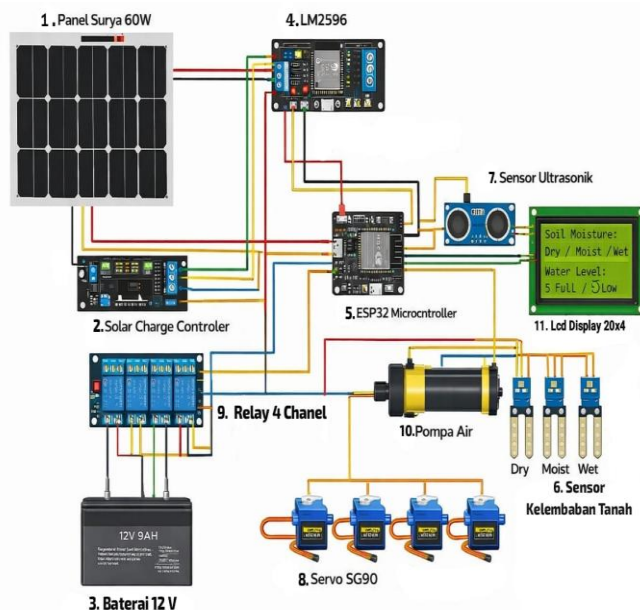


Fig. 4. Control system design

reads soil moisture sensor data and classifies soil conditions into dry (0–30%), moist (31–60%), and wet (61–100%), as well as ultrasonic sensor data to monitor water levels in the main channel and backup reservoir. These data are processed using fuzzy logic to determine irrigation needs based on soil conditions and water

availability. The fuzzy inference results are used by ESP32 to control the SG90 servo motor with opening angles of 0°, 45°, and 90°, and to activate the relay to turn on the 12 V water pump when water is insufficient and the soil is detected as dry. System information is displayed on a 20×4 LCD and transmitted via Wi-Fi-based IoT connection, enabling real-time local and remote monitoring.

2.6 Component Procurement

After the design stage, component procurement was carried out by identifying and collecting all devices required to build the IoT-based irrigation prototype. Components were carefully selected to match the system design and support optimal prototype performance.

2.7 Tool Assembly

The next step after completing component procurement is the assembly process. This stage is carried out based on the designed tool architecture. This stage determines whether the device can operate optimally.

2.8 Experimental Process

In this stage, the assembled device is tested comprehensively to ensure that all components in the system function properly according to the predetermined design and specifications. This stage is performed before data collection to ensure the accuracy of the device in generating the required data.

2.9 Analysis and Evaluation

The final stage of this study is analysis and evaluation, where the test data are analyzed in depth to assess whether the device functions according to the research objectives. This process includes evaluating performance, accuracy, and effectiveness in meeting research needs. The results are expected not only to confirm the success of the prototype but also to serve as a reference for similar future studies.

3. RESULT AND DISCUSSION

3.1 Results

This section presents the system design results based on the research objectives, including the website monitoring interface for displaying soil moisture data and irrigation status in real time, as well as the design of the IoT-based irrigation prototype using soil moisture sensors.

3.1.1 Website Monitoring Design Results

The developed website monitoring platform is used to observe the IoT-based irrigation system in real time. The system displays soil moisture data from four rice field plots, water levels in irrigation channels and reservoir, as well as irrigation system status.

3.1.2. Auto Mode Monitoring Interface

The auto mode interface displays system operation based on fuzzy logic calculations. In this mode, irrigation decisions such as gate opening and pump activation are performed automatically based on sensor data.

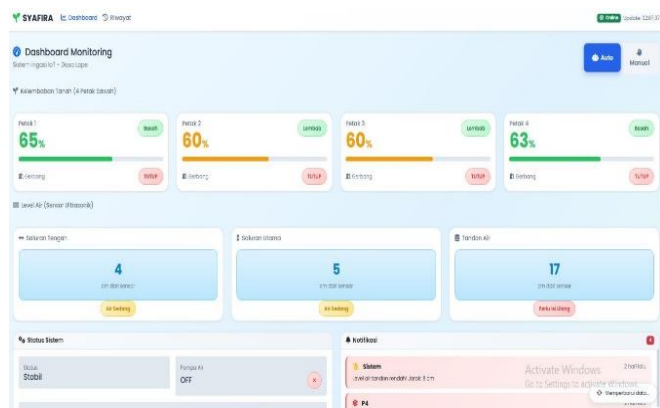


Fig. 5. Website monitoring interface in auto mode

3.1.3. Manual Mode Monitoring Interface

The manual mode interface allows users to directly control the irrigation system through the website by opening or closing irrigation gates.

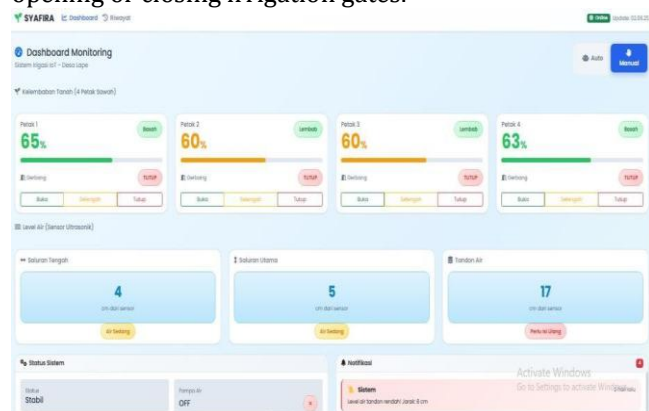


Fig. 6. Website monitoring interface in manual mode

3.1.4. Notification Interface

The The manual mode interface allows users to directly control the irrigation system through the website by opening or closing irrigation gates.



Fig. 7. Website monitoring notification interface

3.1.5. Graph Interface

The graph interface presents sensor readings in graphical form, making it easier for users to analyze changes in soil moisture and water levels over time. This graph is used to monitor data trends and evaluate irrigation system performance continuously.



Fig. 8. Website monitoring graph interface

3.1.6. History Interface

The history interface displays historical monitoring data stored in the system. This history includes soil moisture, water level, and system status information at certain times. This feature functions as evaluation material and documentation to review system performance over a certain period.

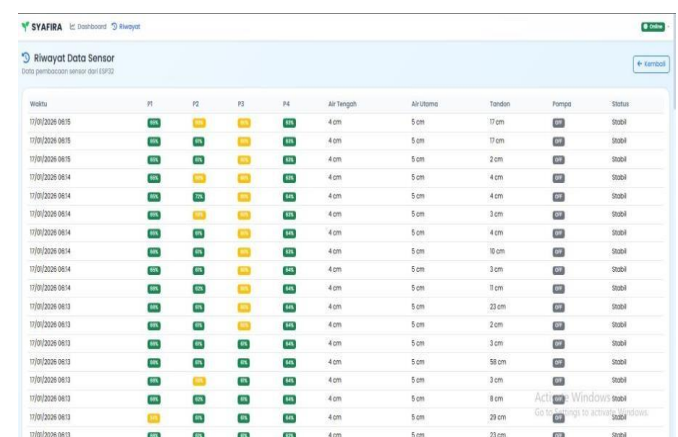


Fig. 9. Website monitoring history interface

3.2 Prototype Design Results

The prototype design results based on the system specifications and requirements are presented in this section.



Fig. 10. Prototype design results

3.3. Control System Design Results

This section presents the results of the control system design used in the prototype.

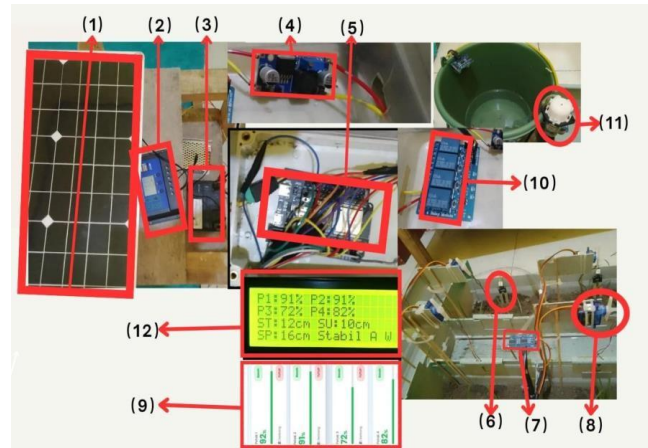


Fig. 11. Control system design results

Table 1. Control system design components			
NO	Component	Main Specifications	Function and Description
1	Solar Panel	60 Watt Peak (WP), 12 V output	Main energy source that converts sunlight into electrical energy for the system

2	Solar Charge Controller	12 V DC input, PWM charging type	Regulates and stabilizes battery charging from the solar panel and prevents overcharging
3	12 V Battery	12 V DC, 7-12 Ah	Stores electrical energy from the solar panel as backup power
4	LM2596 Step-Down	Input 12.6 V, output 5	Reduces battery voltage according to ESP32 and other device requirements
5	ESP32	Wi-Fi and Bluetooth microcontroller	Main controller for processing sensor data, controlling actuators, and connecting to the monitoring website
6	Soil Moisture Sensor	Soil moisture sensor, 3.3 V compatible	Measures soil moisture levels in each rice field plot
7	HC-SR04 Ultrasonic Sensor	5 V DC, 2-200 cm detection range	Measures water level in irrigation channels and reservoir
8	SG90 Servo	5 V DC, ± 1.8 kg-cm torque, 0° - 90°	Controls irrigation gate opening and closing

9	<i>Website Monitoring</i>	Web-based IoT platform	Displays soil moisture, water level, and irrigation status in real time
10	Relay	5 V trigger, 12 V DC load	Electronic switch for controlling the water pump
11	Water Pump	12 V DC, ± 2 -17 ml/s flow rate	Pumps water from the reservoir to the rice field when the soil is dry
12	<i>LCD (I2C Display)</i>	20 columns $\times$ 4 rows, 5 V DC	Displays soil moisture, water level, and pump status directlyseper

3.4 Experimental Results

The overall experiment was conducted to ensure that all components used in the system function optimally and are interconnected properly, thereby supporting the overall performance of the device according to the established design.

Tabel 2. Experimental Results

System Time	P1 (%)	P2 (%)	P3 (%)	P4 (%)	Middle Channel Water Level (cm)	Main Channel Water Level (cm)	Reservoir Water Level (cm)	Pump Status	Fuzzy Logic Value	Fuzzy Logic Status	System Status
12/01/2026 06:13	66	61	60	64	3	5	23	OFF	0.0	Irrigation OFF	Stable
12/01/2026 09:17	45	36	50	54	3	7	11	OFF	0.5	Middle Irrigation (45°)	Middle
12/01/2026 11:14	30	31	28	63	4	3	10	OFF	0.6	Middle Irrigation (45°)	Middle
12/01/2026 15:00	30	22	50	47	7	2	4	OFF	0.8	Main Irrigation (90°)	Main
12/01/2026 18:50	60	23	45	61	8	7	3	ON	1.0	Pump Relay ON	Pumpa

3.5. Discussion

Based on the data in Table 2, the automatic irrigation system based on fuzzy logic is capable of producing irrigation decisions that match the actual field conditions and water availability. When the dominant soil moisture condition is moist to wet and water in the irrigation channels is still sufficient, the fuzzy value is in the range of 0.0, indicating that the system remains in the irrigation OFF condition and the status is displayed as stable.

When soil moisture is in the dry to moist category and water in the middle channel is still available, the fuzzy value is in the range of 0.5–0.6. Under this

condition, the system activates irrigation through the middle channel with a servo opening of 45°, which is displayed on the monitoring website and LCD as middle status.

When the soil is dry and water availability in the main channel is limited, the fuzzy value increases to 0.8. The system then redirects irrigation through the main channel

with a full servo opening of 90°. Furthermore, when the soil still requires water and water availability in all channels is insufficient but water in the reservoir is still available, the

fuzzy value reaches 1.0, causing the relay and pump to be activated automatically. The experimental results indicate that the developed prototype can improve irrigation management efficiency compared to conventional manual irrigation practices. In manual irrigation systems, farmers must regularly inspect field conditions and manually operate irrigation gates, which can lead to delays in water distribution and inefficient water use. By utilizing real-time sensor data and fuzzy logic-based decision-making, the proposed system is capable of automatically determining the appropriate irrigation action according to soil moisture and water availability conditions. In addition, the web-based monitoring platform enables remote observation of field conditions, reducing the need for continuous on-site monitoring and supporting more effective water resource management. Irrigation decisions according to fuzzy logic principles, while displaying all monitoring information in real time through the website and LCD.

4. CONCLUSION

Based on the test results and analysis, this study successfully designed and implemented a prototype of an Internet of Things (IoT)-based irrigation system using soil moisture sensors for monitoring rice field drought in Lape Village. The developed system enables farmers to monitor soil moisture conditions and irrigation water levels in real time through a website-based monitoring platform. Data obtained from the soil moisture sensor and ultrasonic sensor are processed using fuzzy logic as the basis for irrigation decision-making according to soil conditions and water availability. With the support of IoT technology and renewable energy from solar panels, this system supports more efficient, adaptive, and remotely monitored irrigation management, and has the potential to improve water distribution efficiency and rice agricultural productivity in Lape Village.

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