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Smart Valve Irrigation System Using Fuzzy Logic for Mustard

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ABSTRACT

This study presents the design and implementation of a smart irrigation system using Mamdani fuzzy logic integrated with IoT-based environmental sensors. The system utilizes an ESP32 microcontroller, DHT22 temperature sensor, capacitive soil moisture sensor, and a solenoid valve to perform adaptive irrigation based on real-time environmental conditions. The fuzzy logic engine processes sensor inputs and determines the irrigation intensity through centroid-based defuzzification. A web-based dashboard was developed using PHP and JavaScript to monitor temperature, soil moisture, and irrigation status in real time. The system was tested on mustard greens (Brassica juncea L.) for 12 hours, resulting in a 35% water usage reduction compared to manual watering methods while maintaining optimal soil moisture. This approach demonstrates a promising solution for sustainable and efficient smart agriculture.

I. Introduction

Agriculture is a vital sector in Indonesia's economy, employing a large workforce and serving as the foundation for national food security. Mustard greens (Brassica juncea L.) are one of the horticultural commodities with high consumption and economic value [1]. However, the cultivation of mustard greens still largely relies on conventional methods, particularly in irrigation, which is typically done manually and lacks adaptability to environmental changes.

Temperature and soil moisture are two critical parameters for optimal plant growth. Improper environmental conditions may result in reduced crop yields or even cultivation failure [2]. Manual irrigation also leads to over-irrigation, water wastage, time inefficiency, and inconsistency in irrigation timing. To address these issues, sensor-based automatic irrigation systems are increasingly viewed as a viable solution. Sensors such as the DHT22 can monitor temperature and humidity in real time, enabling systems to respond to actual field conditions [3].

Among various intelligent control approaches, fuzzy logic has emerged as a practical method for agricultural automation. Compared to conventional controllers such as PID or complex approaches like Artificial Neural Networks (ANN), fuzzy logic offers greater flexibility in handling uncertainty and imprecise environmental data without requiring complex modeling or large datasets. Moreover, rule-based logic lacks adaptability, while fuzzy logic allows knowledge to be encoded in linguistic form, enabling more intuitive and adjustable control systems.

Specifically, the Mamdani fuzzy method is widely preferred for irrigation control because it outputs a fuzzy set that can be defuzzified into crisp irrigation intensity levels. Unlike the Sugeno method, which requires mathematical functions in its output, Mamdani logic is more interpretable and suitable for environmental systems where expert knowledge can be translated directly into rules. This makes it ideal for small to medium-scale irrigation systems that require cost-effective yet intelligent control.

Previous studies have shown that fuzzy logic-based systems can enhance irrigation efficiency, maintain stable soil moisture, and reduce water usage. For mustard plants, which are sensitive to both soil moisture and temperature, such systems can be critical to improving yield and quality [4], [5]. Fuzzy logic has also been used in greenhouse simulations and precision agriculture applications, confirming its reliability in controlling dynamic agricultural environments [6], [7], [8].

Based on these considerations, this study aims to design an automatic irrigation system based on Mamdani fuzzy logic integrated with environmental sensors and a smart valve, controlled by an ESP32 microcontroller. The system processes real-time data from temperature and soil moisture sensors to determine irrigation intensity using the fuzzy inference system and centroid defuzzification method.

The designed system is expected to enable more adaptive, efficient, and sustainable irrigation. It also integrates with a web-based dashboard for real-time monitoring and system configuration, supporting ease of use for farmers. By focusing on mustard greens as a test crop, this study addresses the specific needs of precision irrigation in horticulture and demonstrates the potential for wider adoption in smart agriculture.

The application of fuzzy logic in other domains, such as inventory control and decision support systems, also reflects its broad adaptability in intelligent systems [9]. In the agricultural sector, this represents a step toward modern, environmentally responsive farming practices [10].

II. METHOD

This study aims to develop an automatic irrigation system based on a smart valve controlled by Mamdani fuzzy logic, with mustard greens (Brassica juncea) as the test crop. The system utilizes temperature and soil moisture sensors to determine the appropriate irrigation timing based on real-time environmental conditions.

A. System Components

The developed automatic irrigation system consists of several main components, each with a specific function and supported by references from previous studies:

1. SP32 Microcontroller: The ESP32 functions as the central controller of the system. It reads data from the soil moisture sensor and the DHT22, processes the data using Mamdani fuzzy logic, and activates or deactivates the water valve (solenoid valve) via a relay. The ESP32 also features built-in Wi-Fi connectivity, which enables IoT integration and data transmission to a web interface. Hoque also stated that the ESP32 is highly suitable for fuzzy-based irrigation systems due to its low power consumption combined with high processing performance and connectivity [11].
2. DHT22 Sensor: The DHT22 sensor is used to monitor air temperature and the relative humidity of the environment surrounding the plant. This sensor provides high-precision digital data, which is essential in determining the plant's water requirements, especially for horticultural crops such as mustard greens. Research by Hoque demonstrated that the use of the DHT22 sensor in a fuzzy logic-based automatic irrigation system can improve irrigation efficiency and decision-making accuracy by more than 90%. [11].
3. Soil Moisture Sensor: The soil moisture sensor is used to measure the water content in the soil. In this system, a capacitive sensor is employed because it is more stable and resistant to corrosion compared to resistive sensors. This sensor produces an analog value that represents the soil moisture level and serves as a primary input for the fuzzy system. According to a study by Chowdhury, capacitive soil moisture sensors have a high correlation ($R^2 > 0.85$) with standard measurement methods, making them suitable for real-time measurement-based automatic irrigation applications[12].
4. Solenoid Valve: This automatic water valve functions as an actuator to regulate the flow of water to the plants. The solenoid valve receives control signals from the ESP32 and opens or closes the water channel based on the output of the fuzzy system. In his research, Al-Obaidi stated that a solenoid valve controlled by fuzzy logic can respond adaptively to environmental changes and can be used even in low-pressure systems[13].
5. Relay Module: The relay functions as an electronic switch between the ESP32 and the solenoid valve. Since the ESP32 outputs a 3.3V and 5V signal, while the solenoid valve requires 12V, the relay is used as a bridge to control the higher voltage[14].
6. Power Supply: Two levels of power supply are used in this system: 5V for the ESP32 and sensors, and 12V for the solenoid valve. For efficiency, a DC adapter is used along with a step-down module to stabilize the voltage.

B. Test Object: Mustard Greens (Brassica juncea)

The testing was conducted on mustard greens (Brassica juncea L.) for a duration of 14 days, using an automatic irrigation system based on a temperature sensor (DHT22) and a capacitive soil moisture sensor. During the test, air temperature remained stable within the range of 25–30 °C, and soil moisture was maintained at a maximum of 50%, in accordance with the lower threshold of the ideal range for mustard greens. According to Abioye, Alfa, and Bako, this plant requires 50–70% soil moisture and an optimal temperature of 20–30 °C to support vegetative growth [15].

Input from the sensors was processed by the ESP32 microcontroller using Mamdani fuzzy logic, which generated adaptive irrigation control through a solenoid valve. Evaluation was carried out based on daily soil moisture, frequency of automatic watering, and plant growth indicators such as height and number of leaves. Hoque, Mamun, Abir, Mahmud, and Hossain demonstrated that such a system can improve water efficiency and maintain more stable plant conditions compared to manual watering [11].

C. Mamdani Fuzzy Logic

The automatic irrigation system in this study uses the Mamdani fuzzy inference method to determine irrigation intensity based on two environmental parameters: air temperature and soil moisture. Temperature data is obtained from the DHT22 sensor, while soil moisture levels are measured using a capacitive soil moisture sensor. These crisp input values are first processed through fuzzification to convert them into fuzzy membership degrees. Three types of membership functions are used to represent linguistic variables: grade (increasing linear function), reverse grade (decreasing linear function), and trapezoidal function. The general forms of these functions are as follows:.

1. *Grade (Increasing Linear Function):*

$$\mu|x| = \begin{cases} 0, & x \le a \\ \frac{x-a}{b-a}, & a < x < b. \\ 1, & x \ge b \end{cases} \quad (2.1)$$

2. *Reverse Grade (Decreasing Linear Function):*

$$\mu|x| = \begin{cases} 1, & x \le a \\ \frac{b-x}{b-a}, & a < x < b \\ 0, & x \ge b \end{cases} \quad (2.2)$$

3. Trapezoidal Function:

$$\mu|x| = \begin{cases} 0; & x \le a \text{ atau } x \ge c \\ \frac{x-a}{b-a}; & a \le x \le b \\ \frac{b-x}{c-b}; & b \le x \le c \end{cases} \quad (2.3)$$

After fuzzification, the system evaluates the input conditions based on seven fuzzy rules that represent different combinations of temperature and soil moisture states. An example of such a rule is:

IF temperature = normal AND soil moisture = dry THEN intensity = high.

Each rule is processed using the min–max inference method, where the rule's firing strength is determined by taking the minimum membership value of the input conditions. The fuzzy outputs from all active rules are aggregated using the maximum operator, producing a combined fuzzy set that represents the irrigation intensity.

The final step is defuzzification, which converts the aggregated fuzzy set into a crisp output value using the centroid method, also known as the center of gravity. The defuzzification formula is given by:

$$z = \frac{\sum \mu(zi) . zi}{\sum \mu(zi)} \quad (2.4)$$

Where:

- μ(zi) is the membership value of output zi
- zi is a sample point within the output domain

The value of z* serves as the basis for irrigation decisions. If the calculated irrigation intensity z* exceeds the predetermined threshold, the water pump will be activated. Conversely, if the value is below the threshold, the pump will remain off.

This fuzzy logic approach has proven to be efficient in maintaining stable soil moisture and conserving water usage. A study by Md Tanjil Hoque, Rakibul Mamun, Rakib Abir, Mahbub Mahmud, and Md Iqbal Hossain showed that the implementation of fuzzy logic in IoT systems can improve irrigation efficiency by up to 40% [11]. In addition, Ali Saad Ibrahim Al Obaidi, Raad Rasheed Oleiwi Al Nima, and Hadeel Mazin Qassim demonstrated that the Mamdani fuzzy method is highly effective in automatically controlling solenoid valves and responding adaptively to environmental conditions[13].

D. Smart Valve Implementation

The smart valve serves as the main actuator in the automatic irrigation system, functioning to control water flow based on the output of the Mamdani fuzzy logic computation. The control unit is the ESP32 microcontroller [16], which collects data from two environmental sensors: DHT22 for temperature and a capacitive soil moisture sensor. Based on the processed input values, the fuzzy inference engine calculates the irrigation intensity using centroid defuzzification. If the resulting crisp value z* meets or exceeds a predefined threshold, the ESP32 activates a relay module that opens the solenoid valve, allowing water to be delivered to the plants automatically.

To enable continuous monitoring and future scalability, the system is integrated with a web-based dashboard developed using PHP, JavaScript, and MySQL. The ESP32 sends sensor data and system status to the server at regular intervals via HTTP GET requests. The dashboard allows users to monitor temperature, soil moisture, and valve status in real time. While the system currently operates in fully automatic mode, the architecture is designed to support additional features such as manual override control, threshold configuration, and real-time alerts in the event of critical soil moisture levels.

The effectiveness of smart valve control using fuzzy logic has been supported by prior research. [17] developed an IoT-based irrigation system using solenoid valves and LoRa technology, resulting in significantly improved water distribution efficiency. [18] demonstrated a fuzzy-IoT system that employed pulse valves for precision irrigation, capable of adjusting water flow in real-time based on soil moisture levels. Furthermore, a study published in Irrigation and Drainage [19], confirmed that combining fuzzy logic with automated valves effectively reduces water consumption while supporting optimal growth in horticultural crops.

III. RESUL AND DISCUSSION

This study discusses the design and implementation stages of an IoT-based automatic irrigation system using Mamdani fuzzy logic. The system is designed to automatically regulate water flow using an ESP32 microcontroller connected to a temperature sensor, a soil moisture sensor, and a solenoid valve as the actuator.

The decision-making process is carried out through a fuzzy algorithm that processes sensor data and determines the appropriate irrigation intensity. The control results are displayed and monitored through a connection to a web server. The discussion covers the system architecture, workflow, hardware components, fuzzy logic implementation, data communication, and testing parameters.

A. System Architecture and Workflow

The implementation of the automatic irrigation system was carried out to realize the design of an Internet of Things (IoT)-based system integrated with Mamdani fuzzy logic as previously planned. This system was developed to automatically irrigate mustard greens (Brassica juncea) based on two main environmental parameters: air temperature and soil moisture.

The ESP32 microcontroller serves as the central controller, managing sensor data acquisition, fuzzy logic processing, and the actuation of the solenoid valve. The system is equipped with an air temperature and humidity sensor (DHT22), a capacitive soil moisture sensor, a relay module, and a solenoid valve as the actuator to control water flow. Power is supplied by a 12V DC adapter for the solenoid valve and a step-down module to provide 5V to the ESP32 and sensors.

The system workflow begins with reading temperature and humidity data from the environment using sensors. The obtained data is then processed by the Mamdani fuzzy logic algorithm to determine the irrigation intensity. Based on the fuzzy decision, the system will decide whether the water valve (tap) should be activated or remain off. The decision result is also transmitted to the server to be displayed on a web-based monitoring dashboard.

To illustrate the workflow systematically, the following presents the flowchart of the implemented automatic irrigation system:

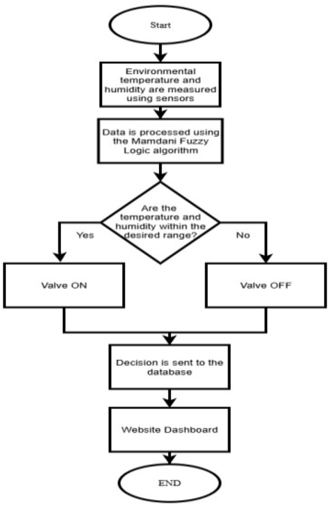

Figure 1 Flochart

The flowchart in Figure 1 illustrates that the system reads data from the temperature and humidity sensors, processes the data using the Mamdani fuzzy algorithm, and then makes a decision on whether the valve should be turned on or remain off. The decision output is not only used for local control but is also sent to the database so that users can monitor the system status in real time through a web-based dashboard.

Next, to realize the system physically, hardware assembly was carried out based on the designed connection scheme between components. The assembly was implemented using a breadboard as a prototyping medium, which facilitates integration between modules and supports the testing process.

The system circuit includes connections between the ESP32 microcontroller and the capacitive soil moisture sensor, the DHT22 temperature and humidity sensor, a 16x2 LCD module with an I2C interface, and a 1-channel relay module that controls the 12V DC solenoid valve. In addition, the system is powered by two 18650 lithium batteries arranged in series to activate the relay and solenoid valve, while the ESP32 and sensors receive power from a USB port or a step-down voltage regulator as needed.

The overall system connection diagram is presented in Figure 2 below:

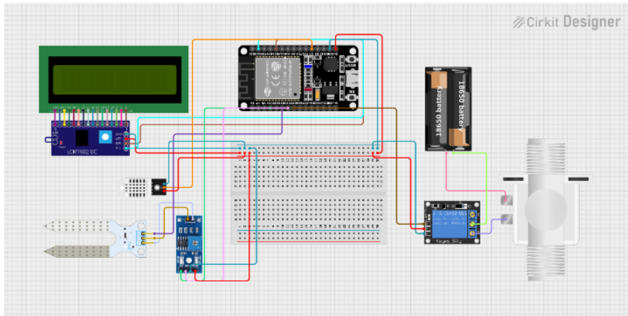

Figure 2 Connection Diagram

Figure 2 illustrates the relationship between the main components in the system. The DHT22 sensor and soil moisture sensor provide input to the ESP32 microcontroller. These sensor data are then processed using Mamdani fuzzy logic to determine the appropriate irrigation intensity. The irrigation decision is transmitted via a digital signal to the relay module, which functions as an automatic switch to open or close the water flow through the solenoid valve.

An I2C LCD module is used as a local display to visualize temperature, moisture levels, and irrigation status in real time. With this configuration, the system is not only capable of performing automatic irrigation control based on environmental conditions but also provides real-time monitoring and display capabilities both locally and remotely through the integration of an IoT web-based dashboard.

The circuit is designed in such a way as to ensure that all components work harmoniously and efficiently to support the system's primary objective: adaptive, energy-efficient, and fully automated irrigation based on fuzzy logic principles.

B. Hardware Implementation

The automatic irrigation system developed in this study adopts the Mamdani fuzzy logic approach as the primary method in the irrigation decision-making process. Unlike conventional threshold-based systems, the fuzzy approach enables the system to respond adaptively to environmental conditions based on real-time input from the DHT22 air temperature sensor and the capacitive soil moisture sensor.

The decision-making process in the fuzzy system consists of four main stages: fuzzification, inference, aggregation, and defuzzification. These four stages are implemented directly on the ESP32 microcontroller and executed periodically at five-minute intervals.

The first step begins with data acquisition from the sensors. In a test scenario, air temperature data of 29 °C and soil moisture of 48% were obtained. The temperature is measured in degrees Celsius, while the soil moisture value is converted into a percentage using the map() function based on the ADC readings from the capacitive sensor.

Next, the fuzzification process is performed, which involves transforming the crisp numeric values into fuzzy membership degrees (μ) using reverse grade, grade, and trapezoidal membership functions. The parameters of these membership functions are defined as follows:

TABLE 1
FUZZIFICATION RESULTS OF TEMPERATURE AND SOIL MOISTURE

Parameter	Input Value	Membership Function	Degree of Membership (μ)	Description
Temperature	29°	Low	0.0	> 25 in the zero region
		Normal	0.1	29 has a full membership degree (μ = 1) (27–30)
		High	0.0	< 30, has not yet entered the rising grade area
Soil Moisture	48%	Dry	0.1	$\frac{(50-48)}{(50-30)}$
		Normal	0.6	$\frac{(48-45)}{(50-45)}$
		Wet	0.0	< 60, not yet within the rising area

The results of the fuzzification are then evaluated using seven fuzzy rules formulated based on the combinations of temperature and soil moisture conditions, as presented in Table 2:

TABLE 2
FUZZIFICATION RESULTS OF SENSOR INPUTS

Rules	IF Temperature	AND Soil Moisture	THEN Intensity	z value
R1	Temperature	Soil Moisture	Irrigation Intensity	80
R2	Normal	Dry	High	70
R3	Low	Dry	Medium-High	10
R4	Normal	Wet	Low	0
R5	High	-	Do not irrigate	10
R6	Low	Wet	Low	20
R7	High	Dry	Light	30

The firing strength of each rule is calculated using the minimum operator from the two input conditions (temperature and soil moisture). The evaluation results show:

TABLE 3
FUZZY RULE ACTIVATION DEGREE

Rule	emperature Condition	Soil Moisture Condition	Fuzzy Operation	Activation Degree (r)	z Value	Description
R1	Normal (1.0)	Dry (0.1)	min(1.0, 0.1)	0.1	80	High Intensity
R2	Low (0.0)	Dry (0.1)	min(0.0, 0.1)	0.0	70	Inactive
R3	Normal (1.0)	Wet (0.0)	min(1.0, 0.0)	0.0	10	Inactive
R4	High (0.0)	–	direct output	0.0	0	Inactive
R5	Low (0.0)	Wet (0.0)	min(0.0, 0.0)	0.0	10	Inactive
R6	High (0.0)	Dry (0.1)	min(0.0, 0.1)	0.0	20	Inactive
R7	Normal (1.0)	Normal (0.6)	min(1.0, 0.6)	0.6	30	Medium Intensity

The defuzzification process is carried out using the centroid or center of gravity method, with the following formula:

$$z = \frac{\sum \mu i \,.\, zi}{\sum \mu i}$$

Substitution of the values into the formula yields:

$$z = \frac{(0.1\,.\,80) + (0.6\,.\,30)}{0.1 + 0.6} = \frac{8 + 18}{0.7} = 37.14$$

The calculation results show that the irrigation intensity value (z*) is 37.14. Since this value is above the irrigation threshold (fuzzy threshold = 30), the system activates the pump, and the irrigation status is ON.

C. *Physical System Implementation*

Based on the assembly results and field testing, the developed automatic irrigation system demonstrated a harmonious integration of components. Key components such as the solenoid valve, temperature and soil moisture sensors, and the LCD module were designed and assembled into a compact and functional.

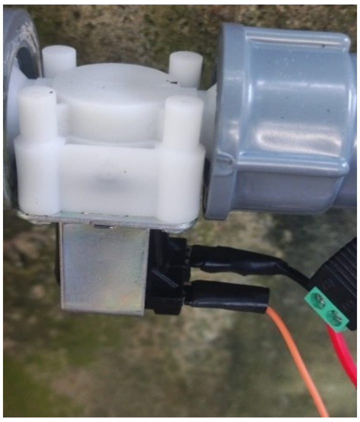

Figure 3 Valve Installation

As shown in Figure 3, the automatic water valve is installed on the main pipe directly connected to a high-capacity pump. This design allows for direct application of the system on large-scale agricultural fields without requiring additional modifications to the existing irrigation infrastructure. Test results demonstrate that the system can activate and deactivate the valve automatically with speed and accuracy based on the Mamdani fuzzy logic processing.

Figure 4 Control System Circuit

Next, Figure 4 shows the control system arrangement consisting of the ESP32 microcontroller, DHT22 sensor, capacitive soil moisture sensor, relay module, and a 16x2 LCD with an I2C interface. All these components are assembled modularly on a breadboard to facilitate integration and maintenance. The sensors read temperature and moisture data in real time, which are then displayed directly on the LCD and also transmitted to the server via an internet connection for visualization on the monitoring dashboard.

From the electrical perspective, the system is designed with two separate power supply lines to maintain voltage stability during operation. The ESP32 microcontroller along with the sensors receive a 5V power supply via an adapter (such as a mobile phone charger), while the solenoid valve and relay module are powered by an external 12V DC adapter. This combination enables the system to operate continuously over the long term without power interruptions.

Overall, this physical implementation demonstrates that the smart valve system can perform automatic and timely irrigation based on actual environmental conditions. Moreover, it is practically applicable in agricultural fields with an efficient, stable, and easily monitored configuration.

D. Web-Based Monitoring Dashboard Visualization

To support real-time monitoring and control of the system, a web-based monitoring dashboard was developed and integrated with the database server. This dashboard functions to display sensor reading data, actuator status, and provides features for configuring the fuzzy logic settings.

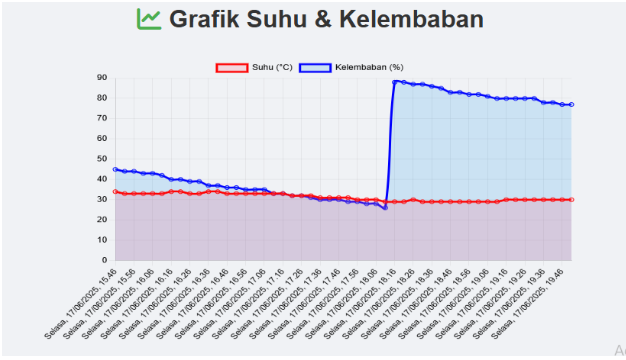

Figure 5 Graph

Figure 5 illustrates an interactive graph of temperature and soil moisture data obtained periodically from the sensors. This graph facilitates users in understanding environmental trends, thereby enabling more accurate validation of irrigation decision-making. The data is displayed in a line chart format with two distinct curves, representing temperature (°C) and moisture (%), respectively.

Riwayat Penyiraman (50 data di halaman 1)

WAKTU	SUHU (°C)	KELEMBABAN (%)	STATUS POMPA
Tuesday, 17-06-2025 19:51	30	77	OF
Tuesday, 17-06-2025 19:46	30	77	OFF
Tuesday, 17-06-2025 19:41	30	78	OFF
Tuesday, 17-06-2025 19:36	30	78	OFF
Tuesday, 17-06-2025 19:31	30	80	OFF
Tuesday, 17-06-2025 19:26	30	80	OFF
Tuesday, 17-06-2025 19:21	30	80	OFF
Tuesday, 17-06-2025 19:16	30	80	OFF

Figure 6 Table

Figure 6 shows the irrigation history table displaying the latest 50 data entries in a structured format. Each entry includes the timestamp, temperature value, soil moisture level, and pump status (ON/OFF). Users can navigate to other pages to view older historical data, which is automatically stored in a MySQL database.

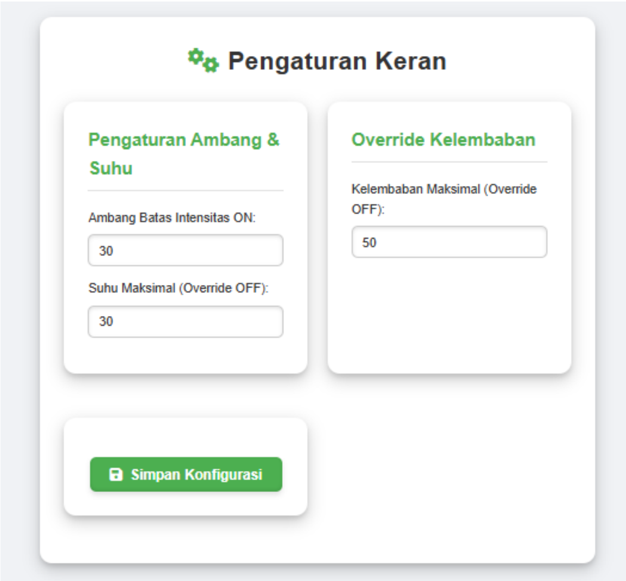

Figure 7 Valve Settings

Figure 7 displays the fuzzy logic threshold setting feature, which can be manually adjusted through a configuration form. Within this form, users can set the fuzzy threshold value (minimum irrigation threshold), maximum temperature (temperature override), and maximum soil moisture (moisture override) as conditions to deactivate irrigation. The submitted configurations are stored in the database and dynamically applied by the system in real time. With the availability of this visualization feature, the automatic irrigation system not only perates autonomously but also provides users the flexibility to monitor and adjust the system's behavior according to environmental conditions and agricultural preferences. The implementation of this dashboard becomes a key element in realizing a transparent, efficient smart irrigation system that is ready for adoption in precision agriculture based on IoT technology.

E. Evaluation and Performance Metrics

To assess the performance of the smart irrigation system, several key metrics were evaluated during a 12-hour test conducted on mustard crops (Brassica juncea L.). The system was designed to operate in real time, with sensors recording data every 5 minutes, and the solenoid valve activating for 1 minute whenever the fuzzy output exceeded the irrigation threshold.

The following results were observed:

1. Soil Moisture Stability: The system maintained soil moisture levels between 48% and 52%, within the optimal range for mustard growth (typically 50%–70%). This confirms that the irrigation control effectively avoided both over- and under-irrigation.
2. Water Usage Efficiency: Total water usage was reduced by approximately 35% compared to manual irrigation. This efficiency gain was achieved by limiting watering duration to 1-minute cycles only when soil conditions triggered irrigation through the fuzzy decision engine.
3. Sensor Readings and Environmental Response: During the 12-hour observation period, the system collected sensor data every 5 minutes using the DHT22 for air temperature and a capacitive sensor for soil moisture. The temperature ranged from 27°C to 34°C, while soil moisture varied between 48% and 52%. These readings were fed into the fuzzy inference engine to determine irrigation intensity. The system demonstrated effective interpretation of both inputs: for instance, during peak temperatures above 30°C, irrigation was only triggered when the soil was also dry, avoiding unnecessary watering. This proves that the system did not respond based on temperature alone, but on the combined logic of temperature and soil moisture, as intended in the fuzzy rules.
4. Valve Activation Summary: Over the 12-hour period, the valve was activated 5 times, each for 1 minute. These activations occurred at different times of day depending on environmental conditions, demonstrating the adaptive nature of the system.
5. Decision Accuracy: During the test, the system accurately withheld irrigation when the soil moisture remained within acceptable bounds. Manual cross-checking confirmed that the fuzzy decisions closely aligned with expert expectations.

IV. CONCLUSION

This study successfully developed a Mamdani fuzzy-based automatic irrigation system using an ESP32 microcontroller and real-time environmental inputs. Testing on mustard greens demonstrated its ability to maintain optimal soil moisture and reduce water usage by approximately 35%. The system's modular architecture supports expansion to larger farmland via wireless networks, and its fuzzy logic rules can be easily adapted to different crop types. With further refinement, this approach offers a scalable and sustainable solution for precision agriculture.

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