

Implementation of Fuzzy Logicbased Control In Melon Plantation Irrigation System

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Abstract

The agricultural sector faces challenges in water resource management due to climate change and limited availability. Melon plants (*Cucumis melo*) require precise irrigation control to maintain productivity and fruit quality. This study aims to implement a Mamdani Fuzzy Logic Controller (FLC) on a MAPPI32 microcontroller for an automatic irrigation system in melon cultivation. The system utilizes soil moisture, soil temperature, ambient humidity, and ambient temperature sensors to monitor environmental conditions in real time. Sensor data are processed through fuzzification, inference with 81 rule bases, and defuzzification using the centroid method to determine irrigation duration. The output is classified into three categories: short (3.9 s), medium (5.72 s), and long (10.4 s). Testing results show that the system provides adaptive and stable irrigation decisions and is more efficient than conventional on-off methods. This implementation demonstrates potential for improving water use efficiency in smart irrigation systems.

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Abstrak

Sektor pertanian menghadapi tantangan dalam pengelolaan sumber daya air akibat perubahan iklim dan ketersediaan yang terbatas. Tanaman melon (*Cucumis melo*) membutuhkan kontrol irigasi yang tepat untuk menjaga produktivitas dan kualitas buah. Studi ini bertujuan untuk mengimplementasikan Pengontrol Logika Fuzzy Mamdani (FLC) pada mikrokontroler MAPPI32 untuk sistem irigasi otomatis dalam budidaya melon. Sistem ini memanfaatkan sensor kelembaban tanah, suhu tanah, kelembaban lingkungan, dan suhu lingkungan untuk memantau kondisi lingkungan secara real-time. Data sensor diproses melalui fuzzifikasi, inferensi dengan 81 basis aturan, dan defuzzifikasi menggunakan metode centroid untuk menentukan durasi irigasi. Output diklasifikasikan menjadi tiga kategori: singkat (3,9 detik), sedang (5,72 detik), dan lama (10,4 detik). Hasil pengujian menunjukkan bahwa sistem ini memberikan keputusan irigasi yang adaptif dan stabil serta lebih efisien daripada metode on-off konvensional. Implementasi ini menunjukkan potensi untuk meningkatkan efisiensi penggunaan air dalam sistem irigasi cerdas.

1. Introduction

Agriculture is a crucial sector that provides food and industrial raw materials for society. However, this sector currently faces major challenges in water resource management due to increasing water scarcity and the impacts of climate change (Bwambale et al., 2022). These conditions demand the implementation of more efficient irrigation technologies to prevent excessive water use while maintaining agricultural productivity (Benzouia et al., 2023). Melon plants (*Cucumis melo* L.), as one of the high-value horticultural commodities, require proper water management to support optimal growth and improve fruit quality.

Melon plants require regular and appropriate irrigation to achieve maximum productivity. Improper water management can reduce crop yields, damage soil quality, and lead to inefficient use of water resources (Ibrahim et

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al., 2022). Therefore, an automatic irrigation system capable of adjusting water supply accurately and efficiently according to plant needs is required.

The development of precision agriculture has encouraged the integration of Internet of Things (IoT) technology into irrigation systems. IoT enables continuous monitoring of environmental parameters, including soil moisture, soil temperature, air temperature, and air humidity, allowing irrigation decisions to be made based on real-time field conditions. Several studies have demonstrated that IoT-based irrigation systems can improve water-use efficiency, optimize irrigation scheduling, and support sustainable agricultural practices (Benyezza et al., 2021; Hoque et al., 2023; Bushnag et al., 2025).

Among intelligent control methods, fuzzy logic has become one of the most widely adopted approaches because it effectively handles uncertainties in agricultural environments. The fuzzy set theory introduced by Zadeh (1965) provides the mathematical foundation for representing uncertain information using linguistic variables, while the Mamdani fuzzy inference method enables decision-making through IF-THEN rules that resemble human reasoning (Mamdani, 1974). Recent studies have reported that integrating fuzzy logic with IoT technologies improves irrigation accuracy, reduces water consumption, and enhances crop productivity by adapting irrigation schedules according to changing environmental conditions (Xie et al., 2022; Bukhari et al., 2024; Morchid et al., 2025).

Several previous studies have proposed fuzzy logic-based smart irrigation systems for precision agriculture (Benzaouia et al., 2023; Bushnag et al., 2025). However, most existing systems focus primarily on soil moisture as the main decision parameter or employ conventional microcontroller platforms. In addition, only a limited number of studies integrate multiple environmental parameters, such as soil moisture, soil temperature, air temperature, and air humidity, into a single Mamdani fuzzy inference system while providing real-time monitoring through cloud-based services.

This research develops an automatic irrigation system based on fuzzy logic using the MAPPI32 microcontroller. The system utilizes soil moisture, soil temperature, ambient temperature, and humidity sensors to monitor land conditions in real time (Bukhari et al., 2024). Sensor data are processed using fuzzy logic methods, enabling the system to determine the appropriate amount of irrigation water according to plant and environmental conditions.

In addition to increasing water-use efficiency, the system is equipped with remote monitoring and control features through a mobile application. This technology is expected to improve the quality and yield of melon crops, reduce the negative impacts of climate change, and support the implementation of modern, efficient, and sustainable agriculture.

2. Research Methods

This research develops an automatic watering system based on Mamdani-type fuzzy logic for melon plants. The system is designed to optimize water use by utilizing real-time sensor data and fuzzy logic's ability to handle environmental uncertainty. The control process is carried out through fuzzification, inference, and defuzzification stages, as shown in Figure 1.

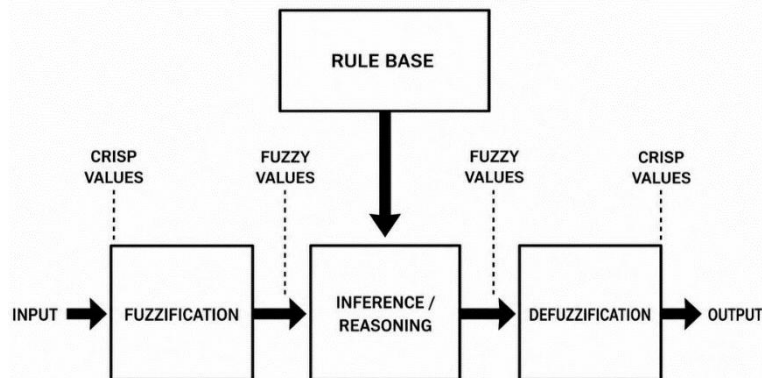


Figure 1. Operational stages of fuzzy logic systems

Fuzzification is the process of taking input values in the form of fuzzy logic system values and determining the degree of unity of the input so that they can be realized in the appropriate fuzzy set. At this stage, crisp input values are converted into fuzzy values and grouped into specific fuzzy sets.

A rule base is a collection of rules consisting of IF-THEN statements, whose antecedents and consequences are linguistic variables. This collection of fuzzy rules represents the input-output relationship of a system.

A fuzzy inference system is a conclusion derived from fuzzy rules or principles based on fuzzy set theory, fuzzy rules in the form of IF-THEN statements, and reasoning that have crisp inputs and outputs.

Defuzzification is the process of converting the resulting fuzzy output into a crisp value that can be used by the control system. In this study, the Centroid (Center of Gravity) method is used for defuzzification. The Centroid method determines the center of area of the aggregated fuzzy output to obtain a single crisp value. The defuzzification process is expressed mathematically as follows:

$$z = \frac{\sum \alpha_i z_i}{\sum \alpha_i} \quad (1)$$

z = defuzzification; α_i = alpha predicate; z_i = inference output.

2.1 Materials, Equipment and System Components

This research uses melon plants (*Cucumis melo* L.) as the primary object. In this system, a MAPPI32 microcontroller serves as the central control unit, responsible for receiving, processing, and transmitting data.

To monitor soil and environmental conditions in real time, several types of sensors are used: a capacitive soil moisture sensor (DFRobot Gravity Soil Moisture Sensor) to measure soil water content, a digital-based DS18B20 soil temperature sensor with the One-Wire protocol to measure temperature in the root area, and a DHT21 sensor (AM2301) to measure air temperature and humidity around the plants. This combination of sensors allows the system to obtain more accurate information about soil conditions and the plant's microclimate.

As part of the control system, a water pump is used as the actuator to distribute irrigation water according to plant needs based on the processed sensor data. Data obtained from the sensors is then sent by the microcontroller to the Firebase database in real time. The data is then forwarded and stored in a spreadsheet for recording and processing. The stored data is then displayed on a web monitoring platform, allowing users to remotely monitor the condition of the irrigation system and the plant environment.

2.2 Mamdani's Fuzzy Logic Method in Watering Control

The automatic irrigation system is controlled using the Mamdani-type fuzzy logic method. The decision-making process involves three main stages:

1. *Fuzzification*. The crisp input values obtained from the sensors are converted into fuzzy values using predetermined membership functions. The input parameters used include soil moisture, soil temperature, environmental humidity, and environmental temperature.
2. *Inference (Fuzzy Reasoning)*. Input fuzzy values are processed based on a rule base constructed using the Mamdani approach with the MIN operator for implication and MAX for aggregation.
3. *Defuzzification*. Output fuzzy values are converted back into explicit values using the Centroid (Center of Gravity) method to determine the optimal watering duration or volume.

3. Results and Discussion

The developed automatic watering system successfully monitors environmental and soil conditions in real time. Sensor measurements are taken every 60 seconds to capture dynamic parameter changes throughout the day. The data is then grouped into four main time periods: morning, afternoon, evening, and night, according to naturally occurring temperature and humidity fluctuation patterns. The fluctuation patterns are presented in Table 1.

Table 1. Soil Moisture Sensor Measurement Time

Time Condition	Time Range
Morning	06:00–09:00
Day	09:00–15:00
Evening	15:00–18:00
Night	18:00–06:00

This regular monitoring is crucial because melon plants' water needs are dynamic and heavily influenced by weather conditions. With accurate and continuous sensor data, the system can quickly detect changing conditions, allowing water for melon plant more precise adjustments to the watering schedule and volume.

3.1 Sensor Reading Variations and Environmental Condition Patterns

Variations in sensor readings in an automatic watering system are a critical aspect in evaluating the system's ability to accurately monitor environmental and soil conditions. Measurements are conducted periodically to capture dynamic parameter changes throughout the day, the system ability given that water requirements can fluctuate depending on the time of day and weather conditions.

Continuous data monitoring allows the system to adjust the watering process more effectively and according to the plants' actual needs. Therefore, analyzing these sensor data variations is necessary to understand patterns of environmental changes, which then inform decision-making in the plant actual need.

1. *Soil Moisture Sensor*. A soil moisture sensor is used as the primary parameter in determining the water requirements of melon plants. Measurements were conducted periodically using a capacitive soil moisture sensor, and the readings showed an average moisture value of 47.4%. This average value was obtained from several sensor data acquisitions under different growing media conditions, as presented in Table 2. These conditions indicate a natural evaporation process in the growing media, making soil moisture data a crucial parameter in determining automatic watering times.

Table 2. Sample Environmental Humidity Sensor Reading Results

Sensor Reading Time	Soil Moisture (%)	Sensor Reading Time	Soil Moisture (%)
8:32:38	47.2	8:54:52	50.2
8:34:58	46.3	8:55:50	46.1
8:38:35	47.3	8:56:53	49.2
8:40:51	46.4	8:57:55	46.6
8:41:51	47.3	8:58:51	46.5
8:42:51	47.3	8:59:51	48.5
8:43:51	48.3	9:00:51	48.7
8:44:51	48.1	9:01:51	46.6
8:45:50	46.1	9:02:50	46.3
8:46:52	48.1	9:03:51	48.5
8:47:50	46.4	9:04:50	46.5
8:48:51	46.4	9:05:50	48.1
8:49:51	48.1	9:06:51	48.4
8:50:51	46.1	9:07:51	48.1
8:51:51	46.3	9:08:52	46.2
8:52:51	48.3	9:09:52	46.3
8:53:51	48.3	Average	47.4 %

Then it is visualized in graphic form in Figure 2. This visualization makes it easier to see the downward trend or momentary fluctuations that may not be immediately visible in Table 2.

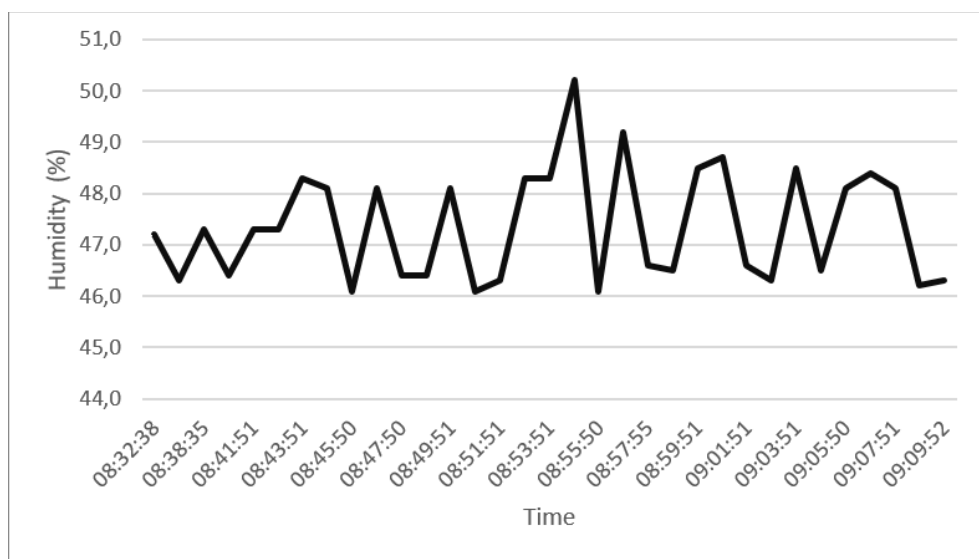


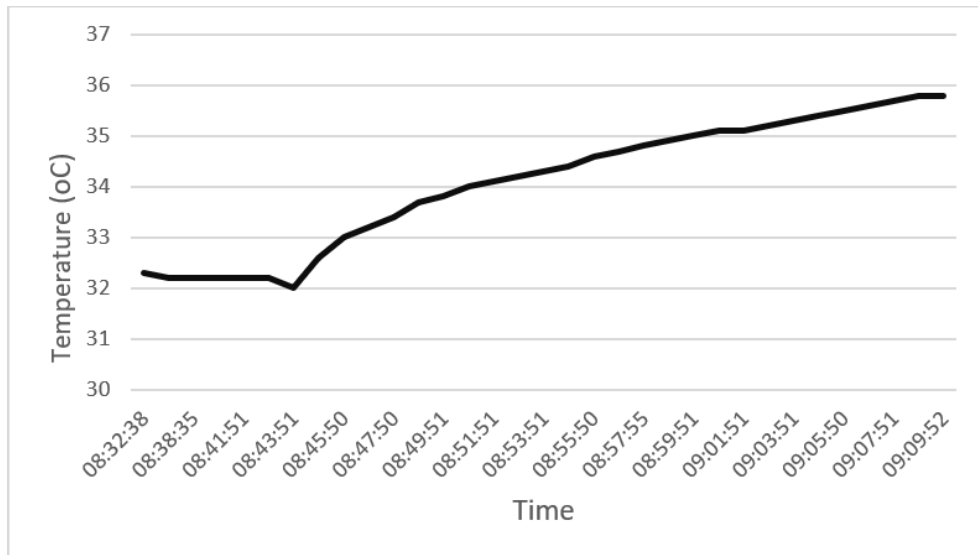
Figure 2. Soil Moisture Sensor

2. Soil Temperature Sensor. Soil temperature measurements were conducted periodically during the same observation period as the soil moisture measurements. Based on the DS18B20 soil temperature sensor readings, an average soil temperature of 34.07°C was obtained. This average value was calculated from several data collection times during the observation process, as presented in Table 3.

The measurement results show a tendency for soil temperature to increase over time, which is visualized in Figure 3. Relatively high soil temperature conditions can increase the rate of water evaporation in the planting medium, so proper watering control is needed to maintain optimal soil moisture for melon plant growth.

Table 3. Sample Soil Temperature Sensor Reading Results

Sensor Reading Time	Soil Temperature (°C)	Sensor Reading Time	Soil Temperature (°C)
8:32:38	32.3	8:54:52	34.4
8:34:58	32.2	8:55:50	34.6
8:38:35	32.2	8:56:53	34.7
8:40:51	32.2	8:57:55	34.8
8:41:51	32.2	8:58:51	34.9
8:42:51	32.2	8:59:51	35.0
8:43:51	32.0	9:00:51	35.1
8:44:51	32.6	9:01:51	35.1
8:45:50	33.0	9:02:50	35.2
8:46:52	33.2	9:03:51	35.3
8:47:50	33.4	9:04:51	35.4
8:48:51	33.7	9:05:50	35.5
8:49:51	33.8	9:06:51	35.6
8:50:51	34.0	9:07:51	35.7
8:51:51	34.1	9:08:52	35.8
8:52:51	34.2	9:09:52	35.8
8:53:51	34.3	Average	34.07

**Figure 3.** Sample Results of Soil Temperature Sensor Measurements

3. Environmental Humidity Sensor. An ambient humidity sensor was used to monitor the water vapor levels in the air around the melon plants during the observation period. Based on DHT21 sensor readings, the average ambient humidity was 58.3%. This value was obtained from several periodic measurements, as shown in Table 4.

The observation results show a tendency for a gradual decrease in environmental humidity, which is visualized in Figure 4. This decrease in air humidity is generally influenced by an increase in environmental temperature during the day which causes the evaporation rate to be higher.

Table 4. Sample Environmental Humidity Sensor Reading Results

Sensor Reading Time	Environmental Humidity (%)	Sensor Reading Time	Environmental Humidity (%)
8:32:38	68.6	8:54:52	60.0
8:34:58	68.5	8:55:50	60.1
8:38:35	68.5	8:56:53	60.0
8:40:51	68.2	8:57:55	59.3
8:41:51	67.7	8:58:51	58.6
8:42:51	67.6	8:59:51	58.3
8:43:51	67.9	9:00:51	57.7
8:44:51	68.1	9:01:51	58.2
8:45:50	67.0	9:02:50	57.9
8:46:52	65.2	9:03:51	58.0
8:47:50	65.5	9:04:50	57.8
8:48:51	62.9	9:05:50	58.2
8:49:51	62.4	9:06:51	57.8
8:50:51	62.4	9:07:51	55.6
8:51:51	62.3	9:08:52	56.8
8:52:51	61.4	9:09:52	56.5
8:53:51	62.2	Average	58.3

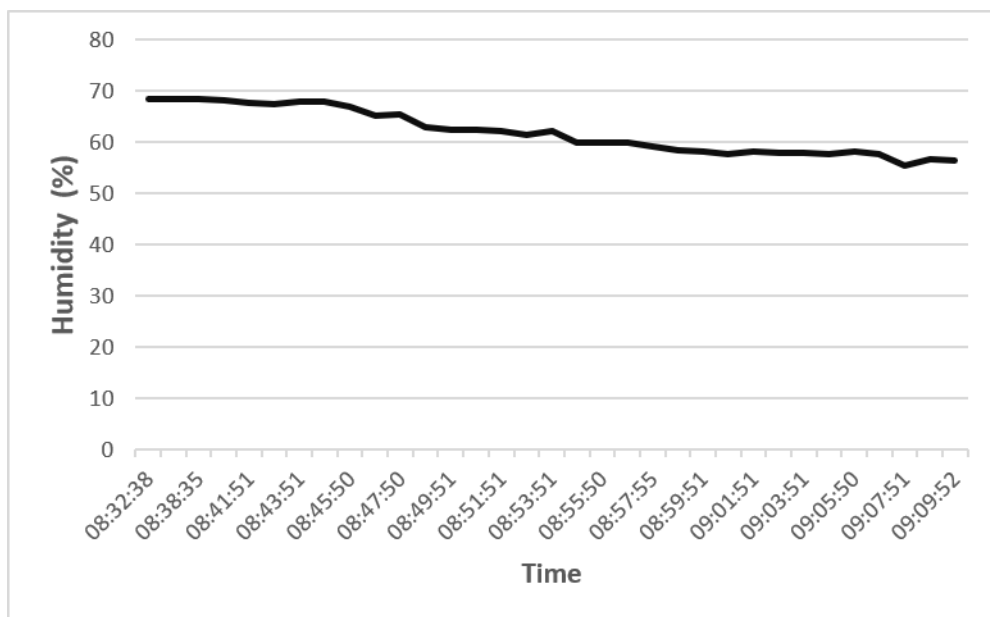


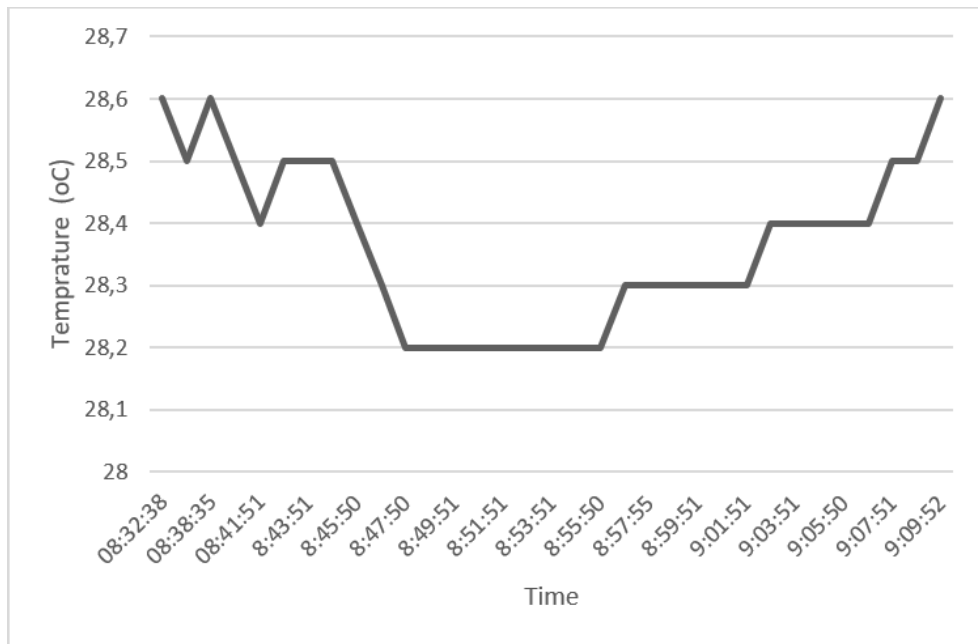
Figure 4. Sample Environmental Humidity Sensor Measurement Results

4. *Environmental Temperature Sensor.* Ambient temperature measurements were taken using a DHT21 sensor throughout the system's observation period. Based on sensor readings, the average ambient temperature was 28.4°C. This average value was obtained from several periodic measurements, as presented in Table 5.

Observations revealed temperature fluctuations at the beginning of the observation period, which then tended to stabilize at around 28°C. The visualization in Figure 5 shows a significant increase in temperature at the beginning of the observation period, followed by a decrease and a relatively stable condition. This pattern of environmental temperature changes is consistent with a decrease in air humidity, indicating a change in microclimate conditions around the plants, becoming warmer and drier.

Table 5. Sample Environmental Temperature Sensor Reading Results

Sensor Reading Time	Environmental Temperature (°C)	Sensor Reading Time	Environmental Temperature (°C)
8:32:38	28.6	8:54:52	28.2
8:34:58	28.5	8:55:50	28.2
8:38:35	28.6	8:56:53	28.3
8:40:51	28.5	8:57:55	28.3
8:41:51	28.4	8:58:51	28.3
8:42:51	28.5	8:59:51	28.3
8:43:51	28.5	9:00:51	28.3
8:44:51	28.5	9:01:51	28.3
8:45:50	28.4	9:02:50	28.4
8:46:52	28.3	9:03:51	28.4
8:47:50	28.2	9:04:51	28.4
8:48:51	28.2	9:05:50	28.4
8:49:51	28.2	9:06:51	28.4
8:50:51	28.2	9:07:51	28.5
8:51:51	28.2	9:08:52	28.5
8:52:51	28.2	9:09:52	28.6
8:53:51	28.2	Average	28.4

**Figure 5.** Sample Results of Environmental Temperature Sensor Measurements

3.2 How the Fuzzy Logic Method Works

As part of the fuzzy logic system testing process, real-time sensor data collection was conducted on August 24, 2025, at 08:07 WIB. The data obtained were soil temperature of 26.69°C, ambient temperature of 32.40°C, soil humidity of 86%, and ambient humidity of 63%. These values were used as crisp inputs in the fuzzification stage to determine the degree of membership of each fuzzy variable.

Fuzzification Based on Sensor Reading Variables

1. *Soil Temperature Variable.* This stage begins with the Soil Temperature variable, where the actual value of 26.69°C is projected into the predefined membership function.

$$\mu_{\text{moderate}}(x) = \{ 0, x \leq 23; (x - 23)/(30 - 23), 23 \leq x \leq 30; (37 - x)/(37 - 30), 30 \leq x \leq 37; 0, x \geq 37 \}$$

$$\mu_{\text{cold}}(x) = \{ (27 - x)/(27 - 20), 20 \leq x \leq 27; 0, x \geq 27 \}$$

The degree of membership of the sensor value is 26.69°C.

$$\mu_{\text{Moderate}}(26.69^\circ\text{C}) = (26.69 - 23)/(30 - 23) = 0.43; \mu_{\text{cold}}(26.69^\circ\text{C}) = (27 - 26.69)/(27 - 20) = 0.044$$

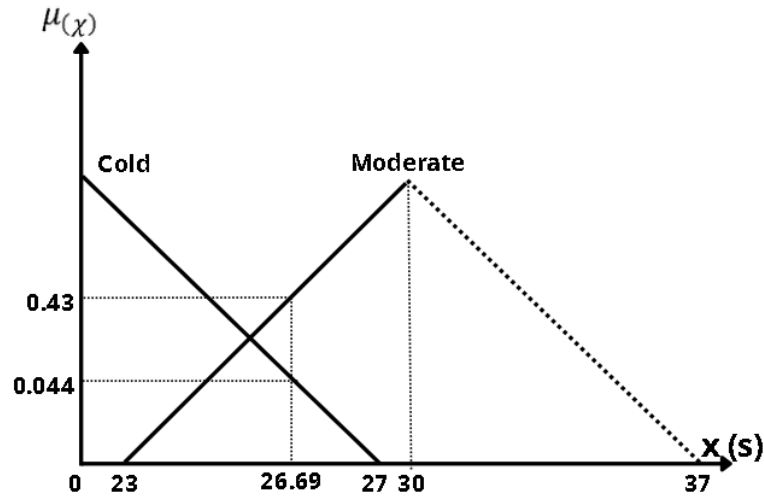


Figure 6. Representation of soil temperature variables 26.69°C

2. *Environmental Temperature Variables.* In the data collection sample, the ambient temperature sensor shows the temperature 32.40°C.

$$\mu_{\text{Moderate}}(x) = \{ 0, x \leq 27.25; (x - 27.25)/(32.5 - 27.25), 27.25 \leq x \leq 32.5; (37.75 - x)/(37.75 - 32.5), 32.5 \leq x \leq 37.75; 0, x \geq 37.75 \}$$

The degree of membership of the sensor value is 32.40°C.

$$\mu_{\text{Moderate}}(32.40^\circ\text{C}) = (37.75 - 32.40)/(37.75 - 32.5) = 0.96$$

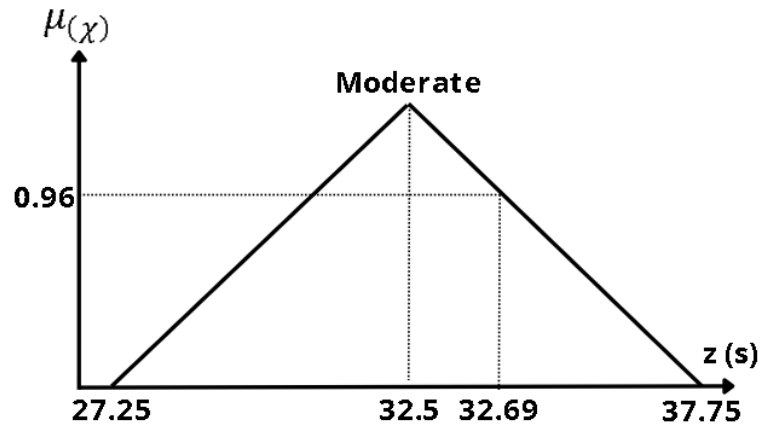


Figure 7. Representation of environmental temperature variables 32.40°C

3. *Soil Moisture Variables.* In the measurement data, the soil moisture sensor records a value of 86%.

$$\mu_{\text{Moderate}}(x) = \{ 0, x \leq 54; (x - 54)/(70 - 54), 54 \leq x \leq 70; (86 - x)/(86 - 70), 70 \leq x \leq 86; 0, x \geq 86 \}$$

$$\mu_{\text{wet}}(x) = \{ 0, x \leq 74; (x - 74)/(90 - 74), 74 \leq x \leq 90; 1, x \geq 90 \}$$

The degree of membership for this sensor value is 86%.

$$\mu_{\text{Moderate}}(86\%) = (86 - 86)/(86 - 70) = 0; \mu_{\text{wet}}(86\%) = (86 - 74)/(90 - 74) = 0.75$$

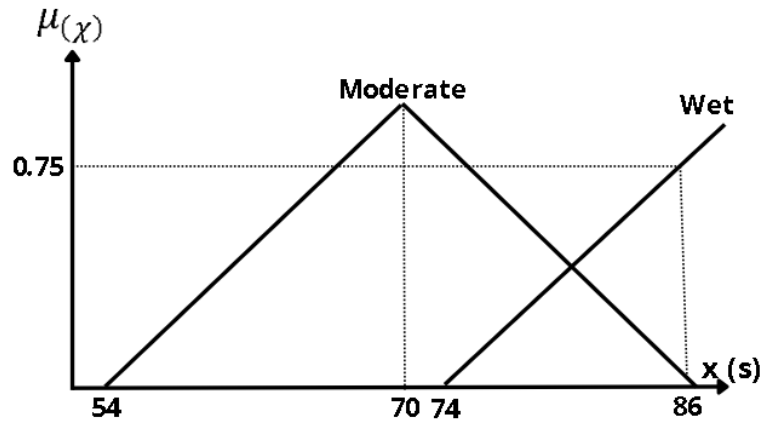


Figure 8. Representation of soil moisture variables 86%

4. *Environmental Humidity Variable*. According to the measurement data, the environmental humidity sensor reading was 63%.

$$\begin{aligned}\mu_{\text{moderate}}(x) &= \{0, x \leq 62; (x - 62)/(70 - 62), 62 \leq x \leq 70; (78 - x)/(78 - 70), 70 \leq x \leq 78; 0, x \geq 78\} \\ \mu_{\text{dry}}(x) &= \{1, x \leq 60; (90 - x)/(90 - 74), 74 \leq x \leq 90; 0, x \geq 90\}\end{aligned}$$

The degree of membership of the sensor value is 63%.

$$\mu_{\text{Moderate}}(63\%) = (63 - 62)/(70 - 62) = 0.125; \mu_{\text{dry}}(63\%) = (68 - 63)/(68 - 60) = 0.75$$

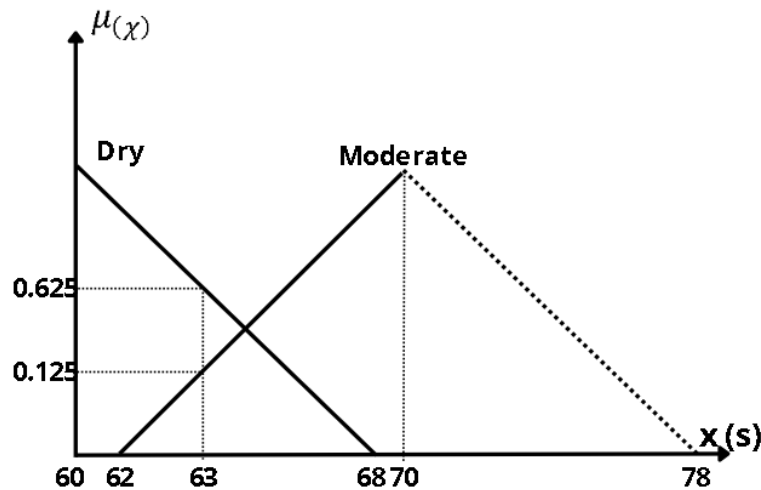


Figure 9. Representation of the environmental humidity variable 63%

5. *Water Variables*. In this study, the FLC output was divided into three linguistic categories: Short, Medium, and Long, each of which has a numerical value range on a fuzzy scale from 0 to 10 as shown in Table 6.

Table 6. Fuzzy Value Range and Watering Duration on FLC Output

Output Category	Fuzzy Value Range	Watering Duration (s)	Water Volume* (mL)
Short	0–3	3.9	250
Medium	>3–7	5.72	410
Long	>7–10	10.4	790

From these three membership functions, the process of mapping input values into the fuzzy system can be carried out precisely.

$$\begin{aligned}\mu_{\text{short}}(z) &= \{(5 - z)/(5 - 0), 0 \leq z \leq 5; 0, z \geq 5\} \\ \mu_{\text{medium}}(z) &= \{0, z \leq 2.5; (z - 2.5)/(7.5 - 2.5), 2.5 \leq z \leq 7.5; (12.5 - z)/(12.5 - 7.5), 7.5 \leq z \leq 12.5; 0, z \geq 12.5\} \\ \mu_{\text{long}}(z) &= \{0, z \leq 10; (z - 10)/(15 - 10), 10 \leq z \leq 15; 1, z \geq 15\}\end{aligned}$$

Inference for Output Determination

Mathematically, it can be written as follows.

$$\alpha_i - \text{predikat} = \min (\mu(\chi)(\chi_k) \cap \mu(\chi)(\chi_k) \cap \mu(\chi)(\chi_k) \cap \mu(\chi)(\chi_k)) \quad (2)$$

From all active rules, the following graph is obtained.

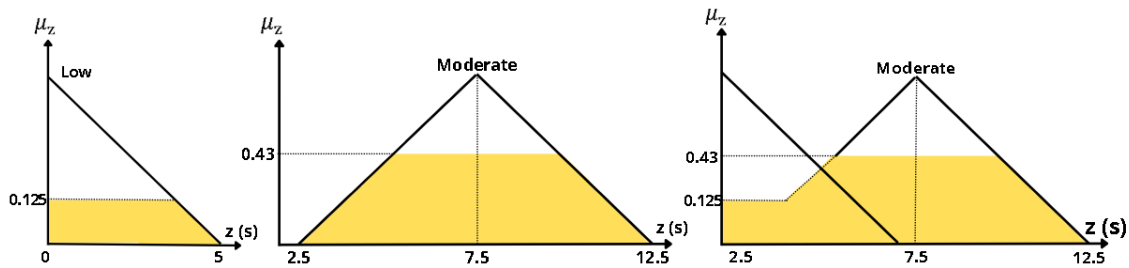


Figure 10. Results of the maximum function rule (MAX)

The maximum value of the two rules is taken using the MAX operator.

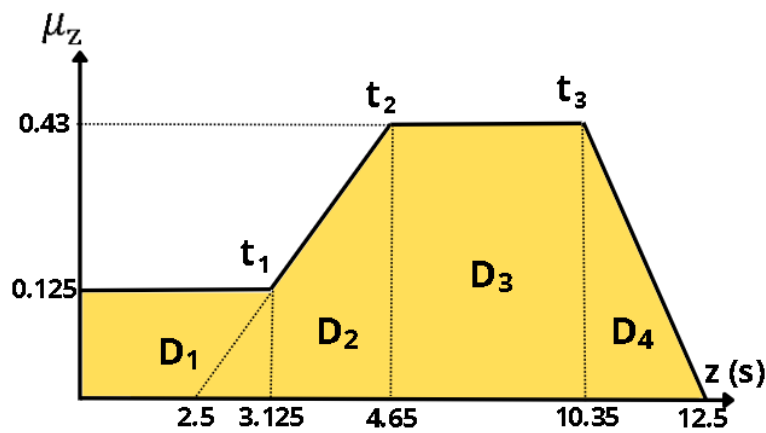


Figure 11. Output area of the composition process

Then it will be used in the defuzzification process to obtain a crisp (clear) value for the system output.

Values t_1 , t_2 , t_3 :

$$(t_1 - 2.5) / (7.5 - 2.5) = 0.125, t_1 = 3.125$$

$$(t_2 - 2.5) / (7.5 - 2.5) = 0.43, t_2 = 4.65$$

$$(12.5 - t_3) / (12.5 - 7.5) = 0.43, t_3 = 10.35$$

D_1 , D_2 , and D_3 with respective areas A_1 , A_2 , and A_3 , and moments M_1 , M_2 , and M_3 .

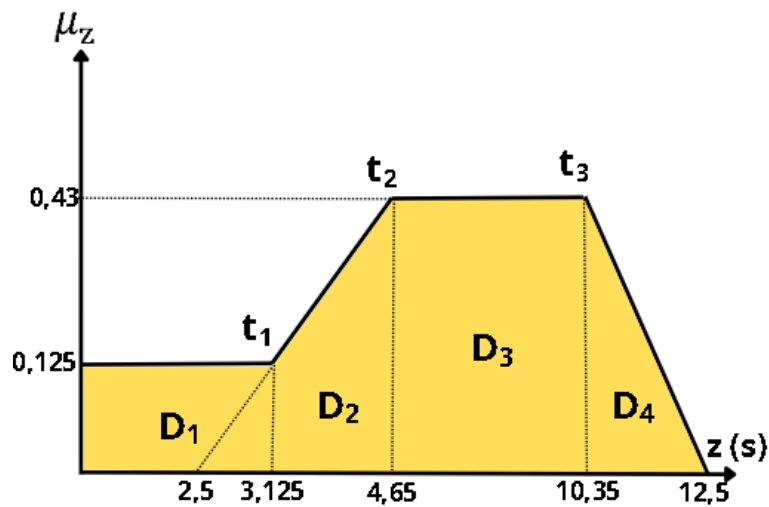


Figure 12. Division of 4 Curve Areas

$$\mu_z = \{ 0.125, z \leq 3.125; (z - 2.5) / (7.5 - 2.5), 3.125 \leq z \leq 4.65; 0.43, 4.65 \leq z \leq 10.35; (12.5 - z) / (12.5 - 7.5), 10.35 \leq z \leq 12.5 \}$$

Defuzzification of Fuzzy Logic Value Determination

The defuzzification formula using the Centroid method is written as.

$$Z = (\int \mu z \cdot z dz) / (\int \mu z dz) \quad (3)$$

Calculating Moments (M)

Calculation in the moment area M_1 , M_2 , M_3 , and M_4 :

$$\begin{aligned} M_1 &= \int_{0^{3,125}} 0.125z dz = 0.61 \\ M_2 &= \int_{3^{,1254,65}} [(z - 2.5)/(7.5 - 2.5)]z dz = 1.704 \\ M_3 &= \int_{4^{,6510,35}} 0.43z dz = 18.382 \\ M_4 &= \int_{10^{,3512,5}} [(12.5 - z)/(12.5 - 7.5)]z dz = 5.116 \end{aligned}$$

Calculating Area (A)

$$\begin{aligned} A_1 &= \int_{0^{3,125}} 0.125 dz = 0.39 \\ A_2 &= \int_{3^{,1254,65}} [(z - 2.5)/(7.5 - 2.5)] dz = 0.423 \\ A_3 &= \int_{4^{,6510,35}} 0.43 dz = 2.451 \\ A_4 &= \int_{10^{,3512,5}} [(12.5 - z)/(12.5 - 7.5)] dz = 0.462 \end{aligned}$$

Determining Z Using the Centroid Method

$$Z^* = [\int \mu(z)z dz] / [\int \mu(z) dz] = (M_1 + M_2 + M_3) / (A_1 + A_2 + A_3) = 6.93$$

Based on these results, the system produces an output value of 6.93 which is in the medium intensity category, so that the water pump is in an active condition for 5.72 seconds (relay ON).

4. Conclusion

Based on the design, implementation, and testing of an automatic watering system based on the Mamdani Fuzzy Logic Controller method on melon plants, this system demonstrates the ability to process data from various sensors to produce more adaptive watering decisions compared to conventional methods. The integration of soil temperature and humidity parameters and the environment allows the system to adjust watering conditions proportionally, thereby supporting efficient water use and maintaining optimal plant conditions. Therefore, the following conclusions were obtained:

1. The Mamdani Fuzzy Logic system is capable of processing sensor data (temperature and soil as well as environmental humidity) into adaptive irrigation decisions based on actual conditions.
2. The defuzzification result using the centroid method produces an output value of 6.93, which falls into the moderate irrigation category.
3. Based on this value, the system automatically activates the water pump for approximately 5 seconds, making the irrigation process more efficient and aligned with the plants needs.

5. Bibliography

- Ahmed, Z., Gui, D., Murtaza, G., Yunfei, L., & Ali, S. (2023). An overview of smart irrigation management for improving water productivity under climate change in drylands. *Agronomy*, 13(8), 2113. <https://doi.org/10.3390/agronomy13082113>
- Benyezza, H., Bouhedda, M., & Rebouh, S. (2021). Zoning irrigation smart system based on fuzzy control technology and IoT for water and energy saving. *Journal of Cleaner Production*, 302, 127001. <https://doi.org/10.1016/j.jclepro.2021.127001>
- Benzaouia, M., Hajji, B., Mellit, A., & Rabhi, A. (2023). Fuzzy-IoT smart irrigation system for precision scheduling and monitoring. *Computers and Electronics in Agriculture*, 215, 108431. <https://doi.org/10.1016/j.compag.2023.108431>
- Bushnag, A., Chaabane, S. B., & Harrabi, R. (2025). Smart agriculture: IoT-based smart irrigation with advanced fuzzy logic control. *Expert Systems with Applications*, 235, 121234. <https://doi.org/10.1016/j.eswa.2025.121234>
- Bukhari, M., Athar, S. O., Ullah, M., & Lee, M. Y. (2024). A fuzzy-logic-based smart irrigation controller for precision agriculture. *IEEE Internet of Things Journal*, 11(18), 31245–31258. <https://doi.org/10.1109/JIOT.2024.3398745>
- Bwambale, E., Abagale, F. K., & Anornu, G. K. (2022). Smart irrigation monitoring and control strategies for improving water use efficiency in precision agriculture: A review. *Agricultural Water Management*, 260, 107324. <https://doi.org/10.1016/j.agwat.2021.107324>
- Et-Taibi, B., Abid, M. R., Boufounas, E. M., Morchid, A., & Siano, P. (2024). Enhancing water management in smart agriculture: A cloud and IoT-based smart irrigation system. *Results in Engineering*, 24, 103256. <https://doi.org/10.1016/j.rineng.2024.103256>

- Hoque, M. D. J., Islam, M. S., & Khaliluzzaman, M. (2023). A fuzzy logic and Internet of Things-based smart irrigation system. *Engineering Proceedings*, 58(1), Article 93. <https://doi.org/10.3390/engproc2023058093>
- Ibrahim, F. S., Konditi, D., & Musyoki, S. (2022). Smart irrigation system using a fuzzy logic method. *International Journal of Engineering Research & Technology*, 11(9), 140–146.
- Kafiev, I., Romanov, P., & Romanova, I. (2021). Control system of a robotic irrigation machine based on the Mamdani fuzzy algorithm. *Journal of Physics: Conference Series*, 2096(1), 012014. <https://doi.org/10.1088/1742-6596/2096/1/012014>
- Mamdani, E. H. (1974). Application of fuzzy algorithms for control of simple dynamic plant. *Proceedings of the IEE*, 121(12), 1585–1588. <https://doi.org/10.1049/piee.1974.0328>
- Morchid, A., Said, Z., Abdelaziz, A. Y., & Siano, P. (2025). Fuzzy logic-based IoT system for optimizing irrigation with cloud computing: Enhancing water sustainability in smart agriculture. *Smart Agricultural Technology*, 6, 100321. <https://doi.org/10.1016/j.atech.2025.100321>
- Pang, Y., Marinello, F., Tang, P., Li, H., & Liang, Q. (2023). Bibliometric analysis of trends in smart irrigation for smart agriculture. *Sustainability*, 15(23), 16420. <https://doi.org/10.3390/su152316420>
- Pierre, N. J., Sefu, B., Venuste, B., D'Amour, M. J., Ndayisaba, A., & Mbarushimana, V. (2023). Smart crops irrigation system with low energy consumption. *Journal of Appropriate Technology*, 9(2), 1–13.
- Xie, J., Chen, Y., Gao, P., Sun, D., Xue, X., & Yin, D. (2022). Smart fuzzy irrigation system for litchi orchards. *Computers and Electronics in Agriculture*, 197, 106914. <https://doi.org/10.1016/j.compag.2022.106914>
- Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*, 8(3), 338–353. [https://doi.org/10.1016/S0019-9958\(65\)90241-X](https://doi.org/10.1016/S0019-9958(65)90241-X)