Journal of Computer Engineering, Electronics and Information Technology (COELITE)

Journal homepage: https://ejournal.upi.edu/index.php/COELITE

Prototype Design of Automatic Irrigation System for Precision Agriculture Application Using Mamdani Fuzzy Logic Controller

Anugrah Adiwilaga[1], Rafli Maulid Firmansyah[1], R. Irzia Fitri Muthmainah[1]*

[1]Departemen of Computer Engineering, Universitas Pendidikan Indonesia, Indonesia

Correspondence E-mail: anugrah.adiwilaga@upi.edu

ABSTRACT

Precision Agriculture aims to make every determining variable in agriculture measurable and used precisely or efficiently to maximize agricultural productivity, so we intend to develop smart irrigation systems that are controlled based on soil humidity and temperature level using Fuzzy Logic to improve water use. This study aims to design, implement, and evaluate an automated system capable of real-time monitoring of soil moisture and temperature conditions to regulate crop irrigation. This research utilizes soil moisture and temperature sensor technology connected to a system controller. The data obtained from these sensors is processed using a fuzzy logic approach to decide the amount of water that must be distributed to the plants. The fuzzy logic concept is used to handle uncertainty and ambiguity in sensor data, allowing the system to make irrigation decisions that are more adaptive and responsive to changes in soil conditions. Our experiment was tested in a lab-scale agricultural environment, and the evaluation results showed that this automatic irrigation system is capable of providing more efficient and timely irrigation according to crop needs. The results of the Fuzzy Logic Implementation concept using low-cost components to automate the irrigation system are possible and pave the way for wider use of agricultural water management in barren or arid areas and precision agriculture environment systems.

ARTICLE INFO

Article History:
Submitted/Received 06 Sep 2024
First Revised 20 Sep 2024
Accepted 01 Oct 2024
First Available online 31 Oct 2024
Publication Date 31 Oct 2024

Keyword:
Irrigation,
Fuzzy Logic,
Mamdani,
Automation,
Precision Agriculture.

1. INTRODUCTION

Agriculture is one of the main sectors in human life that are affected by environmental factors, especially the proper supply of water and soil conditions. One example is the rice paddy sector, which receives water that does not match the required soil moisture and temperature accuracy, necessitating improvement to manage water resources effectively. Furthermore, if resources are well-managed, the agricultural sector will improve [1]. In efforts to enhance agricultural yields and resource use efficiency, the development of automatic irrigation systems that detect soil moisture and temperature is increasingly needed [2]. Soil moisture control according to plant requirements is conducted by watering when the soil moisture and air temperature do not meet the expected levels and stopping watering when sufficient moisture is detected, using fuzzy logic methods [3]. This research discusses the design, implementation, and testing of such a system. The automatic irrigation system is tailored to the needs of rice plants based on soil moisture. This system is beneficial for automatic irrigation and saves labor and time in watering rice plants [4].

The integration of soil moisture and temperature sensor technology with fuzzy logic provides a solid foundation for developing intelligent irrigation systems. This is expected to increase water use efficiency, promote balanced plant growth, and provide a better understanding of plant water needs under various environmental conditions [5][6][7]. The research utilizes electronic components with an ESP32 microcontroller, soil sensor, DHT11, relay to switch electrical currents, water pump, and LCD as output. It is hoped that this research will be beneficial for a wide audience, from the agricultural sector to education, for future research applications.

2. METHODS

The methods discussed in this research include problem identification, literature review, device design, prototype development, prototype testing, and prototype evaluation. The design process for creating the prototype begins with block diagrams, flowchart diagrams, wiring diagrams, and fuzzy logic designs for the device.

2.1. Research Flow

The research flow outlines the steps to research and create a prototype to ensure the research stays on track and does not deviate from the plan. The researcher begins by identifying the problem and then conducts a literature review on similar devices. After the literature review, the next step is to design the device and build a prototype according to the planned design. The device is then tested and evaluated for further improvements. The Research Flow is shown schematically in **Figure 1.**

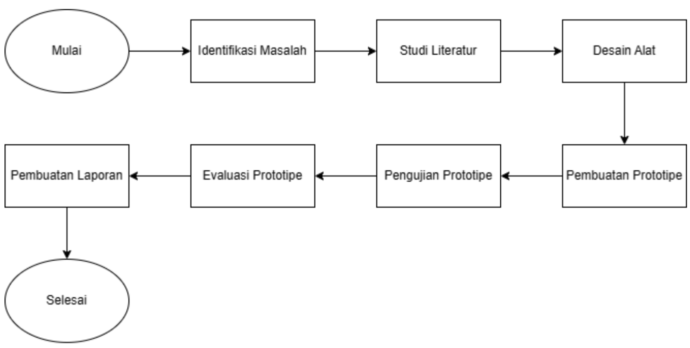

Figure 1. Schematic diagram of Research Flow.

DOI: https://doi.org/10.17509/coelite.v3i2.76025
p- ISSN 2829-4157 e- ISSN 2829-4149

2.2. Problem Identification

The agricultural sector currently still uses manual and natural irrigation systems, relying on natural resources. This makes the irrigation system unregulated and less accurate in agricultural irrigation using water resources [8]. Often, the water received does not match the required soil moisture and temperature, necessitating improvement for better water resource management.

2.3. Literature Review

The agricultural sector currently still uses manual and natural irrigation systems, relying on natural resources.

2.3.1. ESP32

ESP32 is a microcontroller developed by Espressif Systems. This microcontroller has various features that allow it to be used in various electronic applications, especially in Internet of Things (IoT) projects [9]. With many advantageous features at an affordable price, ESP32 has dual-core capabilities and larger memory. In this research, ESP is used because of its features and the availability of ESP32, which supports software and IoT project users [10].

2.3.2. Capacitive Soil Sensor

A soil sensor is a type of sensor used to measure soil moisture levels. Its working principle is based on changes in soil capacitance correlated with soil moisture [11][12]. Capacitive soil sensors use electrodes embedded in or around the soil [13][14]. When the soil contains water, the capacitance (capacity to store electric charge) around the electrodes changes. When the soil is dry, the capacitance is low, while when the soil is wet, the capacitance is high.

2.3.3. DHT11 Sensor

DHT11 is a simple and easy-to-use temperature and humidity sensor. This sensor is often used in DIY (Do It Yourself) projects and various electronic applications that require temperature and humidity monitoring. In this research, DHT11 is used as a temperature sensor for soil and air [15].

2.3.4. Relay

A relay is an electronic component that acts as a switch that can be automatically activated or deactivated by electrical signals from control devices such as microcontrollers, sensors, or other devices. When an electric current passes through the relay, it can change the state of its contacts from open to closed or vice versa, depending on the signal given to the relay. Relays typically have two states, open and closed [16]. When a relay is activated through an electrical signal, its contacts switch to the opposite state.

2.3.5. Water Pump

A water pump is a component used to move water from one place to another. The water pump works by converting electrical energy into mechanical energy to move water through pipes or channels [17]. When the pump is turned on, the motor starts spinning and drives the impeller inside. This spinning motion causes the surrounding water to enter the pump through the intake channel. The impeller then pumps the water out through the outlet channel, moving it to the desired location.

DOI: https://doi.org/10.17509/coelite.v3i2.76025
p- ISSN 2829-4157 e- ISSN 2829-4149

2.3.6. Fuzzy Logic

Fuzzy logic is an algorithm with a computer science and mathematics approach similar to human thinking in making decisions in uncertain or gray areas. This concept departs from conventional logic that considers something only true or false [18]. In general, fuzzy logic extends the thinking framework in describing problems that do not have clear boundaries between conditions. This helps us handle uncertainty and ambiguity in decision-making. Fuzzy logic is widely used in control systems with uncertain conditions, such as room temperature control, car braking systems, or washing machine control systems [19][20].

2.4. Block Diagram

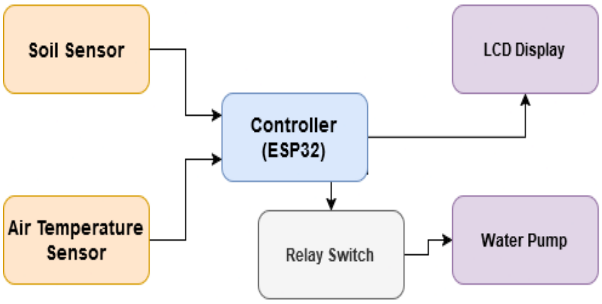

Figure 2. Block Diagram.

Figure 2. A block diagram representing the graphic depiction of the system or process functions, elements, or components in the automatic soil moisture and temperature irrigation system. Initial interactions from the sensors and fuzzy logic to the microcontroller are processed in the ESP32, then the data is sent to the LCD and relay to be forwarded to the water pump.

2.5. Flowchart Diagram

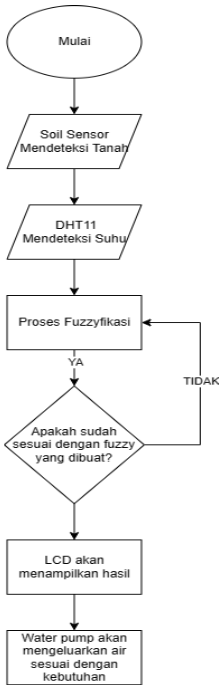

Figure 3. Flowchart

Figure 3. The flowchart above shows the working procedure of the automatic irrigation system during the irrigation conditioning process. The system starts the flow by reading

DOI: https://doi.org/10.17509/coelite.v3i2.76025
p- ISSN 2829-4157 e- ISSN 2829-4149

sensor detections, which are then processed using fuzzy logic with the established conditions. The output will then appear on the LCD and the water pump according to the results of the fuzzy processing.

2.6. Wiring Diagram

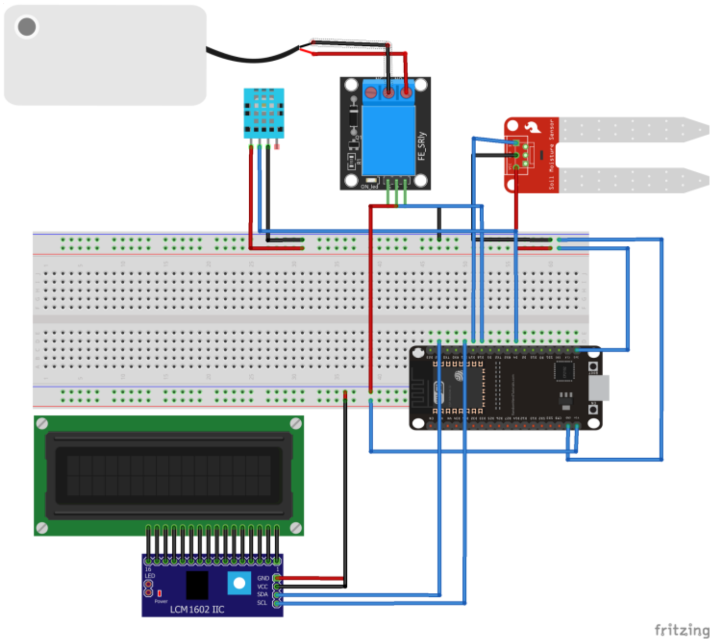

Figure 4. Wiring Diagram

Figure 4. The wiring diagram above shows the wiring design to connect one component to another. This wiring diagram also functions to identify the connections and interactions that occur, which will then be adjusted according to the algorithm.

2.7. Architecture Diagram

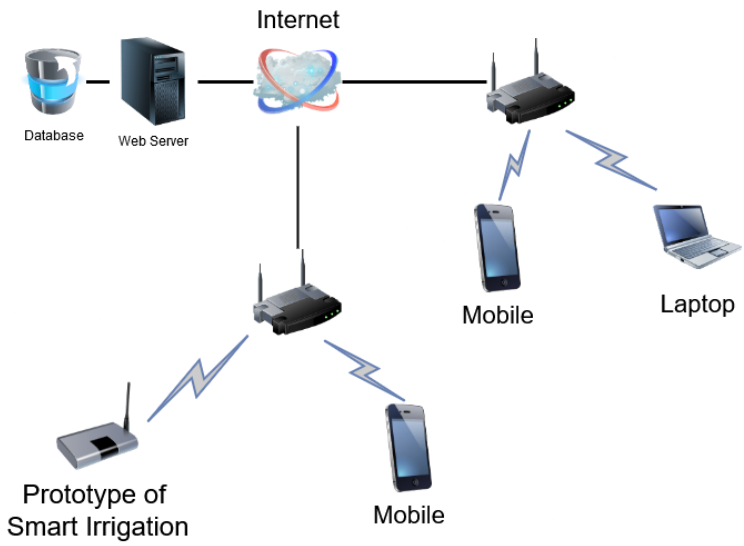

Figure 5. Architecture Diagram

Figure 5. The architecture diagram above represents the relationships or connections in the design system. The components used in this prototype development include the ESP32

DOI: https://doi.org/10.17509/coelite.v3i2.76025
p- ISSN 2829-4157 e- ISSN 2829-4149

microcontroller, Capacitive Soil Sensor, DHT11 Sensor, LCD, Relay, and Water Pump, as well as a 5 Volt Adapter as the power source.

2.8. Implementation of Fuzzy Logic

The implementation of fuzzy logic in MATLAB involves several stages. Here are the steps for fuzzy logic implementation.

2.8.1. Fuzzification

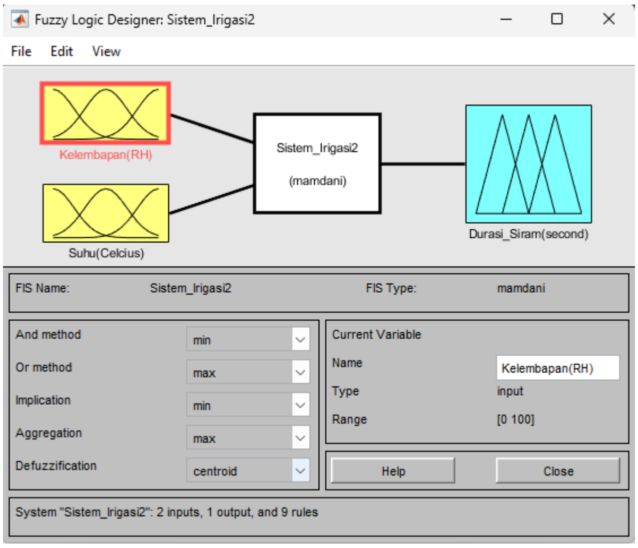

Figure 6. Fuzzification MATLAB

Figure 6. The fuzzification above includes inputs for humidity (RH) and temperature (Celsius), which will produce a watering duration using the Mamdani method.

2.8.2. Membership Function

1. Humidity (Input)

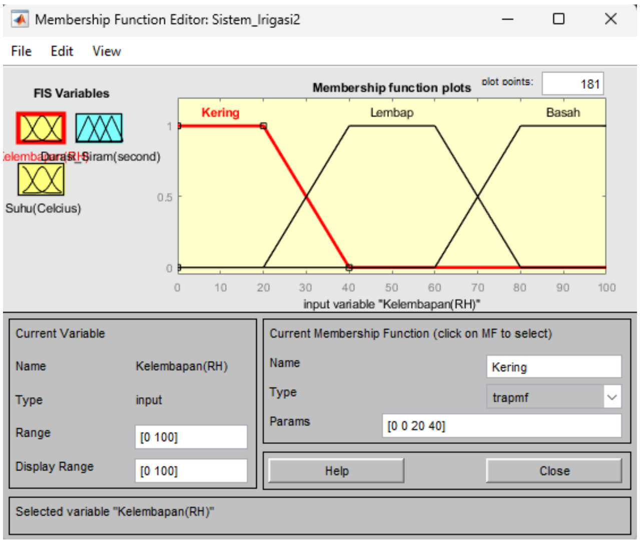

Figure 7. Membership function for Humidity

Figure 7. the input for humidity has the following ranges

DOI: https://doi.org/10.17509/coelite.v3i2.76025
p- ISSN 2829-4157 e- ISSN 2829-4149

In the image above, the input for humidity has the following ranges: Dry [0 0 20 40], Moist [20 40 60 80], and Wet [60 80 100 100].

2. Temperature (Input)

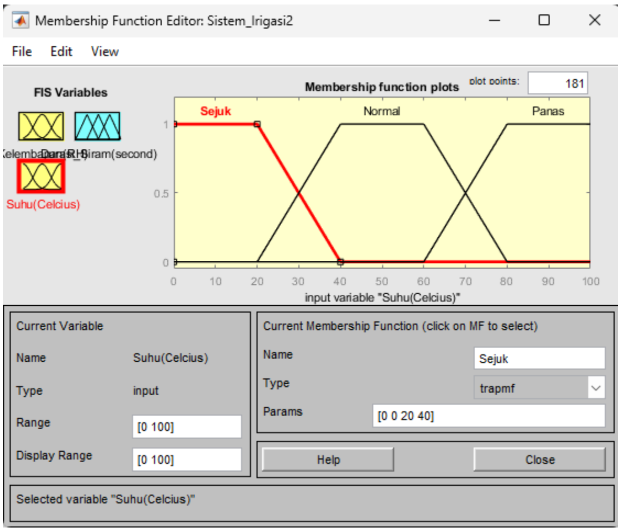

Figure 8. Membership function temperature

Figure 8. the input for temperature has the following ranges: Cool [0 0 20 40], Normal [20 40 60 80], and Hot [60 80 100 100].

3. Watering Duration (Output)

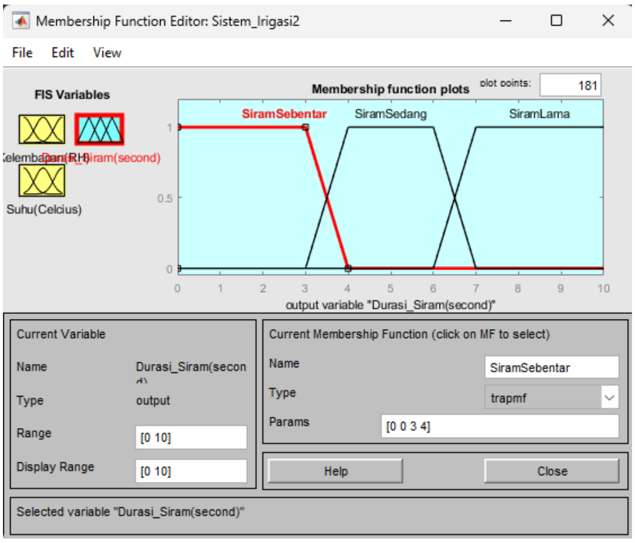

Figure 9. Membership function Durasi_Siram

Figure 6. the output is Durasi_Siram or the duration for watering the plants. It has the following ranges: Siram Sebentar (Short Watering) [0 0 3 4], Siram Sedang (Medium Watering) [3 4 6 7], and Siram Lama (Long Watering) [6 7 10 10].

DOI: https://doi.org/10.17509/coelite.v3i2.76025
p- ISSN 2829-4157 e- ISSN 2829-4149

2.8.3. Fuzzy Interface

1. Fuzzy Rules

1. If (Kelembapan(RH) is Kering) and (Suhu(Celcius) is Sejuk) then (Durasi_Siram(second) is SiramLama) (1
2. If (Kelembapan(RH) is Kering) and (Suhu(Celcius) is Normal) then (Durasi_Siram(second) is SiramLama) (
3. If (Kelembapan(RH) is Kering) and (Suhu(Celcius) is Panas) then (Durasi_Siram(second) is SiramLama) (
4. If (Kelembapan(RH) is Lembap) and (Suhu(Celcius) is Sejuk) then (Durasi_Siram(second) is SiramSebent
5. If (Kelembapan(RH) is Lembap) and (Suhu(Celcius) is Normal) then (Durasi_Siram(second) is SiramSeber
6. If (Kelembapan(RH) is Lembap) and (Suhu(Celcius) is Panas) then (Durasi_Siram(second) is SiramSedan
7. If (Kelembapan(RH) is Basah) and (Suhu(Celcius) is Sejuk) then (Durasi_Siram(second) is SiramSebentar
8. If (Kelembapan(RH) is Basah) and (Suhu(Celcius) is Normal) then (Durasi_Siram(second) is SiramSebent
9. If (Kelembapan(RH) is Basah) and (Suhu(Celcius) is Panas) then (Durasi_Siram(second) is SiramSebenta

Figure 10. Fuzzy Rules

Figure 10. In the image above, the fuzzy rules for the two inputs, humidity and temperature, are shown, resulting in the output Durasi_Siram (Watering Duration). There are 9 rules, each with 3 conditions.

2. Tabel Interface

	Suhu Sejuk	Suhu Normal	Suhu Panas
Kelembapan Kering	Siram Lama	Siram Lama	Siram Lama
Kelembapan Lembap	Siram Sebentar	Siram Sebentar	Siram Sedang
Kelembapan Basah	Siram Sebentar	Siram Sebentar	Siram Sebentar

Figure 11. Tabel Interface

Figure 11. The Interface Table for conditioning humidity with ranges dry, moist, and wet, then temperature with ranges cool, normal, and hot, producing the output for watering duration with ranges long, medium, and short.

2. Defuzzification

The defuzzification stage results from the trials of each condition set in the fuzzy interface stage.

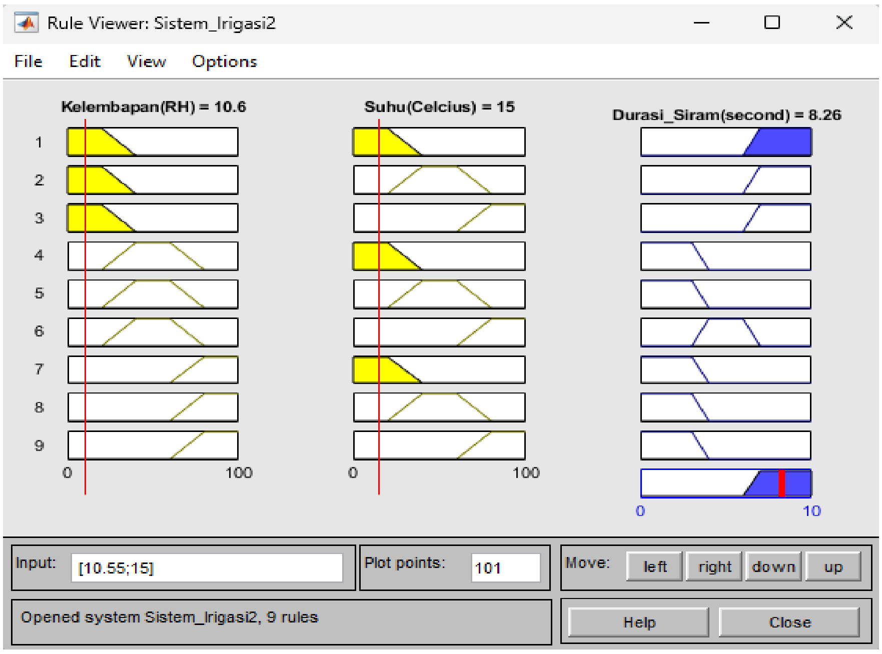

Figure 12. (a) Defuzzification with the rule [If (Humidity(RH) is Dry) and (Temperature_(Celsius) is Cool) then (Watering_Duration is Long_Watering)]

DOI: https://doi.org/10.17509/coelite.v3i2.76025
p- ISSN 2829-4157 e- ISSN 2829-4149

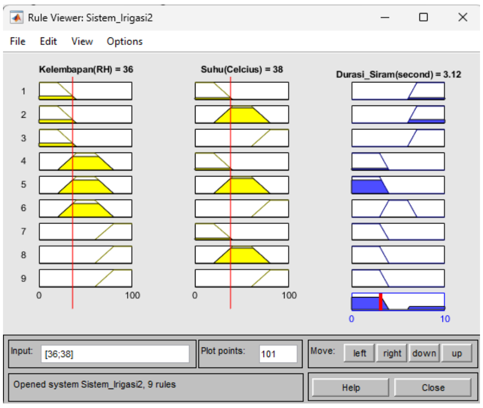

Figure 13. (b) Defuzzification with the rule [If (Humidity(RH) is Moist) and (Temperature_(Celsius) is Normal) then (Watering_Duration is Medium_Watering)]

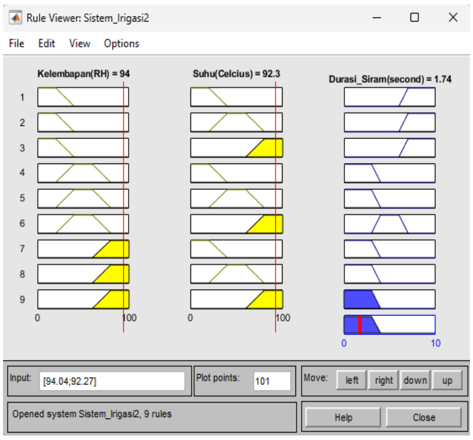

Figure 14. (c) Defuzzification with the rule [If (Humidity(RH) is Wet) and (Temperature_(Celsius) is Hot) then (Watering_Duration is Short_Watering)]

3. RESULTS AND DISCUSSION

3.3. Testing Results on the Device

Table 1. Test result on device

Humidity (RH)	Temperature (Celsius)	Watering Duration (seconds)	Conformity
36.00	29.30	3.61	Discrepancy in interval value > 2
37.00	29.80	3.33	Discrepancy in interval value > 2
37.00	30.80	3.26	Discrepancy in interval value > 1
59.00	30.80	1.87	Discrepancy in interval value > 3
38.00	30.80	2.88	Discrepancy in interval value > 2
36.00	30.80	3.59	Discrepancy in interval value > 1
36.00	30.20	3.67	Discrepancy in interval value > 2

DOI: https://doi.org/10.17509/coelite.v3i2.76025
p- ISSN 2829-4157 e- ISSN 2829-4149

3.4. Testing Results on MATLAB

Table 2. Testing Results on MATLAB

Humidity (RH)	Temperature (Celsius)	Watering Duration (seconds)	Conformity
36.00	29.30	3.59	Discrepancy in interval value > 2
37.00	29.80	3.31	Discrepancy in interval value > 2
37.00	30.80	3.25	Discrepancy in interval value > 1
59.00	30.80	1.84	Discrepancy in interval value > 3
38.00	30.80	2.86	Discrepancy in interval value > 2
36.00	30.80	3.58	Discrepancy in interval value > 1
36.00	30.20	3.65	Discrepancy in interval value > 2

4. DISCUSSION

The irrigation system implemented with fuzzy logic achieved results with a discrepancy value of 1 to 2 between the device and the fuzzy logic. However, with a small difference, the implementation of fuzzy logic is considered acceptable. From the above tests, the fuzzy logic using the Mamdani method in the automatic irrigation system prototype for plants was successfully achieved as desired. Fuzzy logic can demonstrate that this method can handle the uncertainty of watering duration, aligning it with soil moisture and temperature conditions. In the discussion, researchers utilized soil and DHT11 sensors, where the DHT11 sensor can detect both room temperature and humidity. Researchers have not yet tried using the DHT11 sensor in the soil.

5. CONCLUSION

This journal aims to design and implement an automatic irrigation system that can monitor soil moisture and temperature using the fuzzy logic concept with soil moisture and temperature sensors to measure soil environmental conditions. The information obtained from these sensors forms the basis for decision-making in the irrigation system. The fuzzy logic approach is used to process data obtained from the soil moisture and temperature sensors. This concept allows the system to make irrigation decisions by considering uncertain or fuzzy soil moisture and temperature values. In conclusion, despite some discrepancies in the device implementation and MATLAB conditioning, this is considered normal due to possible sensor inaccuracies. However, the application of the Mamdani fuzzy method successfully enhances the management of water resources and periodic plant irrigation automatically.

DOI: https://doi.org/10.17509/coelite.v3i2.76025
p- ISSN 2829-4157 e- ISSN 2829-4149

6. REFERENCES

[1] Dzulkifli. S. M., Rivai. M., Suwito. (2016). “Rancang Bangun Sistem Irigasi Tanaman Otomatis Menggunakan Wireless Sensor Network”. Jurnal Teknik ITS. 5(2)

[2] As’ri. C. J. (2021). “Rancang Bangun Irigasi Otomatis dan Monitoring Pada Lahan Pertanian Berbasis Internet Of Things”.

[3] Musyaffa. (2023). “Smart Plant Monitoring System Kelembaban Tanah Menggunakan Metode Fuzzy Logic Pada TUmbuhan Cabai Berbasis IoT”. Jurnal Khatulistiwa Informatika. 11(1): 35-42.

[4] Setiobudio. R., & Suharyanto. C. E. (2019). “Sistem Irigasi Otomatis pada Tanaman Padi Menggunakan Arduino dan Sensor Kelembaban Tanah”. Jurnal ICT: Information Communication & Technology. 18(1).

[5] Samsugi. S., Mardiyansyah. Z., & Nurkholis. A. (2020). “Sistem Pengontrol Irigasi Otomatis Menggunakan Mikrokontroler Arduino Uno”. Jurnal Teknologi dan Sistem Tertanam. 1(1):17

[6] Merbawani. L. A. Y., Rivai. M., & Pirgani. H. (2021). “Sistem Monitoring Prodil Kedalaman Tingkat Kelembaban Tanah Berbasis IoT dan LoRa”. Jurnal Teknik ITS. 10(2).

[7] Hendrawati, Dewi. T., & Algifary. K. (2022). “Pengembangan Sistem Kontrol Dan Monitoring Pada Irigasi Tanaman Cabe Berbasis Node Nirkabel Dan Internet of Things (IoT) Menggunakan Metode Fuzzy Logic.” Pp. 4-7 in.

[8] Sugandi. B., & Armentaria. J. (2021. “Sistem Penyiraman Tanaman Otomatis Berbasis Fuzzy Logic”. Journal Of Applied Electrical Engineering. 5(1)

[9] Wandi. I. A., & Ashari. A. (2023). “Monitoring Ketinggian Air dan Curah Hujan Dalam Early Warning System Bencana Banjir Berbasis IoT”. IJEIS (Indonesian Journal of Electronics and Instrumentations Systems). 13(1):101-110.

[10] Abrar. A., & Tukino. (2023). “Pengembangan Sistem Pengontrolan Irigasi Cerdas dengan Teknologi Internet of Things (IoT)”. PROSIDING: Seminar Nasional Ilmu Sosial & Teknologi.

[11] Sukmono. H., Wardati. N. K., & Sutikno. (2020). “Prototipe Sistem Otomasi Gerbang Irigasi Dengan Implementasi MIkrokontroler Berbasis IoT”. Jurnal Teknik Elektro dan Komputasi. 2(1):30-40.

[12] Ahmad. N. S., Javaid. S., & Qasim. U. (2018). “Real-time Monitoring and Control System Using Arduino Based Microcontroller through C# Programming”. International Journal of Engineering & Technology. 7(4):519-514.

[13] Asriya. P., & Yusfi. M., (2016). “Rancang Bangun Sistem Monitoring Kelembaban Tanah Menggunakan Wireless Sensor Berbasis Arduino,” J. Fis. Unand, 5(4).Khechekhouche, A., Benhaoua, B., Manokar, M., Sathyamurthy, R., and Driss, Z. (2020). Sand dunes effect on the productivity of a single slope solar distiller. Heat and Mass Transfer, 56(4), 1117-1126.

[14] Setiawan. R., & Arvita. Y. (2022). “Penerapan Sistem Kontrol Suhu dan Monitoring Serta Kelembapan pada Kumbung Jamur Tiram Berbasis IoT Menggunakan Metode Fuzzy Logic". Jurnal Sains dan Informatika. 8(2).

[15] Iqsyahiro. K. A. (2022). “Perancangan Sistem Irigasi Berbasis IoT Pada Sawah Padi di Kecamatan Wangon, Kabupaten Banyumas”. Jurnal Informatic and Information Technology. 1(3).

DOI: https://doi.org/10.17509/coelite.v3i2.76025
p- ISSN 2829-4157 e- ISSN 2829-4149

[16] Setiawan. P., & Anggraeni. E. Y. (2018). “Purwarupa Sistem Pengairan Sawah Otomatis Dengan Arduino Berbasis Artificial Intelligence”. Jurnal Sistem Informasi dan Telematika. 9(2).

[17] Santosa. S. P., & Wijayanto. F. (2022). “Rancang Bangun Akses Pintu Dengan Sensor Suhu dan Handsanitizer Otomatis Berbasis Arduino”. Jurnal Elektro. 10(1): 20-31.

[18] Dwimawati, Eny, Beliansyah. F., & Zulfa. S. A. (2019). “Pemberdayaan Masyarakat Melalui Pemanfaatan Teknologi Dalam Rangka Meningkatkan Kualitas Sumber Daya Manusia Di Desa Gunung Menyan”. Abdi Dosen : Jurnal Pengabdian Pada Masyarakat. 3(1).

[19] Rasna, & Alam. S. N. (2022). “Smart Farming Berbasis Iot Pada Tanaman Cabai Untuk Pengendalian Dan Monitoring Kelembaban Tanah Dengan Metode Fuzzy.” Jurnal Teknologi Dan Sistem Tertanam 3(1):25–35.

[20] Ruminta. R., Wahyudin. A., & Sakinah. S. (2017). “Respon pertumbuhan dan hasil tanaman padi terhadap jarak tanam pada lahan tadah hujan dengan menggunakan pengairan intermittent,” Agrin J. Penelit. Pertan. 21(1).

DOI: https://doi.org/10.17509/coelite.v3i2.76025
p- ISSN 2829-4157 e- ISSN 2829-4149