Implementation of Fuzzy Logic in Soil Moisture and Temperature Control System for Araceae Plants Based on LoRa

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***Abstract* – The Araceae plants are highly popular among plant enthusiasts worldwide. The Araceae family has more than 100 different types and thousands of species. Despite ever-evolving times, these plants have a high market value and challenging breeding methods. To achieve optimal quality, it is important to maintain the appropriate humidity and temperature according to the natural conditions of these plants in the tropical rainforest. The Node MCU ESP32 is a processor for instructions from the room temperature sensor, room humidity sensor, and soil moisture sensor. Additionally, this component controls the blower and misting system as output, which will be processed through LoRa technology to transmit monitoring data to the Blynk software. This study utilizes fuzzy logic to categorize room temperature, humidity, soil moisture, and output results for different Araceae plants. LoRa technology is used to send monitoring data efficiently in the data transmission process. During data retrieval using long-range technology, a delay of approximately 5 seconds is known between the receiver and transmitter at a distance of 700 meters. Constraints that cause issues with this long-range technology are influenced by wind, which affects antenna signal strength, and the presence of trees and buildings as obstacles. The monitoring results show an average temperature in normal conditions and an average humidity in wet conditions. At the same time, soil moisture is monitored to maintain normal humidity, resulting in all outputs being off.**
Keywords: Fuzzy logic, soil moisture control, temperature control, Araceae plants, LoRa

I. INTRODUCTION

The Araceae plants are highly sought-after by plant enthusiasts worldwide. The Araceae family comprises over 100 genera and thousands of diverse species [1]. Their presence remains relevant due to their high commercial value and the challenging and time-consuming breeding process. Each genus within the Araceae family has distinct characteristics, making it crucial to provide the appropriate environmental conditions for their optimal growth [2] and [3].

Two significant factors influencing the growth of Araceae plants are soil moisture and temperature. To achieve optimal plant quality, it is essential to regulate humidity and temperature appropriately, adapting them to the native habitat conditions of these plants in tropical rainforests [4]. One practical approach to addressing this challenge is the application of fuzzy logic. Fuzzy logic is a method that allows decision-making based on uncertain or indistinct values [5]. This approach offers high flexibility in system control and can handle uncertainties in agricultural environments [6].

Although many studies have been conducted on monitoring and controlling temperature and humidity in ornamental plants, such as the automatic watering system for Aglaonema plants [7] or automatic monitoring of temperature and humidity in greenhouses via a web server, there is still a need for more efficient and practical systems for ornamental plant farmers [8]. Previous research using the Raspberry Pi and MQTT protocol has significantly contributed to precision agriculture, but there is a need for more affordable and energy-efficient tools [9].

This study proposes using the ESP32 as a microcontroller with parallel sensor arrangement and communication using the LoRa protocol for monitoring and controlling temperature and humidity in Araceae plants. By upgrading this system, it is expected that farmers and plant enthusiasts can optimize plant conditions with lower costs and improved energy efficiency. Furthermore, this research will likely reduce potential losses in cultivating high-value Araceae plants.

This article will explain the implementation of fuzzy logic in the soil moisture and temperature control system for Araceae plants based on LoRa. The report will discuss the system development steps, appropriate sensor selection, LoRa communication setup, and fuzzy logic implementation. Additionally, it will cover the research results and performance evaluation of the system tested in an agricultural environment. This research is expected to contribute meaningfully to the development of ornamental plant agriculture technology and enhance Araceae plants' efficient cultivation.

II. Basic of Theory

The Araceae family has a native habitat in a humid environment with loose (humus) and fertile soil conditions[10]. However, this native habitat does not result in muddy soil. Some types of Araceae can grow in shaded areas, while others prefer full sunlight. Araceae plants thrive in an average annual temperature range of 14-35°C, with rainfall between 2000-2500 mm yearly, 120-140 rainy days annually, and relative humidity of 80%. In Fuzzy logic theory, a value can simultaneously have true and false values, but the degree of truth and falsity depends on its membership weight. A suitable method for mapping input space to an output space is fuzzy logic[11].

Several components used in fuzzy logic are:

1. Fuzzy variables: Variables discussed within a fuzzy system, such as humidity, temperature, light intensity, etc.
2. Fuzzy sets: A group representing a certain condition or state within a fuzzy variable.
3. Universe of discourse: The entire range of values allowed to operate within a fuzzy variable.
4. Domain: The range of values allowed within the universe of discourse and can be operated within a fuzzy set.
5. Membership function: A curve that shows the mapping of input data points into their membership values, which range from 0 to 1.

The stages involved in interpreting fuzzy logic conclusions are as follows:

1. Fuzzification: The input variables are transformed into fuzzy variables using membership functions.
2. Application of implication functions The process of applying predetermined rules.
3. Rule composition: Combining fuzzy rules creates a new fuzzy set.
4. Defuzzification: Converting the degree of membership in fuzzy sets into specific decisions or crisp values.

Figure 1. LoRa E32-433T30D

LoRa is a long-range wireless communication system designed for low-power battery-operated devices to achieve long-lasting operation. Each transmission payload can range from 2 to 255 octets, and data rates can reach up to 50 Kbps. LoRa modulation technique is a technology owned by Semtech. LoRa E32-433T30D is a type of LoRa that has a wide spectrum spreading technology, allowing it to transmit over longer distances compared to other LoRa types. Its advantage lies in having the same power while exhibiting better anti-interference performance[12].

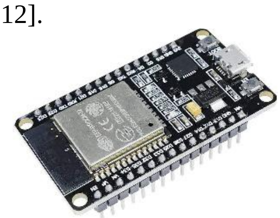

Figure 2. Node MCU ESP32

The ESP32 is a microcontroller equipped with high-speed Wi-Fi, making it highly suitable for supporting the Internet of Things (IoT) network implementations and Bluetooth Low Energy capabilities[13].

Figure 3. BME280

The BME280 sensor measures temperature and humidity with a maximum voltage limit of 4.25V and a temperature range of -40°C to 85°C. A suitable method for mapping input space to an output space is fuzzy logic[14].

Figure 4. Soil Moisture

The soil moisture sensor is a humidity sensor that can detect moisture levels in the soil. This sensor is simple but ideal for monitoring water levels in plants. It consists of two probes that pass current through the soil, and then read the resistance to obtain the moisture level value. More water in the soil makes it easier to conduct electricity (lower resistance), while dry soil is more resistant to conducting electricity (higher resistance)[15].

Figure 5. Relay

Relays use electromagnetic force to actuate switch contacts, allowing the conduction of higher voltage electricity with a small electric current (low power). For example, a Relay that utilizes a 5V Electromagnet and draws 50mA of wind can move the Relay's Armature (which functions as its switch) to conduct electricity at 220V and 2A[16].

III. METHOD AND DESIGN

This research method involves several stages, starting with a literature study that includes reviewing theoretical frameworks from various journals, books, and online sources to enhance the researched concepts and theories. Next, the formation of a block diagram of the overall system. The operation of the entire circuit system can be understood from the circuit's block diagram, which is one of the most crucial parts of designing a device. In this design, the Mamdani fuzzy method is incorporated to determine accurate decision-making in the output.

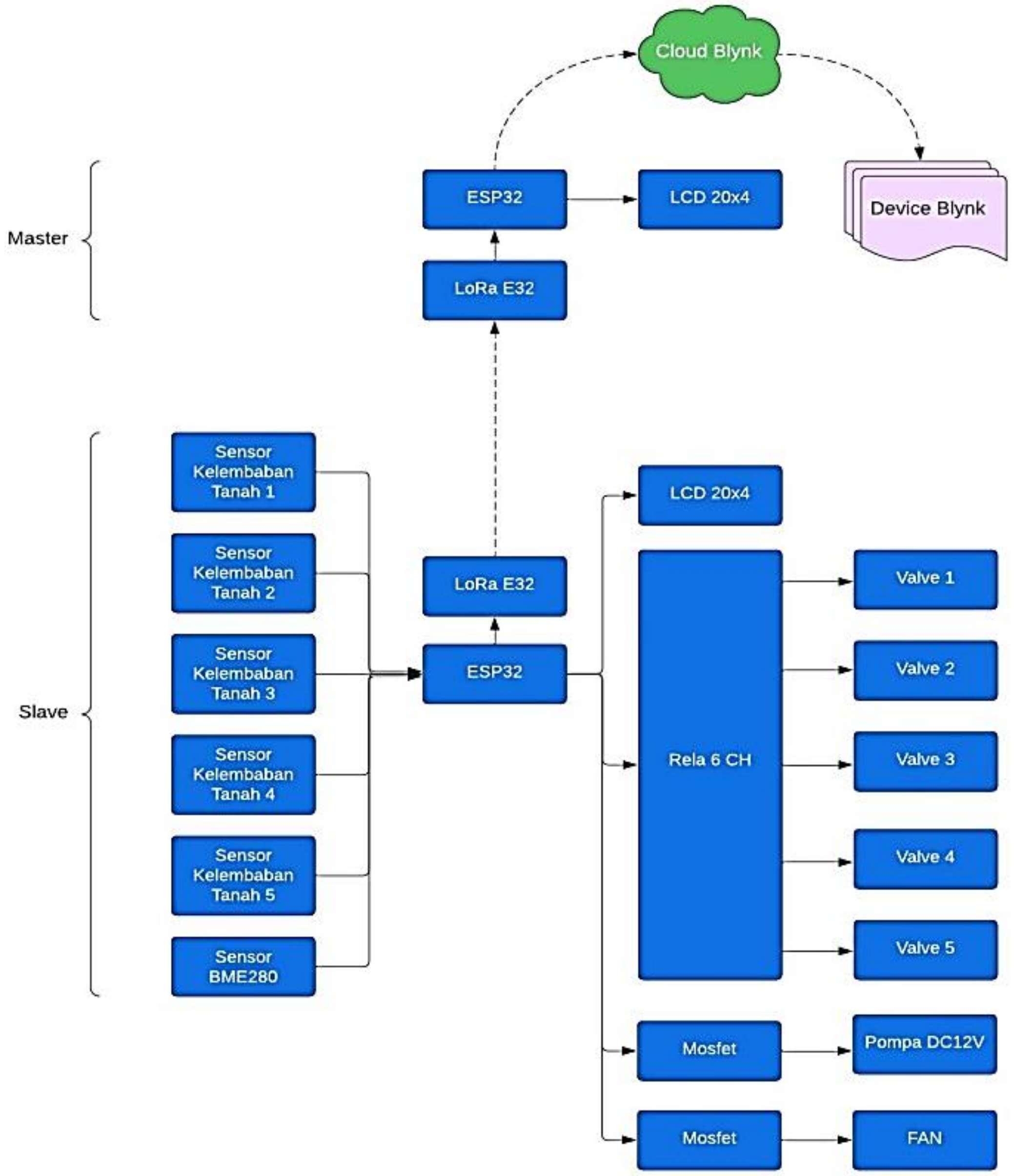

Figure 6. Block diagram

From Figure of block diagram, it can be observed that the temperature sensor and soil moisture sensor are inputs to the ESP32. The BME280 temperature sensor detects room temperature and humidity within the greenhouse, while the soil moisture sensor detects soil moisture. The Node MCU ESP32 is the component to process input commands from the temperature sensor, room humidity sensor, and soil moisture sensor. It also controls the output, which includes the blower and misting system. A relay controls the circuit, turning it on or off automatically. The relay is an essential component that activates the blower and misting pump as output.

For an IoT-based monitoring system, an internet connection is required. Internet access is established through a WiFi network, allowing the Node MCU ESP32 to send data to the Blynk device. In transmitting data from the Node MCU ESP32 to the

Blynk device, LoRa is used to send the monitoring data results.

Applying the Mamdani fuzzy method for data processing in this system begins with the input and output using two rounds of fuzzification. The first fuzzification focuses on room temperature and humidity to create a natural tropical rainforest condition. The second fuzzification solely focuses on the moisture of the different media for Araceae plants while incorporating the room temperature input to generate the output for the solenoid valve.

The Mamdani fuzzy method divides variables into one or more fuzzy sets. For this research, the fuzzy variables are divided into 10, which are room temperature, room humidity, Monstera planting media humidity, Philodendron planting media humidity, Caladium planting media humidity, Aglonema planting media humidity, Alocasia planting media humidity, blower, misting, and solenoid valve. To get the output of determining room conditions and plant soil media, a fuzzification stage is needed, which begins with determining the set of rules.

Table 1. Range of discourse for each fuzzy variable.

No.	Variable fuzzy	Universe of talk
1.	Room temperature	[0-45]
2.	Room humidity	[0-100]
3.	Soil moisture monstera	[0-100]
4.	Soil moisture philodendron	[0-100]
5.	Soil moisture aglonema	[0-100]
6.	Soil moisture caladium	[0-100]
7.	Soil moisture alocasia	[0-100]
8.	Blower	[0-255]
9.	Misting	[0-255]
10.	Valve selenoid	On-off

Variable input and output are presented as follows:

a. The fuzzy variable set for temperature

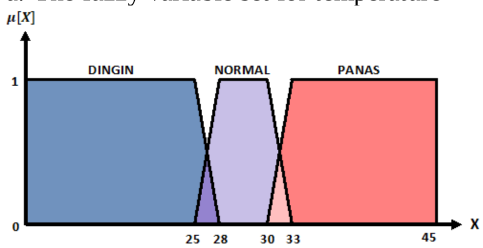

Figure 7. The fuzzy set of temperature

The calculation of the membership function for each of the cold, normal, and hot sets.

$$\mu\, dingin\,(x) = \begin{cases} 1, x \leq 35 \\ \frac{28-x}{28-25}, 25 \leq x \leq 28 \\ 0, x \geq 28 \end{cases} \quad (1)$$

$$\mu\, normal\,(x) = \begin{cases} \frac{x-25}{28-25}, 25 \leq x \leq 28 \\ 1, 28 \leq x \leq 30 \\ \frac{33-x}{33-30}, 30 \leq x \leq 33 \end{cases} \quad (2)$$

$$\mu\, panas\,(x) = \begin{cases} 0, x \leq 30 \\ \frac{x-30}{33-30}, 30 \leq x \leq 33 \\ 1, x \geq 33 \end{cases} \quad (3)$$

b. The fuzzy variable set for humadity

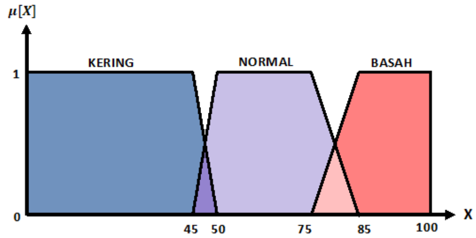

Figure 8. The fuzzy set of room humidity

The calculation of the membership function for each of the dry, normal, and wet sets.

$$\mu\, kering\,(x) = \begin{cases} 1, x \leq 45 \\ \frac{50-x}{50-45}, 45 \leq x \leq 50 \\ 0, x \geq 50 \end{cases} \quad (4)$$

$$\mu\, normal\,(x) = \begin{cases} \frac{x-45}{50-45}, 45 \leq x \leq 50 \\ 1, 50 \leq x \leq 75 \\ \frac{85-x}{85-75}, 75 \leq x \leq 85 \end{cases} \quad (5)$$

$$\mu\, basah\,(x) = \begin{cases} 0, x \leq 75 \\ \frac{x-75}{10}, 75 \leq x \leq 85 \\ 1, x \geq 85 \end{cases} \quad (6)$$

c. The fuzzy variable set for pump

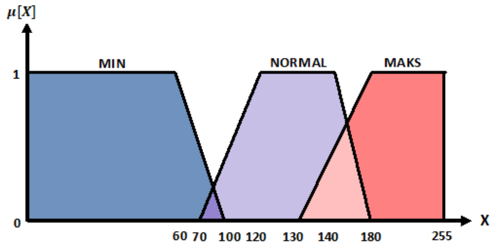

Figure 9. The fuzzy set of the pump output for misting

The calculation of the membership function foreach of the minimal, normal, and maximal sets.

$$\mu\, min\,(x) = \begin{cases} 1, x \leq 60 \\ \frac{100-x}{100-60}, 60 \leq x \leq 100 \\ 0, x \geq 100 \end{cases} \quad (7)$$

$$\mu\, normal\,(x) = \begin{cases} \frac{x-70}{120-70}, 70 \leq x \leq 120 \\ 1, 120 \leq x \leq 140 \\ \frac{180-x}{180-130}, 140 \leq x \leq 180 \end{cases} \quad (8)$$

$$\mu\, maks\,(x) = \begin{cases} 0, x \leq 130 \\ \frac{x-130}{180-130}, 130 \leq x \leq 180 \\ 1, x \geq 255 \end{cases} \quad (9)$$

d. The fuzzy variable set for blower output

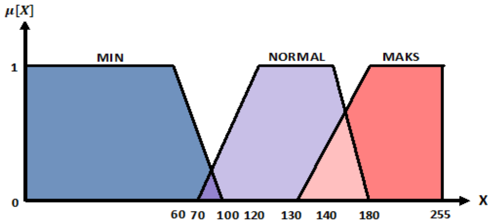

Figure 10. Blower output fuzzy set

The calculation of the membership function for each of the minimal, normal, and maximal sets.

$$\mu\, min\ (x) = \begin{cases} 1, x \leq 60 \\ \frac{100-x}{100-60}, 60 \leq x \leq 100 \\ 0, x \geq 100 \end{cases} \quad (10)$$

$$\mu\, normal\ (x) = \begin{cases} \frac{x-70}{120-70}, 70 \leq x \leq 120 \\ 1, 120 \leq x \leq 140 \\ \frac{180-x}{180-130}, 140 \leq x \leq 180 \end{cases} \quad (11)$$

$$\mu\, maks\ (x) = \begin{cases} 0, x \leq 130 \\ \frac{x-130}{180-130}, 130 \leq x \leq 180 \\ 1, x \geq 255 \end{cases} \quad (12)$$

e. The fuzzy variable set for soil moisture 1

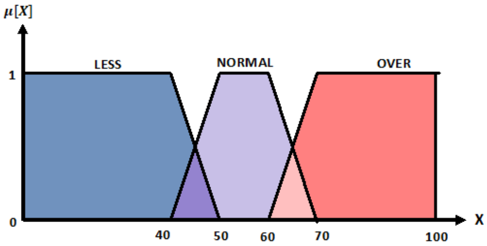

Figure 11. The fuzzy set of soil moisture (humidity) 1

The calculation of the membership function for each of the Less, Normal, dan Over.

$$\mu\, less\ (x) = \begin{cases} 1, x \leq 40 \\ \frac{50-x}{50-40}, 40 \leq x \leq 50 \\ 0, x \geq 50 \end{cases} \quad (13)$$

$$\mu\, normal\ (x) = \begin{cases} \frac{x-40}{50-40}, 40 \leq x \leq 50 \\ 1, 50 \leq x \leq 60 \\ \frac{70-x}{70-60}, 60 \leq x \leq 70 \end{cases} \quad (14)$$

$$\mu\, over\ (x) = \begin{cases} 0, x \leq 60 \\ \frac{x-60}{70-60}, 60 \leq x \leq 70 \\ 1, x \geq 70 \end{cases} \quad (15)$$

f. The fuzzy variable set for soil moisture 2

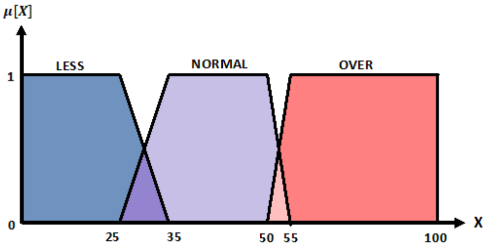

Figure 12. The fuzzy set of soil moisture (humidity) 2

The calculation of the membership function for each of the Less, Normal, dan Over.

$$\mu\, less\ (x) = \begin{cases} 1, x \leq 25 \\ \frac{35-x}{35-25}, 25 \leq x \leq 35 \\ 0, x \geq 35 \end{cases} \quad (16)$$

$$\mu\, normal\ (x) = \begin{cases} \frac{x-25}{35-25}, 25 \leq x \leq 35 \\ 1, 35 \leq x \leq 50 \\ \frac{50-x}{55-50}, 50 \leq x \leq 55 \end{cases} \quad (17)$$

$$\mu\, over\ (x) = \begin{cases} 0, x \leq 50 \\ \frac{x-50}{55-50}, 50 \leq x \leq 55 \\ 1, x \geq 55 \end{cases} \quad (18)$$

g. The fuzzy variable set for soil moisture 3

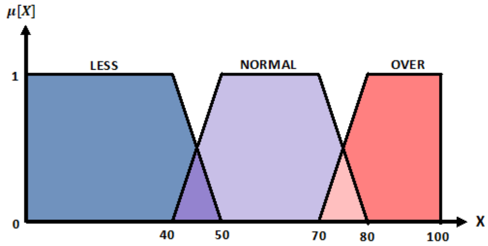

Figure 13. The fuzzy set of soil moisture (humidity) 3

The calculation of the membership function for each of the Less, Normal, dan Over.

$$\mu\, less\ (x) = \begin{cases} 1, x \leq 40 \\ \frac{50-x}{50-40}, 40 \leq x \leq 50 \\ 0, x \geq 50 \end{cases} \quad (19)$$

$$\mu\, normal\ (x) = \begin{cases} \frac{x-40}{50-40}, 40 \leq x \leq 50 \\ 1, 50 \leq x \leq 70 \\ \frac{80-x}{80-70}, 70 \leq x \leq 80 \end{cases} \quad (20)$$

$$\mu\, over\ (x) = \begin{cases} 0, x \leq 70 \\ \frac{x-70}{80-70}, 70 \leq x \leq 80 \\ 1, x \geq 80 \end{cases} \quad (21)$$

h. The fuzzy variable set for soil moisture 4

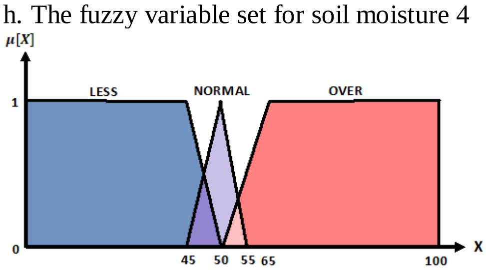

Figure 14. The fuzzy set of soil moisture (humidity) 4

The calculation of the membership function for each of the Less, Normal, dan Over.

$$\mu\, less\ (x) = \begin{cases} 1, x \leq 45 \\ \frac{50-x}{50-45}, 45 \leq x \leq 50 \\ 0, x \geq 50 \end{cases} \quad (22)$$

$$\mu\, normal\ (x) = \begin{cases} \frac{x-45}{50-45}, 45 \leq x \leq 50 \\ 0, x \leq 45\ atau\ x \geq 55 \\ \frac{55-x}{55-50}, 50 \leq x \leq 55 \end{cases} \quad (23)$$

$$\mu\ over\ (x) = \begin{cases} 0, x \leq 50 \\ \frac{x-50}{60-50}, 50 \leq x \leq 60 \\ 1, x \geq 60 \end{cases} \quad (24)$$

i. The fuzzy variable set for soil moisture 5

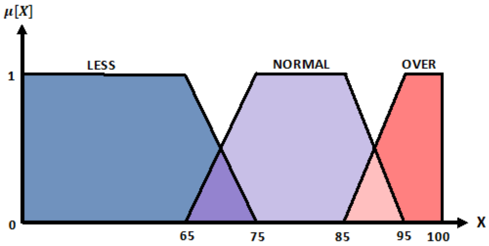

Figure 15. The fuzzy set of soil moisture (humidity) 5

$$\mu\ less\ (x) = \begin{cases} 1, x \leq 65 \\ \frac{75-x}{75-65}, 65 \leq x \leq 75 \\ 0, x \geq 75 \end{cases} \quad (25)$$

$$\mu\ normal\ (x) = \begin{cases} \frac{x-65}{75-65}, 65 \leq x \leq 75 \\ 1, 75 \leq x \leq 85 \\ \frac{95-x}{95-85}, 85 \leq x \leq 95 \end{cases} \quad (26)$$

$$\mu\ over\ (x) = \begin{cases} 0, x \leq 85 \\ \frac{x-85}{95-85}, 85 \leq x \leq 95 \\ 1, x \geq 95 \end{cases} \quad (27)$$

This study uses two fuzzy rules: one for the room and one for the soil moisture.

Table 2. Room Rule Fuzzy

No	Input		Output	
	Room tempera-ture	Room humadi-ty	Pump Misting	Fan Blower
1.	Cold	Dry	Normal	Minimal
2.	Cold	Normal	Minimal	Minimal
3.	Cold	Wet	Minimal	Minimal
4.	Normal	Normal	Minimal	Minimal
5.	Normal	Dry	Normal	Normal
6.	Normal	Wet	Minimal	Normal
7.	Hot	Wet	Maksimal	Maksimal
8.	Hot	Normal	Normal	Maksimal
9.	Hot	Wet	Normal	Maksimal

Table 3. Soil Moisture Rule Fuzzy

One of the defuzzification methods used in the defuzzification process is the centroid (centre point) method. The centroid method is a method that uses the centre of gravity of a fuzzy set along the x-axis. Therefore, many refer to this method as the Centre of Gravitation (CoG) method. If we have an area with

No.	Input		Output Valve
	Room Tempertur	Soil moisture	
1.	Cold	Less	On
2.	Cold	Normal	Off
3.	Cold	Over	Off
4.	Normal	Less	On
5.	Normal	Normal	Off
6.	Normal	Over	Off
7.	Hot	Less	On
8.	Hot	Normal	Off
9.	Hot	Over	Off

uniform density, the centroid is the point along the x-axis that balances the left gap with the right area. The centroid is calculated using the following equation:
μ (x) is the membership value for point x in the universal set.

$$x\ centroid = \frac{\sum_i \mu(x_i) x_i}{\sum_i \mu(x_i)}, or\ \frac{\int_{xi}^{xn} (x)dx}{\int_{xi}^{xn} (x)dx} \quad (28)$$

IV. Results and Discussion

In this study, system testing was carried out directly in a greenhouse with a monitoring distance of about 700 meters between the receiver and transmitter. This test includes collecting data from the results of the BME280 sensor, capacitive soil moisture sensor, and data from the channel output results, namely blowers, misting, and solenoid valves.

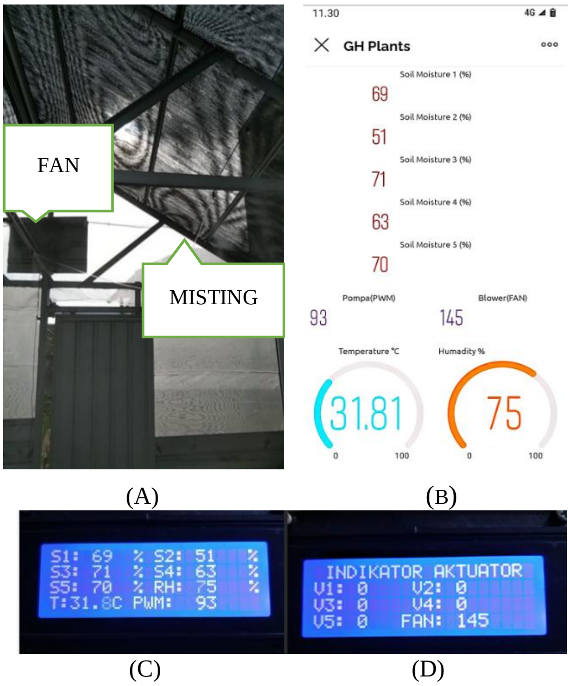

Figure 16. (A).Installation of output devices in the greenhouse, (B).Monitoring results through the bynk application, (C) and (D) Monitoring results through the actuator incubator

The BME280 sensor measures several environmental parameters, such as temperature, air humidity, and air pressure inside the greenhouse. The capacitive soil moisture sensor aims to measure the soil moisture level, which is crucial information for optimizing plant growth conditions inside the greenhouse.

Additionally, output data from the blower, misting, and solenoid valve channels are collected during testing. The blower is responsible for air circulation inside the greenhouse, the misting system sprays small amounts of water to maintain proper humidity and environmental conditions, and the solenoid valve controls the flow of water or other fluids per the system's requirements. By collecting and analyzing data from these sensors and controlling the outputs from these channels, this research aims to understand and optimize the environmental conditions inside the greenhouse for efficient and effective plant growth. The results of this study are expected to provide valuable insights and recommendations for the development of greenhouse-based agricultural technologies.

Test results on the first fuzzy rule where the BME280 sensor will control the room conditions in the greenhouse by adjusting the blower and pump according to the conditions set.

Table 4. Results of monitoring the condition of the room from morning to evening

Time (WIB)	**Temperatur (°C)**	**Humidity (%)**	**FAN (pwm)**	**PUMP (pwm)**
08.00	26.6°C	80%	85	45
08.30	26.7°C	80%	85	45
09.30	28°C	81%	93	45
10.30	30°C	82%	100	93
11.30	31.8°C	75%	147	93
12.30	30°C	75%	41	41
13.30	31.6°C	72%	135	90
14.30	29.8°C	80%	85	45
15.30	28.9°C	81%	93	42
16.30	28.8°C	80%	117	41
17.30	28.5	85%	127	41

Test results on the second fuzzy rule where the soil moisture sensor detects moisture in different soil media and in different plant genera. The fuzzy method is manually calculated using the input values in the first fuzzy rule system, given an input value of 31.8°C for temperature and an output value of 75% for humidity. The first step is to identify to what extent the input corresponds to the fuzzy sets. The temperature has three categories of values: cold, normal, and hot, while the humidity has three categories: dry, normal, and wet. Next, in the fuzzyification process, inference is carried out to evaluate the fuzzy rules and obtain the output value.

After performing fuzzification, the next step is inference, where we obtain the output value in the set that will be tested.

Is known: mark input 31.8°C

mark output 75%

Regarding the pump output, the centroid value obtained is 92.67 PWM, while for the fan output, the centroid value obtained is 142.94 PWM. When looking at the values generated by MATLAB, the output values for the pump are 92.1 and for the fan are 145. Several factors, such as sensor and device tolerances, environmental influences during testing, or the centroid calculation method, can cause these differences. Despite the slight variances, overall, the test results and comparisons with values generated by MATLAB demonstrate that the system performs consistently and reliably.

It is important to note that these small differences in values were not significant during testing and experimentation and are still within acceptable tolerance limits. Therefore, this research provides valuable insights into how the system functions in regulating the pump and fan outputs using centroid values obtained from sensors and how these results can be correlated with values produced by software such as MATLAB..

Table 5. results of monitoring the condition of the soil media 1-5 from morning to evening

Time	Soil (%)	Valve	Soil (%)	Valve	Soil (%)	Valve	Soil (%)	Valve	Soil (%)	Valve
	1	1	2	2	3	3	4	4	5	5
08.00	60%	0	46%	0	67%	0	62%	0	68%	0
08.30	63%	0	46%	0	67%	0	61%	0	68%	0
09.30	65%	0	46%	0	67%	0	62%	0	68%	0
10.30	67%	0	46%	0	67%	0	62%	0	68%	0
11.30	68%	0	47%	0	69%	0	63%	0	68%	0
12.30	68%	0	47%	0	69%	0	63%	0	68%	0
13.30	69%	0	51%	0	71%	0	63%	0	70%	0
14.30	68%	0	51%	0	71%	0	62%	0	70%	0
15.30	69%	0	51%	0	71%	0	62%	0	70%	0
16.30	68%	0	51%	0	71%	0	62%	0	70%	0
17.30	68%	0	51%	0	71%	0	62%	0	70%	0

The valve value is 0 for all cases based on the soil moisture output results. This is because the soil moisture sensor detects that the soil condition is as desired, meaning that the test results focus on the regular watering required by the nutritional needs of the Araceae plants.

V. CONCLUSION

The designed system can effectively monitor and control temperature and humidity sensors in the room with the assistance of the BME280 sensor and capacitive soil moisture sensor. In the manual fuzzy calculation compared to the fuzzy calculation in MATLAB, there is a noise value with an average difference of 1.31. The implementation of long-range monitoring for this monitoring is done at a distance of approximately 700 meters. During the monitoring, the transmission noise from the transmitter to the receiver was observed to have an average delay of 2 seconds caused by weather conditions.

REFERENCES

[1] M. A. Hutasuhut, “Inventarisasi Jenis-Jenis Arecaceae Di Kawasan Hutan Taman Nasional Gunung Leuser Desa Telagah Kabupaten Langkat Sumatera Utara,” *KLOROFIL J. Ilmu Biol. dan Terap.*, vol. 2, no. 2, p. 1, 2020, doi: 10.30821/kfl:jibt.v2i2.7823.

[2] L. Qodriyah, B. F. Wahidah, S. Hidayat, and R. Khasanah, “Karakterisasi Stomata Daun Pada Tanaman Hias Familia Araceae,” *Pros. Biol. Achiev. Sustain. Dev. Goals with Biodivers. Confronting Clim. Chang.*, no. November, pp. 242–254, 2021, [Online]. Available: http://journal.uin-alauddin.ac.id/index.php/psb.

[3] M. M. Fahmi, *Struktur Komunitas Fauna Tanah Berbeda Di Taman Safari Indonesia II prigen jawa timur*, vol. Surabaya. 2016.

[4] A. M. Siregar, H. Febriani, and M. A. Hutasuhut, “Analisis Biodiversitas Jenis-Jenis Tumbuhan Liana Di Taman Nasional Batang Gadis Resort 7 Sopotinjak Kabupaten Mandailing Natal Sumatera Utara,” *KLOROFIL J. Ilmu Biol. dan Terap.*, vol. 5, no. 2, p. 83, 2021, doi: 10.30821/kfl:jibt.v5i2.9403.

[5] M. Setiani Asih, “Sistem Pendukung Keputusan Fuzzy Mamdani pada Alat Penyiraman Tanaman Otomatis,” *J. Sist. Inf.*, vol. 5341, no. April, p. 1, 2018.

[6] J. Agustina, R. Arifah, A. Yuliyati, and Dkk, *Sistem Greenhouse di Iklim Tropis dan Subtropis*. 2022.

[7] J. Beyerer, G. Bretthauer, and T. Längle, “Smart agriculture,” *At-Automatisierungstechnik*, vol. 69, no. 4, pp. 275–277, 2021, doi: 10.1515/auto-2021-2049.

[8] A. Syarief, Teuku. Handayani, Hanny. dan juwita, “Rancang Bangun Penyiram Tanaman Aglaonema Otomatis Menggunakan Sensor Kelembaban Tanah dan Suhu Udara dengan Metode Fuzzy Logic Berbasis IoT,” *Sci. student J. information, Technol. Sci.*, vol. vol.3 no.2, 2022, [Online]. Available: http://journal.ubpkarawang.ac.id/mahasiswa/index.php/ssj/article/view/438.

[9] J. Gresl, S. Fazackerley, and R. Lawrence, “Practical precision agriculture with LoRa based wireless sensor networks,” *SENSORNETS 2021 - Proc. 10th Int. Conf. Sens. Networks*, no. Sensornets, pp. 131–140, 2021, doi: 10.5220/0010394401310140.

[10] W. Paramita, Yulianty, B. Irawan, and Suratman, “Diversity of Herbaceous Plant in The Utilization Block of Sumber,” *Ilm. Biol. dan Keanekaragaman Hayati*, vol. 6, no. 2, pp. 31–40, 2019.

[11] H. Nasution, “Implementasi Logika Fuzzy pada Sistem Kecerdasan Buatan,” *ELKHA J. Tek. Elektro*, vol. 4, no. 2, pp. 4–8, 2020, [Online]. Available: https://jurnal.untan.ac.id/index.php/Elkha/article/view/512%0Ahttp://download.garuda.kemdikbud.go.id/article.php?article=1559615&val=2337&title=Implementasi Logika Fuzzy pada Sistem Kecerdasan Buatan.

[12] M. Arrofiq, “Implementasi Analisis NIDS Berbasis Snort Dengan Metode Fuzy Untuk Mengatasi Serangan LoRaWAN,” *J. RESTI (Rekayasa Sist. Dan Teknol. Informasi)*, vol. 2, no. 3, pp. 685–696, 2018.

[13] A. Augustin, J. Yi, T. Clausen, and W. M. Townsley, “A study of LoRa: Long range & low power networks for the internet of things,” *Sensors*, vol. 16, no. 9, p. 1466, 2016.

[14] L. S. Vaz and L. P. S. Neto, “Developing the altitude and communication subsystem using COTS components applied to the Tycho CubeSat,” no. Restivo, 2019.

[15] O. Nurdiawan, I. Ali, C. L. Rohmat, and A. R. Rinaldi, “Sistem Kendali Sensor Tanah Sebagai Pemonitor Tingkat Kelembaban Media Tanam Padi,” *InfoTekJar J. Nas. Inform. dan Teknol. Jar.*, vol. 5, no. 1, pp. 14–17, 2020.

[16] A. R. Wijaya and Z. Lutfiyani, “Rancang Bangun Prototype Kendali Motor Pompa Tendon Air Dengan Automatic Transfer Switch (ATS) PLTS Dan PLN,” *JTERAF (Jurnal Tek. Elektro Raflesia)*, vol. 1, no. 2, pp. 1–7, 2021.