Development of an IoT-Based Smart Greenhouse with Fuzzy Logic for Chrysanthemum Cultivation

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ABSTRACT

Conventional cultivation of Chrysanthemum plants in greenhouses faces serious challenges such as inefficiency, response delays, and errors in temperature and humidity settings due to manual management. These conditions result in unsuitable growing environments that can reduce the quality and quantity of harvests. To overcome these problems, this study developed a smart greenhouse system based on the Internet of Things (IoT) and cloud computing with the application of fuzzy logic. The system is designed to automatically monitor and control temperature, humidity, and light intensity using NodeMCU ESP32, DHT22 and BH1750 sensors, as well as relay-based actuators and mini air conditioners. Environmental data is sent to the cloud and processed using the Sugeno fuzzy method to produce adaptive and precise control decisions. Test results show that the system can maintain stable and optimal environmental conditions with an average temperature control difference of 30.341% and an actuator efficiency of 9.34% against microcontroller commands. This system provides a modern solution to the limitations of traditional methods, and supports smart agriculture in tropical climates such as Lhokseumawe.

I. INTRODUCTION

Chrysanthemum morifolium is a highly valued ornamental plant known for its diverse colors and commercial significance. Its cultivation requires specific environmental conditions, particularly in terms of temperature, humidity, and light intensity [1], [2]. In tropical regions such as Lhokseumawe, Indonesia, where the temperature ranges between 23°C and 32°C, maintaining optimal growth conditions becomes a challenge [3]. Traditional greenhouses with manual control methods often fail to efficiently regulate such variables, resulting in decreased crop quality and yield [4].

Internet of Things (IoT) is a digital transformation platform that can be the backbone for developing a digital data-based ecosystem [5]. The use of IoT in smart greenhouse systems enables monitoring and control of the cultivation environment. This IoT system enables automation in greenhouse environmental management, so that plants can grow in optimal conditions [6]. Computing is a critical component in IoT-based smart greenhouse systems [7]. By storing and processing data in the cloud, data management becomes more efficient and flexible. Cloud computing integration also facilitates more in-depth data analysis that can be accessed via mobile devices [8], [9], [10].

The adoption of Internet of Things (IoT) technologies has revolutionized precision agriculture by enabling real-time data monitoring through sensors that detect environmental parameters such as temperature, humidity, and light intensity [11]. These data are transmitted via microcontrollers like NodeMCU ESP32 to cloud computing platforms, where they can be stored, processed, and analyzed remotely [12], [13]. This enhances data-driven decision-making, automation, and access through mobile devices.

Furthermore, integrating fuzzy logic into this system introduces intelligent control for dynamic and uncertain environments. Fuzzy logic, particularly the Sugeno method, provides crisp decision outputs based on fuzzy input sets and is ideal for controlling actuators like fans or cooling systems [14]. Combined with IoT and cloud computing, fuzzy logic enables autonomous regulation of environmental variables to maintain the desired growing conditions for sensitive plants like chrysanthemums.

Several previous studies have demonstrated the effectiveness of integrating this technology to support sustainable agriculture [15]. Small-scale greenhouse systems using fuzzy logic and IoT, resulting in self-regulation suitable for unsupervised plant growth and can improve agricultural efficiency and sustainability [16], [17]. Smart greenhouse systems can monitor environmental conditions automatically control watering duration and light intensity using fuzzy logic methods [18]. IoT-based greenhouse farming systems improve crop management and promote sustainable agriculture [19]. Smart greenhouse systems using IoT can optimize plant growth and reduce waste of agricultural resources, increase crop yields and promote sustainable agriculture [20], [21].

The use of Internet of Things (IoT) and cloud computing technologies enables automatic, real-time monitoring and control of environmental parameters. Data from temperature, humidity, and light sensors can be sent to the cloud for analysis and use in automated decision-making through control algorithms. However, the choice of control method is key to the success of such a system.

Conventional control methods such as Proportional-Integral-Derivative (PID) are often used due to their simplicity. While effective in linear systems and stable conditions, PID is difficult to adapt to non-linear system dynamics such as temperature and humidity fluctuations in greenhouses, and is intolerant of data uncertainty. Meanwhile, Mamdani fuzzy logic is known for its ability to handle linguistic data and generate rule-based decisions. However, Mamdani produces output in the form of fuzzy sets that require a relatively computationally intensive defuzzification process. This makes it less efficient in microcontroller-based implementations with limited processing power. On the other hand, the Sugeno fuzzy logic method offers advantages in terms of efficiency and speed because its output is in the form of crisp numerical values, without the need for a complex defuzzification process. Furthermore, Sugeno excels in controlling non-linear systems and is suitable for real-time systems running on low-power devices such as the NodeMCU ESP32. The combination of Sugeno fuzzy logic with IoT and cloud computing enables intelligent, adaptive, and energy-efficient greenhouse automation, capable of responding quickly to environmental changes.

This research aims to develop an IoT- and cloud computing-based smart greenhouse system using Sugeno fuzzy logic for chrysanthemum cultivation. This system is designed to automatically monitor and control temperature, humidity, and light intensity and evaluate the effectiveness of the Sugeno method in improving environmental control efficiency. This approach is expected to yield adaptive and effective precision agriculture solutions, particularly in addressing the challenges of tropical climates such as those in Lhokseumawe City.

II. METHODOLOGY

Study this including type research and development because will research and develop smart greenhouse for plant chrysanthemum with utilise internet of things and cloud computing with stages core that is survey initial, design, test try, validate, test validation and implementation. Literature study is the collection of data using literature in the form of online media, articles or reading materials related to this research. Design system usually built to know description information about the system to be built.

In this first stage, researchers naturally observe and see the great potential in the problem for the data collection process in the field. Then, before developing the system, it is necessary to collect initial data, namely by searching for various types of literature such as journals, library books, and other sources related to the development of this system. Collection data beginning important done For gather data related to the design of this system, then verified, sorted and separated to become data that is suitable for use in the initial data collection stage process in the field.

This research was conducted over a period of approximately six months, starting from January to June 2025. This time span covered all stages of activities, from system preparation and implementation to testing and evaluation of system performance in the field. During this duration, the system was tested in the context of continuous real-world use, including observing the stability of sensor functions, automatic control using Sugeno fuzzy logic, and data transmission through the ThingsBoard platform over a long period. This longitudinal approach allowed researchers to assess the system's overall performance throughout the growing season and the dynamics of microclimate changes in the greenhouse.

A. System Block Diagram Design

Block diagram design is a form of diagram that uses blocks to represent components or parts of a system or process, and the relationships between these blocks. The block diagram contains information about inputs, outputs, and functions or tasks carried out by system components. The block diagram illustration of a smart greenhouse system for chrysanthemums based on the Internet of Things (IoT) and cloud computing with the fuzzy logic method is shown in Figure 1.

Following explanation from input, process, and output from block diagram above: The block diagram of the Chrysanthemum Plant Smart Greenhouse system shows an IoT-based automation workflow that starts with input in the form of environmental data collected by the DHT22 sensor (for temperature and humidity) and the BH1750 sensor (for light intensity). This data is sent to the ESP32 microcontroller which processes it using fuzzy logic to analyze environmental conditions and determine the necessary actions. Based on the analysis results, the ESP32 controls actuators in the form of servos to open or close water taps for the irrigation system, as well as relays to activate a portable mini AC to maintain optimal temperatures in the greenhouse.

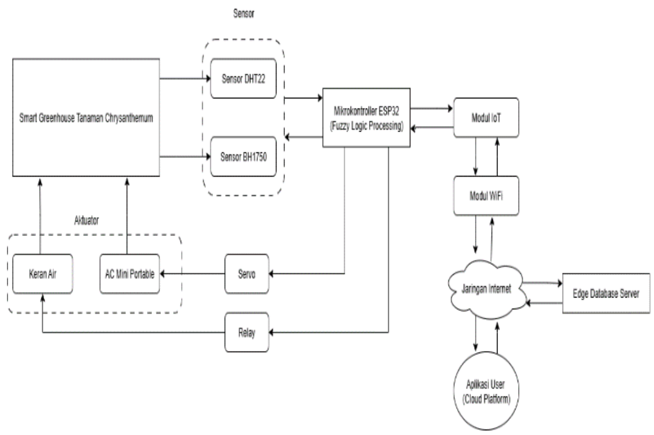

Figure 1. Block System Diagram

In addition to local control, the microcontroller also sends data to the IoT module and WiFi module to be forwarded to the internet network, so that information can be accessed by users through cloud platform applications and stored on the edge database server. Thus, this system produces output in the form of automatic control of temperature, humidity, and plant irrigation and provides real-time remote monitoring for users.

B. Flowchart Design System Monitoring

System started with sensor detect parameter environment like temperature, humidity, and light intensity, which are then sent to the microcontroller to processing initial data the furthermore transmitted to cloud via communication network to be stored in a database, where the fuzzy logic algorithm on The cloud processes the data to analyze environmental conditions and provide action recommendations that are sent to the user's dashboard in a web or mobile application, while automatically controlling actuators such as water pumps, fans, and lights based on the analysis results, so that users can monitor And control system in a way manual and automatic. The monitoring system flowchart is shown in Figure 2.

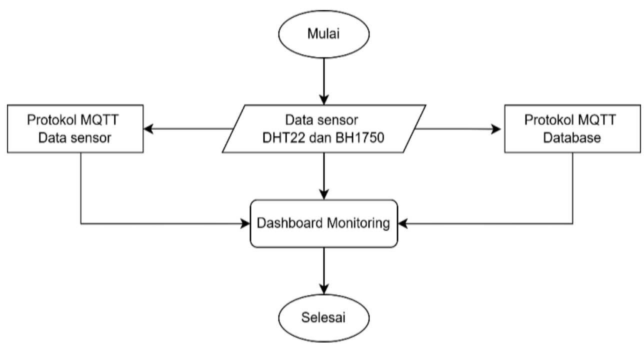

Figure 2. Flowchart System Monitoring

C. Automation System Flowchart

Temperature and humidity data are read by the DHT22 sensor and light intensity data read by sensor BH1750 will in process to microcontroller For pre-processed before being transmitted to the cloud via the network using the fuzzy sugeno method. Then data output from calculation will customized with rule The results are sent to the user dashboard for monitoring, while actuators are automatically activated based on the analysis results, ensuring environmental conditions remain ideal for plant growth. The automation system flowchart is shown in Figure 3.

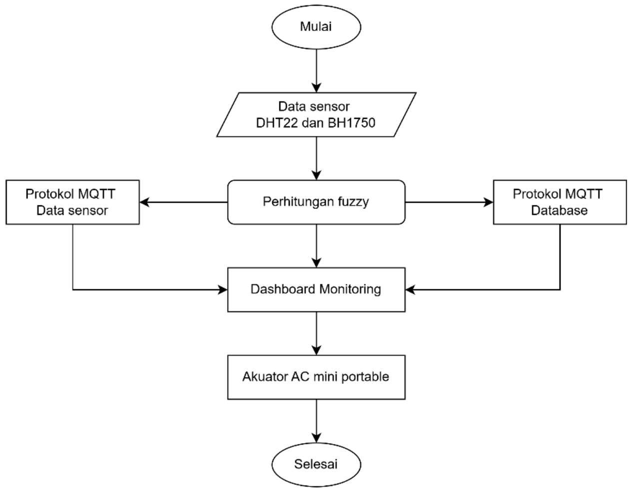

Figure 3. Flowchart System Automation

D. Flowchart Fuzzy Sugeno on System

In this fuzzy process flowchart, it starts from input from the DHT22 sensor data and BH1750 Then done calculation use method fuzzy Sugeno, which will be explained in a predefined process flowchart (fuzzy Sugeno calculation method), and the results will be sent to the database, then the data from the calculation results or the status of the actuator automation is displayed on the website's monitoring dashboard. The process stages of the calculation using the fuzzy Sugeno method are shown in Figure 4.

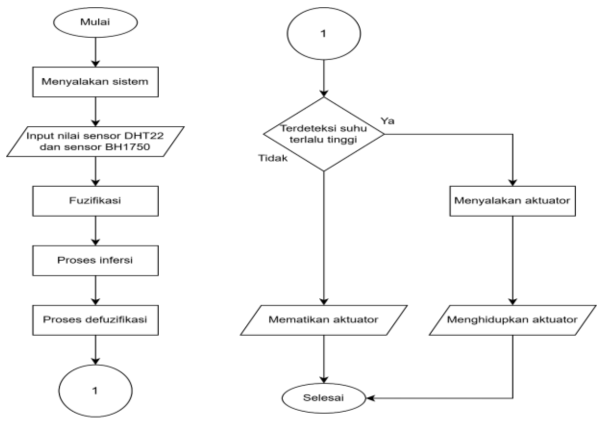

Figure 4. Process Fuzzy Sugeno on System

E. Design Fuzzy Logic

Fuzzy logic is a logic that has a fuzzy value (Fuzzyness) between mark Correct And mark Wrong. Possible more he explained, logic Fuzzy is a logic that can clarify the value between true or false. Fuzzy logic is commonly used in control theory, decision-making, and some areas of science. The advantage of fuzzy logic is that it uses linguistic reasoning , eliminating the need for mathematical equations for the object being controlled. For example, when We want to discuss something mark from movement, distance whether Far or If it's close, then with fuzzy logic, the rules can be far, medium, and close. Then, the qualification of which range is far, medium, or close. The design of the fuzzy logic circuit expected in this research is is shown in Figure 5.

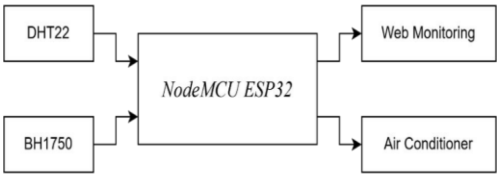

Figure 5. Fuzzy Circuit

From picture in on, can seen that there is two fruit input, that is DHT22 sensor And sensor BH1750. NodeMCU ESP32 on duty read data from both sensors the And send data to cloud For processed. Furthermore, calculation process logic fuzzy done For optimize arrangement climate in a greenhouse , such as regulating temperature and humidity by turning the air conditioner on or off. In this control, temperature and humidity data are used as input. input, whereas action arrangement temperature or humidity be the resulting output. The fuzzy logic approach allows for handling uncertainty in decision making, Mark For temperature air ranges between <18°C until >26°C, whereas humidity air own range <50% to >70%. As for condition mark threshold set fuzzy has grouped into low, normal, and high categories, as described in the previous table as explained in table I.

TABEL I

SET FUZZY DHT22

No	Type	Variables	Mark
1	Input	Temperature Air (°C)	Low: < 17°C
			Normal: 18°C - 26°C
			Height: > 30°C
2	Output	Cooling Status	Active: If high temperature > 26°C
			Non Active : If the temperature is normal or low < 26°C
3	Input	Humidity Air (%)	Low: < 50%
			Normal: 50% - 70%
			Height: > 70%
4	Output	Moisturizing Status	Active: If humidity low is < 50%
			Non-active: If humidity normal or high is 50% - 70%

III. RESULT AND DISCUSSION

The system testing stage is one of the steps in preparing the system so that Ready For operated. Testing system done For ensure that sensor temperature And humidity is working properly and the IoT system can transmit data in real-time. Testing is carried out in several stages to get perfect results. method do testing on tool And do testing For send data to thingsboard.

ThingsBoard is an open-source platform that supports real-time monitoring and control of IoT devices. It is used to store, visualize, and analyze data from temperature, humidity, and light sensors sent by the NodeMCU ESP32 microcontroller via the MQTT communication protocol. ThingsBoard was chosen as the cloud platform based on its advantages in providing an interactive dashboard, its ability to integrate with various IoT protocols such as MQTT and HTTP, and its ease of device management and flexible data visualization. Furthermore, ThingsBoard can be accessed through a web browser or mobile app, making it easy for users to remotely monitor greenhouse conditions in real time.

A. Sensor Testing

Sensor testing was conducted by examining several types of sensors used in the smart greenhouse system . The purpose of this testing was to ensure that the sensors were functioning properly and as expected. The sensors tested included temperature and humidity sensors.

1) DHT22 Temperature Testing with a Thermometer

Temperature testing was conducted by placing a sensor device inside the greenhouse to measure the ambient temperature. The measurement results were then compared with data from a thermometer used as a comparative measuring tool to evaluate its accuracy. The measurement process was carried out in several trials. The temperature results inside the greenhouse are presented in Table II.

TABEL II

TESTING DHT22 TEMPERATURE VALUE WITH A THERMOMETER

No	Testing	Data sensor (° C)	Data thermometer (° C)	difference
1.	Testing 1	28.6 °C	28.9 °C	1%
2.	Testing 2	28.6 °C	28.8 °C	2%
3.	Testing 3	28.7 °C	28.7 °C	0%
4.	Testing 4	28.3 °C	28.3 °C	0%
5.	Testing 5	28.6 °C	28.6 °C	0%
6.	Testing 6	27.3°C	27.3 °C	0%
7.	Testing 7	26.1 °C	26.1 °C	0%
8.	Testing 8	26.3 °C	26.1 °C	2%
9.	Testing 9	25.8 °C	25.5 °C	3%
10.	Testing 10	25.5 °C	25.4 °C	1%

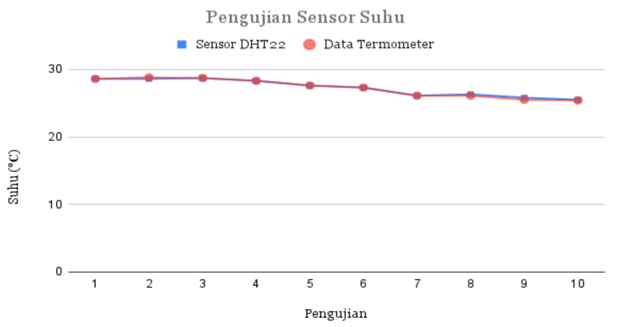

Figure 6. DHT22 Temperature Sensor Test Results with a thermometer

Based on the test results shown in Table I, it can be concluded that the temperature sensor generally provides accurate measurements and is close to the values indicated by the thermometer. Most tests show very small differences, some even showing a difference of 0%. However, there were several experiments where the sensor recorded slightly higher values than the thermometer, with differences ranging from 1 to 3%. In general, this temperature sensor is reliable enough for use in applications requiring a high level of accuracy. For example, in the fifth test, no difference was found between the sensor and thermometer results, as shown in Figure 6.

Figure 7. Temperature Data Sensor And Data Thermometer

In the first test, the results showed no difference between the data measured by the sensor and the data from the thermometer. In other words, both devices produced identical results, so no significant measurement errors were found. Meanwhile, in the second test, there was a 2% difference between the sensor and thermometer data, as shown in Figure 7.

Figure 8. Temperature Data Sensor And Data Thermometer

In the second test, a difference in results was observed compared to the first test, with a 2% difference between the data generated by the sensor and the thermometer. This difference indicates variation in the readings of the two measuring instruments, likely caused by factors such as the accuracy level or the calibration conditions of the devices.

The data in Table I represents the temperature values read by the DHT22 sensor and thermometer. Figure 8, presents a difference in the temperature test results. The percentage difference and the average difference are then calculated for both data sets. The difference is obtained by calculating the relative difference between the two sets. The following is a calculation of the difference compared to the actual values in the first data set from the DHT22 and thermometer.

$$difference = \frac{sensor\ temperature\ DHT22 - thermometer\ temperature}{thermometer\ temperature} x\ 100\ \%$$

$$difference = \frac{28{,}6 - 28{,}9}{28{,}9} x\ 100\ \%$$

$$difference = -1.04\ \%$$

The results obtained from calculating the difference using the first data of the DHT22 sensor temperature with the thermometer temperature are -1.04%.

$$average\ difference = \sum \frac{0.61}{10}$$

$$average\ difference = 0.061\%$$

The result of the average difference in the comparison between the DHT22 sensor temperature and the thermometer is 0.061%.

2) *Testing Humadity*

Humidity testing is performed by placing a measuring device inside the greenhouse to record the humidity level. These measurements are then compared with data from a thermometer used as a benchmark to evaluate the sensor's accuracy. The test is conducted in several trials to obtain a more accurate picture of the humidity inside the greenhouse.

TABEL III
TESTING HUMADITY

No	Testing	Data sensor (%)	Data thermometer (%)	difference
1.	Testing 1	73%	73%	0%
2.	Testing 2	71%	73%	2%
3.	Testing 3	71%	72%	1%
4.	Testing 4	70%	68%	2%
5.	Testing 5	72%	72%	0%
6.	Testing 6	70%	71%	2%
7.	Testing 7	69%	71%	2%
8.	Testing 8	71%	71%	0%
9.	Testing 9	70%	69%	1%
10.	Testing 10	70%	70%	0%

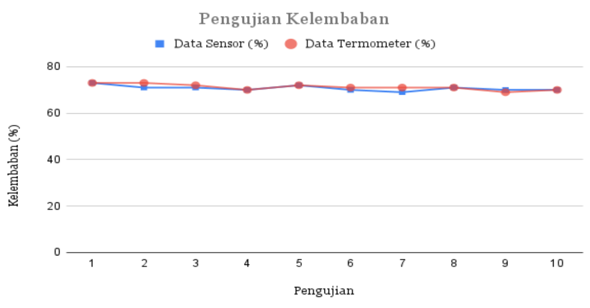

Figure 9. 1of DHT22 humidity test results with a thermometer

Based on the test results listed in Table III, the humidity sensor generally showed measurement results close to those recorded by the humidity thermometer. Most tests recorded a difference of 0% between the two devices, indicating a high level of accuracy. However, there were some tests that showed differences between 1 and 2%. Overall, this humidity sensor is considered reliable for use in humidity monitoring systems that require high precision. In the first test, no difference was found between the sensor and thermometer results, as shown in Figure 9.

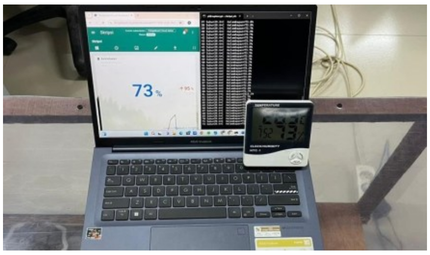

Figure 10. Humidity Data Sensor And Data Thermometer

In the first test, the identical results between the sensor and the humidity thermometer, namely 73%, indicate that the sensor is the right choice for applications that require accurate and consistent humidity monitoring. With stable performance and good precision, this sensor is able to provide reliable data under various conditions, thus supporting effective decision-making in environmental management. Meanwhile, in the second test, there was a difference of 2% between the sensor and thermometer readings, as shown in Figure 10.

Figure 11. Humidity Data Sensor and Data Thermometer

In the second test, a difference was observed compared to the first test, where the sensor recorded 71% humidity while the thermometer showed 73%, resulting in a 2% difference. This difference reflects variations in sensor accuracy under certain conditions. While the sensor generally yielded results close to those measured by the thermometer, this finding suggests that more attention to calibration or environmental monitoring is needed to maintain long-term measurement consistency and accuracy.

Table III displays the temperature readings obtained from the DHT22 sensor and thermometer. Figure 13 illustrates the differences in measurement results between the two devices. This data was then used to calculate the percentage difference and the average difference across all tests. The difference value was calculated using the relative difference method between the two sets of data. The following is the calculation of the difference based on the actual values in the first set of data obtained from the DHT22 sensor and thermometer.

$$difference = \frac{humidity - thermometer\ temperature}{thermometer\ temperature} x\ 100\ \%$$

$$difference = \frac{73 - 73}{73} x\ 100\ \%$$

$$difference = 0.00\ \%$$

The results obtained from calculating the difference using the first data of the DHT22 sensor temperature with the thermometer temperature are 0.00%

$$average\ difference = \sum \frac{-3.97}{10}$$

$$average\ difference = -0.397\%$$

The result of the average difference in comparison between the DHT22 sensor temperature and the thermometer is -0.397%.

B. Sugeno Fuzzy Testing

The Sugeno fuzzy test was conducted to determine the accuracy of the Sugeno fuzzy calculation. The input data used were temperature and humidity from sensors, then the values were processed using Sugeno fuzzy, producing an output value in the form of time in seconds. The results of the Mamdani fuzzy calculation were compared with the Mamdani fuzzy. The test results of the Sugeno fuzzy method can be seen in Table IV.

TABEL IV
COMPARISON TESTING LOGUC FUZZY WATERING

Sensor Input		Watering Time (seconds)		Difference (%)	
Temp	Hum	Sug	Mam	Sug	Mam
25	78	0.0	13.0	100.00	0.00
26	82	15.0	22.7	33.92	0.00
32	51	29.0	29.0	0.00	0.00
28	74	31.0	31.0	0.00	0.00
30	72	15.5	21.0	26.19	0.00
29	69	5.0	18.0	72.22	0.00
30	63	8.0	19.0	57.89	0.00
32	54	25.8	27.6	6.52	0.00
33	52	30.0	30.0	0.00	0.00
34	45	40.0	37.5	6.67	0.00

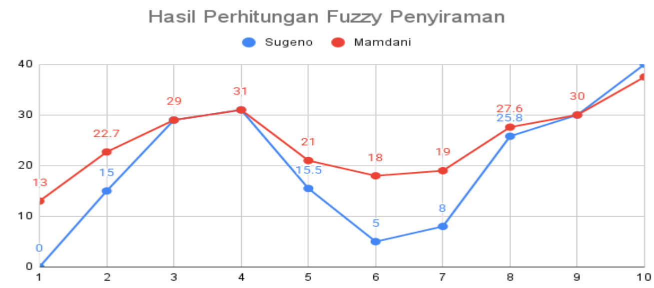

Figure 12. Result Graph Fuzzy Watering

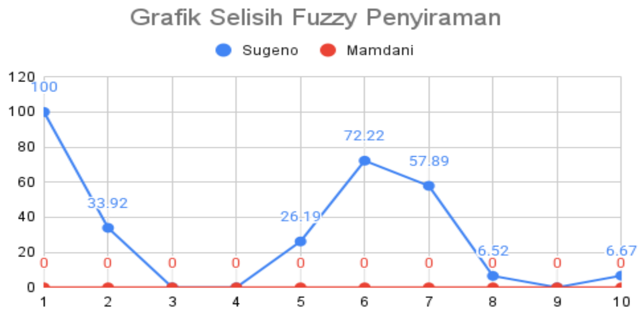

Figure 13. Fuzzy Difference Graph Watering

The test data in Table IV shows the calculation results for watering And difference value on method fuzzy Mamdani And sugeno . On Figure 12 shows a graph of the differences in the calculation results, namely in fuzzy Sugeno and Mamdani . Figure 13 shows a graph of the differences. from the fuzzy Sugeno and Mamdani methods. The results of the calculation of the average difference The results obtained from watering are added up to get the total difference. from the method system fuzzy sugeno and mamdani. Following is calculation total difference on fuzzy mamdani calculations .

$$Sugeno\ fuzzy\ difference = \sum \frac{watering\ difference}{2}$$

$$Sugeno\ fuzzy\ difference = \sum \frac{303.41}{2}$$

$$Sugeno\ fuzzy\ difference = 69.65\%$$

The 30.341% deviation obtained in this study is the result of calculating the average difference between the watering time control output generated by the Sugeno fuzzy method and the reference value considered ideal. Results from calculation total difference on fuzzy Sugeno that is as big as 69.65%. Meanwhile for total difference on fuzzy Mamdani is as follows.

$$Mamdani\ Fuzzy\ difference = \sum \frac{watering\ difference}{2}$$

$$Mamdani\ Fuzzy\ difference = \sum \frac{0.00}{2}$$

$$Mamdani\ Fuzzy\ difference = 0.00\%$$

The result of the calculation of the total difference in fuzzy sugeno is 0.00%. From the data of the total difference in fuzzy mamdani and fuzzy sugeno, it shows that the percentage of success in fuzzy mamdani is 100% and in fuzzy sugeno it is 69.65%.

C. *Actuator Automation Testing*

Testing was conducted to determine the accuracy level of the actuator automation . The NodeMCU ESP32 performs calculations from input data, namely temperature and humidity. Which originate from sensor to get mark output second (seconds) . Results from calculation method fuzzy The NodeMCU ESP32 is compared with the actuator's on time to determine the accuracy of the watering time. The test results for the actuator automation are shown in Table V.

TABEL V
COMPARISON RESULT OF WATERING ACTUATOR TESTING

Sensor Input		Watering Time		Difference
Temperature	Humidity	NodeMCU ESP32	Actuator	
25	80	15.0	18.0	3.0
26	82	24.7	27.3	2.6
30	60	31.0	33.5	2.5
29	79	30.0	35.7	5.7
34	78	22.3	22.7	0.4
28	69	16.0	21.0	5.0
30	70	20.3	21.6	1.3
32	55	24.6	25.6	1.0
28	52	30.0	33.0	3.0
33	45	38.5	40.0	1.5

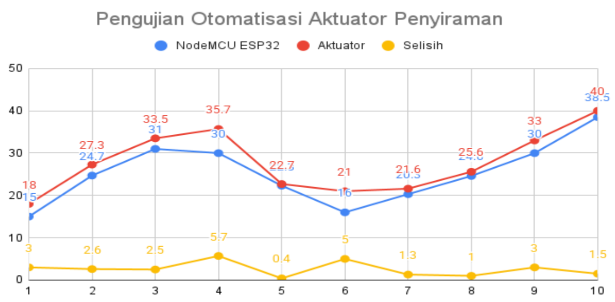

Figure 14. Watering Actuator Test Results Graph

Based on the data in Table IV, regarding fuzzy calculations for the watering process, the difference value is obtained from the comparison between the watering duration calculated by the microcontroller and that carried out by the actuator. Figure 14, illustrates the difference in the results of the fuzzy calculation test on the watering process. The average difference from the watering calculation results is then added up to obtain the total system difference using the Sugeno fuzzy method. The following is the result of the total fuzzy difference calculation on the NodeMCU ESP32.

$$Actuator\ difference = \sum \frac{watering\ difference}{2}$$

$$Actuator\ difference = \sum \frac{26.0}{2}$$

$$Actuator\ difference = 9{,}34\%$$

Results from calculation total difference on automation actuator that is as big as 9.34%. From the total difference data on the microcontroller and actuator, it shows that the percentage of success in actuator automation is 90.65%.

D. BH1750 Sensor Testing

Testing was conducted to determine the accuracy of the BH1750 sensor in reading light intensity in the greenhouse . The first step began by turning on the laptop and running the programming application that had been integrated with the NodeMCU ESP32. Next, the ESP32 microcontroller was connected to the laptop using a USB cable. After that, the BH1750 sensor was connected to the ESP32 microcontroller via the appropriate I2C pin. The sensor reading program was then run to obtain real-time light intensity data. The reading results from the BH1750 sensor were then compared with a standard measuring instrument, namely a lux meter, to evaluate the accuracy of the sensor data in detecting the level of lighting required by chrysanthemums. The test results of the BH1750 sensor are shown in Table VI.

TABEL VI
COMPARISON RESULT OF WATERING ACTUATOR TESTING

No	Sensor Test		Difference
	BH1750	Lux Meter	
1	1.60	4	1.60
2	32.5	41	32.5
3	70	42	70
4	88.2	62	88.2
5	92	73	92
6	131.60	86	131.60
7	125.3	89	125.3
8	163.9	90	163.9
9	220	110	220
10	235	123	235

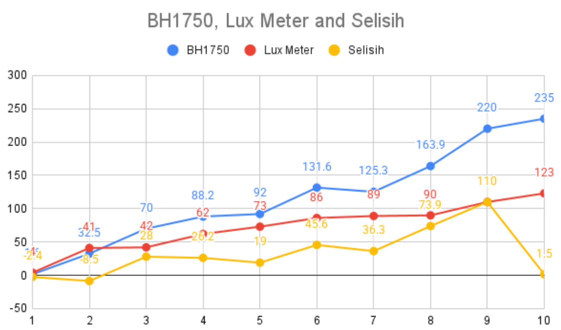

Figure 15. BH1750 Sensor Test Results

The experiment was conducted with the light source getting closer and closer to the sensor. The closer the light source is to the sensor, the more tall mark Which detected like on picture 15, From test BH1750 sensor in Table V, mark sensor compared to with luxury meters And have an average The differences in the calculation results are added together to obtain the total difference. The following is the total calculation result for BH1750.

$$Percentage\ Difference = \sum \frac{sensor\ BH1750 - Lux\ Meter}{Lux\ Meter} x100\%$$

$$Percentage\ Difference = \sum \frac{420.15}{10} x100\%$$

$$Percentage\ Difference = 42{,}02\ \%$$

The result of the calculation of the total difference in the light sensor test is 420.15%, with an average difference of 42.02%. From these results, it can be concluded that the percentage of success of the BH1750 sensor test in detecting light intensity is 57.98%, which shows that the sensor still has a fairly large deviation compared to the lux meter measuring instrument, especially at high light intensity.

E. Measurement Growth Plant Chrysanthemum

Besides testing technical to sensor accuracy and response system automation , observations are also carried out direct to growth plant chrysanthemum during time implementation smart greenhouse system. Measurement done in a way periodically every two Sunday during One cycle planting (about 12 weeks), without accompanied by documentation photo , but with quantitative data recording And descriptive.

Three main parameters observed , namely tall plants (in cm), number shoots flowers and condition leaf visually. Results observation displayed in table VII.

TABEL VII
MEASUREMENT GROWTH PLANT CHRYSANTHEMUM

No	week	Avarage Height (cm)	Amount of Interest	Condition Leaf
1.	2	12.5	0	Green young , healthy
2.	4	25.3	3-5	Green fresh , without spots
3.	6	38.7	7-9	Green old , growth evenly
4.	8	50.2	10-12	Leaf wide , healthy
5.	10	56.2	14-16	No There is sign stress plant
6.	12	61.1	15-18	Flower bloom , ready harvest

The data shows that plant chrysanthemum experience stable growth And Healthy throughout time planting. Average height plant increase consistent every two week, reach more from 60 cm on end week 12. Total shoots flower Also increase in a way gradual, showing that arrangement temperature, humidity, and controlled light in a way automatic by system based Sugeno fuzzy logic give condition optimal microclimate. Visual condition of the leaves remains the same green, fresh, and free from symptom stress environment (such as spot, wilt, or yellowish) too support conclusion that system capable guard stability environment in a way effective.With so, no only from side technical, impact system to performance biological plants are also proven positive, making system this worthy implemented for support agriculture precision in the region tropical like Lhokseumawe.

F. Achiecment of Research Objectives

Based on the implementation and testing results described, it can be concluded that all research objectives formulated in Chapter I have been successfully achieved. The smart greenhouse system developed using the ESP32 microcontroller, DHT22 sensor, BH1750 sensor, and the Sugeno fuzzy logic method has been able to automatically monitor and control environmental variables such as temperature, humidity, and light intensity. The application of the fuzzy logic method has proven effective in increasing the efficiency of the environmental control system, as demonstrated by the results of actuator and sensor tests that show deviations within tolerance limits. In addition, this system has also successfully integrated the Internet of Things and cloud computing through real-time data transmission using the MQTT protocol to the monitoring dashboard. And during field implementation, the system faced several real challenges, including fluctuations in electrical power that caused the microcontroller to restart, as well as unstable internet connectivity that disrupted real-time monitoring via the cloud. In addition, noise and drift in the sensors caused inaccurate readings of temperature, humidity, and light data. The system also relies on a third-party service (ThingsBoard), which is vulnerable to server outages, and must adapt to extreme tropical climate conditions that accelerate cooling device wear.

Thus, the developed system can create an optimal chrysanthemum cultivation environment, adaptive to tropical climate conditions, and support the implementation of technology-based precision agriculture in areas such as Lhokseumawe City.

IV. CONCLUSION

An IoT and cloud computing-based smart greenhouse system was successfully developed for chrysanthemum cultivation using fuzzy logic. The ESP32 microcontroller effectively monitored and automatically controlled temperature, humidity, and light intensity using DHT22 and BH1750 sensors. The Mamdani fuzzy logic method demonstrated excellent performance with 100% accuracy in irrigation control, while the Sugeno method resulted in a total error of 30.341%, indicating lower accuracy. Actuator automation testing demonstrated an average time difference of 9.34% compared to microcontroller commands, and the BH1750 light sensor demonstrated an average deviation of 42.02% compared to a lux meter, with a 57.98% success rate for light readings. The integration of IoT, cloud computing, and fuzzy logic has proven effective in creating adaptive and efficient environmental control, particularly suitable for tropical regions like Lhokseumawe to support optimal chrysanthemum growth. Compared with conventional systems such as on/off and PID control, fuzzy logic—particularly Sugeno demonstrates greater flexibility and resilience in the face of unstable environmental dynamics. On/off systems tend to produce coarse and reactive control, while PID requires sensitive and suboptimal tuning under non-linear conditions. In contrast, the fuzzy approach enables more refined and adaptive decision-making to simultaneous changes in temperature and humidity.

For future development, it is recommended to enhance the system by adding soil moisture sensors and AI-based cameras for visual detection of crop conditions, as well as developing a mobile monitoring and control app for Android or iOS to increase accessibility for farmers. Long-term testing across multiple seasons is also needed to evaluate the system's stability under changing environmental conditions, and the BH1750 sensor should be recalibrated or replaced with a more accurate light sensor to improve the precision of light intensity data. For commercial-scale deployment, the system can be expanded by distributing data to a central dashboard to support integrated, real-time, data-driven decision-making.

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