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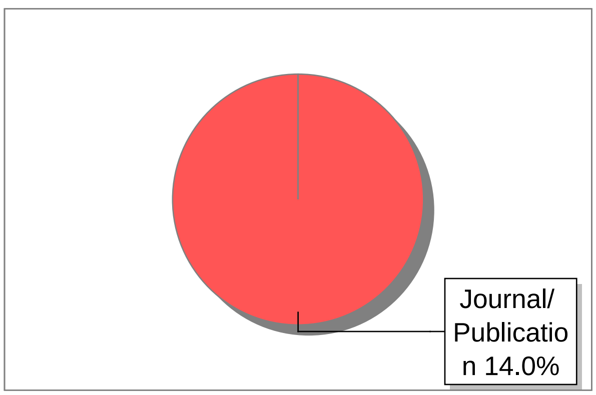

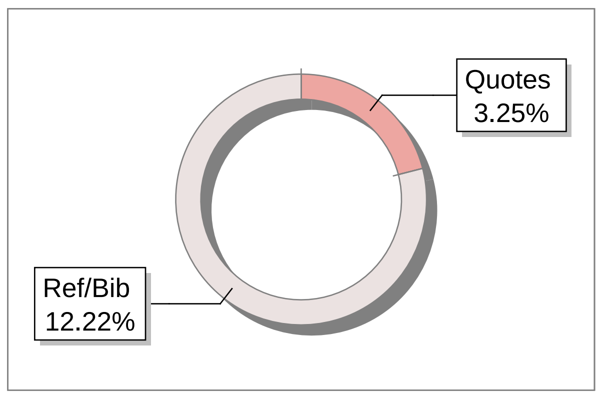

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Temperature Measurement and Light Intensity Monitoring in Mini Greenhouses for Microgreen Plants Using the Tsukamoto Fuzzy Logic Method

Dea Suryaningsih, Riky Dwi Puriyanto
Department of Electrical Engineering, Universitas Ahmad Dahlan, Yogyakarta, Indonesia

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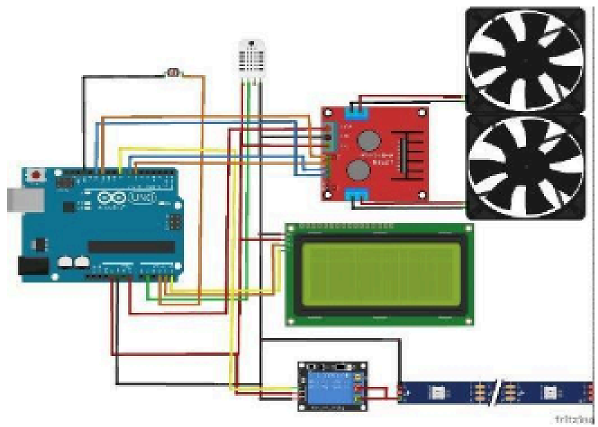
Corresponding Author:

Riky Dwi Puriyanto,
Department of Electrical Engineering, Universitas Ahmad Dahlan, Bantul, Yogyakarta, Indonesia.
Email: rikydp@ee.uad.ac.id

ABSTRACT



Microgreens are tender young plants that can be harvested as seeds and are a type of vegetable that can be harvested in about 7-14 days. Microgreen growth is influenced by several factors, including ambient temperature and light intensity. Microgreen plants require temperatures between 24°C – 30°C at all times during growth. These microgreen plants were grown on cocopeat growing media and given in a special room called a mini greenhouse with a size of 60 × 50 cm. The research method used is Tsukamoto's Fuzzy Logic. This research aims to make a tool to detect the temperature in a mini greenhouse. The research method used is Tsukamoto's Fuzzy Logic. Increasing temperature stability to keep the temperature in the mini greenhouse room at the ideal temperature. In this study, the sensors used were DHT 11 and grow light lamps. The results of this study indicate that the temperature and light intensity in this mini greenhouse are very stable and are at a temperature of 24°C-30°C with the accuracy of the sensor in this tool showing an error value of 5.39%.

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1. INTRODUCTION

Microgreens are young and tender plant seeds that can be harvested within 7-14 days after the seeds are planted. This type of vegetable has vitamins and nutrients which are higher than vegetables grown by the usual planting method [1]. This plant needs sunlight, but not directly so it is replaced with a grow light, and the temperature in the room for this plant must remain stable at 24°C to 29°C for optimal growth [2].

Therefore, regulating the temperature and intensity of light is an important thing to do. By using the ATMega 328 automated microcontroller, farmers do not need to spend time every day in the greenhouse, so they can focus on other activities [3].

Tsukamoto's fuzzy logic method has flexibility and tolerance for data. This method is intuitive and capable of providing answers based on unclear, incorrect, and qualitative information. This approach uses fuzzification. The growth of microgreens is influenced by several factors, namely light intensity and ambient temperature. Based on, monotone membership function, to describe each rule as a Fuzzy set [4]. Fuzzy logic is a method which is suitable for implementing small, simple systems, control systems, embedded systems, as well as, computer networks. In contrast to classical logic which only has 2 possible membership values, fuzzy logic allows a state to have different membership values [5].

This study uses a fuzzy approach to temperature regulation assisted by a DHT 11 sensor to detect temperature and produce an output in the form of a PWM fan. How DHT 11 works by using a thermistor sensor mounted on the surface. Thermistor is a variable resistor with a resistance that varies with temperature. This study also uses LDR sensors, often known as light-dependent resistors for monitoring light intensity in mini-greenhouses [6].

Previous researchers have conducted research on the Effect of LED Light Distance and Type of Growing Media on Microgreen Basil (Ocimum basilicum L.). This study aims to determine the effect of spacing LED lights and the type of planting media on the growth and yield of microgreen basil production. The method used in this study is the ANOVA analysis method. The results of this study show that the closer the distance of the lights, the higher the light intensity, but the temperature and humidity in the microclimate of the study are not much different [7].

Previous researchers have conducted research on the implementation of Tsukamoto's fuzzy logic and IOT on parking density level decision support systems. The method used in this research is Tsukamoto's fuzzy logic method. The result of this research is that the Tsukamoto method is implemented to recognize patterns of density rules and determine the density of parking lots and the duration of parking. Based on testing, the system is determined by how much data is used to create fuzzy rule patterns. Because the pattern of fuzzy rules is obtained by averaging the output of the membership function for each variable, the more the amount of data calculated, the more accurate the results are, the average value [5].

Previous researchers have conducted research on Room Temperature Control Systems and Watering Onion Plants in Greenhouses with Smartphones. The research method starts from the stages of making a greenhouse starting with designing a smart greenhouse model image. Then the steps for making a greenhouse frame from wood, for making a plant rack frame using iron, assembling power plant components, making an automatic control system for the greenhouse. The results of this study are when the air temperature in the greenhouse is more than 32°C, the fan will turn on. The fan causes hot air to escape [8].

Previous researchers conducted research on the design of climate control systems using microcontrollers for smart greenhouses. Greenhouse conditions without climate control were recorded and showed the highest temperature inside was between 25°C and 42°C while the temperature outside was between 23°C and 38°C. To observe the different conditions, the system is set to a minimum temperature and the result is between 20°C to 28°C inside, while the temperature outside is between 20°C to 38°C. The final experiment was to set the controller at the specified conditions and revealed that it managed to maintain the temperature between 25oC to 30°C while the outside temperature was between 20°C to 42°C. During the experiment the humidity inside the greenhouse was able to maintain between 75%-93% while the outside humidity fluctuated between 53%-93% [9].

Past researchers have conducted research to develop Using fuzzy logic, intelligent systems can regulate the temperature, humidity, and airflow of greenhouses. The method used in this study is the fuzzy method, the fuzzy method is applied to the system to control actuators in the form of fans and heaters as needed. The result of this research is that the system can work well with fuzzy accuracy reaching 100%. This proves that the system works well in managing automation on prototypes [10].

Previous researchers have conducted research on the fuzzy logic method in the concept of water irrigation. This study uses the Mamdani fuzzy logic method. The results of the experiments that have been carried out are to produce a water use efficiency value of 80% and an effective watering time of 71%, this is based on a comparison with conventional plant watering systems [11].

Previous researchers have conducted research on determining the combination of the number of catalysts in methanol production using the fuzzy method. In this study, two methods were used, namely the fuzzy method and the evolution strategies method. The fuzzy method is used to calculate the amount of production based on several experiments in the laboratory and the evolution strategies algorithm is used to find the right combination of catalyst amounts. The results of this study are that the success of obtaining a solution is highly dependent on the parameters used such as for population, offspring size and number of generations [12].

Previous researchers have conducted research on temperature control systems for mini greenhouses using DHT 22 sensors and fuzzy logic. The method used in this study is the fuzzy logic method. The results of this study are that the system can display and maintain normal temperature in the greenhouse with a DHT 22 sensor error percentage of 0.34% for temperature, 0.315% for air humidity and a percentage of system output sensor errors of 4.15% [13].

2. METHODS

The research was conducted using the fuzzy method. In general there are three steps to determine the fan speed with PWM for this tool the Tsukamoto fuzzy inference method.

2.1. Mini Greenhouse Specifications

The greenhouse framework used in this study is iron with a hole angle of 1.5mm, and uses impraboard with a thickness of 2mm, using plywood as the top cover with a thickness of 3mm. The mini greenhouse framework can be seen in Figure 1.

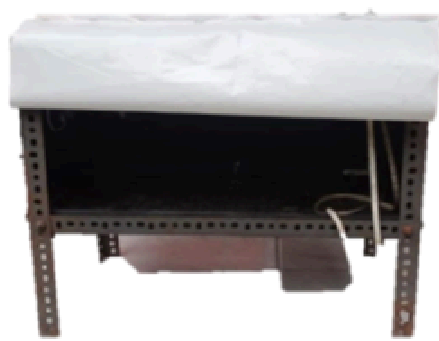


Figure 1. Mini greenhouse framework

This mini greenhouse framework is used for growing microgreen spinach plants for 7 – 14 days. When the microgreens are growing, the minigreenhouse is closed and occasionally opened to check the height of the microgreens.

2.2. System Block Diagram

In this study the block diagram serves to explain the relationship between components. The system block diagram display can be seen in Figure 2.

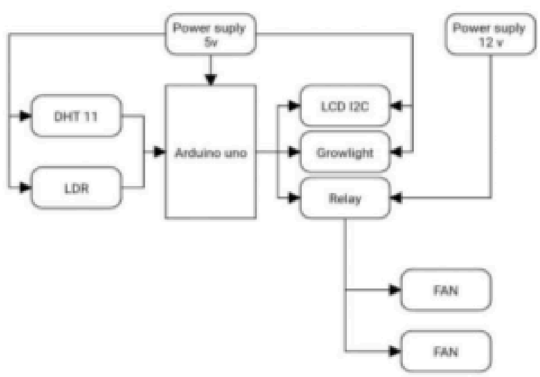


Figure 2. Block diagram of the mini greenhouse system

In the block diagram above Arduino gets input from the DHT11 sensor and LDR sensor where Arduino and other components get supply from a 5V power supply, then Arduino uno gives output to the LCD to display data from the DHT11 sensor and LDR sensor, and to the growlight and to the relay for turn on the fan or adjust the fan speed where the fan gets 12v supply from the power supply.

2.3. Flowchart

Every process planned in the research can be seen through the flowchart in Figure 3. The flowchart display can be seen in Figure 3.

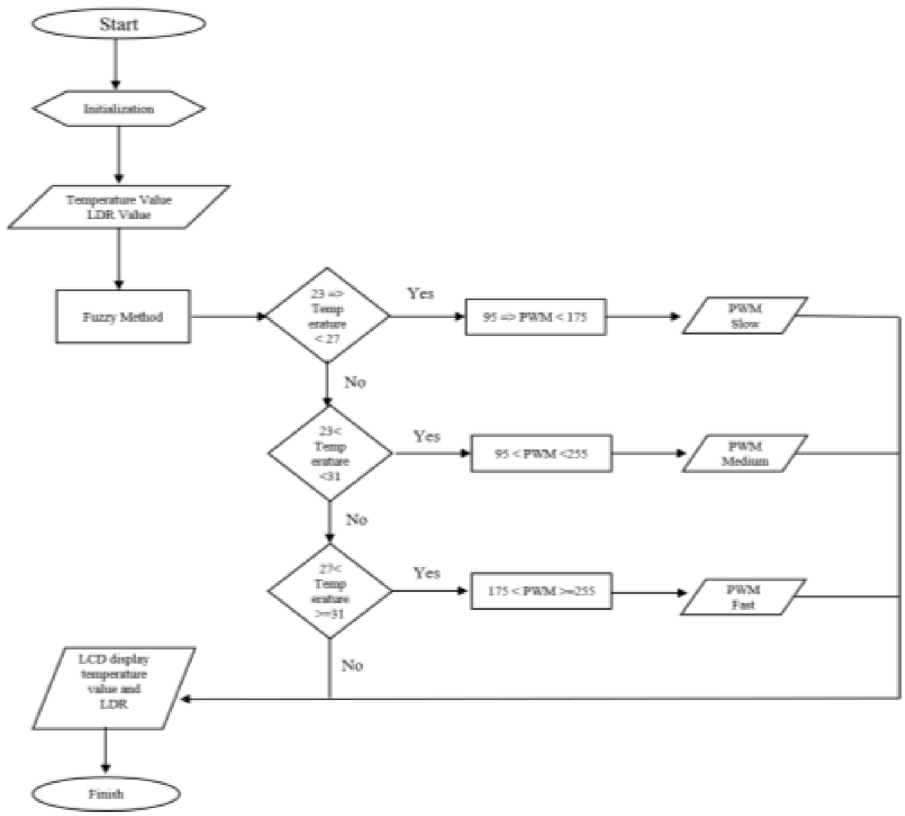


Figure 3. Flowchart

In Figure 3, Arduino uno gets input from the DHT 11 sensor and the LDR sensor. DHT 11 sensor readings are processed using the fuzzy method, if the temperature is less than 23 degrees Celsius then the pwm speed is vulnerable to 95 rpm and less than or equal to 175 rpm (slow), and if the temperature is more than or equal to 23 degrees Celsius below 31 degrees celsius then the pwm speed value is above 95 – 255 rpm (medium), then if the temperature is more than or equal to 27 degrees celsius and below 31 degrees then the pwm speed is more than or equal to 175 -255 rpm (fast), then the value that appears on the LCD is the value of the LDR sensor reading and the DHT 11 sensor [14].

2.4. System Wiring

In this wiring system DHT 11 has 3 pins connected, namely VCC gets a supply of 5V, the GND pin is connected to the GND pin then the signal pi is connected to Analog pin 1 on the Arduino Uno. Then the L298N driver gets GND from the power supply, 12 V from the power supply then pin in A is connected to pin 11, in B is connected to pin 6, in c is connected to pin 7, in D is connected to pin 12. Then the output of the L298N is connected to The fan, then the LCD has VCC 5V and GND from the power supply, the SDA pin is connected to analog pin 4 and SCL is connected to analog pin 5 on Arduino Uno. The system wiring display can be seen in Figure 4.

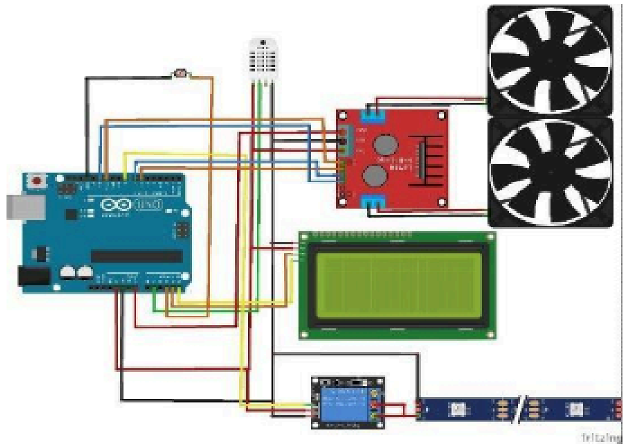


Figure 4. System wiring

Then the relay pin VCC to 5V, GND to GND, in is connected to digital pin 8, COM is connected to 5V and NO (Normally Open) is connected to 5V Grow-light. Then the LDR has 2 pins, one pin is connected to GND and the other pin is connected to the Analog pin on Arduino at pin 3. The table for the use of pins in the system wiring is shown in Table 1.

Table 1. Pin wiring system

Arduino Uno Pins	Sensors or Components
VCC 5 V	VCC (Sensors DHT11, LCD, Fan Relay, Lamp Relay and Driver LN298N)
VCC 12 V	VCC (Driver LN298N)
GND	GND (Sensors DHT11, LDR Sensors, LCD, Fan Relay, Lamp Relay and Driver LN298N)
A5	SCL LCD
A4	SDA LCD
A2	LDR Sensors
A1	DHT11 Sensors
5	ENA Driver LN298N
6	IN1 Driver LN298N
7	IN2 Driver LN298N
9	Fan Relay Kipas
11	IN4 Driver LN298N
12	IN3 Driver LN298N
13	Fan Relay Lampu

3. RESULT AND DISCUSSION

System testing is carried out to ensure that the system created runs according to the research objectives. The process of calibrating the DHT 11 sensor and the LDR sensor is carried out with a temperature measuring device and a Lux Meter on a mobile phone [15]. By using the process of calculating the error value obtained from the comparison of measuring results. The error value is obtained from equations (1) and (2).

$$Difference = |Reference\ value - Sensor\ Value| \quad (1)$$

$$Error\ Percentage = \frac{|Difference|}{|Reference\ Value|} \times 100\ \% \quad (2)$$

.

3.1. Sensor Testing and Calibration

Sensor testing is done by reading the DHT 11 sensor by comparing the sensor readings with the temperature measuring device on the cellphone. The calibration process is carried out with several trials to determine the value of the division of categories that have been carried out. With reference to equations (1) and (2), comparative data is obtained to obtain the error value of the sensor used so that it can be used as a benchmark for the accuracy of the sensor used [16].

Because in DHT11 the unit used is Celsius, an adjustment is made to get the same unit as in the benchmark measuring instrument used is the temperature listed on the cellphone [17].

The following is a table of the results of the DHT 11 sensor test for temperature readings in the mini greenhouse. It can be seen in Table 2 the results of the DHT 11 sensor test. The sensor test results can be seen in Table 2.

Table 2. Test result

Temperature DHT 11	Temperature on Handphone	Difference	Error Value
23	24	1	4.17%
24	25	1	4%
27	29	2	6.8%
24	26	2	7.69%
30	29	1	3.44%
26	26	0	0%
25	27	2	7.40%
28	31	3	9.67%
Error Rate			5.39%

Table 2 is the value obtained from the calibration results with the aim of getting the sensor error value with a predetermined measuring instrument comparison for more efficient results. In the value of this measuring instrument, the value is obtained from observations made on temperature monitoring on mobile phones. Graphical display of the comparison of the DHT 11 sensor with measuring instruments can be seen in Figure 5.

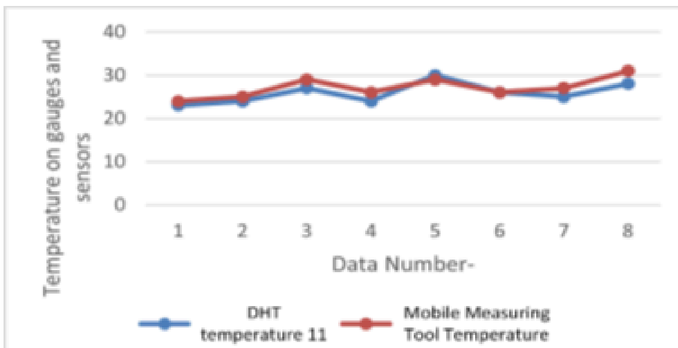


Figure 5. Comparison graph of the DHT 11 sensor with measuring instruments

Sensor testing is done by reading the LDR sensor by comparing the results of the sensor readings with the Lux Meter measuring device on the cellphone. The calibration process is carried out with several trials to determine the value of the division of categories that have been carried out. With reference to equation (1) and (2), comparative data is obtained to obtain the error value of the sensor used so that it can be used as a benchmark for the accuracy of the sensor used. The following are the results of testing the LDR sensor with a Lux Meter on a cellphone. It can be seen in Table 3. is the result of the LDR sensor test.

Table 3. LDR sensor test results

Intensity LDR Light	Lux Meter on Handphone	Difference	Error Value
90.43	90	0.43	0.43%
86.5	85	1.5	1.76%
85.53	85	0.53	0.62%
86.56	86	0.56	0.65%
48.83	49	1.83	3.73%
87.45	88	3.55	4.03%
90.50	90	0.50	0.55%
87.46	87	0.46	0.52%
Error Rate			1.53%

Based on Table 3 is the value obtained from the calibration results with the aim of getting the sensor error value with a predetermined measuring instrument comparison for more efficient results. In the value of this measuring instrument, the value is obtained from observations made on temperature monitoring on mobile phones. Graphical display of the comparison of the LDR sensor with measuring instruments can be seen in Figure 6.

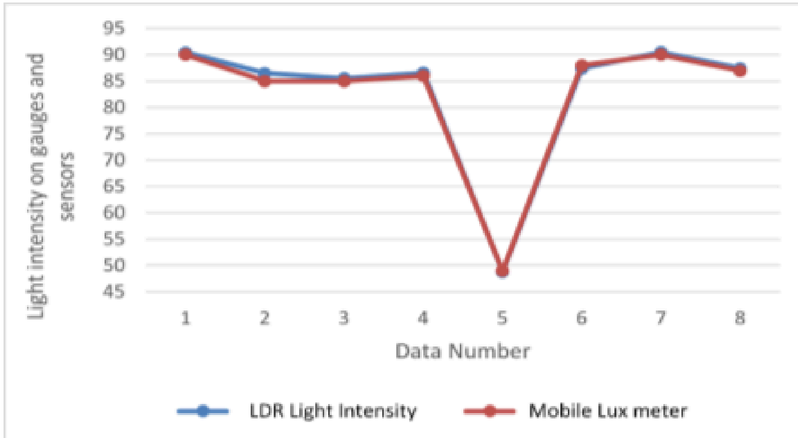


Figure 6. Graph comparison of LDR sensors and measuring instruments

In the graph of Figure 6 it can be seen that the highest LDR sensor value is at 90.50 Lux while the lowest value is at 48.83 Lux. The highest amount of light intensity on the measuring instrument in the Lux Meter is 90 Lux while the lowest light intensity is on a cellphone, namely 49 Lux. In this test, the average error value is 1.53%.

3.2. Fuzzification Calculation Process

In this study the data collection process was carried out in the morning, afternoon and evening. The data collection process for minigreenhouses for microgreens is carried out using the Tsukamoto Fuzzy Logic method, in which Tsukamoto's Fuzzy Logic is generally divided into 3 stages. In fuzzy set theory. The membership value is the main characteristic of fuzzy logic. In Tsukamoto's fuzzy method, each rule is in the form of IF-THEN and must be represented by a fuzzy set with a monotonous membership function [18].

3.2.1. Fuzzification

Fuzzification is the initial process of the fuzzy method to change an input from a crisp form (crisp) to a fuzzy (linguistic variable) which is usually presented in the form of fuzzy sets with a membership function each. In this system the input uses a temperature sensor which is divided into 3 categories namely Cold, Ideal, and Hot [19]. The division of this category is to get linguistic variables or fuzzy variables for each variable. The temperature membership using equation (3), (4), and (5).

$$\mu cold(x)\begin{cases} 1, & x \leq 23 \\ \frac{27-x}{4}, & 23 < x < 27 \\ 0, & x \geq 27 \end{cases} \tag{3}$$

$$\mu ideal(x)\begin{cases} 0, & x < 27 \\ \frac{x-27}{4}, & 23 < x < 27 \\ \frac{31-x}{4}, & 27 < x < 31 \\ 0, & x \geq 31 \end{cases} \tag{4}$$

$$\mu hot(x)\begin{cases} 1, & x \geq 31 \\ \frac{x-31}{4}, & 27 < x < 31 \\ 0, & x \leq 27 \end{cases} \tag{5}$$

Based on the membership function, a graph is also obtained which will show the relationship of the three linguistic variables that have been arranged as shown in Figure 7.

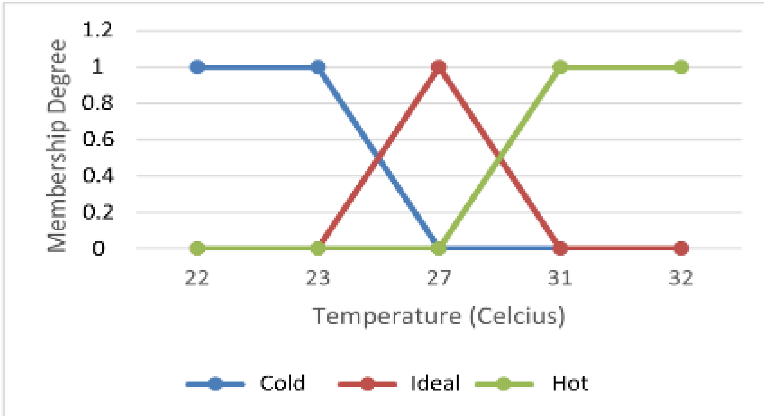


Figure 7. Relationship of the three linguistic variables

From the Figure 7, it can be seen that the y-axis function is the truth value or predicate logic contained in fuzzy logic with a value between 0-1. Determination of fuzzy sets or linguistic variables is also made to determine the PWM value of the fan to get an output value that corresponds to the category that has been made. the output pwm value is also divided into 3 categories, namely slow, ideal, and fast. This value will affect the fan speed. The fan PWM membership using equation (6), (7), and (8).

$$\mu slow(x)\begin{cases} 1, & x \leq 135 \\ \dfrac{175-x}{40}, & 135 < x < 175 \\ 0, & x \geq 175 \end{cases} \tag{6}$$

$$\mu medium(x)\begin{cases} 0, & x \leq 135 \\ \dfrac{x-135}{40}, & 135 < x < 175 \\ \dfrac{215-x}{40}, & 175 < x < 215 \\ 0, & x \geq 215 \end{cases} \tag{7}$$

$$\mu fast(x)\begin{cases} 1, & x \geq 215 \\ \dfrac{x-175}{40}, & 175 < x < 215 \\ 0, & x \leq 175 \end{cases} \tag{8}$$

Based on the membership function, a graph is also obtained which will show the relationship of the three linguistic variables that have been arranged as shown in Figure 8.

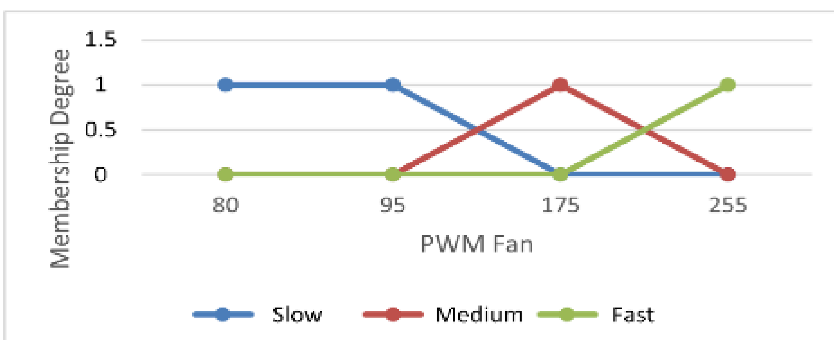


Figure 8. Fuzzification

3.2.2. Inference

In the Tsukamoto method, each consequence of an if – then rule must be represented by a fuzzy set with a monotone membership function. As a result, the output of the inference results from each rule is given crisply (crisp) based on the α-predicate (fire strength). The final results from Tsukamoto use weighted averages and in their inferences. In short, the inference stage is making rules for determining the output of the fuzzy value you want to determine. In this study the inference stage contains the possibilities of the values obtained by the system so that the rules for the resulting PWM output are obtained. There are 6 rules using 3 predetermined linguistic variables.

3.2.3. Defuzzification

Defuzzification is the last step in a fuzzy logic system with the aim of converting every result from the inference engine which is expressed in the form of a fuzzy set to a real number. The conversion result is an action taken by the fuzzy logic control system. In this study the determination of defuzzification will automatically produce a PWM fan output based on fuzzy logic. Because the values generated are based on the Tsukamoto fuzzy method, the way to get the average value from the defuzzification process is done by the equation (9).

$$Z = \frac{\sum_i^n \alpha predicate_i \ x \ z_i}{\sum_i^n \alpha predicate_i} \tag{9}$$

3.3. Data Retrieval Process

In this data collection process, it will be divided into 3 data collection times in one day with a data collection range of 14 days according to the growth of microgreen plants. This data collection was taken based on the best time for microgreen plant growth. The experimental results on the temperature measurement tool at the mini-greenhouse for microgreens through sensor readings and using LCD readings [20]. In Table 4 are the results of the first 3 days of experiments that have been carried out.

Table 4. Test Results for the first 3 days

Days to	Temperature (1)	Temperature (2)	Explanation	PWM	Explanation	Light intensity (Lux)
1	22	23	Cold	95	Slow	86.43
	23	24	Cold	112	Slow	86.5
	25	25	Ideal	135	Medium	85.55
	30	31	Hot	175	Fast	45.88
	26	26	Ideal	146	Medium	84.05
	24	25	Ideal	146	Medium	85.53
	Temperature (1)	**Temperature (2)**	**Explanation**	**PWM**	**Explanation**	**Light intensity (Lux)**
2	23	24	Cold	100	Slow	90
	25	25	Ideal	137	Medium	80.96
	32	32	Hot	215	Fast	40.98
	25	24	Cold	115	Slow	86.56
	26	25	Hot	200	Fast	48.83
	27	26	Ideal	155	Medium	87.45
	Temperature (1)	**Temperature (2)**	**Explanation**	**PWM**	**Explanation**	**Light intensity (Lux)**
3	22	22	Cold	95	Slow	97.54
	25	25	Ideal	136	Medium	88.76
	24	25	Ideal	146	Medium	87.56
	29	29	Hot	180	Fast	48.83
	26	26	Ideal	140	Medium	87.46
	25	25	Ideal	140	Medium	85.94

Based on Table 4, on the first day of seeding the spinach plants on cocopeat growing media with semi-dry cocopeat conditions. On this first day the temperature is still less than the temperature set for the growth of microgreen plants. On this first day the plants are still in the form of seeds, the temperature values are obtained based on actual conditions. The PWM values in the table are obtained automatically which are affected by temperature. For light intensity adjusted to the light contained in the mini greenhouse. On the second and third day the temperature has started to normal and stable. The graph of the test results is shown in Figure 9.

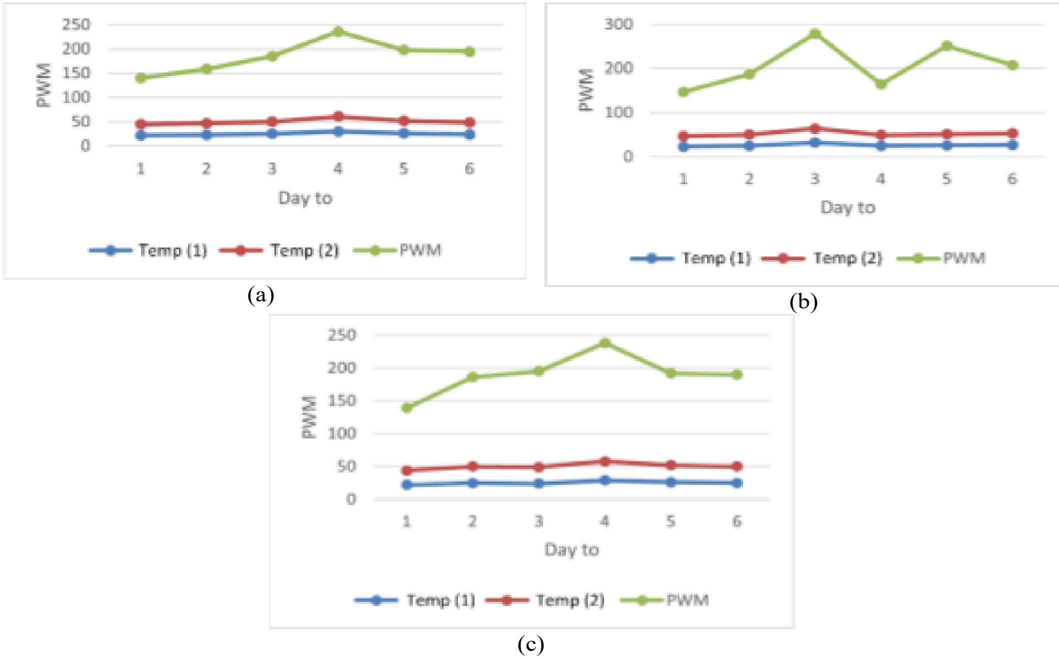


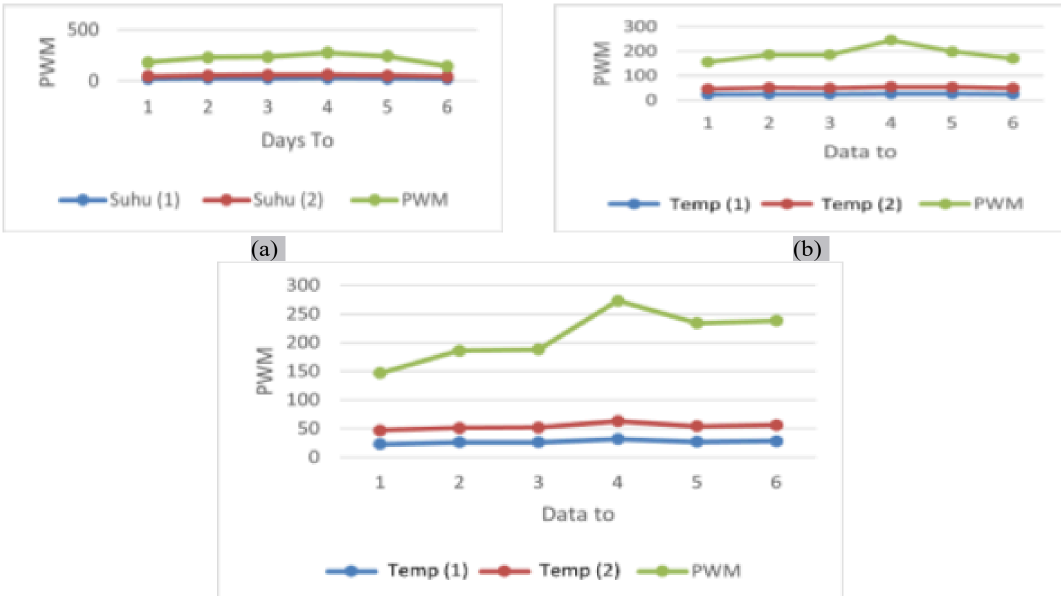
Figure 9. Graph of test results for the first 3 days, (a) day 1, (b) day 2, and (c) day 3. Temp is the Temperature

Experimental results on the temperature measurement tool for microgreens for microgreens using sensor readings and using LCD readings. Table 5 shows the results of the second 3-day experiment that was carried out.

Table 5. Results of the second 3-day test

Days to	Temperature (1)	Temperature (2)	Explanation	PWM	Explanation	Light intensity (Lux)
4	23	24	Ideal	136	Medium	86.7
	27	27	Hot	178	Fast	79.55
	29	29	Hot	179	Fast	55.67
	30	32	Hot	215	Fast	45.44
	26	28	Hot	190	Fast	43.22
	22	23	Cold	100	Slow	85.88
	Temperature (1)	**Temperature (2)**	**Explanation**	**PWM**	**Explanation**	**Light intensity (Lux)**
5	23	23	Cold	110	Slow	97.54
	25	26	Ideal	135	Medium	85.66
	25	25	Ideal	136	Medium	87.56
	27	28	Hot	190	Fast	56.34
	27	27	Ideal	145	Medium	70.95
	25	25	Ideal	120	Medium	85.76
	Temperature (1)	**Temperature (2)**	**Explanation**	**PWM**	**Explanation**	**Light intensity (Lux)**
6	23	24	Cold	100	Slow	89.65
	26	25	Ideal	135	Medium	76.77
	26	26	Ideal	136	Medium	67.65
	32	31	Hot	210	Fast	46.77
	27	27	Ideal	180	Medium	7.8
	28	28	Hot	182	Fast	4.54

On the 4th day the microgreen plants have started to grow by about 1 cm and have not yet bloomed. For days 5 and 6 the temperature and PWM tend to be ideal and the light intensity inside the mini greenhouse also adjusts the need for ultra violet light for microgreen plant growth. The second 3-day test graph is shown in Figure 10.



(c)

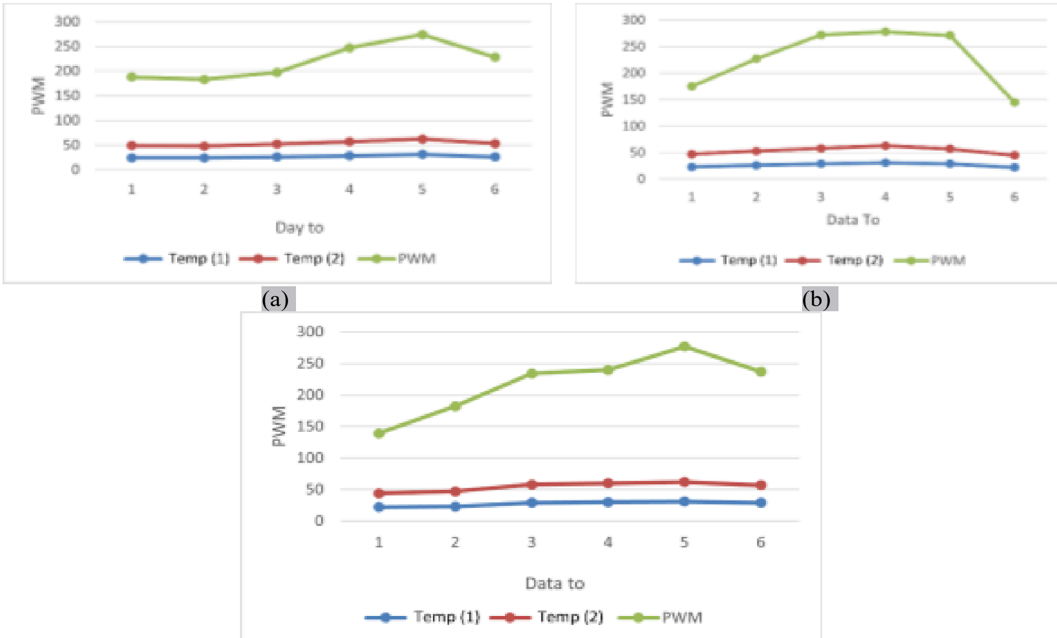
Figure 10. Graph of Test Results for the second 3 days, (a) day 4, (b) day 5, and (c) day 6. Temp is the Temperature

The experimental results on the temperature measurement tool on the microgreen through sensor readings and using monitoring via the LCD. In Table 6 are the results of the third 3-day test that has been carried out.

Table 6. Third day 3 test results

Days to	Temperature (1)	Temperature (2)	Explanation	PWM	Explanation	Light intensity (Lux)
7	24	25	Ideal	139	Medium	80.87
	24	24	Ideal	135	Medium	78.98
	26	26	Ideal	145	Medium	84.97
	28	29	Hot	190	Fast	40.34
	31	31	Hot	212	Fast	46.77
	26	27	Ideal	175	Medium	78.65
	Temperature (1)	**Temperature (2)**	**Explanation**	**PWM**	**Explanation**	**Light intensity (Lux)**
8	23	24	Cold	128	Slow	97.7
	26	27	Ideal	174	Medium	79.9
	29	29	Hot	214	Fast	42.45
	31	32	Hot	215	Fast	49.65
	29	28	Hot	214	Fast	49.77
	22	23	Cold	100	Slow	91.21
	Temperature (1)	**Temperature (2)**	**Explanation**	**PWM**	**Explanation**	**Light intensity (Lux)**
9	22	22	Cold	95	Slow	96.77
	23	24	Cold	135	Slow	96.87
	29	29	Hot	176	Fast	50.87
	30	30	Hot	180	Fast	49.77
	31	31	Hot	215	Fast	47.22
	29	28	Hot	180	Fast	72.34

Based on Table 6 on day 7 these microgreen plants have grown well because on day 7 these microgreen plants can be harvested but on day 7 these microgreen plants are still vulnerable to being traded because their growth is not yet optimal. On the 8th and 9th day the microgreen plants have started to bloom. Because the temperature on day 7 to day 9 is quite drastic, the values displayed on the LCD also change significantly. The graph of the results of the third 3-day test can be seen in Figure 11.



(a) (b) (c)

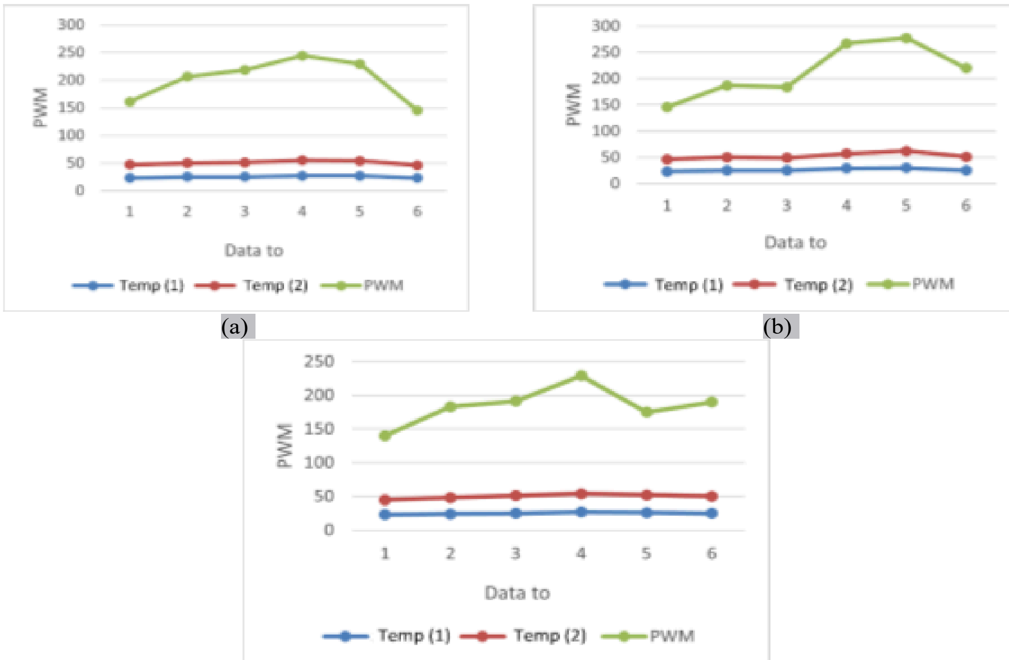
Figure 11. Graph of the third 3-day test, (a) day 7, (b) day 8, and (c) day 9. Temp is the Temperature

The experimental results on the temperature measurement tool on the microgreen through sensor readings and using readings via the LCD. Table 7 shows the results of the fourth 3-day test that has been carried out.

Table 7. Test Results for the fourth 3 days

Days to	Temperature (1)	Temperature (2)	Explanation	PWM	Explanation	Light intensity (Lux)
10	23	24	Cold	114	Slow	89.76
	25	25	Ideal	156	Medium	78.76
	25	26	Ideal	167	Medium	67.76
	27	28	Hot	189	Fast	46.99
	27	27	Ideal	175	Medium	56.78
	23	23	Cold	99	Slow	85.55
	Temperature (1)	**Temperature (2)**	**Explanation**	**PWM**	**Explanation**	**Light intensity (Lux)**
11	23	23	Cold	100	Slow	92.55
	25	25	Ideal	137	Medium	78.77
	25	24	Cold	135	Slow	89.78
	29	28	Hot	210	Fast	54.7
	30	32	Hot	215	Fast	57.99
	25	26	Ideal	169	Medium	87.45
	Temperature (1)	**Temperature (2)**	**Explanation**	**PWM**	**Explanation**	**Light intensity (Lux)**
12	23	22	Cold	95	Slow	85.88
	24	24	Cold	135	Slow	85.94
	25	26	Ideal	140	Medium	78.9
	27	27	Ideal	175	Medium	778
	26	26	Ideal	123	Medium	80.9
	25	25	Ideal	140	Medium	86.73

On days 10 to 12 this is the harvest preparation period for microgreen plants because the nutrients in these plants meet the standards for harvesting. On days 10 to 12, the temperature and PWM are fairly stable and tend to be ideal, so microgreen growth is very good due to temperature regulation in the mini planting media. The graph of the results of the fourth 3-day test is shown in Figure 12.



(c)

Figure 12. Graph of the results of the fourth 3-day test, (a) day 10, (b) day 11, and (c) day 12. Temp is the Temperature

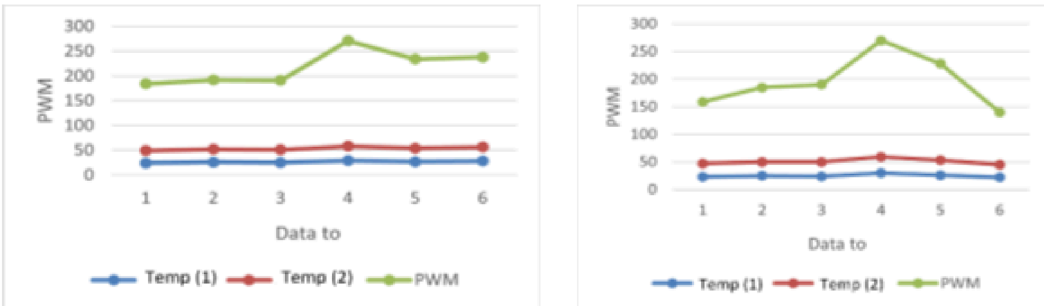
The experimental results on the temperature measurement device on the mini-greenhouse for microgreens are through sensor readings and using LCD readings. In Table 8 are the results of the last 2 days of experiments that have been carried out.

Table 8. Test results for the last 2 days

Days to	Temperature (1)	Temperature (2)	Explanation	PWM	Explanation	Light intensity (Lux)
13	24	25	Ideal	135	Medium	86.76
	26	26	Ideal	140	Medium	88.7
	25	26	Ideal	140	Medium	87.9
	29	29	Hot	213	Fast	49.57
	27	27	Ideal	180	Medium	59.53
	28	28	Hot	182	Fast	56.44
	Temperature (1)	**Temperature (2)**	**Explanation**	**PWM**	**Explanation**	**Light intensity (Lux)**
14	23	24	Cold	112	Slow	85.94
	25	25	Ideal	135	Medium	88.96
	24	26	Ideal	140	Medium	87.88
	30	29	Hot	211	Fast	46.76
	26	27	Hot	175	Fast	58.77
	22	23	Cold	95	Slow	90.31

In the last 2 days, the plants can be harvested because the nutrients are perfect for microgreen plants. The temperature and PWM values on the last day tended to be more stable and did not change significantly. The graph for the last 2 days of testing can be seen in Figure 13.

Based on the 14 test tables, the fan speed if the temperature increases, the PWM value of the fan will be higher because the temperature value affects the PWM speed value of the fan itself. Up to 31°C the PWM value is almost close to the maximum value of 255 rpm. From the data taken, the PWM values are different. There are 3 temperature categories, namely cold, ideal and hot, while there are also 3 PWM categories, namely slow, fast and medium. These results will be obtained from the stages of the Fuzzy method.



(a) (b)

Figure 13. Graph of test results for the last 2 days, (a) day 13 and (b) day 14. Temp is the Temperature

4. CONCLUSION

Based on the research that has been done, it can be concluded that this research uses the Tsukamoto fuzzy logic method which is to control PWM so that the temperature inside the mini greenhouse remains stable and maintained according to the needs of the microgreen plants. Error calibration results show 5.39% for the DHT 11 sensor and 1.53% for the LDR sensor. The main conditions are ideal, covering the ideal category with a value range of 23-27 degrees Celsius with a fan PWM value that adjusts to conditions so that the temperature remains ideal.

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