INTENSIF, Vol.7 No.2 August 2023
ISSN: 2580-409X (Print) / 2549-6824 (Online)
DOI: https://doi.org/10.29407/intensif.v7i2.19652

Impact of Fuzzy Tsukamoto in Controlling Room Temperature and Humidity

Received:
14 February 2023
Accepted:
17 July 2023
Published:
1 August 2023

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Abstract— Dry season is a season where the room temperature exceeds the needs of the body so that it is unpleasant, unhealthy and can interfere with human productivity. In addition, the efficiency of use and resource requirements are also a concern for some people. To overcome this problem, an automatic room temperature control device was created using the ESP32 microcontroller with Tsukamoto's fuzzy algorithm optimization as a data processing technique to produce optimal fan speeds in duty cycle units based on temperature and humidity conditions in realtime. Four tests by running a fan for 30 minutes on each showed that the average difference between the maximum and minimum temperatures in the room was 0.95°C, while the average difference between maximum and minimum humidity was 2.0%. In addition, the test graph shows that when the fan is rotated in a closed room without air circulation, the relative temperature change increases from the initial minute to the last minute of the test. Meanwhile, changes in relative humidity decrease, although fluctuations increase within 1-4 minutes. This study found that fans are not effective in lowering room temperature optimally. Therefore, it is recommended to replace with an exhaust fan in future research.

Keywords— Fuzzy Logic; Duty Cycle; Temperature; Humidity; Room Control

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ISSN: 2580-409X (Print) / 2549-6824 (Online)
DOI: https://doi.org/10.29407/intensif.v7i2.19652

I. INTRODUCTION

In the tropical nation of Indonesia, there are two seasons: the wet season and the dry season [1]. For activities to be pleasant in the room, air conditioning is absolutely necessary, especially during the hot or dry season [2]. Inspite of more advanced technology like air conditioners, fans are still often utilized. However, using air conditioning (AC) comes with a very significant cost both in terms of original investment and ongoing expenses. Due to budgetary restrictions, not everyone can afford AC, thus utilizing a fan is more effective than doing so. Modern fans typically come with a remote control with many speed settings (usually levels 1-3). By using the buttons on the body or fan pole or the remote control, the speed may be changed. Manual control is not a reliable and efficient method [3]. Then this manual method is also considered to consume more sources of electrical energy. The fan uses a motor with AC voltage to give rotation to the fan. The greater the rotation produced, the greater the power required [4]. But when compared to air conditioning, fans are indeed much cheaper and economical.

In addition, health factors are also an important problem in the relationship between temperature and humidity with fans. Especially in the dry season, the room temperature tends to increase significantly and exceed the needs of the human body. This not only causes discomfort, but also negatively affects health. Too high a room temperature can cause dehydration and exhaustion in humans. The discomfort caused by high temperatures can also interfere with sleep and good rest, thus affecting the quality of daily life. In addition, temperatures that do not match the needs of the body can also affect the immune system, increase the risk of disease, and worsen existing health conditions.

In the context of human productivity, too high a room temperature can also have a negative impact. At uncomfortable temperatures, concentration and focus may decrease, cognitive performance may be impaired, and work ability may decrease. This can hinder productivity, creativity, and work efficiency, potentially harming both individuals and the organization as a whole. Therefore, it is important to maintain the temperature and humidity of the room at a comfortable and healthy level.

One of the efforts that is tried is to use a fan and combined with a smart algorithm to regulate the speed. In this research, an intelligent Fuzzy Inference System (FIS) algorithm will be used to develop a fan that can spin in response to surrounding temperatures and humidity levels. Additionally, utilizing sensors nearby, this fan will switch off automatically when no objects (people) are present in the room. Users no longer need to manually switch on and off or vary the fan's speed thanks to sensors. The ESP32 microcontroller serves as the data processing center during the study, which is carried out in the living room. The ESP32 performs almost identical

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tasks to the Arduino [5],[6],[7], because these two microcontrollers can be used in Arduino IDE applications [8], [9]. In addition to having similar functions with Arduino, the ESP32 is also almost similar to the Wemos D1 Mini [10]. The microcontroller will be in charge of controlling all devices integrated with it [11], including temperature sensor, humidity sensor, human motion detection sensor, and other hardware [12]. The Tsukamoto FIS technique will be used to process the DHT22 sensor's measurement output. This approach was chosen due to its benefits, including its ability to construct fuzzy values from assessment data and its ability to immediately build upon and utilize the experiences of experts without the need for training [13].

Based on fuzzy logic, the Fuzzy Inference System (FIS) is a full procedure that uses a set of crisp inputs for crisp outputs. All crisp inputs undergo linguistic fuzzy values conversion during fuzzification. After that, an if-else rule based on these linguistic values is developed. Then, using the AND, OR, NOT, etc. operations, all possible combinations of fuzzy rules and membership functions are used to produce fuzzy output. In defuzzification, any approach is used to turn fuzzy outputs into crisp values [14]. In fuzzy logic, there is no way to estimate beyond the fuzzy range where a statement or estimate is ambiguous [15]. Given its power, fuzzy logic has the ability to overcome uncertainty problems [16]. Another advantage is that fuzzy logic is able to apply the experience of experts directly without having to go through the training process [17].

In previous studies, there have been several researchers who have conducted related research. In one of the previous studies, researchers examined the application of Fuzzy Logic Mamdani as a control system for air temperature and humidity in the server room. The main indicators in this study are air temperature and humidity controlled by a fuzzy logic algorithm based on an embedded system. The output in this study is the value of heater rpm and coolant rpm in one engine. If the humidity increases, the heater system will start, while if the temperature is high, the rpm coolant will ON [18].

In another previous study, researchers also examined fuzzy logic-based temperature control. The main components controlling the device in this study are the Atmega2560 microcontroller integrated with the DS18B20 sensor to measure large temperatures and the PING sensor to measure the distance of objects. The output of this study is the fan speed which is set based on the calculation of Fuzzy Logic Mamdani. This research was simulated through the Matlab and Proteus applications, then the actual prototype [19].

In other studies, previous researchers have also examined the control of lamp light intensity and fan rotation speed with Fuzzy Logic Mamdani. In this study, it was stated that fuzzy logic can answer the uncertainty of home smart systems used to control fan speed and lamp intensity. Temperature and humidity were used as indicators in this study to determine fan speed and lamp intensity using fuzzy logic. Then to adjust the intensity of the lamp, the factor of light intensity

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and ambient time is also used [20]. Similar research has also been researched by Lestari et al, namely about the fan speed control monitoring system using fuzzy logic. The indicator used in this study is temperature with DHT11 sensor measurements. The measurement results are processed by fuzzy logic and produce fan speed output [21].

In addition to Lestari et al, Zulkarnain et al have also researched the temperature and humidity control system in DSLR camera storage boxes using fuzzy logic and arduino microcontrollers. The sensor used in this study was the DHT11. The input values used are in the form of air temperature and humidity. This value will be processed by fuzzy logic to produce a fan speed suitable for regulating temperature and humidity in the camera storage box. This research was conducted to perform maintenance on DSLR cameras optimally [22].

Related studies that have discussed the use of fuzzy logic as a control system. Inter-research has similarities in the use of fuzzy logic as a way to process uncertain or undefined inputs, and produce outputs that are based on rules defined within the system. In addition, all such studies use sensors to obtain input data, and use microcontrollers or embedded systems to control the system automatically based on the results of fuzzy logic. Fuzzy logic is applied in various control systems such as temperature, humidity, and light intensity control.

In the first [18] and second [19] studies, fuzzy logic was used to control server room temperature and ambient temperature using microcontrollers and certain sensors. While in the third study [20], fuzzy logic was used to control light intensity and fan speed in smart home systems that used temperature and humidity indicators. In the fourth [21] and fifth [22] studies, fuzzy logic was used to control fan speed in the monitoring system and control the temperature and humidity in the storage box of DSLR cameras. In all these studies, fuzzy logic managed to produce precise output based on input processing from the sensors used. From the results of the study, it can be concluded that the application of fuzzy logic can be used in various control systems and can produce accurate output.

Based on several literature reviews that have been described, this research will use one of the FIS methods, namely FIS Tsukamoto. This model was chosen because it has several advantages compared to other model approaches such as Mamdani and Sugeno. First, this model stands out in the clarity and simplicity of the fuzzy rules used. The fuzzy rules in this model are easy for humans to understand and implement, thus allowing for more intuitive modeling and decision making. In addition, this model can also address problems involving linguistic input and output, making it more suitable for problems with linguistic characteristics. Thus, the model provides a simple, intuitive, and flexible approach to modeling and taking decisions based on uncertain knowledge. This fuzzy model will be used to obtain fan speed values in duty cycle units based on temperature and humidity inputs. The speed of this fan is distributed by the PWM Dimmer AC

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from the ESP32 module (algorithm processing center) to the AC fan. As a result, real-time changes in temperature and humidity can be observed, and the fan speed will always adjust to temperature and humidity conditions.

II. RESEARCH METHOD

A. Research Stage

Overall, this research consists of six main stages, namely needs analysis, control system design, creation and development of control systems, application of fuzzy logic of Tsukamoto's FIS model, testing and analysis of the impact of control systems on the room, as well as drawing conclusions and suggestions from the results of the analysis. These stages make it possible to ensure that the research carried out is in accordance with the objectives and can give the expected results. The research stages is listed in Fig 1.

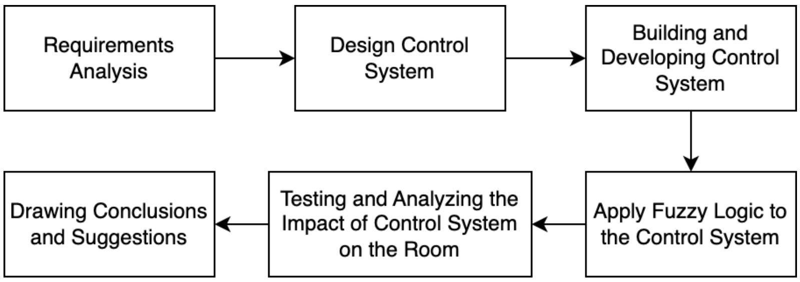

Fig 1. Research Stages

The first stage is requirement analysis. At this stage, information will be collected about what is needed in the research. This is done to ensure that the research carried out is in accordance with the objectives and can provide the expected results. In this study, this stage aims to analyze the needs regarding the room temperature and humidity control device to be made. Once the needs have been understood, the next stage is to design a room temperature and humidity control device. At this stage, it will be designed how the temperature and humidity control device of the room will work. Things that need to be considered in designing this control system are function, practicality, and efficiency.

The next stage is to build and develop a control system. At this stage, room temperature and humidity control devices will be developed with program code using the Arduino IDE. The form of the control system to be developed according to the design that has been made. This development process involves the use of appropriate hardware and software to ensure that the control system can function properly. Once the control system is developed, the next stage is to

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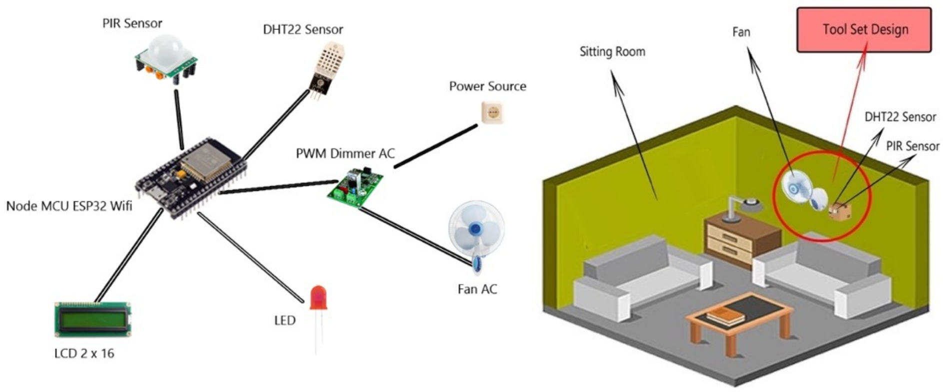
apply the fuzzy logic of Tsukamoto's FIS model. At this stage, a fuzzy logic model will be developed on the built room temperature and humidity control system.

After the control system is developed and the fuzzy logic model is applied, the next stage is to test and analyze the impact of the control system on the room. At this stage, the room temperature and humidity control device will be tested in a real environment. This test aims to ensure that the system can function properly in regulating the temperature and humidity of the room. In addition, the impact of this control system on the room will also be analyzed to see how effective the control system is in maintaining room temperature and humidity. After the results of testing and analysis are obtained, the last stage is to draw conclusions and suggestions from the results of the analysis. At this stage, conclusions will be made from the results of the analysis that has been done. This conclusion can be used as a basis for providing advice or recommendations for related parties. For example, suggestions for further development, suggestions for improvements to the system of regulation of room temperature and humidity, or suggestions for the development of better models of fuzzy logic.

B. System architecture

The microcontroller used in the built control system is ESP32. Some components are directly connected to the ESP32 as a contact center, and some require intermediaries of other components [23]. The input components to be used are the PIR sensor and the DHT22 sensor [24]. While the main output component is the AC PWM Dimmer which is used to set the Duty Cycle on the fan [25], [26]. Fig 2 illustrates the design form of the control system and simulates its application to the room in this study.



(1) (2)

Fig 2. (1) Control System Design (2) Simulation of Control System Implementation

Based on Fig 2 point 1, the components used include ESP32, DHT22 sensor, PIR sensor, PWM Dimmer AC, AC Fan, LED, and LCD. In addition, jumper cables are also used to connect devices with DC voltage and electrical cables for AC voltage. While the AC fan is directly connected to

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the electric current through the PWM AC Dimmer intermediary. In its implementation, this control system is used in living rooms. The form of simulation design for its application is shown in Fig 2 point 2. However, to find out how the control system design and simulation works in Fig 2, the control system workflow diagram is described in Fig 3.

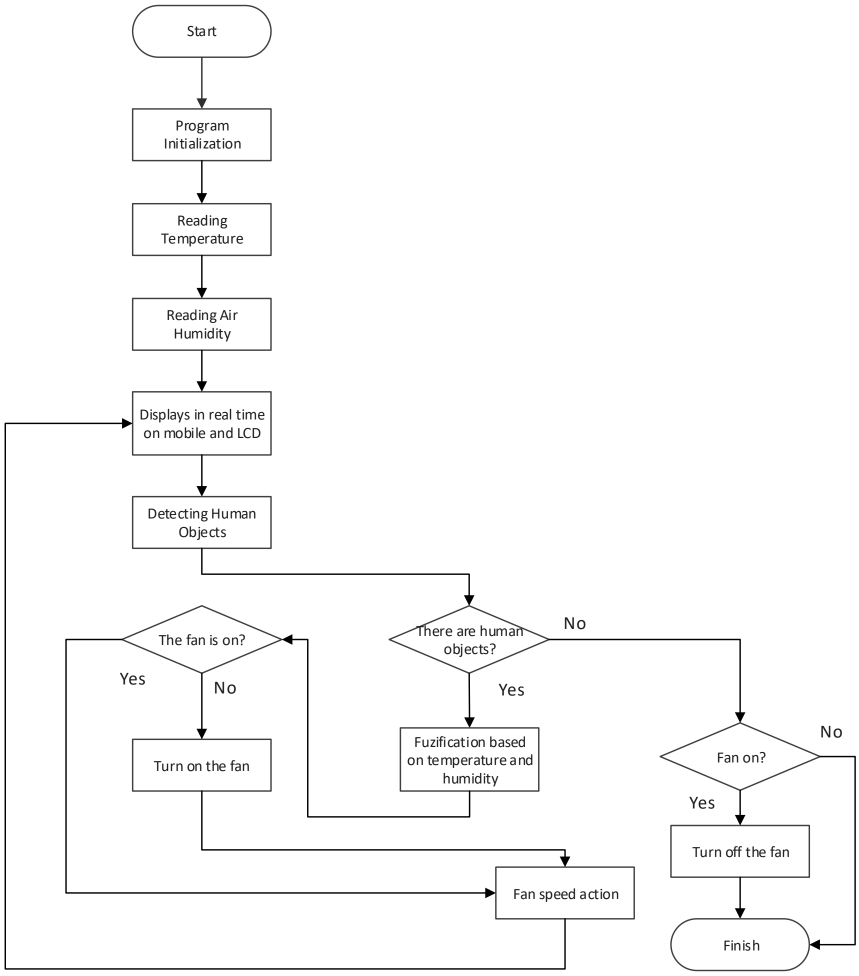

Fig 3. Flowchart of the Control System

At first, DHT22 will read the room temperature and humidity for processing by fuzzy logic on the ESP32 microcontroller as the processing and control center. This processing will produce fan speed in units of duty cycle. Then the speed value of this fan is sent to the fan through the PWM AC Dimmer intermediary. Furthermore, the fan will provide action in the form of fan rotation according to the value sent by the PWM AC Dimmer. The rotation of this fan will produce relatively different temperature and humidity values than before. These temperature and humidity values will be measured again by the DHT22 sensor as a new form of input value. This stage will repeat continuously until the system is stopped by the user or the power source goes out.

In addition, ESP32 also sends data to MySQL so that data can be stored and visualized in graphic form. It aims to draw conclusions and evaluate the performance of the tool. The general

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description of its application is as in Fig 4. In Fig 4, the role of the PIR sensor is not shown because the PIR sensor does not play a role in the application of fuzzy logic directly, but only plays a role in detecting human objects before the fuzzy system is run.

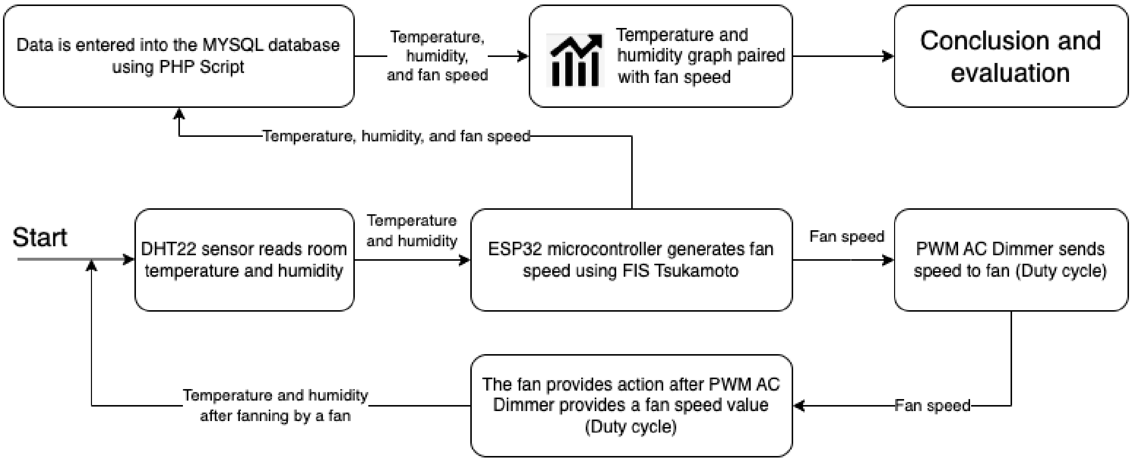

Fig 4. Overview of The Application of Fuzzy Logic Until Conclusions and Evaluation are Obtained

C. Fuzzy Logic

Fuzzy inference system is divided into three models, namely Sugeno [27], Tsukamoto, and Mamdani [28]. This study uses the Fuzzy Tsukamoto model. Fuzzification, machine inference, and defuzzification are the three stages of this fuzzy model's output generation process [29]. Additionally, each rule in this fuzzy model is subjected to monotonous reasoning [30]. Each IF-THEN rule's implication must be represented as a fuzzy set with a monotonous membership function. The output of the inference results from each rule is explicitly (clearly) presented based on the -predicate (fire strength). The method of aggregating the rules to produce the result is performed using defuzzification and the concept of a weighted average [31]. This fuzzy flow has been described in Fig 5.

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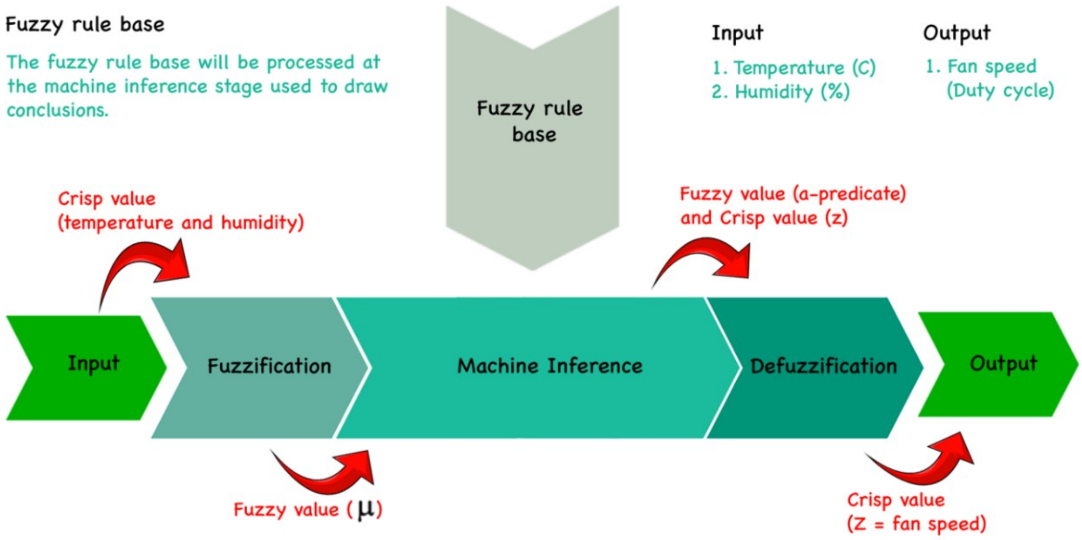

Fig 5. Fuzzy Flow

The first stage in the fuzzy calculation is Fuzzification, namely changing the firm value to a fuzzy value [32]. The fuzzification process is shown in the Equation 1.

$$x = fuzzifier(x_0) \tag{1}$$

with x is the definition of the variable from the fuzzy set vector, fuzzifier is the definition of transforming fuzzy collections from crisp values, and x_0 is a vector of firm values of an input variable.

Utilization of fuzzy logic there are several curves that can be used to represent the value of fuzzy membership [33]. However, only three membership functions will be used in this study, namely the descending linear curve, the shoulder curve, and the triangle curve. A descending linear curve is a straight line moving to the right for a lower membership value [34]. A descending linear curve is drawn in Fig 6 point 1 annotated in Equation 2. Then a triangular curve is the union of two lines (linear) i.e., a descending linear curve and an ascending linear curve [35]. The triangle curve is depicted in Fig 6 point 2 and annotated in Equation 3.

In addition to the descending linear curve and the triangular curve, there is still a shoulder curve. The shoulder curve is another way to determine fuzzy membership value. The fuzzy area variable, which has an unchanged right or left side, ends up using a shoulder curve. The left shoulder curve and the right shoulder curve are two models used to describe this type of curve.

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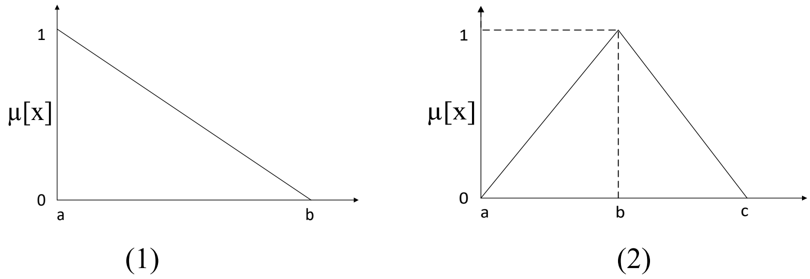

Fig 6. (1) Descending Linear Curve (2) Triangular Curve

$$\mu[x] = \begin{cases} 1; x \leq a \\ \frac{(b-x)}{(b-a)}; a < x < b \\ 0; x \geq b \end{cases} \quad (2)$$

$$\mu[x] = \begin{cases} 0; x \leq a \text{ } or \text{ } x \geq c \\ \frac{(x-a)}{(b-a)}; a < x < b \\ \frac{(c-x)}{(c-b)}; b < x < c \\ 1; x = b \end{cases} \quad (3)$$

After the fuzzification stage is completed, then proceed to the inference machine stage. This stage aims to process the fuzzy value of the fuzzification stage results based on rules formed with logical operators (if more than one input). When developing fuzzy rules based on fuzzy set theory, Zadeh divided them into three basic operators at the inference system stage, namely AND, OR, and NOT operators [36]. The AND operator is an operator used to search for the value of an α-predicate by selecting the lowest item in the rule [37]. The AND operator is annotated in Equation 4. The OR operator handles union operations. The value of α-predicate is determined based on the value of the largest element in the rule set [38]. The OR operator is annotated like Equation 5. While α-predicate as a result of operation of the NOT operator is obtained by subtracting the membership value of the element by the value of 1 [39]. This operator is annotated like Equation 6.

$$\mu K \cap L = \min(\mu K[x], \mu L[x]) \quad (4)$$

$$\mu K U L = \max(\mu K[x], \mu L[x]) \quad (5)$$

$$\mu K' = 1 - \mu K(x) \quad (6)$$

The last step is defuzzification which is a stage to convert the fuzzy output into crisp values using the membership function provided [40]. In the defuzzification process, this study uses the

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Weighted Average Method. Where this process can only be used if the output membership function of several fuzzy processes has the same form [31]. This method is represented in Equation 7. Z is defuzzification, α_i is alpha predicate, and z_i is inference output.

$$Z = \frac{\sum \alpha_i z_i}{\sum \alpha_i} \tag{7}$$

III. RESULT AND DISCUSSION

In the Tsukamoto FIS method, there are input variables and output variables as objects for which the fuzzy value will be searched [41]. Temperature, humidity, and fan speed were the three factors used in this study. The input variables are temperature and humidity, and the output variables are the fan speed, as shown in Table 1. But in Table 1 it only explains the universe of discussions that are still general in nature. A more detailed explanation can be seen in Table 2 which has been accompanied by the set, domain, membership function, and parameters for each domain.

Table 1. Universe Talks All Fuzzy Variables

Function	Variable Name	Unit	Universe of Conversation
Input	Temperature	°C	[1, 50]
	Humidity	%	[1, 100]
Output	Fan Speed	Duty Cycle (%)	[1, 100]

Table 2. The Set of All Fuzzy Variables

Variable	Set	Domain	Membership Function	Parameter
Temperature	Very Cold	<=25	Left shoulder	[0, 20, 25]
	Cold	20-30	Triangle	[20, 25, 30]
	Normal	25-35	Triangle	[25, 30, 35]
	Hot	30-40	Triangle	[30, 35, 40]
	Very Hot	>=35	Right shoulder	[35, 40, 50]
Humidity	Very Dry	<=20	Left shoulder	[0, 10, 20]
	Dry	15-40	Triangle	[15, 30, 40]
	Normal	38-60	Triangle	[38, 50, 60]
	Wet	57-80	Triangle	[57, 70, 80]
	Very Wet	>=75	Right shoulder	[75, 85, 100]
Fan Speed	Slow	<=40	Left shoulder	[0, 20, 40]
	Medium	35-50	Triangle	[35, 43, 50]
	Fast	>=45	Right shoulder	[45, 60, 100]

Table 1 provides a fuzzy logic system depiction that takes two input variables, namely Temperature and Humidity. In addition, it also provides one output variable, namely Fan Speed. The temperature variable uses degrees Celsius (°C) with a talking universe of 1-50, the humidity

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variable in percentage units (%) with a talking universe of 1-100, and the fan speed variable in duty cycle units (%) with a talk universe of 1-100.

Table **2** shows the set on each of the input and output variables. Variable Temperature has five fuzzy sets, namely Very Cold, Cold, Normal, Hot, and Very Hot. The Humidity variable has five fuzzy sets, namely Very Dry, Dry, Normal, Wet, and Very Wet. While the Fan Speed variable has three fuzzy sets, namely Slow, Medium, and Fast. The input and output variables used are each characterized by three membership function curves, namely the Left Shoulder, the Triangle, and the Right Shoulder.

To determine the membership value of each set in each of its variables, the membership function curve for each variable in fuzzy logic of both input and output variables will be used. Based on the set of all fuzzy variables listed in

Table **2**, a curve of the membership function is formed. The membership function curve of the temperature variable is shown in Fig 7, the humidity variable in Fig 8, and the fan speed variable curve in Figure 9. These fuzzy variable curves will apply the formulas found in Equations 2 and 3. The formula of the temperature variable curve is outlined in Equations 8-12. The formula of the variable curve of humidity is outlined in Equations 13-17. While the variable curve of fan speed is outlined in Equations 18-20.

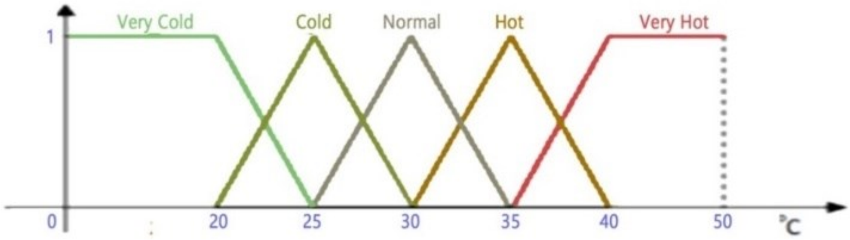

Fig 7. Temperature Variable Membership Function Curve

Fig 7 is a temperature variable membership function curve with five fuzzy sets, namely one set for the left shoulder curve (Very Cold), three sets for the triangle curve (Cold, Normal, and Hot), and one set for the right shoulder curve (Very Hot). Each fuzzy set has a different range of domains, namely Very Cold with domain <=25°C, Cold with domain between 20°C and 30°C, Normal with domain between 25°C and 35°C, Hot with domain between 30°C and 40°C, and Very Hot with domain >=35°C.

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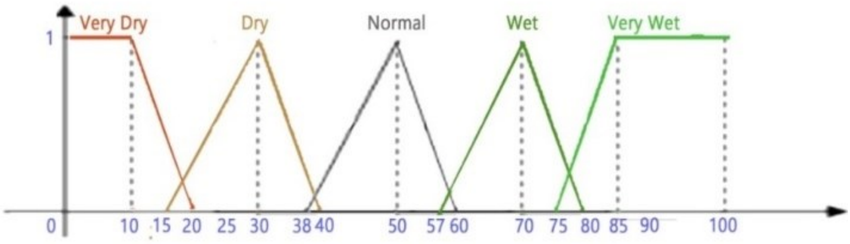

Fig 8. Humidity Variable Membership Function Curve

Fig 8 is a curve of the humidity variable membership function with five fuzzy sets, namely one set for the left shoulder curve (Very Dry), three sets for the triangle curve (Dry, Normal, and Wet), and one set for the right shoulder curve (Very Wet). Each fuzzy set has a different range of domains, namely Very Dry with domain <=20%, Dry with domain between 15% and 40%, Normal with domain between 38% and 60%, Wet with domain between 57% and 80%, and Very Wet with domain >=75%.

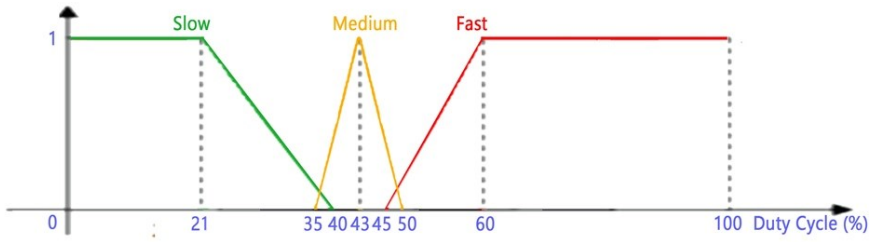

Figure 9 FAN SPEED VARIABLE MEMBERSHIP FUNCTION CURVE

Figure 9 is a variable fan speed membership function curve with three fuzzy sets, namely one set for the left shoulder curve (Slow), one set for the triangle curve (Medium), and one set for the right shoulder curve (Fast). Each fuzzy set has a different range of domains, namely Slow with domain <=40%, Medium with domain between 35% and 50%, and Very Wet with domain >=45%.

$$\mu\, VeryCool[x] = \begin{cases} 1, & x \leq 20 \\ \frac{25-x}{25-20}, & 20 < x < 25 \\ 0, & x \geq 25 \end{cases} \tag{8}$$

$$\mu\, Cool[x] = \begin{cases} 0, & x \leq 20 \; or \; x \geq 30 \\ \frac{x-20}{25-20}, & 20 < x < 25 \\ \frac{30-x}{30-25}, & 25 < x < 30 \\ 1, & x = 25 \end{cases} \tag{9}$$

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$$\mu\, Normal[x] = \begin{cases} 0, & x \leq 25 \text{ or } x \geq 35 \\ \frac{x-25}{30-25}, & 25 < x < 30 \\ \frac{35-x}{35-30}, & 30 < x < 35 \\ 1, & x = 30 \end{cases} \tag{10}$$

$$\mu\, Hot[x] = \begin{cases} 0, & x \leq 30 \text{ or } x \geq 40 \\ \frac{x-30}{35-30}, & 30 < x < 35 \\ \frac{40-x}{40-35}, & 35 < x < 40 \\ 1, & x = 35 \end{cases} \tag{11}$$

$$\mu\, VeryHot[x] = \begin{cases} 0, & x \leq 35 \\ \frac{40-x}{40-35}, & 35 < x < 40 \\ 1, & x \geq 40 \end{cases} \tag{12}$$

$$\mu\, VeryDry[x] = \begin{cases} 1, & x \leq 10 \\ \frac{20-x}{20-10}, & 10 < x < 20 \\ 0, & x \geq 20 \end{cases} \tag{13}$$

$$\mu\, Dry[x] = \begin{cases} 0, & x \leq 15 \text{ or } x \geq 40 \\ \frac{x-15}{30-15}, & 15 < x < 30 \\ \frac{40-x}{40-30}, & 30 < x < 40 \\ 1, & x = 30 \end{cases} \tag{14}$$

$$\mu\, Normal[x] = \begin{cases} 0, & x \leq 38 \text{ or } x \geq 60 \\ \frac{x-38}{50-38}, & 38 < x < 50 \\ \frac{60-x}{60-50}, & 50 < x < 60 \\ 1, & x = 50 \end{cases} \tag{15}$$

$$\mu\, Wet[x] = \begin{cases} 0, & x \leq 57 \text{ or } x \geq 80 \\ \frac{x-57}{70-57}, & 57 < x < 70 \\ \frac{80-x}{80-70}, & 70 < x < 80 \\ 1, & x = 70 \end{cases} \tag{16}$$

$$\mu\, VeryWet[x] = \begin{cases} 0, & x \leq 75 \\ \frac{85-x}{85-75}, & 75 < x < 85 \\ 1, & x \geq 85 \end{cases} \tag{17}$$

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$$\mu\, Slow[x] = \begin{cases} 1, \; x \le 1 \\ \frac{40-x}{40-1}, \; 1 < x < 40 \\ 0, \; x \ge 40 \end{cases} \tag{18}$$

$$\mu\, Medium[x] = \begin{cases} 0, \; x \le 35 \; or \; x \ge 50 \\ \frac{x-35}{43-35}, \; 35 < x < 43 \\ \frac{50-x}{50-43}, \; 43 < x < 50 \\ 1, \; x = 43 \end{cases} \tag{19}$$

$$\mu\, Fast[x] = \begin{cases} 0, \; x \le 45 \\ \frac{60-x}{60-45}, \; 45 < x < 60 \\ 1, \; x \ge 60 \end{cases} \tag{20}$$

The domain and set parameters of each variable listed in Table 1 and Table 2 are represented in Fig 7-Figure **9**. Domain and parameter values are created taking into account the potential results of temperature and humidity monitoring. Each of these two input variables contains five fuzzy sets, resulting in a total of 25 rules that can be created and represented in the calculation of the fuzzy inference system. The rules formed are IF-THEN rules that represent two input variables and one output variable. The form of the formed fuzzy rule is shown in Table 3.

Table 3. Fuzzy Rules

IF Temperature AND Humidity THEN Fan speed		**Temperature**				
		Very Cool	**Cool**	**Normal**	**Hot**	**Very Hot**
Humidity	Very Dry	Slow	Slow	Medium	Fast	Fast
	Dry	Slow	Slow	Medium	Fast	Fast
	Normal	Slow	Slow	Slow	Medium	Fast
	Wet	Slow	Slow	Slow	Slow	Medium
	Very Wet	Slow	Slow	Slow	Slow	Medium

The fuzzy rules in Table 3 will be applied to the inference stage of the machine used to draw conclusions. After the conclusion of each rule is obtained, it will then be processed at the defuzzification stage to obtain crisp values. The crisp value referred to here is the fan speed in the duty cycle unit which ranges from 1-100%. This range corresponds to the curve of the fan speed membership function depicted in Figure 9. This 1-100% duty cycle value has been divided into 3 domains, namely slow, medium, and fast. In addition, the duty cycle of this fan is also divided

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into 2 conditions, namely OFF and ON conditions. In the control system test carried out, the duty cycle at 1-20% indicates that the fan cannot rotate so that in this condition the fan is considered to be in the OFF condition and the rest is in the ON condition.

This fuzzy logic ability is tested to find out how much it affects temperature and humidity control using a tool in the form of a fan. A limited room measuring 3 x 3 meters was used for testing, with a closed state to prevent the ingress of fresh air from outside. At this stage of testing, the fan is attached to the wall and rotated/turned on for 30 minutes. Then the fan speed as well as its impact on the temperature and humidity of the room is stored and presented in the graph shown in Fig 10-Fig ***13***. Temperature and humidity are juxtaposed with fan speeds that are directly regulated by fuzzy logic. A comparison of the pairings can be seen in each of the images. The temperature pairing with the fan speed is on the left. While the humidity pairing and fan speed are on the right.

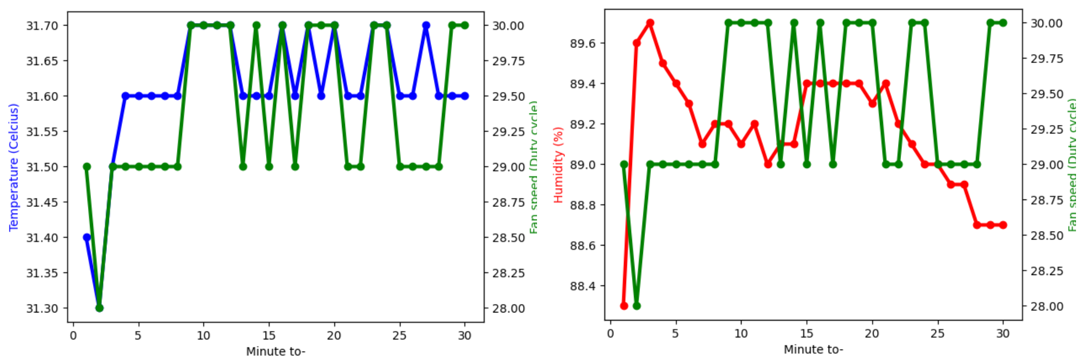

Fig 10. Effect of Fuzzy Logic (Test 1)

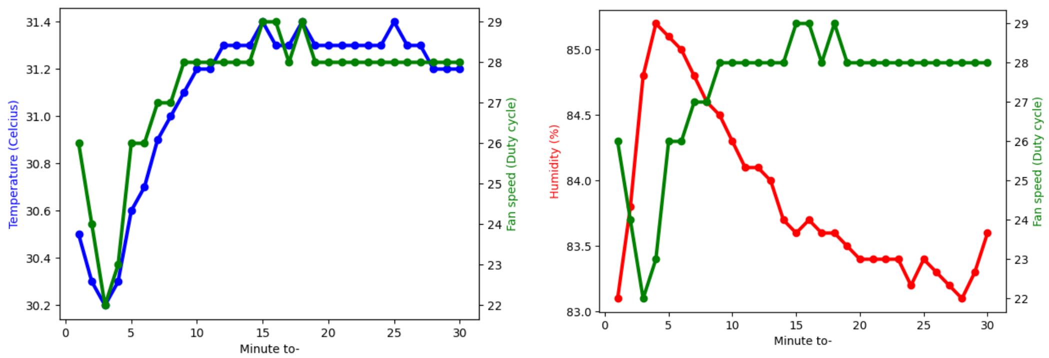

Fig 11. Effect of Fuzzy Logic (Test 2)

ISSN: 2580-409X (Print) / 2549-6824 (Online)
DOI: https://doi.org/10.29407/intensif.v7i2.19652

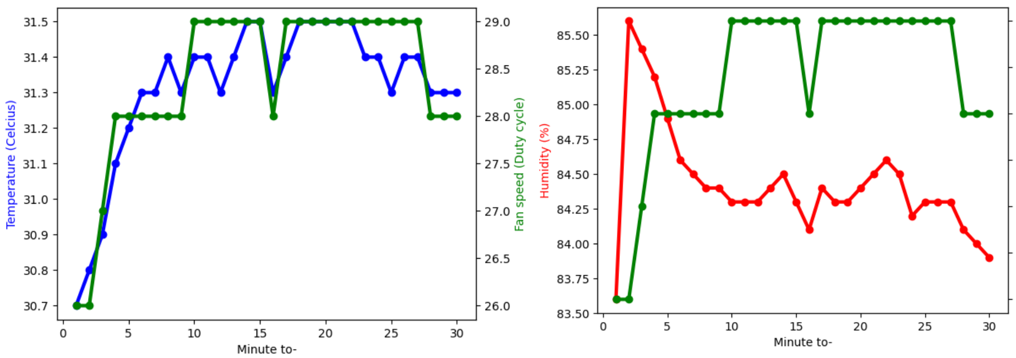

Fig 12. Effect of Fuzzy Logic (Test 3)

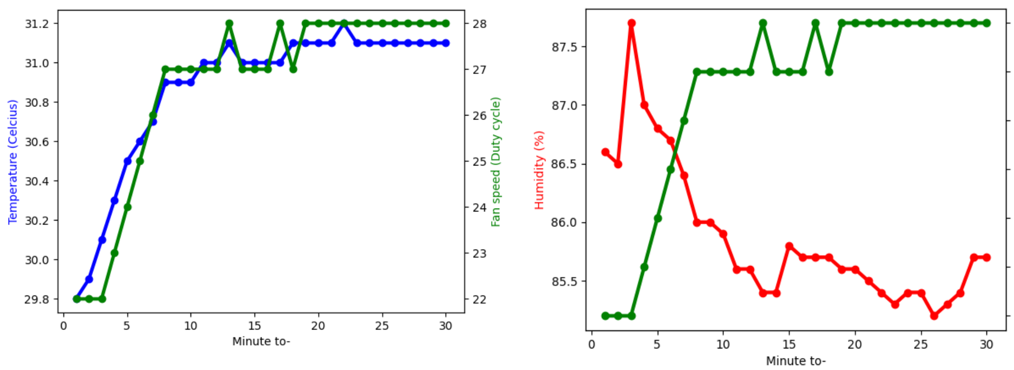

Fig 13. Effect of Fuzzy Logic (Test 4)

Tests on Fig 10-Fig ***13*** showed almost the same results on each of the charts. When the fan is turned in a closed room, the temperature in the room tends to rise/increase. Meanwhile, the humidity tends to decrease. The temperature value is marked with a blue line graph, the humidity value is marked with a red line graph, and the fan speed is marked with a green line graph.

The first test on Fig 10 of the humidity range was at 88.3-89.7%. While the temperature range is at 31.3-31.7◦C, so a humidity difference of 1.4% and a temperature difference of 0.4◦C are obtained. The second test on Fig 11 of the humidity range was at 83.1-85.2%. While the temperature range is at 30.2-31.4◦C, so a humidity difference of 2.1% and a temperature difference of 1.2◦C are obtained. The third test in Fig 12 of the humidity range is at 83.6-85.6%. While the temperature range is at 30.7-31.5◦C, so a humidity difference of 2% and a temperature difference of 0.8◦C are obtained. The last test or the fourth test in Fig 13 of the humidity range is at 85.2-87.7%. While the temperature range is at 29.8-31.2◦C, so a humidity difference of 2.5% and a temperature difference of 1.4◦C are obtained. The comparative conclusions of these four tests are listed in Table 4.

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Table 4. Comparison of the Difference in Temperature and Humidity Changes

Testing	Temperature (°C)		Humidity (%)		Difference in temperature changes (°C)	Difference in humidity changes (%)
	Min	Max	Min	Max		
1	31.3	31.7	88.3	89.7	0.4	1.4
2	30.2	31.4	83.1	85.2	1.2	2.1
3	30.7	31.5	83.6	85.6	0.8	2.0
4	29.8	31.2	85.2	87.7	1.4	2.5
Average					**0.95**	**2.0**

Table 4 provides data on minimum and maximum temperature and humidity readings, as well as temperature and humidity differences for the four tests performed. In addition, the difference in temperature and average humidity is also listed. The temperature range ranges from 29.8°C to 31.7°C, with temperature differences ranging from 0.4°C to 1.4°C. While the humidity range ranges from 83.1% to 89.7%, with the difference in humidity ranging from 1.4% to 2.5%. These results reveal that the test environment is relatively stable and consistent, with only slight fluctuations in temperature and humidity. Small differences in temperature and humidity indicate that the environment is controlled and monitored during the test, which is critical for accurate and reliable test results.

The average difference between maximum and minimum temperatures is 0.95°C. While the average difference between maximum and minimum humidity is 2.0%. In addition, based on the shape of the test graph in Figures 10-13 shows that when the fan is rotated in a closed room without air circulation, the relative temperature graph changes up from the initial minute to the last minute of the test. While the change in the relative humidity graph decreases, although in minutes 1-4 there are fluctuations up. Therefore, these results show that the fan is not a good tool in optimally lowering the temperature of a closed room.

Therefore, in the next study it was suggested to change the cooling device to an Exhaust Fan. Exhaust fan is a fan that functions to maintain the cleanliness of the air in the room, especially for rooms with poor air circulation [42]. The way the exhaust fan works is by drawing in the air in the room, then throwing it outdoors. This electronic fan can help stuffy and dirty air to be discharged outdoors, then replaced with cleaner air [43]. So that the results of future research can be compared with the results of this study to get a stronger basis.

ISSN: 2580-409X (Print) / 2549-6824 (Online)
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IV. CONCLUSION

In this study, the determination of the fan duty cycle was determined by the FIS Tsukamoto algorithm based on temperature and humidity input variables read in realtime by the DHT22 sensor integrated with the ESP32. The changes in temperature and humidity shown in the results of this study are not very optimal. Based on the test results, the relative temperature change is increasing with an average difference of 0.95°C, while the relative air humidity change is decreasing with an average difference of 2%. These results show that the fan is not a good tool in optimally lowering the room temperature. Therefore, in the next study it was suggested to change the cooling device to an Exhaust Fan. On the other hand, fuzzy logic can have a good impact, that is, the speed of the fan can be controlled according to the surrounding temperature and humidity level. This result is a correlation between fuzzy logic and temperature and humidity in the room. The fan is not always rotated at high speed, so this method is quite good at optimizing the use of electrical energy sources. The fan uses a motor with AC voltage to give rotation to the fan. The greater the rotation generated, the greater the power required [4].

ACKNOWLEDGMENTS

This work is supported by the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia based With Contract number : 181/E5/PG.02.00.PL/2023. The authors also gratefully acknowledge the helpfull comments and suggestions of the reviewers, which have improved this article.

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