

# Comparison of Fuzzy Mamdani and Fuzzy Tsukamoto Methods on Automatic Spray Fan

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**Abstract**—This study evaluates the implementation of Fuzzy Mamdani and Fuzzy Tsukamoto inference methods in an automated spray fan system designed to mitigate thermal discomfort in tropical climates. Utilizing an Arduino UNO integrated with DHT11 and PIR sensors, the system regulates fan speed and a water pump based on ambient temperature and human presence. Experimental results from 22 data points (25,8°C to 33,3°C) indicate that the Mamdani method exhibits higher sensitivity, initiating fan speed increases at 26,1°C and spray activation at 29,5°C. In contrast, the Tsukamoto method provides a more stable and gradual response, with fan transitions occurring at 28,4°C and spray activation at 30,5°C. While Mamdani is suitable for rapid cooling requirements, Tsukamoto demonstrates superior operational stability and energy efficiency through monotonic output functions. Manual calculations for both methods showed 100% consistency with experimental hardware outputs.

**Keywords:** Arduino UNO, Automatic Spray Fan, Fuzzy Mamdani, Fuzzy Tsukamoto, Sensor.

## I. INTRODUCTION

Batam City is located in a tropical climate zone with an average temperature ranging from 27°C to 32°C, based on data from the Batam City Statistics Agency. These environmental conditions often cause discomfort, especially in enclosed spaces with high levels of human activity. The increase in global temperature due to the greenhouse effect also exacerbates thermal instability in indoor environments, which directly impacts comfort and productivity, especially in public facilities [1].

Although various innovations in air conditioning systems, such as air conditioners (AC) and mist fans, have been introduced, these technologies are not always accessible or suitable for every user segment [2]. Therefore, efficient, automatic, and adaptive cooling systems are needed to meet the needs of various environments.

Observations in several public facilities including places of worship, classrooms, and multipurpose rooms show that conventional fans are often insufficient to significantly lower

room temperatures, especially in crowded conditions. Additionally, manual fan operation tends to result in energy inefficiency due to delays in activation or deactivation.

To address this issue, an automatic cooling system was developed using sensors to detect environmental temperature and human presence. This system employs an Arduino UNO microcontroller as the main controller, integrated with a DHT11 temperature sensor for thermal monitoring and a PIR sensor for motion detection [3], [4], [5]. The goal is to create an automatic spray fan system that only activates when needed, thereby improving energy efficiency.

To regulate the system's behavior, fuzzy logic control is applied due to its robustness in performing functions and handling inaccurate input values from the environment. This study uses two fuzzy logic methods Mamdani and Tsukamoto to evaluate their effectiveness in managing the cooling system [6].

The Mamdani method is widely used due to its intuitive rule base derived from linguistic variables, making it popular in academic and industrial applications. Meanwhile, the Tsukamoto method provides more stable and gradual output changes because each rule generates a fuzzy set with a monotonically increasing overall function. Comparing these two methods is important to determine which is more suitable for an automatic spray fan system that requires operational responsibility and stability.

## II. METHOD

### A. System Architecture

The automatic spray fan system is a cooling device designed to improve energy efficiency in small indoor spaces. It operates based on environmental inputs and activates automatically without manual control. Figure 1 shows the system. The system integrates a DHT11 (Digital Humidity and Temperature) sensor to monitor ambient temperature and a Passive Infrared (PIR) motion sensor to detect human presence. When a human is detected and the temperature ranges between 24°C and 34°C, the fan is activated. If the

temperature exceeds 30°C, the spray function is triggered to reduce the ambient temperature. An Arduino UNO microcontroller serves as the main processing unit, while a water pump functions as the actuator for the spray system.



Figure 1. Automatic Spray Fan

### B. Fuzzy Logic

Fuzzy logic was introduced by Lotfi A. Zadeh at the University of California, Berkeley, in 1965. It is a form of multi-valued logic that represents reasoning with degrees of truth ranging between 0 and 1, rather than the classical binary logic of true or false [6]. The term “fuzzy” refers to uncertainty or vagueness, which makes fuzzy logic suitable for modeling complex, imprecise, or human-like reasoning [7].

A membership function maps each input value to a membership degree within a fuzzy set, typically ranging from 0 to 1. The symbol  $\mu(x)$  is commonly used to denote the degree of membership of variable  $x$ .

The Mamdani method, introduced by Ibrahim Mamdani in 1973, is widely used in fuzzy control systems. This method represents both inputs and outputs as fuzzy sets and applies minimum (MIN) for rule implication and maximum (MAX) for aggregation.

The Tsukamoto method applies monotonic membership functions for each rule output [8]. Each rule is structured in the IF-THEN form, and produces a crisp output using a weighted average of all rule outputs. The final output  $Z$  is computed as:

$$Z = \frac{w_1z_1 + w_2z_2}{w_1 + w_2} \quad (1)$$

The defuzzified output  $Z$  represents the final result obtained from the fuzzy inference process as expressed in (1). In this formulation,  $Z$  denotes the crisp output, while  $w_1$  and  $w_2$  represent the firing strengths of rule 1 and rule 2, respectively, indicating the degree to which each rule is activated. Meanwhile,  $z_1$  and  $z_2$  correspond to the crisp output values generated by rule 1 and rule 2. The final value of  $Z$  is computed by weighting each rule’s output according to its firing strength, resulting in a balanced and representative overall output.

### C. Mamdani Fuzzy Method Design

For comparison purposes, the Mamdani fuzzy logic method was used as the first system. Introduced in 1973, the Mamdani method is known for its ease of implementation and readability [9]. This method represents inputs and outputs in fuzzy sets and generally uses centroid defuzzification [10]. It has the advantages of being easy to understand, simple, flexible, and accurate. The Mamdani fuzzy logic method will be used to analyze the temperature. This fuzzy logic uses two inputs and two outputs. The desired output is the time required to maintain the temperature of the air to suit the needs of the people in the room. If the output is appropriate, the output of the fuzzy logic process, namely the relay output, will adjust the fan speed and turn on the spray if it matches the specified temperature. If the output is not appropriate, the defuzzification stage will be performed again. Figure 2 (a) shows the algorithm of the Mamdani Fuzzy.

### D. Tsukamoto Fuzzy Method Design

In the process of planning automatic spray fan products, the use of appropriate analysis methods is crucial to ensure the accuracy of the data used in system development. One of the methods used in the second sub-system is the Tsukamoto fuzzy method. This method has the main objective of analyzing data efficiently while still maintaining a high level of accuracy [11]. The implementation of this method provides significant benefits in fan control, where the system can regulate room temperature with a high level of intelligence [12]. The use of the Fuzzy Tsukamoto method in analyzing the temperature in the room with inputs and outputs that are in line with the measurement mechanism in the previous subchapter. Evaluation of the analysis results of this method will be compared with previous methods to determine the advantages and suitability of its application in the development of optimal automatic spray fan products. The flowchart of the Tsukamoto method is shown in Figure 2 (b).

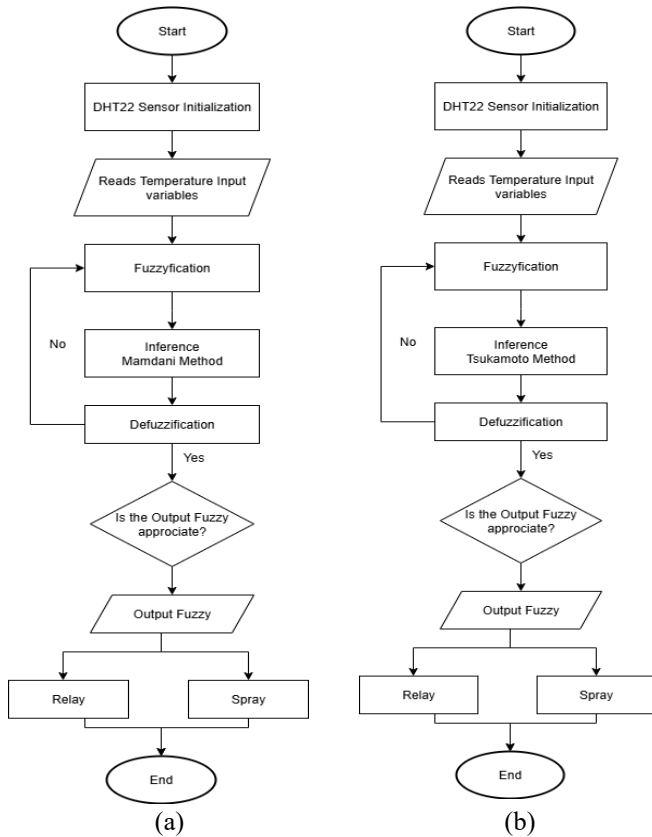


Figure 2.(a) Flowchart of Mamdani Fuzzy and (b) Flowchart of Tsukamoto Fuzzy

Fuzzy Mamdani and Fuzzy Tsukamoto methods are implemented to control the automatic spray fan system. The selection of this method is based on its characteristics that are in accordance with the needs of a fuzzy logic-based control system, allowing adaptive settings to changes in temperature detected. The following is a table of temperature class groupings, and the graph of memberships of the function is shown in Figure 3

TABLE I  
TEMPERATURE CLASS GROUPINGS

Category	Temperature
Cool	24°C - 28°C
Normal	26°C - 30°C
Hot	29°C - 34°C

Table 1 presents the grouping of temperature classes along with their corresponding ranges. The temperatures are categorized into three classes: Cool (24°C–28°C), Normal (26°C–30°C), and Hot (29°C–34°C). These ranges overlap, indicating that a single temperature value can partially belong to more than one class. This concept is commonly used in fuzzy logic systems, where temperature membership is not strictly divided but instead allows gradual transitions between categories.

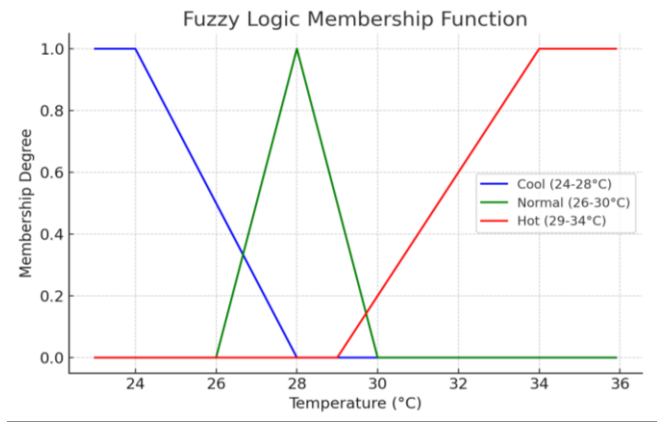


Figure 3. Membership Function Graphic

Fuzzy logic membership function in the temperature range 24°C to 34°C.

1) *Cool Class Membership Function*

$$\mu_{cool}(x) = \begin{cases} 1 & , x \leq 24 \\ \frac{28-x}{28-24} & , 24 < x \leq 28 \\ 0 & , x > 28 \end{cases} \quad (2)$$

2) *Normal Class Membership Function*

$$\mu_{normal}(x) = \begin{cases} \frac{x-26}{28-26} & , 26 \leq x \leq 28 \\ \frac{30-x}{30-28} & , 28 \leq x \leq 30 \\ 0 & , 26 > x > 30 \end{cases} \quad (3)$$

3) *Hot Class Membership Function*

$$\mu_{hot}(x) = \begin{cases} 0 & , x \leq 29 \\ \frac{x-29}{34-29} & , 29 < x \leq 34 \\ 1 & , x \geq 34 \end{cases} \quad (4)$$

III. RESULT AND DISCUSSION

A. *PIR Sensor Testing Results*

Number The test shows that the PIR sensor works well in detecting human movement up to 6 meters away. Based on the test results, the PIR sensor shows an active response to human movement at a distance of 1 to 6 meters and remains active within that distance but cannot detect movement beyond 6 meters. This indicates that the PIR sensor has a limited range, which may affect the effectiveness of the automation system if the object moves outside the detection zone. Nevertheless, the PIR sensor has performed to the expected specifications in a controlled environment, ensuring that the system will only activate when there is movement within the detectable range [13]. Therefore, the fan and spray control system will only operate if an individual is detected by the PIR sensor considering the limited detection range of the sensor.

In addition, testing the DHT11 sensor and the dynamo on the pump motor shows that the system runs according to the temperature conditions detected by the temperature sensor [14]. In the temperature range of 24°C to 34°C, the system activates the automatic fan and spray. The spray system works by means of an active pump, which sends water through a small pipe to the spray nozzle [15]. The spray is only activated

at a speed of 3. The function of the device is not only influenced by temperature, but also by the ability of the PIR sensor to detect human movement. If the PIR sensor does not detect human presence, the device will remain non-functional despite the high temperature detected. The results of the test prove that the system operates properly and as expected, i.e. it only activates at a predetermined temperature and when human movement is detected.

**B. DHT11 Sensor and Motor Pump Testing Results**

The calibrated DHT sensor detects temperature and activates the fan when the temperature is between 24°C and 34°C. The output of the temperature data is fan speed (1, 2, 3) and the pump motor will activate when the output speed is 3. The following is the test data for the DHT sensor with the PIR sensor detecting human movement.

Table 2 presents the testing results of the DHT11 sensor and the pump motor output using the Mamdani and Tsukamoto methods. The temperature data ranges from 25,8°C to 33,3°C, with two main output parameters: speed and spray. Figure 4 shows the Fan speed level produced by each fuzzy controller at different temperatures.

TABLE II  
DHT11 SENSOR AND MOTOR PUMP TESTING RESULTS

No	Temp (°C)	Mamdani Output		Tsukamoto Output	
		Speed	Spray	Speed	Spray
1	25,8	1	0	1	0
2	26	1	0	1	0
3	26,1	2	0	1	0
4	26,7	2	0	1	0
5	26,8	2	0	1	0
6	27	2	0	1	0
7	27,3	2	0	1	0
8	27,9	2	0	1	0
9	28,4	2	0	2	0
10	28,7	2	0	2	0
11	28,9	2	0	2	0
12	29	2	0	2	0
13	29,5	3	1	2	0
14	29,8	3	1	2	0
15	30,5	3	1	3	1
16	31,2	3	1	3	1
17	31,5	3	1	3	1
18	31,8	3	1	3	1
19	32,1	3	1	3	1
20	32,6	3	1	3	1
21	32,8	3	1	3	1
22	33,3	3	1	3	1

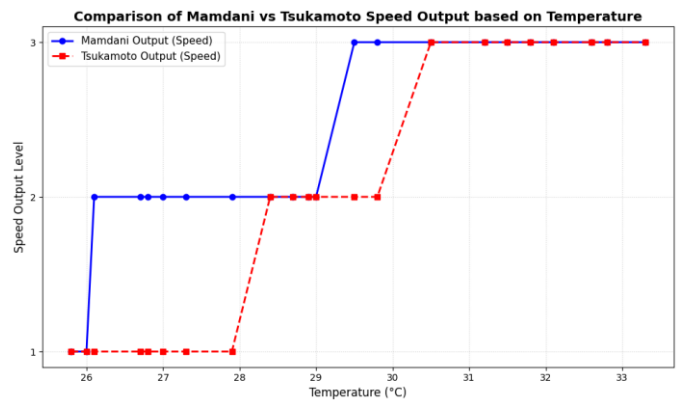


Figure 4. Comparison output of Speed of Fan for each algorithm

Based on the experimental, both fuzzy logic methods exhibit a aligned progressive trend in adjusting the fan speed output level from 1 to 3 in response to rising temperatures; however, the Mamdani method demonstrates a significantly higher sensitivity and faster response threshold compared to Tsukamoto. Specifically, Mamdani initiates the transition from level 1 to level 2 at a lower temperature of 26,1°C and reaches the maximum speed (level 3) at 29,5°C, whereas Tsukamoto delays these transitions until the temperature hits 28,4°C and 30,5°C, respectively. This distinct operational lag in the Tsukamoto method is inherently tied to its weighted-average defuzzification over monotonic membership functions, which provides greater mechanical stability and minimizes chattering, while Mamdani's centroid-based approach proves superior for applications requiring immediate and aggressive thermal regulation.

**C. Manual Calculation of Mamdani and Tsukamoto Fuzzy Logic**

The z value in the Tsukamoto calculation using the average method is 1,787; resulting in an output speed of 1. At a temperature of 27,3°C, manual calculations using Mamdani fuzzy logic produced the highest membership value of 0,65 in the Normal category, so the fan was set to speed 2. Meanwhile, manual calculations using the Tsukamoto method produced a value of z = 1,787, which was within the speed output range of 1. When compared with the actual test data: Mamdani also produces speed 2 (consistent with the manual result), Tsukamoto provides speed output 1 (also consistent).

**1) Manual Calculation of Mamdani Fuzzy Logic Fuzzification:**

x = 27,3°C  
 Cool = (28-27,3)/(28-24) = 0,175  
 Normal = (27,3-26)/(28-26) = 0,65  
 Hot = 0

Inference:

- [R1] IF temperature is cool THEN speed 1
- [R2] IF temperature is normal THEN speed 2
- [R3] IF temperature is hot THEN speed 3

Using the MIN rule:

[R1]  $\mu_{\text{predicate1}} = \mu_{\text{cool temperature}}(27,3) = 0,175$   
 [R2]  $\mu_{\text{predicate2}} = \mu_{\text{normal temperature}}(27,3) = 0,65$   
 [R3]  $\mu_{\text{predicate3}} = \mu_{\text{hot temperature}}(27) = 0$

Defuzzification:

Using the MAX rule

$$\mu_{\text{output}}(27,3) = \max(0,175, 0,65, 0) = 0,65$$

Description:

At a temperature of 27,3°C, the defuzzification result using the MAX method is 0,65, which falls under [R2], thus activating the fan at speed 2.

## 2) Manual Fuzzy Tsukamoto Calculation

Fuzzification:

$$x = 27,3^{\circ}\text{C}$$

$$\text{Cool} = (28-27,3)/(28-24) = 0,175$$

$$\text{Normal} = (27,3-26)/(28-26) = 0,65$$

$$\text{Hot} = 0$$

Inference:

[R1] IF temperature is cool THEN speed 1

[R2] IF temperature is normal THEN speed 2

[R3] IF temperature is hot THEN speed 3

Defuzzification:

In the Fuzzy Tsukamoto calculation, crisp values between 1 and 3 are produced. Therefore, output classification rules are established. If the z value is between 1 and 1,99, it will produce an output at speed 1; if the z value is between 2 and 2,99, it will produce an output at speed 2; and if the z value is 3, it will produce an output at speed 3 and activate the spray.

$$z = \frac{(0,175 \times 1) + (0,65 \times 2) + (0 \times 3)}{0,175 + 0,65 + 0}$$

$$z = \frac{1,475}{0,825}$$

$$z = 1,787$$

Therefore, it can be concluded that the manual calculation results are consistent with the experimental results. This indicates that the Mamdani method is more responsive to small temperature changes, while Tsukamoto provides a more gradual and stable response.

## D. Comparative Comparison Results of Fuzzy Mamdani and Tsukamoto Methods

Fuzzy Mamdani and Tsukamoto methods show significant differences in characteristics in responding to temperature changes based on testing 22 data samples with a temperature range of 25,8°C to 33,3°C. Mamdani tends to respond to temperature changes faster, such as at 26,1°C, where the fan speed immediately changes from speed 1 to speed 2. The spray also starts to activate at 29,5°C. While this shows high sensitivity, too fast and frequent changes in output can lead to instability in the system. For example, in the temperature range of 26,7°C to 29,0°C, Mamdani has produced a speed 2 output consistently, but previous speed changes that occurred at small temperatures indicate a less stable system in response to changes.

In contrast, the Tsukamoto method produces a more gradual and consistent output. At 28,4°C, Tsukamoto only increased the fan speed to speed 2, and the new spray was active at 30,5°C. This gradual response shows that Tsukamoto is more stable in managing temperature changes, avoiding unnecessary fluctuations. At 27,9°C to 28,9°C, the Tsukamoto kept the output at speed 1 until the temperature was significant enough to change the output to speed 2. This proves that the

Tsukamoto is more suitable for applications that require continuity and energy efficiency without frequent changes.

Considering the test data, it can be seen that Mamdani has a weakness in output instability due to too rapid changes, while Tsukamoto shows an advantage in stability due to more gradual and controlled changes. Tsukamoto's stability makes it more reliable for systems that require consistency and operational comfort especially in fluctuating temperature ranges. This shows that in applications that prioritize stability, Tsukamoto Fuzzy method is superior to Mamdani.

## IV. CONCLUSION

This study confirms that both Mamdani and Tsukamoto fuzzy inference methods are capable of controlling the automatic spray fan system based on temperature inputs ranging from 25,8°C to 33,3°C, with full consistency (100%) between manual calculations and experimental results. The Mamdani method demonstrates higher sensitivity, as indicated by earlier fan speed transitions at 26,1°C and spray activation at 29,5°C, whereas the Tsukamoto method shows a more gradual response, with transitions occurring at 28,4°C and spray activation at 30,5°C, resulting in greater operational stability and reduced fluctuation. However, this study is limited by the use of only 22 data samples, a relatively narrow temperature range, and reliance on a PIR sensor with a maximum detection distance of 6 meters, which may affect system responsiveness in broader or more dynamic environments. Additionally, the use of a single sensor type (DHT11) may limit measurement accuracy. Future research is recommended to involve larger datasets, wider environmental variations, higher-precision sensors, and hybrid or optimized fuzzy approaches to enhance system adaptability, robustness, and energy efficiency in real-world applications.

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