



Mamdani Fuzzy Logic-Based Room Temperature Monitoring and Control System

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ABSTRACT

Automatic room temperature control is a crucial need for maintaining comfort and energy efficiency, especially in enclosed environments such as offices, laboratories, and homes. This research aims to design and develop a room temperature monitoring and control system based on Mamdani fuzzy logic. The system utilizes a temperature sensor to monitor real-time environmental conditions and actuators (fans or heaters) as outputs to adjust the temperature. The Mamdani fuzzy logic method is chosen for its ability to handle uncertainty and provide decisions that resemble human reasoning. Test results show that the system can maintain the room temperature within the desired range responsively and efficiently. By implementing this system, thermal comfort can be achieved automatically without manual intervention, while also supporting energy savings in the operation of cooling and heating devices.

1. Introduction

Thermal comfort is a crucial factor in creating a healthy, productive, and efficient living and working environment. Poorly regulated indoor temperatures—whether too cold or too hot—can negatively affect the occupants' productivity, concentration, and physical as well as mental health [1], [2]. Furthermore, inefficient temperature control can lead to significant energy waste, particularly in heating and cooling systems that operate continuously without dynamically adapting to environmental conditions [3].

Most temperature control systems currently in use still rely on conventional control logic, such as threshold-based ON/OFF mechanisms. This approach has limitations in responding to dynamic and complex temperature variations, as it operates in a binary manner and does not consider gradual changes or contextual information [4]. As a result, such systems may produce extreme and inefficient responses, accelerating device wear and increasing electricity consumption.

To address these challenges, the Mamdani fuzzy logic approach presents a promising solution. It is capable of handling uncertainty and making decisions based on linguistic rules that mimic human reasoning. Fuzzy logic enables smoother control (soft switching) compared to conventional methods, as it does not rely solely on raw input values but also considers the degree of membership within several categories (e.g., “cold,” “warm,” “hot”) [5], [6].

Previous studies have shown that applying fuzzy logic to batch-type grain dryer control systems results in better performance and improved energy efficiency [7]. Similarly, in smart home automation systems, fuzzy logic has demonstrated the ability to adjust room temperature in real time without the need for manual intervention [8].

With the advancement of the Internet of Things (IoT) technology, the integration of temperature monitoring systems using sensors such as the DHT22 with intelligent fuzzy-based controllers has become increasingly significant. The DHT22 sensor provides accurate temperature and humidity data. However, to effectively utilize this data for controlling actuators such as fans and heaters, a smart and adaptive control system is required. The Mamdani fuzzy logic approach is highly relevant, as it offers flexibility in decision-making based on various environmental conditions [9], [10].

In this context, the aim of this research is to design and implement a temperature monitoring and control system based on Mamdani fuzzy logic. The system is developed to automatically control a fan and a heating lamp based on temperature input from the DHT22 sensor. This setup is expected to achieve a balance between thermal comfort and energy efficiency. Additionally, it serves as an initial prototype for the development of adaptive and eco-friendly smart home technologies.

The urgency of this research lies in the need for a temperature control system that is not only automatic but also intelligent, efficient, and adaptive to changing environmental conditions. In the long term, this system has the potential to be implemented not only in homes and offices but also in laboratories, storage rooms for sensitive goods, and HVAC (Heating, Ventilation, and Air Conditioning) systems in multi-story buildings.

2. Methods

The experimental method was applied to test the accuracy of the sensors and the effectiveness of the system in automatically monitoring and controlling temperature. The DHT22 sensor was used to measure temperature, ensuring the accuracy and reliability of the readings within the system. This experiment was conducted to observe how the system responds to temperature changes and to evaluate the effectiveness of the cooling fan, which is activated by the module when the temperature exceeds a predefined threshold.

The following is a schematic or hardware design of the entire temperature monitoring system circuit, which includes the main components that are interconnected to measure and detect indoor temperature, as seen in Figure 1.

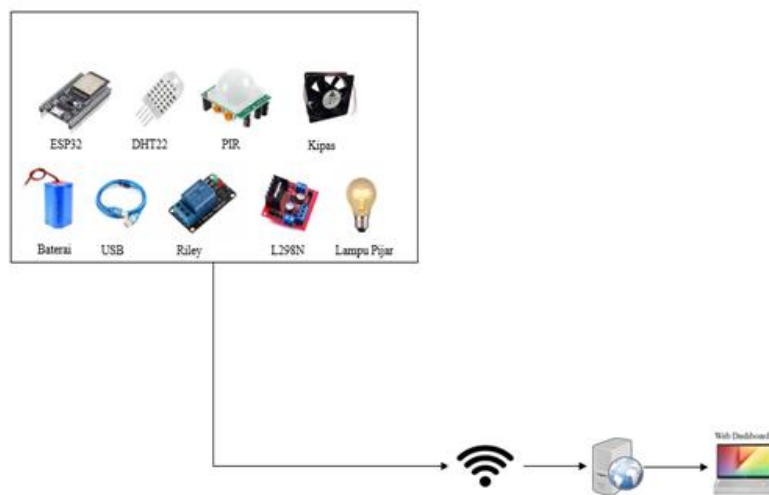


Figure 1: Hardware design scheme

To realize an ESP32-based automatic monitoring and control system, a hardware circuit is required that includes sensors, actuators, and a power module. The following figure shows the overall system circuit, which involves connections between the ESP32 microcontroller, temperature and humidity sensor (DHT22), motion sensor (PIR), relay module, fan, lamp, and power supply from an 18650 battery via the TP4056 module.

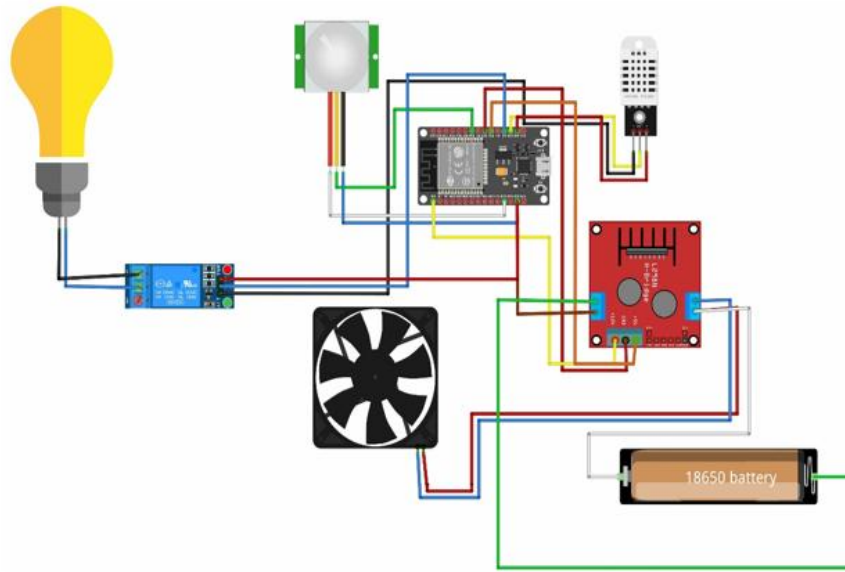


Figure 2: Overall series of monitoring

In the design of this monitoring system, several hardware components are required to build a room temperature monitoring system. These include the DHT22 sensor for detecting temperature and humidity, the ESP32 microcontroller as the main processing and control unit, and a Wi-Fi module for wireless data transmission. The L298N motor driver is used to control a DC fan, which functions to maintain air circulation, while a PIR sensor is utilized to detect the presence of objects or individuals in the room. In addition, a router or hotspot plays a crucial role in maintaining connectivity between devices by providing a wireless network that enables smooth data exchange among the sensors, microcontroller, and server. The availability of a stable network is essential for the entire system to operate cohesively and to ensure seamless data transmission and reception.

Meanwhile, a web-based dashboard allows users to conveniently monitor the data in real time. The next step involves designing the Mamdani fuzzy logic system. The fuzzification stage is carried out to create fuzzy sets for the input variables from the sensors and the output variables, in order to determine the degree of membership. The sensors used in this system are the DHT22 and PIR sensors. Each sensor variable has two or more membership functions based on specific value ranges. For instance, the DHT22 sensor uses three fuzzy sets: *cold*, *moderate*, and *hot*, measured in degrees Celsius ($^{\circ}\text{C}$).

The output variables consist of two actuators: the fan and the lamp. The fan has three membership functions: *Slow*, *Normal*, and *Fast*, while the lamp has two: *Off* and *On*. Each of these represents the degree of membership for each output category based on the defined rules. These rules and their respective fuzzy sets are detailed in Table 1. Figure 3-6 and equation 1-8 are the setting for the Mamdani Fuzzy Logic.

Table 1: Input and Output Variables

Input	DHT22	Cool	0-23 °C
		Warm	21-27 °C
		Hot	26-50 °C
Output	Fan	Slow	0-120 PWM
		Normal	115-190 PWM
		Fast	185-255 PWM
	Light	OFF	0-0,5 Volt
		ON	0,4-1 Volt

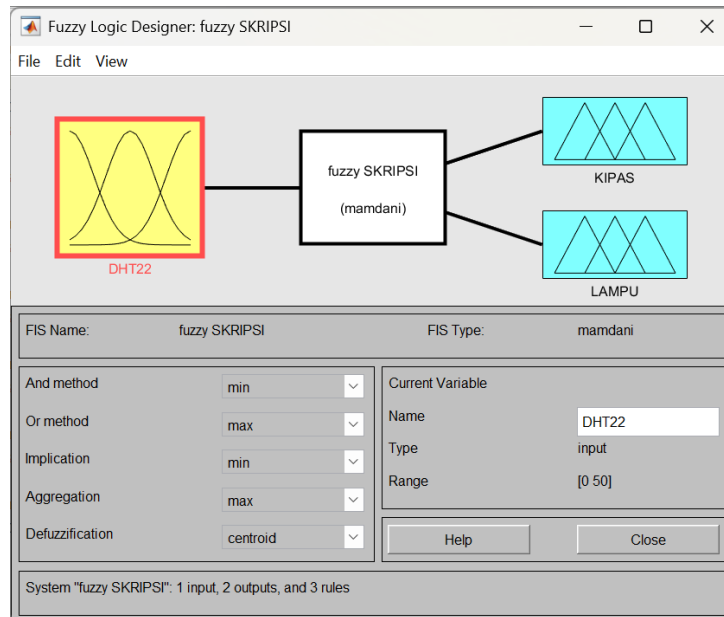


Figure 3: Fuzzy Input DHT11 Fan and Light Output

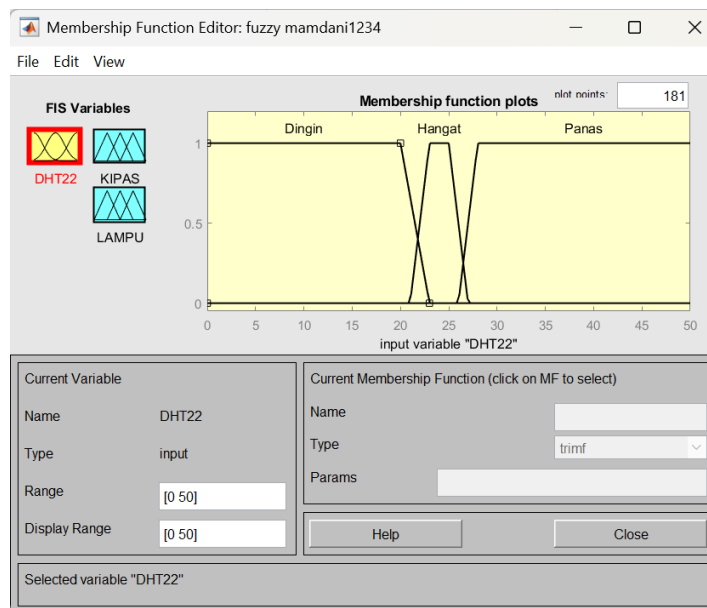


Figure 4: Temperature Membership Function Curve

$$\mu_{dingin}(x) = \begin{cases} 1, & x \leq 0 \\ \frac{23-x}{23}, & 0 < x < 23 \\ 0, & x \geq 23 \end{cases} \quad (1)$$

$$\mu_{hangat}(x) = \begin{cases} 0, & x \leq 21 \text{ atau } x \geq 27 \\ \frac{x-21}{3}, & 21 < x \leq 24 \\ \frac{27-x}{3}, & 24 < x < 27 \end{cases} \quad (2)$$

$$\mu_{panas}(x) = \begin{cases} 0, & x \leq 26 \\ \frac{x-26}{24}, & 26 < x < 50 \\ 1, & x \geq 50 \end{cases} \quad (3)$$

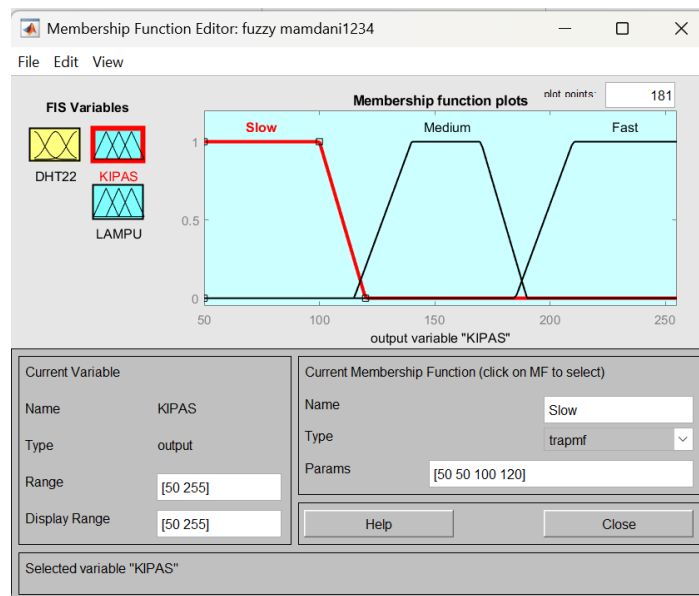


Figure 5: Fan Membership Function Curve

$$\mu_{slow}(x) = \begin{cases} 1, & x \leq 50 \\ 1, & 50 < x \leq 100 \\ \frac{120-x}{20}, & 100 < x < 120 \\ 0, & x \geq 120 \end{cases} \quad (4)$$

$$\mu_{medium}(x) = \begin{cases} 0, & x \leq 115 \text{ atau } x \geq 190 \\ \frac{x-115}{37.5}, & 115 < x \leq 152.5 \\ \frac{190-x}{37.5}, & 152.5 < x < 190 \end{cases} \quad (5)$$

$$\mu_{fast}(x) = \begin{cases} 0, & x \leq 185 \\ \frac{x-185}{20}, & 185 < x \leq 205 \\ 1, & 205 < x \leq 255 \end{cases} \quad (6)$$

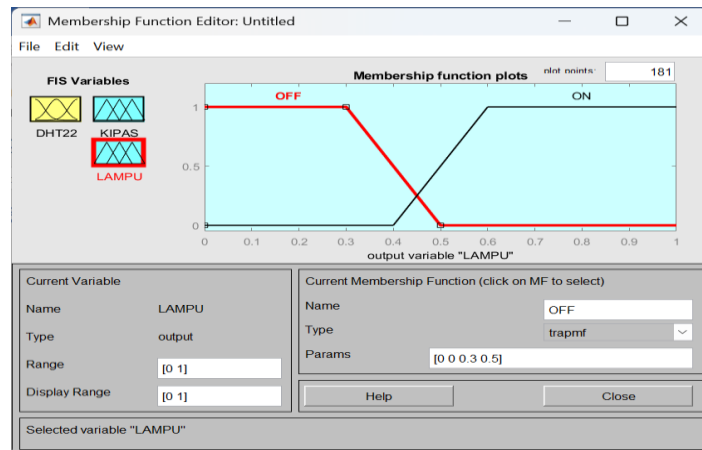


Figure 6: Lamp Membership Function

$$\mu_{\text{OFF}}(x) = \begin{cases} 1, & x \leq 0.3 \\ \frac{0.5-x}{0.2}, & 0.3 < x < 0.5 \\ 0, & x \geq 0.5 \end{cases} \quad (7)$$

$$\mu_{\text{ON}}(x) = \begin{cases} 0, & x \leq 0.4 \\ \frac{x-0.4}{0.2}, & 0.4 < x < 0.6 \\ 1, & x \geq 0.6 \end{cases} \quad (8)$$

3. Results and Discussion

3.1. Results

At this stage, testing was conducted on an automatic temperature control system using a DHT11 sensor and fan and light actuators controlled by Mamdani fuzzy logic. The purpose of this testing was to evaluate the system's response to variations in environmental temperature and the system's accuracy in activating the actuators based on the designed fuzzy rules. The following presents the results of 15 trials with different temperature variations.

Table 2: Overall Output Results

No	Temperature (°C)	Temperature Category (Fuzzy)	PWM Fan	Fan Speed	Volt Light	Light Status	Information
1	22.0	Cool	0	Slow	0.9 V	ON	Cold temperature, lights on for heating
2	23.0	Cool	30	Slow	0.8 V	ON	Still cold, fan not active yet
3	24.5	Cool-Warm	80	Slow	0.7 V	ON	The temperature starts to rise, the lights are still on
4	25.5	Warm	120	Normal	0.5 V	ON	Temperature is close to optimal, lights are still on
5	26.5	Warm-Hot	160	Normal	0.3 V	OFF	Temperature rises, lights start to go out, fans turn on
6	27.5	Hot	200	Fast	0.1 V	OFF	Hot temperature, fan on full blast
7	29.0	Hot	255	Fast	0.0 V	OFF	Maximum fan, light OFF
8	30.5	Hot	255	Fast	0.0 V	OFF	High temperature, temperature stabilization system
9	28.0	Hot	230	Fast	0.1 V	OFF	The fan is still active to lower the temperature.
10	26.0	Warm	140	Normal	0.4 V	ON	Temperature drops, lights start to turn ON, fans adjust
11	24.0	Cool-Warm	90	Slow	0.6 V	ON	The temperature is close to cold
12	21.5	Cool	0	Slow	1.0 V	ON	the temperature cools down again
13	23.5	Cool	60	Slow	0.8 V	ON	The heating of the room starts again
14	27.0	Warm-Hot	180	Normal	0.2 V	OFF	Transition to heat, lights OFF
15	25.0	Warm	110	Normal	0.6 V	ON	Comfortable temperature, fans and lights working lightly

Testing was conducted 15 times to evaluate the performance of the room temperature control system based on Mamdani fuzzy logic. This system is designed to control two actuators—a heating lamp and a cooling fan—based on temperature input from sensors and the processing of fuzzy logic rules.

At low temperatures, such as 21.5°C to 23.5°C, the system categorizes the temperature as "Cold", causing the heating lamp to turn ON with a high voltage output (approximately 0.9–1.0 V), while the fan

remains inactive or runs at low PWM, indicating a slow fan speed. This condition is intended to gradually raise the room temperature.

As the temperature rises to a range of 24°C to 25.5°C, the system transitions between the "Cold–Warm" and "Warm" categories. At this stage, the lamp remains ON but with a reduced voltage, and the fan starts to operate, although only at a low to moderate speed. This indicates that the system is beginning to adjust the conditions to prevent the temperature from becoming too high.

When the temperature reaches between 26°C and 27.5°C, which is categorized as "Warm–Hot" or "Hot", the lamp automatically turns OFF and the fan operates actively at a higher PWM value, with the fan speed increasing to "Fast". This shows that the system has detected a hot condition and automatically prioritizes cooling to reduce the room temperature.

At very high temperatures, such as 28°C to 30.5°C, the system keeps the fan running at maximum PWM (255) to efficiently lower the temperature, while the lamp remains off. Once the temperature starts to drop back to a more comfortable range (around 25°C to 26°C), the system readjusts the output: the lamp turns ON with moderate voltage, and the fan runs at medium to low speed.

From these results, it can be concluded that the Mamdani fuzzy logic-based system is capable of regulating room temperature automatically, smoothly, and efficiently, taking into account temperature transitions and user comfort. The system's adaptive response demonstrates the advantage of using fuzzy logic over conventional ON/OFF control, as it allows for gradual actuator output adjustments based on actual environmental conditions.

3.2. Discussion

Based on the results of 15 tests with temperature variations ranging from 21.5°C to 30.5°C, the Mamdani fuzzy logic-based room temperature control system demonstrated adaptive and responsive performance in maintaining a comfortable indoor environment. The system is capable of identifying temperature categories linguistically—such as "Cold", "Warm", "Hot", and transitional states—and automatically adjusts the actuators (lamp and fan) based on predefined fuzzy rules.

One key finding is that the system does not operate in a binary (ON/OFF) manner, but rather regulates output gradually through PWM control of the fan and voltage control of the lamp. For example, at a temperature of around 23°C, categorized as "Cold", the fan operates at a very low speed or remains off, while the lamp turns on to act as a heater. Conversely, at higher temperatures (above 28°C), the system turns off the lamp and activates the fan at maximum PWM to accelerate the cooling process.

Temperature transitions also indicate that fuzzy logic can respond to temperature changes smoothly. In transitional temperature categories such as "*Cold–Warm*" or "*Warm–Hot*", the system simultaneously adjusts both the fan and the lamp, avoiding sudden spikes or abrupt changes in room temperature control. This smooth transition is essential for ensuring comfort and energy efficiency.

The system's effectiveness is further evidenced by the changes in lamp voltage and fan speed, showing that the fuzzy control provides outputs that are tailored to actual needs, rather than fixed threshold responses as seen in conventional systems.

Based on 15 test results with temperature variations ranging from 21.5°C to 30.5°C, the Mamdani fuzzy logic-based room temperature control system demonstrated adaptive and responsive performance in maintaining a comfortable indoor environment. The system interprets temperature inputs in linguistic categories—such as "Cold", "Warm", and "Hot"—and adjusts the fan and lamp output gradually, based on defined fuzzy rules.

This non-binary control logic contrasts sharply with conventional ON/OFF systems, such as the microcontroller-based ON/OFF air conditioner system studied by Laili [3], which triggers fixed responses once a specific threshold is passed. Unlike such rigid systems, the fuzzy logic system offers soft switching, enabling smoother transitions and more energy-efficient responses. This advantage is also highlighted by Santoso and Waris [7], who applied fuzzy logic to grain dryers and reported reduced energy usage and better temperature stability.

Moreover, the fuzzy control system developed in this research shares similarities with the one used by Raffel and Utama [8], which applies fuzzy logic for automatic temperature adjustment using an air conditioner. However, a key improvement in this study is the integration of dual actuators—a fan and a heating lamp—along with real-time monitoring through an IoT-based dashboard. This allows not only cooling but also heating when necessary, providing bidirectional thermal control that was not implemented in [8].

Advantages of the proposed system include, Smooth response to temperature fluctuations using fuzzy rules, Adaptive actuator control using PWM and voltage variations, rather than fixed ON/OFF states, Integration with PIR sensors to add occupancy-based control potential, Real-time monitoring via a web-based dashboard, enhancing user interaction.

However, there are also limitations, including The lack of humidity-based control, despite the DHT22 sensor providing humidity data, The limited scope of testing, which was conducted in a single indoor environment with 15 test cases, Energy efficiency was not quantified, unlike in [7], which reported measurable energy savings.

4. Conclusion

In conclusion, the fuzzy logic-based temperature control system demonstrated clear advantages in responsiveness, comfort, and adaptability over conventional threshold-based systems. By comparing with previous studies such as [3], [7], and [8], this research highlights the practical benefits of implementing intelligent fuzzy logic control in microcontroller-based systems. Nevertheless, further research is needed to optimize energy consumption, expand testing environments, and explore multi-sensor integration for more robust applications in smart buildings.

Overall, these results confirm that the Mamdani fuzzy logic approach is effective for implementation in microcontroller-based temperature control systems. The system operates in real time and can be adapted for various temperature monitoring and control applications, such as storage rooms, laboratories, or other IoT-based thermal comfort systems.

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