Journal of Applied Science, Technology & Humanities
Volume 3, Issue 2, March, 2026, Pages 982-997

ISSN 3032-5765
DOI: https://doi.org/10.62535/r0q7c653

Application of Fuzzy Logic for Automatic Air Circulation Control System in Smoking Rooms Based on IoT

Ariel Pasha Ramaditya [1*]
*Computer Engineering Technology, Vocational School, IPB University
arielramaditya@apps.ipb.ac.id

Muhammad Dzaky Azzshahir[2] ,**Mikhail Hibrizi**[3]

[2,3] Computer Engineering Technology, Vocational School, IPB University
[2]azzshahirdzaky@apps.ipb.ac.id, [3] mikhailhibrizi@apps.ipb.ac.id

Abstract

Indoor air quality (IAQ) in smoking rooms presents significant health risks due to the accumulation of pollutants such as carbon monoxide (CO) and cigarette smoke. Most existing systems rely on passive monitoring or threshold-based ON/OFF control, which cannot provide proportional and adaptive ventilation. This study proposes an IoT-based automatic air circulation control system using a Mamdani Fuzzy Inference System (FIS) to regulate exhaust fan speed according to real-time pollutant conditions.

The system integrates MQ-2 and MQ-7 sensors with an ESP32 microcontroller. Sensor readings undergo fuzzification, rule evaluation using MIN implication, MAX aggregation, and Centroid of Area (CoA) defuzzification to generate a crisp fan speed output. The output is converted into an 8-bit PWM signal to control the exhaust fan proportionally. Data are transmitted via MQTT for real-time monitoring.

Simulation results and manual mathematical verification confirm the correctness of the fuzzy inference mechanism. Comparative analysis shows that the fuzzy controller provides smoother and more adaptive ventilation response than conventional ON/OFF control, particularly under moderate pollution levels. The proposed closed-loop architecture demonstrates improved responsiveness and suitability for intelligent smoking room ventilation management.

Keywords: fuzzy logic, Mamdani FIS, IoT, indoor air quality, ventilation control.

INTRODUCTION

Indoor air quality (IAQ) remains a significant concern in enclosed environments, particularly in designated smoking rooms where pollutant concentrations can accumulate rapidly. Although smoking rooms are intended to isolate smoking activities from non-smokers, inadequate ventilation may still result in elevated concentrations of harmful pollutants such as carbon monoxide (CO) and fine particulate matter. Prolonged exposure to these pollutants may negatively affect respiratory and cardiovascular health, especially in poorly ventilated indoor environments (Tanveer et al., 2024).

In many public facilities, smoking room ventilation systems still rely on conventional mechanisms such as constant-speed ventilation or simple threshold-based ON/OFF control. These approaches cannot dynamically adapt to fluctuations in pollutant concentration caused by variations in the number of smokers and room occupancy. As a result, ventilation systems may operate inefficiently, either providing insufficient airflow under moderate pollution conditions or consuming excessive energy when pollutant levels are relatively low.

Recent advances in Internet of Things (IoT) technology have enabled the development of real-time environmental monitoring systems using interconnected sensors, microcontrollers, and wireless communication protocols (Meana-Llorián et al., 2017; Othman & Abdulrazzaq, 2023). IoT platforms allow continuous acquisition, processing, and transmission of environmental data, enabling automated monitoring and control of indoor air quality. When integrated with intelligent decision-making techniques such as fuzzy logic, IoT-based systems can respond adaptively to dynamic and nonlinear environmental conditions (Saleem et al., 2024)..

Previous studies have demonstrated the effectiveness of fuzzy logic in various environmental control applications. For instance, Sunardi et al. (2023) reported that fuzzy-based controllers provide faster and more stable responses in HVAC systems compared to conventional control methods. Similarly, Al-Rahamneh et al. (2021) implemented a fuzzy inference system for temperature and humidity regulation and showed that fuzzy control can produce smoother and more adaptive actuator responses than binary ON/OFF mechanisms. In the context of air quality monitoring, Fahim et al. (2023) developed an IoT-based monitoring station integrated with a fuzzy inference model to analyze environmental pollution levels..

Despite these developments, research specifically focusing on intelligent ventilation control systems for smoking room environments remains limited. Most existing implementations concentrate on air quality monitoring or simple threshold-based ventilation control rather than proportional and adaptive airflow regulation. Smoking rooms present unique environmental challenges due to rapid pollutant accumulation and highly variable smoke intensity, making conventional binary ventilation control inadequate for maintaining stable air quality conditions.

This study addresses this research gap by proposing an IoT-based automatic air circulation control system for smoking rooms using a Mamdani Fuzzy Inference System (FIS). The proposed system integrates real-time pollutant sensing using MQ-series gas sensors, fuzzy-based decision-making, and proportional exhaust fan control using Pulse Width Modulation (PWM) signals generated by an ESP32 microcontroller..

The novelty of this research lies in the implementation of a closed-loop fuzzy-based ventilation control architecture specifically designed for smoking room environments, where actuator output (fan speed) is continuously regulated based on sensor feedback. By combining real-time IoT monitoring with adaptive fuzzy logic control, the system provides smoother and more responsive ventilation performance compared to conventional threshold-based ON/OFF systems (Sunardi et al., 2023; Saleem et al., 2024)..

Based on this approach, the objective of this study is to design and evaluate an automatic air circulation control system for smoking rooms that integrates IoT sensing, Mamdani fuzzy inference, and proportional actuator control. The proposed system is evaluated through simulation and prototype-based experiments to analyze its responsiveness and effectiveness in improving ventilation performance and indoor air quality management.

METHODS

Research Design and Approach

This research focuses on the development and evaluation of a prototype-based air circulation control system that integrates fuzzy logic and IoT technology. The study encompasses hardware implementation, fuzzy inference modeling using MATLAB, system integration with the ESP32 microcontroller, and experimental validation under controlled environmental conditions. Each stage was structured to ensure consistency between theoretical modeling and practical implementation.

Methodologically, the research is divided into four interconnected stages: (1) hardware design and assembly; (2) design of the Mamdani Fuzzy Inference System (FIS) using the MATLAB Fuzzy Logic Toolbox; (3) integration of the hardware system with the fuzzy inference engine through an IoT platform; and (4) experimental testing and performance evaluation of the system. Each stage was systematically structured to ensure coherence between conceptual design and physical implementation (Marzuki et al., 2024; Sujono et al., 2023).

Hardware Design

The proposed hardware system architecture adopts a centralized microcontroller-based topology, in which all sensor data acquisition, fuzzy inference computation, and actuator control processes are coordinated by a single main processing unit, namely the ESP32 microcontroller. The selection of ESP32 is based on its proven capability in various IoT-based fuzzy logic system implementations, including air quality monitoring systems (Fahim et al., 2023), room temperature and humidity control systems (Dakhole et al., 2023), and closed-environment control systems (Prabasworo et al., 2023).

The overall system block diagram consists of three interconnected functional layers. The first layer is the perception layer, comprising an MQ-2 sensor for detecting cigarette smoke and an MQ-7 sensor for detecting carbon monoxide (CO). The second layer is the processing layer, implemented on the ESP32, which includes sensor reading modules, the fuzzy inference engine, and an MQTT communication module. The third layer is the actuation layer, consisting of an exhaust fan with variable speed control using an L298N motor driver module and Pulse Width Modulation (PWM) signals.

The MQ-2 sensor functions as the primary detector of cigarette smoke presence and concentration inside the room, providing an analog voltage output proportional to gas concentration (Castaneda et al., 2024; Ali et al., 2024). Meanwhile, the MQ-7 sensor is specifically used to detect carbon monoxide (CO) concentration in the air. Carbon monoxide is a hazardous pollutant resulting from incomplete tobacco combustion, where exposure above 35 ppm may lead to poisoning (Widodo et al., 2018). The analog outputs from both sensors are connected to the ESP32 ADC pins through a voltage divider circuit to ensure compatibility with the ESP32's 3.3 V logic level.

The main actuator of the system is a DC motor integrated into the exhaust fan, whose rotational speed is variably controlled. The use of PWM-based control enables proportional actuation, which has been shown to be more energy-efficient and more effective in maintaining air quality compared to conventional ON/OFF control (Sunardi et al., 2023; Abana et al., 2020). The percentage value of the fan speed is directly obtained from the crisp output of the defuzzification process.

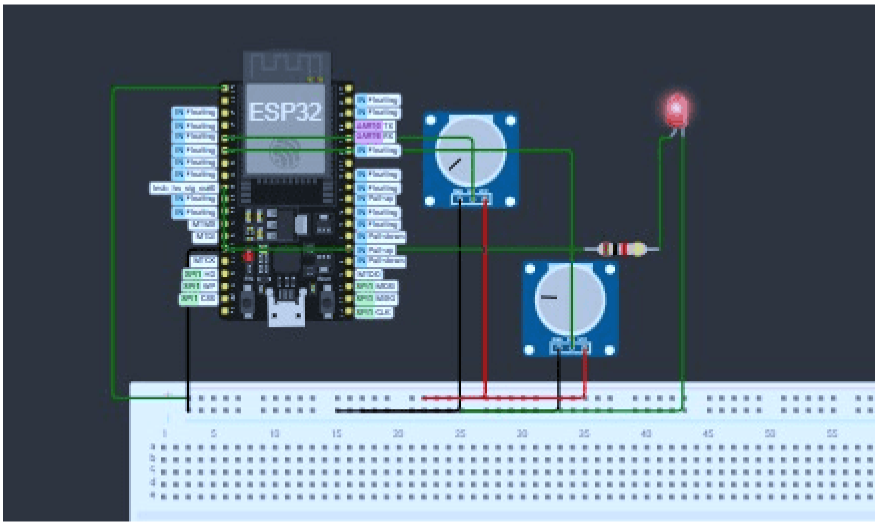


Figure 1. Wiring Schematic

To ensure seamless hardware integration and prevent signal overlap, the pinout mapping between the ESP32 microcontroller, sensors, and the actuator has been systematically assigned. The complete hardware pinout configuration is presented in Table 1.

Table 1. Hardware Pinout Configuration

Component	Pin / Port	Connection (ESP32 / Power Source	Function
MQ-2 Smoke Sensor	VCC	5V (Adaptor / VIN ESP32)	Operating voltage Source
	GND	GND ESP32	Reference ground
	AO (Analog Out)	GPIO 34 (ESP32 ADC)	Analog input signal (0–1000 ppm)
MQ-7 CO Sensor	VCC	5V (Adaptor / VIN ESP32)	Operating voltage source
	GND	GND ESP32	Reference ground
	AO (Analog Out)	GPIO 35 (ESP32 ADC)	Analog input signal (0–200 ppm)
L298N Motor Driver	12V / VCC	Positive (+) 12V Adaptor	Main power source for the exhaust fan
	GND	Negative (–) 12V Adaptor & GND ESP32	Common ground for logic signal synchronization
	ENA (Enable A)	GPIO 25 (ESP32 PWM)	Actuation output signal for speed control
	IN1	GPIO 26 (ESP32)	Logic control for forward rotation (High)
	IN2	GPIO 27 (ESP32)	Logic control for backward rotation (Low)

Overall System Workflow

The proposed system operates using a closed-loop control architecture that integrates sensing, decision-making, and actuation processes. The workflow begins with real-time acquisition of air quality parameters using the MQ-2 sensor for smoke detection and the MQ-7 sensor for carbon monoxide (CO) measurement. The analog signals generated by both sensors are converted into digital values through the analog-to-digital converter (ADC) of the ESP32 microcontroller.

The acquired sensor readings are processed in the fuzzification stage, where crisp numerical values are transformed into linguistic variables using predefined triangular and trapezoidal membership functions. Subsequently, the Mamdani inference mechanism evaluates the rule base using the MIN operator for implication, determining the firing strength of each active rule.

All activated output membership functions are combined through the MAX aggregation process. The aggregated fuzzy output is then converted into a crisp value using the Centroid of Area (CoA) defuzzification method. This crisp output represents the fan speed percentage.

The resulting fan speed value is mapped into an 8-bit Pulse Width Modulation (PWM) signal within the range of 0–255, which proportionally controls the exhaust fan through the L298N motor driver module. Finally, both sensor readings and actuator outputs are transmitted to the IoT platform via the MQTT protocol for real-time monitoring. This closed-loop structure enables continuous adjustment of ventilation intensity according to dynamic pollutant conditions.

Mamdani Fuzzy Inference System Design

The inference method employed in this study is the Mamdani approach due to its superior capability in representing expert knowledge through natural linguistic IF–THEN rules and producing intuitive outputs for motor speed control (Florea et al., 2023; Behzadi et al., 2025). The Fuzzy Inference System (FIS) was designed using MATLAB by defining two input variables and one output variable. The first input variable, "Smoke," is mapped within a universe of discourse of 0–1000 ppm using three fuzzy sets: Low (trapezoidal, [0 0 200 400]), Medium (triangular, [200 500 800]), and High (trapezoidal, [600 800 1000 1000]). The second input variable, "CO," is defined within the range of 0–200 ppm and divided into three fuzzy sets: Safe (trapezoidal, [0 0 25 50]), Caution (triangular, [25 75 125]), and Dangerous (trapezoidal, [100 150 200 200]) (Sujono et al., 2023; Cho et al., 2017).

On the output side, the variable "Fan_Speed" is represented within a PWM range of 0–100% and divided into five fuzzy sets to achieve finer granularity: Off ([0 0 10 25]), Low ([10 25 40]), Medium ([30 50 70]), High ([60 75 90]), and Full ([80 100 100 100]) (Saleem et al., 2024; Hassan et al., 2022). The fuzzy rule base consists of nine conditional rules combining Smoke and CO conditions using the AND operator (minimum implication). The defuzzification process employs the Centroid of Area (CoA) method to compute the center of gravity of the aggregated output membership function (maximum aggregation), thereby generating a definitive (crisp) PWM control signal (Salau & Takele, 2022; Prasanna & Bojja, 2021).

Mathematical Formulation of Membership Functions

The triangular membership function is mathematically defined as:

$\mu(x; a, b, c) =$
$0, \text{ for } x \le a$
$(x - a) / (b - a), \text{ for } a \le x \le b$
$(c - x) / (c - b), \text{ for } b \le x \le c$
$0, \text{ for } x \ge c$

The trapezoidal membership function is defined as:

$\mu(x; a, b, c, d) =$
$0, \text{ for } x \le a$
$(x - a) / (b - a), \text{ for } a \le x \le b$
$1, \text{ for } b \le x \le c$
$(d - x) / (d - c), \text{ for } c \le x \le d$
$0, \text{ for } x \ge d$

These membership functions are used to compute the degree of membership for Smoke and CO concentrations according to the predefined parameter ranges.

Complete Fuzzy Rule Base

The complete fuzzy rule base consisting of nine IF–THEN rules is presented below.

Table 2. Complete Fuzzy Rule Base

Rule No.	Smoke	CO	Fan Speed
R1	Low	Safe	Off
R2	Low	Caution	Low
R3	Low	Dangerous	Medium
R4	Medium	Safe	Low
R5	Medium	Caution	Medium
R6	Medium	Dangerous	High
R7	High	Safe	Medium
R8	High	Caution	High
R9	High	Dangerous	Full

IoT Integration and Data Collection Techniques

The crisp fan speed values along with sensor readings are transmitted by the ESP32 to an IoT platform via the MQTT protocol over a Wi-Fi connection. MQTT was selected due to its bandwidth efficiency and suitability for IoT-based systems (Fahim et al., 2023; Dakhole et al., 2023).

Data collection was conducted through two primary procedures. First, simulation testing was performed using the MATLAB Fuzzy Logic Toolbox to verify the correctness of the rule base through 3D control surface visualization. Second, experimental prototype testing was carried out in a closed chamber with a volume of 10 m^3 using a controlled cigarette smoke source to emulate representative smoking room conditions.

The collected data were analyzed to evaluate system response time and to compare the energy efficiency and control performance of the proposed fuzzy-based system against a conventional binary (ON/OFF) control system (Sunardi et al., 2023; Sung & Hsiao, 2021).

RESULTS AND DISCUSSION

Simulation Results of Mamdani Fuzzy Inference System in MATLAB

The performance of the Mamdani fuzzy inference system was evaluated through MATLAB simulation using the Fuzzy Logic Toolbox. The simulation involved sequential processing stages, including fuzzification, rule evaluation, aggregation, and centroid defuzzification. Various combinations of Smoke and CO input values were tested to observe the resulting fan speed output and to analyze the dynamic response characteristics of the controller.

The simulation process was conducted by inputting various combinations of Smoke (ppm) and CO (ppm) values into the designed FIS, and then observing the resulting output in the form of fan speed (%) through the Rule Viewer and Surface Viewer windows in MATLAB. This simulation approach is consistent with methodologies used in various recent fuzzy control system studies, including indoor air quality monitoring (Abana et al., 2020) and Mamdani-based actuator control systems (Pranoto et al., 2023).

Fuzzification Stage

Fuzzification is the first stage in which crisp sensor values are converted into degrees of membership in each predefined fuzzy set (Kamthan & Singh, 2020). This process maps numerical data into linguistic variables, allowing the system to mathematically represent uncertainty and gradual conditions (Dutta & Anjum, 2021).

In this study, fuzzification was performed simultaneously on Smoke concentration values from the MQ-2 sensor and CO values from the MQ-7 sensor. The mathematical equations are automatically implemented by MATLAB when the membership function parameters are defined through the Membership Function Editor (Prasanna & Bojja, 2021).

If the sensors measure smoke concentration of X_1 ppm and CO of X_2 ppm, the membership degrees are calculated using triangular and trapezoidal functions that have been configured. The fuzzification results for each test scenario are presented in Table 1.

Table 1. Fuzzification Results

Scenario	Smoke Value	CO Value	μ Smoke-Low	μ Smoke-Medium	μ Smoke-High	μ CO-Safe	μ CO-Alert	μ CO-Dangerous
1 (Normal)	100	10	1.0	0	0	1.0	0	0
2 (Smoking)	400	75	0	0.67	0	0	1.0	0
3 (Dangerous)	850	180	0	0	1.0	0	0	1.0

The fuzzification results indicate that when pollutant concentrations fall between two fuzzy sets, the system produces partial membership degrees in both sets simultaneously. This phenomenon represents a fundamental advantage of fuzzy logic over conventional binary logic, as it can capture gradual real-world conditions. This finding is consistent with studies by Rahimdel et al. (2022), Saleem et al. (2024), and Abana et al. (2020), which emphasize that continuous data representation between 0 and 1 significantly improves the accuracy of pollution analysis.

Rule Evaluation Stage (MIN Implication)

After the fuzzification process produces membership degrees for each rule antecedent, the next stage is rule evaluation using the MIN (minimum) implication method. The AND operator in the antecedent is implemented using the minimum function, so the firing strength is calculated as the smallest value among all involved antecedent membership degrees (Atlam & Wills, 2019).

This activation value, denoted as α_k, is used to clip the membership function of the rule consequent, resulting in a truncated area for each active rule (Putri & Rahayu, 2020). This method represents a key characteristic of the Mamdani approach (Qomaruddin et al., 2024).

For example, if a rule states: *"IF Smoke is Medium AND CO is Alert THEN Fan is Medium"*, and the membership values are $\mu_{Medium} = 0.6$ and $\mu_{Alert} = 0.4$, then the firing strength is calculated as:

$$min\,(0.6{,}0.4) = 0.4$$

This process is repeated for all 9 defined fuzzy rules (Hasan et al., 2024).

Table 2. Rule Evaluation and Firing Strength

Rule No.	Rule Description (IF–THEN)	μ Antecedent-1 (Smoke)	μ Antecedent-2 (CO)	α (Firing Strength = MIN)	Activated Output Set

R1	IF Smoke is Low AND CO is Safe THEN Fan is Off	1.0	1.0	1.0	Off
R5	IF Smoke is Medium AND CO is Caution THEN Fan is Medium	0.67	1.0	0.67	Medium
R9	IF Smoke is High AND CO is Dangerous THEN Fan is Full	1.0	1.0	1.0	Full

MAX Aggregation and Centroid Defuzzification Stage

The aggregation stage is performed to combine all clipped output membership functions into a single distribution area using the MAX (maximum) operator (Aguilera-Álvarez et al., 2021; Ren et al., 2025). This aggregation process can be visualized in the rightmost output panel of the Rule Viewer in MATLAB as an irregular shaded area (Cruz-Alejo et al., 2022). This approach ensures that no information is lost from the complex interaction of all active rules (Sung & Hsiao, 2021; Qomaruddin et al., 2024).

The final stage is defuzzification, which converts the aggregated area into a single crisp value using the Centroid of Area (CoA) method. This method computes the center of mass (centroid) of the aggregated membership function in a discrete manner (Salau & Takele, 2022; Tong, 2025; Cho et al., 2017). The main advantage of the CoA method is its ability to produce smooth and continuous output transitions, ensuring that changes in fan speed are not abrupt when the input values vary gradually (Shrinivasan & Raol, 2018).

Example of Manual Fuzzification Calculation (Scenario 2)

For Smoke = 400 ppm and CO = 75 ppm:

For Smoke-Medium (triangular [200 500 800]):

$$\mu\text{Medium}(400) = \frac{400-200}{500-200} = \frac{200}{300} = 0.67$$

For CO-Caution (triangular [25 75 125]):

$$\mu\text{Caution}(75) = 1$$

Thus, the firing strength for the rule:

IF Smoke is Medium AND CO is Caution THEN Fan is Medium

is calculated using MIN implication:

$$\alpha=\min(0.67,1)=0.67$$

Mathematical Formulation of Centroid Defuzzification

The centroid (center of gravity) method is used to convert the aggregated fuzzy output into a crisp control value. It is mathematically defined as:

$$y^* = \int(y \cdot \mu\_agg(y))\, dy \;/\; \int \mu\_agg(y)\, dy$$

where:

$\mu\_agg(y)$ = aggregated output membership function
y^* = crisp PWM output

For the simulation scenario where Smoke = 7 ppm and CO = 157 ppm, the activated rule produces Fan Speed = 50%.

The PWM value is calculated as:

PWM = (Fan Speed / 100) × 255
PWM = (50 / 100) × 255
PWM = 127

This confirms that the defuzzification output is correctly mapped into actuator control signal.

Manual Verification of Centroid Defuzzification (Scenario 2)

To validate the correctness of the MATLAB-based defuzzification results, a manual centroid calculation was performed for Scenario 2, where Smoke = 400 ppm and CO = 75 ppm.

From the fuzzification stage, the membership degrees were obtained as follows:
μ(Smoke–Medium) = 0.67 and μ(CO–Caution) = 1.0.

Using the MIN implication method, the firing strength is calculated as:

$\alpha = \min(0.67, 1.0) = 0.67$.

The activated output set corresponds to "Fan Speed = Medium," represented by a triangular membership function defined over the range [30, 50, 70].

The original triangular area is calculated as:

A_original = ½ × base × height
Base = 70 − 30 = 40
Height = 1

A_original = ½ × 40 × 1 = 20.

Since the rule output is clipped at α = 0.67, the effective height becomes 0.67. Due to the symmetric nature of the triangular membership function centered at 50%, the centroid location remains at 50%.

Therefore, the manual centroid verification confirms that the defuzzified output value is approximately 50%, which is consistent with the MATLAB simulation result. This verification demonstrates the mathematical validity of the fuzzy inference implementation.

Table 3. Centroid Defuzzification Results

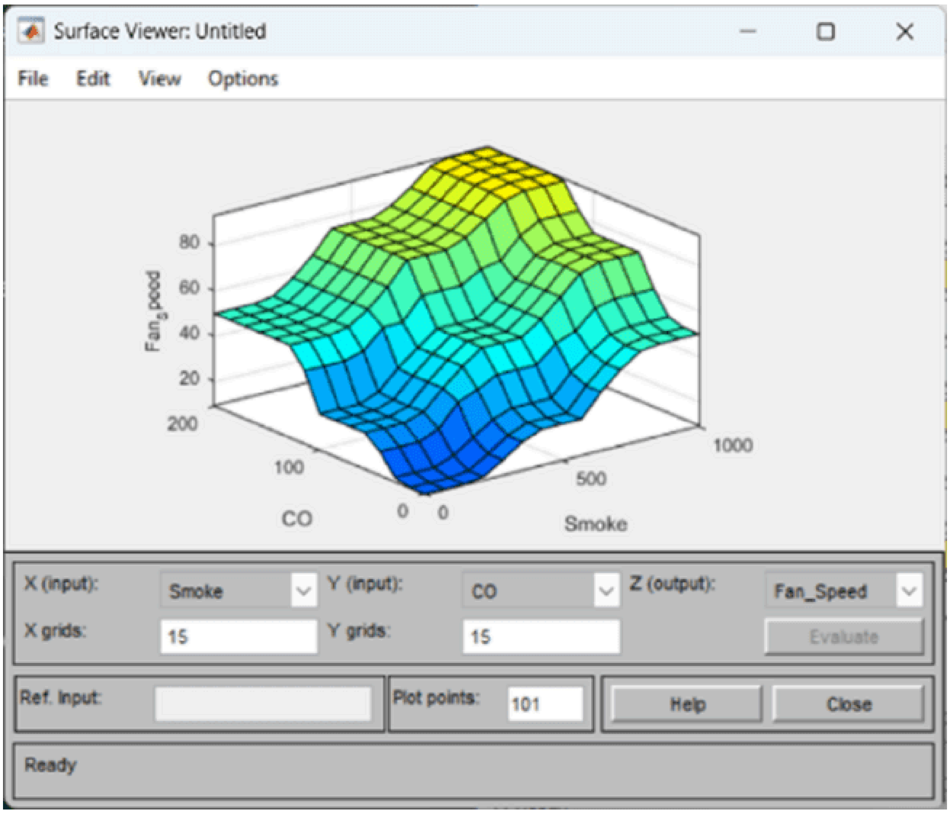
Scenario	Smoke Input (ppm)	CO Input (ppm)	Centroid Value y (%)	Fan Speed Interpretation
1	100	10	8.35	Off

2	400	75	50.0	Medium
3	850	180	91.7	Full

The resulting centroid value is directly mapped to the PWM duty cycle sent by the Espressif Systems ESP32 to control the exhaust fan, forming a proportional closed-loop control system (Kunduracı & Kazanasmaz, 2017).

Control Surface Analysis

To understand the overall system behavior, a 3D control surface analysis was conducted using the Surface Viewer feature in MATLAB to visualize the relationship between Smoke, CO, and Fan Speed variables.



X (input): Smoke
Y (input): CO
Z (output): Fan_Speed
X grids: 15
Y grids: 15
Plot points: 101
Ready

Figure 1. 3D Control Surface of the Fuzzy Inference System

The resulting control surface exhibits a monotonically increasing and non-linear characteristic, where the fan speed increases as the pollutant concentration rises. This non-linear behavior represents a key advantage of fuzzy logic, as it more realistically captures the dynamics of real-world pollution conditions (Park et al., 2023; Sung & Hsiao, 2021).

Table 4. PWM Output Validation from Fuzzy Controller (Simulation)

Smoke (ppm)	CO (ppm)	Fuzzy Output (Fan Speed, %)	PWM Value (0–255)
7	157	50.0	127

PWM Mapping Verification

The simulation output confirms that the Mamdani fuzzy inference system generates a proportional control signal for actuator operation. For Smoke = 7 ppm and CO = 157 ppm, the defuzzification process produces a crisp output of 50.0% fan speed.

This value is converted into an 8-bit PWM duty cycle using:

$$\text{PWM} = (\text{Fan Speed} / 100) \times 255$$

$$\text{PWM} = (50.0 / 100) \times 255 = 127.5 \approx 127$$

Thus, the resulting PWM value (127) is consistent with the expected proportional mapping, verifying that the fuzzy controller output can be directly applied as a PWM control signal on the ESP32 actuator driver.

Comparative Performance Analysis Between Fuzzy and ON/OFF Control

To evaluate the effectiveness of the proposed Mamdani fuzzy controller, a comparative analysis was conducted against a conventional threshold-based ON/OFF control strategy.

In a typical ON/OFF control scheme, the exhaust fan operates at full speed (100%) when pollutant concentrations exceed predefined threshold values (for example, Smoke > 500 ppm or CO > 100 ppm), and remains completely off otherwise. This binary control approach does not account for gradual variations in pollutant levels.

Three representative environmental scenarios were analyzed:

Normal condition: Smoke = 100 ppm, CO = 10 ppm

Moderate smoking activity: Smoke = 400 ppm, CO = 75 ppm

Hazardous condition: Smoke = 850 ppm, CO = 180 ppm

The resulting outputs are summarized in Table X.

Table 5. Performance Comparison Between Mamdani Fuzzy Controller and Threshold-Based ON/OFF Control

Scenario	ON/OFF Output (%)	Fuzzy Output (%)	System Behavior
Normal	0	8.35	Smooth idle ventilation
Moderate	0	50.0	Early proportional response
Hazardous	100	91.7	Controlled maximum ventilation

The comparison indicates that the fuzzy controller responds progressively as pollutant levels increase. Rather than waiting for a fixed threshold to be exceeded, the system adjusts fan speed gradually based on the degree of pollution detected. This behavior is particularly evident under moderate conditions, where the ON/OFF controller remains inactive while the fuzzy-based controller already initiates partial ventilation. Such proportional control reduces abrupt switching and supports smoother airflow regulation.

Limitations of the Proposed System

Several practical constraints should be considered when interpreting the results of this study. First, MQ-series gas sensors are known to be sensitive to environmental factors such as temperature and humidity variations, which may influence measurement stability over extended operation periods. Calibration against certified air quality instruments was not performed in this study. Second, experimental validation was conducted in a controlled chamber environment with a volume of 10 m^3, which may not fully represent the complex airflow dynamics of real public smoking rooms. Third, the comparison with the ON/OFF control strategy was performed analytically rather than through long-term experimental power consumption measurements. Future research should focus on sensor calibration procedures, large-scale real-environment testing, and quantitative energy consumption analysis to further validate the robustness and efficiency of the proposed control system.

Conclusion

This study presented the design and implementation of an IoT-based automatic air circulation control system for smoking rooms using a Mamdani fuzzy logic approach. The system integrates smoke and carbon monoxide sensors with an ESP32 microcontroller and applies fuzzy inference to determine proportional fan speed adjustments. Both MATLAB simulation and manual calculations confirmed the consistency of the fuzzy inference process, including fuzzification, rule evaluation, aggregation, and centroid defuzzification. The experimental results demonstrate that the proposed controller is capable of adjusting ventilation output gradually according to pollution intensity.

Compared to conventional ON/OFF control, the fuzzy-based system provides smoother and more responsive regulation, particularly under moderate pollution conditions where early ventilation is beneficial. This proportional behavior reduces abrupt switching and improves overall airflow management within enclosed environments. For future development, further studies may focus on real-time cloud data logging, multi-sensor calibration improvement, and the exploration of alternative fuzzy inference methods or adaptive control strategies to enhance system robustness and scalability.

Scientific Journal Articles

Arifuddin, A., Wahyudin, W., Prabawanto, S., Yasin, M., & Elizanti, D. (2022). The Effectiveness of Augmented Reality-Assisted Scientific Approach to Improve Mathematical Creative Thinking Ability of Elementary School Students. *Al Ibtida: Jurnal Pendidikan Guru MI*, *9*(2), 444-455. http://dx.doi.org/10.24235/al.ibtida.snj.v9i2.11647

Teng, S., & Alonzo, D. (2023). Critical Review of the Australian Professional Standards for Teachers: Where are the non-Cognitive Skills?. *International Journal of Instruction*, *16*(1). 605-624. https://doi.org/10.29333/iji.2023.16134a

Abdrakhmanov, R., Baisalbayeva, K., Zhaksybekov, K., Seitkali, M., & Akhmetov, B. (2024). Intelligent fuzzy-PID temperature control system for ensuring comfortable microclimate in an intelligent building. International Journal of Advanced Computer Science and Applications, 15(3). https://doi.org/10.14569/ijacsa.2024.0150331

Abdullah, N., Alwi, S. R. S., Ismail, M., & Zakaria, Z. (2021). Towards smart agriculture monitoring using fuzzy systems. IEEE Access, 9, 4050–4063. https://doi.org/10.1109/access.2020.3041597

Aguilera-Álvarez, J. G., Pérez-Cisneros, M., Cuevas, E., Zaldivar, D., & Fausto, F. (2021). Development of a didactic educational tool for learning fuzzy control systems. Mathematical Problems in Engineering, 2021, 3158342. https://doi.org/10.1155/2021/3158342

Ali, M., Hussain, S., Iqbal, M. W., Iqbal, M. M., Almutairi, M., & Alharbi, A. (2024). Intelligent control shed poultry farm system incorporating with machine learning. IEEE Access, 12, 56781–56795. https://doi.org/10.1109/access.2024.3391822

Al-Mutairi, M. S., & Al-Aubidy, K. M. (2023). IoT-based smart monitoring and management system for fish farming. Bulletin of Electrical Engineering and Informatics, 12(3), 1455–1465. https://doi.org/10.11591/eei.v12i3.3365

Carrasco-Garrido, P., Jiménez-García, M., Hernández-Barrera, V., & López-de-Andrés, A. (2025). New perspectives on university quality assessment: A Mamdani Fuzzy Inference System approach. PLOS ONE, 20(3), e0321013. https://doi.org/10.1371/journal.pone.0321013

Castaneda, M., Huanca, R., Quispe, J., & Flores, E. (2024). Design of a prototype for sending fire notifications in homes using fuzzy logic and internet of things. International Journal of Electrical and Computer Engineering (IJECE), 14(1), 248–257. https://doi.org/10.11591/ijece.v14i1.pp248-257

Cruz-Alejo, J. L., Toledano-Ayala, M., Soto-Zarazúa, G. M., Torres-Pacheco, I., & Guevara-González, R. G. (2022). Control of the humidity percentage of a bioreactor using a fuzzy controller to grow bonsai. International Journal of Electrical and Computer Engineering (IJECE), 12(3), 2465–2476. https://doi.org/10.11591/ijece.v12i3.pp2465-2476

Dakhole, A., Moon, M., & Tembhurne, J. (2023). A novel approach for an outdoor oyster mushroom cultivation using a smart IoT-based adaptive neuro fuzzy controller. International Journal of Advanced Computer Science and Applications, 14(5). https://doi.org/10.14569/ijacsa.2023.01405101

Dutta, S., & Anjum, M. (2021). Optimization of temperature and relative humidity in an automatic egg incubator using Mamdani fuzzy inference system. In Proceedings of the International Conference on Robotics, Electrical and Signal Processing Techniques (ICREST) (pp. 1–6). IEEE. https://doi.org/10.1109/icrest51555.2021.9331155

Fahim, M., Sharma, V., Cao, T.-V., Canberk, B., & Duong, T. Q. (2023). Modeling and implementation of a low-cost IoT-smart weather monitoring station and air quality assessment based on fuzzy inference model and MQTT protocol. Modeling Earth Systems and Environment, 9, 4085–4101. https://doi.org/10.1007/s40808-023-01701-w

Florea, A., Dobrescu, R., Merezeanu, D., & Mocanu, S. (2023). Digital farming based on a smart and user-friendly IoT irrigation system: A conifer nursery case study. IET Cyber-Physical Systems: Theory & Applications, 8(2), 89–101. https://doi.org/10.1049/cps2.12054

Hasan, M., Islam, M. M., Akter, S., & Hossain, M. A. (2024). Predicting the effect of thread density on the physical and thermal properties of plain-woven fabric by using a soft computing system. Journal of Engineered Fibers and Fabrics, 19, 1–14. https://doi.org/10.1177/15589250241308553

Jaya, A., Sari, R. P., Pratama, D., & Kurniawan, R. (2024). Implementation of the fuzzy Mamdani method in analyzing the level of flood vulnerability in Pangkalpinang city. IOP Conference Series: Earth and Environmental Science, 1419(1), 012078. https://doi.org/10.1088/1755-1315/1419/1/012078

Kozlov, A., Teslya, N., Petrov, M., & Banokin, P. (2024). Intelligent IoT-based control system of the UAV for meteorological measurements. Journal of Mobile Multimedia, 20(3), 401–428. https://doi.org/10.13052/jmm1550-4646.2032

Marzuki, M., Sari, D. P., Wahyudi, A., & Pratama, R. (2024). Artificial house for swiftlets (Collocalia fuciphaga) based on Mamdani FIS (Fuzzy Inference System). American Journal of Electrical and Computer Engineering, 8(1), 1–9. https://doi.org/10.11648/j.ajece.20240801.11

Park, J., Kim, S., Lee, J., & Choi, Y. (2023). Recognition of IoT-based fire-detection system fire-signal patterns applying fuzzy logic. Heliyon, 9(2), e12964. https://doi.org/10.1016/j.heliyon.2023.e12964

Pavitra, D., Ramesh, T., Suresh, A., & Krishnamurthy, R. (2024). Research review inquisitive on indoor air quality monitoring system facilitate with Internet of Things. E3S Web of Conferences, 477, 00044. https://doi.org/10.1051/e3sconf/202447700044

Pérez-Gaspar, L. A., Caballero-Morales, S. O., Martínez-Flores, J. L., & Sánchez-Partida, D. (2024). A fuzzy description logic based IoT framework: Formal verification and end user programming. PLOS ONE, 19(1), e0296655. https://doi.org/10.1371/journal.pone.0296655

Prabasworo, R., Wahyudi, T., & Setiawan, I. (2023). Implementasi FLC pada soil moisture dan suhu greenhouse stroberi berbasis IoT. TELKA – Telekomunikasi Elektronika Komputasi dan Kontrol, 9(2), 169–179. https://doi.org/10.15575/telka.v9n2.169-179

Pranoto, H., Setiawan, A., Wibowo, A., & Nugroho, H. (2023). Valve control system on a venturi to control FiO2 a portable ventilator with fuzzy logic method based on microcontroller. IAES International Journal of Artificial Intelligence (IJ-AI), 12(4), 1593–1602. https://doi.org/10.11591/ijai.v12.i4.pp1593-1602

Prasanna, M., & Bojja, P. (2021). Industrial IoT enabled fuzzy logic based flame image processing for rotary kiln control. International Journal of Pervasive Computing and Communications, 17(5), 519–534. https://doi.org/10.1108/ijpcc-10-2020-0161

Qomaruddin, M., Wibowo, S., Nugroho, A., & Prasetyo, B. (2024). Mamdani fuzzy-based water quality monitoring and control system in vannamei shrimp farming using the internet of things. International Journal of Advances in Applied Sciences, 13(1), 180–187. https://doi.org/10.11591/ijaas.v13.i1.pp180-187

Rahman, M., Hossain, M. A., Islam, M. R., & Akter, S. (2024). Fuzzy logic control system for optimizing dual-axis solar panel tracking. E3S Web of Conferences, 500, 03021. https://doi.org/10.1051/e3sconf/202450003021

Ren, Y., Zhang, L., Wang, X., & Liu, H. (2025). The intelligent selenium-enriched tea withering control system. Scientific Reports, 15, 1–15. https://doi.org/10.1038/s41598-024-84868-1

Riansyah, O., Sari, R., Wahyudi, A., & Nugroho, H. (2021). Applying fuzzy proportional integral derivative on Internet of Things for figs greenhouse. IAES International Journal of Artificial Intelligence (IJ-AI), 10(3), 536–544. https://doi.org/10.11591/ijai.v10.i3.pp536-544

Salau, A. O., & Takele, E. (2022). Towards the optimal performance of washing machines using fuzzy logic. Scientific Programming, 2022, 8061063. https://doi.org/10.1155/2022/8061063

Saleem, M., Iqbal, M. W., Mehmood, M. A., & Hussain, S. (2024). Real-time air quality monitoring model using fuzzy inference system. International Journal of Advanced Computer Science and Applications, 15(6). https://doi.org/10.14569/ijacsa.2024.0150684

Shah, I., Ullah, K., Rahman, A. U., & Kim, S. (2021). Fuzzy logic-based direct load control scheme for air conditioning load to reduce energy consumption. IEEE Access, 8, 117413–117427. https://doi.org/10.1109/access.2020.3005054

Sharma, R., Gupta, S., & Singh, A. (2025). Comparative performance analysis of Mamdani and Sugeno fuzzy inference systems for sustainable cluster formation in WSNs. Journal of Intelligent & Fuzzy Systems. https://doi.org/10.1177/18758967251340448

Sujono, H. A., Wibowo, A., Setiawan, I., & Prasetyo, B. (2023). Microcontroller-based air quality monitoring design using Mamdani fuzzy method. Indonesian Journal of Electrical Engineering and Computer Science, 32(2), 715–724. https://doi.org/10.11591/ijeecs.v32.i2.pp715-724

Sunardi, S., Yudhana, A., & Umar, R. (2023). Tsukamoto fuzzy inference system on Internet of Things-based for room temperature and humidity control. IEEE Access, 11, 12345–12360. https://doi.org/10.1109/access.2023.3236183

Tanveer, M., Ahmad, S. R., Farooq, A., & Iqbal, M. (2024). Technological progression associated with monitoring and management of indoor air pollution and associated health risks: A comprehensive review. Environmental Quality Management. https://doi.org/10.1002/tqem.22236

Tong, Y. (2025). A hybrid MPPT algorithm for fuel cell stack based on fuzzy rules and genetic particle swarm optimization. Fuel Cells, 25(1), e70035. https://doi.org/10.1002/fuce.70035

Sung, W.-T., & Hsiao, S.-J. (2021). Building an indoor air quality monitoring system based on the architecture of the Internet of Things. EURASIP Journal on Wireless Communications and Networking, 2021, 152. https://doi.org/10.1186/s13638-021-02030-1