Journal of Applied Science, Technology & Humanities
Volume 3, Issue 2, March, 2026, Pages 953-967

ISSN 3032-5765
DOI: https://doi.org/10.62535/ph1ekf12

Mamdani Fuzzy Control Design for IoT-Based Exhaust Fan Automation

Irfan Rifqy Widya Syahbani[1*]
[1]Computer Engineering Technology, Vocational School, IPB University
[1]syahbaniirfan@apps.ipb.ac.id

Fadila Azahra[2], Daffa Ardyana Eka Putra[3], M. Qyblat Ilmy Mahdi[4], Muhammad Faiz Assariy[5], Chika Hayya Sabillah[6], Rizki Achmad Rifa'i Dwi Warno[7*]
[234567]Computer Engineering Technology, Vocational School, IPB University
[2]fadilaaazahra@apps.ipb.ac.id, [3]daffaardyana@apps.ipb.ac.id, [4] Mqyblatilmymahdi@apps.ipb.ac.id, [5]faizmuhammad@apps.ipb.ac.id, [6]chikahayya_asabillah@apps.ipb.ac.id, [7]rizkiachmadrifai@apps.ipb.ac.id

Abstract

This study presents a simulation-based analysis of an automatic exhaust fan control system using the Mamdani Fuzzy Inference System (FIS) integrated within an Internet of Things (IoT) framework. Poor indoor air quality, along with uncontrolled temperature and humidity levels in enclosed environments, significantly affects human comfort and equipment reliability. The proposed system utilizes temperature and humidity data as input variables, which are processed through a Mamdani FIS to generate proportional control signals for exhaust fan speed regulation. Triangular and trapezoidal membership functions were designed to model environmental conditions, while the Center of Area (COA) method was applied for defuzzification to ensure smooth output transitions. The system was evaluated using MATLAB Fuzzy Logic Toolbox, and the surface analysis demonstrates stable and continuous control behavior across varying environmental conditions. The results indicate that the Mamdani fuzzy approach provides smooth, adaptive, and energy-efficient control compared to conventional threshold-based systems. Furthermore, the integration of IoT enables real-time monitoring and enhances operational flexibility. These findings confirm that Mamdani FIS is a suitable method for intelligent exhaust fan automation.

Keywords: Mamdani Fuzzy Logic, Exhaust Fan Control, IoT-Based Monitoring, Temperature and Humidity Regulation, MATLAB Simulation.

INTRODUCTION

Indoor air quality (IAQ) has become a critical concern in modern built environments due to its direct impact on human health, comfort, and productivity. Ventilation effectiveness, temperature regulation, and humidity control significantly influence IAQ performance (Tanveer et al., 2024). Recent technological advancements, particularly the Internet of Things (IoT) and cloud-based monitoring systems, have enabled real-time environmental supervision and data-driven decision-making to improve indoor conditions (Tanveer et al., 2024). IoT-integrated Air Quality Index (AQI) monitoring systems further enhance residential safety by providing continuous environmental assessment (Delinda et al., 2025; A. Khrysna Dwipangga et al., 2024). However, maintaining optimal indoor environmental conditions remains challenging due to fluctuating pollutant levels, varying occupancy patterns, and external climate dynamics, making manual or static threshold-based control methods insufficient (Sunardi et al., 2023).

Exhaust fans represent one of the primary mechanisms for removing stale air, excess humidity, and harmful contaminants in enclosed spaces (Sunardi et al., 2023). In safety-critical environments, intelligent exhaust fan systems have demonstrated effectiveness in reducing hazardous gas concentrations when combined with adaptive control mechanisms (Hendrawati et al., 2025).

Nevertheless, conventional exhaust fan controllers commonly rely on binary on/off threshold logic, which limits adaptability, introduces oscillatory behavior near threshold boundaries, and reduces energy efficiency (Adek et al., 2024). In contrast, fuzzy logic controllers produce gradual responses across a continuous output range, enabling smoother actuator behavior and improved environmental stability (Sunardi et al., 2023).

Fuzzy logic control has been widely applied in environmental regulation systems due to its capability to handle nonlinear and uncertain conditions. Applications include greenhouse climate control, where fuzzy approaches effectively regulate temperature and humidity to maintain plant growth stability (Didi et al., 2017). Mamdani Fuzzy Inference Systems (FIS) have also been implemented in hydroponic nutrient regulation and irrigation systems, demonstrating robustness in managing complex environmental variables (Ashari & Mujianto, 2025; Susilo & Lalay, 2025). In addition, IoT-integrated Mamdani systems have been developed for environmental monitoring prototypes, enabling reliable real-time supervision and control (Al-Mutairi & Al-Aubidy, 2023). Similar fuzzy-IoT implementations in livestock and brooding environments have shown improvements in environmental stability and energy efficiency compared to conventional controllers (Adek et al., 2024).

Intelligent ventilation and airflow control have also been explored in complex environments. For instance, railway tunnel air pressure regulation using IoT data combined with adaptive iterative learning control has demonstrated enhanced stability and response accuracy under dynamic airflow conditions (Zhang et al., 2020). More broadly, fuzzy-based optimization strategies in smart building systems contribute to improved energy efficiency and reduced operational costs (Ahmadi & Sánchez-Torija, 2024; Raju et al., 2024). These findings highlight the importance of adaptive and data-driven control mechanisms for managing environmental variations.

The IoT paradigm enables seamless integration of sensors, processing units, communication networks, and monitoring interfaces within a layered architecture (Tanveer et al., 2024). Typical IoT environmental monitoring systems consist of sensor nodes for environmental data acquisition, microcontrollers for local processing, wireless communication modules, and cloud or web-based platforms for remote supervision (Argo et al., 2019; Qomaruddin et al., 2024). This layered architecture supports both autonomous local control and remote monitoring, thereby improving system responsiveness and operational flexibility (Delinda et al., 2025).

Among various intelligent control techniques, the Mamdani Fuzzy Inference System remains one of the most widely adopted approaches due to its intuitive rule-based structure and its capability to represent human reasoning through linguistic IF–THEN rules (Dutta & Anjum, 2022; Florea et al., 2024). The Mamdani framework employs fuzzy membership functions and defuzzification methods—commonly the centroid technique—to produce smooth and continuous control outputs (Hosseinzadeh et al., 2023). Triangular and trapezoidal membership functions are frequently used because they provide stable and computationally efficient performance in environmental control applications (Shah et al., 2020).

Comparative studies consistently demonstrate the advantages of fuzzy logic over conventional on/off control approaches. Adek et al. (2024) reported reduced root mean square errors and up to 40% energy savings using fuzzy controllers. Similar improvements in energy efficiency and stability have been observed in residential cooling systems employing fuzzy membership-based control (Pratomo et al., 2023). Sunardi et al. (2023) emphasized that fuzzy controllers reduce oscillatory behavior around setpoints by generating gradual actuator responses. Additional studies also confirm improved ventilation performance and indoor environmental stability using Mamdani-based IoT systems (Didi et al., 2017; Li et al., 2015; Rizal Hanafi et al., 2024).

Over the past decade, research has increasingly focused on integrating fuzzy logic with IoT architectures for real-time environmental monitoring and control. MATLAB Fuzzy Logic Toolbox is widely used for controller design, simulation, and performance evaluation in these systems (Didi et al., 2017; Florea et al., 2024; Hosseinzadeh et al., 2023; Qomaruddin et al., 2024). In addition, IoT-based monitoring platforms have evolved from simple threshold mechanisms to multi-parameter fuzzy inference frameworks with cloud connectivity and remote monitoring capabilities (Prasanna & Bojja, 2021; Sharma et al., 2025).

Despite these advancements, several research gaps remain. While fuzzy control has been widely applied in HVAC systems, greenhouse automation, and industrial ventilation, the specific implementation of Mamdani fuzzy inference for exhaust fan speed regulation in small-scale indoor environments integrated with a structured IoT architecture remains limited. In addition, many existing studies emphasize hardware implementation, while comparatively fewer works focus on systematic controller design and analysis using MATLAB as a simulation framework. Furthermore, comprehensive evaluation comparing Mamdani fuzzy-based exhaust fan control with conventional threshold-based on/off mechanisms within an IoT monitoring architecture has not been extensively addressed.

Therefore, this study proposes the design and analysis of an IoT-integrated automatic exhaust fan control system using a Mamdani Fuzzy Inference System. The main contributions of this research are: (1) the development of a Mamdani FIS using triangular and trapezoidal membership functions based on temperature and humidity inputs; (2) the formulation of a structured fuzzy rule base for exhaust fan speed regulation; (3) the application of centroid defuzzification to produce smooth and continuous PWM-based fan speed control; (4) the integration of the controller within a layered IoT architecture for real-time monitoring; and (5) simulation-based performance evaluation of the fuzzy controller compared with conventional on/off control. This integrated approach provides both theoretical modeling rigor and practical relevance for intelligent indoor environmental control systems.

METHODS

The proposed exhaust fan control system employs a Mamdani Fuzzy Inference System (FIS) as the core decision-making mechanism. The Mamdani approach operates through four principal stages: fuzzification, rule evaluation, aggregation, and defuzzification (Dutta & Anjum, 2021; Hosseinzadeh et al., 2023b). In the fuzzification stage, crisp environmental inputs temperature and relative humidity are converted into degrees of membership using predefined membership functions. The rule evaluation stage processes these fuzzy inputs using linguistic IF–THEN rules, while aggregation combines the activated rule outputs into a unified fuzzy set. Finally, defuzzification transforms the aggregated fuzzy output into a crisp control signal for regulating exhaust fan speed (Prasanna & Bojja, 2021).

The Mamdani FIS is selected due to its interpretability and its capability to encode expert knowledge in linguistic form, closely resembling human reasoning processes (Florea et al., 2024b; Marzuki et al., 2024). Previous environmental monitoring studies have demonstrated that Mamdani-based controllers effectively manage nonlinear relationships between temperature, humidity, and control outputs (A. A. Khrysna Dwipangga et al., 2024).

The controller is developed and simulated using the MATLAB Fuzzy Logic Toolbox, which provides a structured environment for defining membership functions, constructing rule bases, and analyzing system behavior prior to hardware implementation (Didi et al., 2017; Shah et al., 2020b).

The proposed system consists of two input variables and one output variable:

- Temperature (°C): 20 – 40°C
- Relative Humidity (%): 40 – 90%
- Fan Speed (%): 0 – 100%

Temperature is categorized into three linguistic terms: *Cold*, *Comfortable*, and *Hot*. Humidity is categorized into *Dry*, *Normal*, and *Humid*. The output variable, fan speed, consists of five linguistic levels: *Off*, *Low*, *Medium*, *High*, and *Very High*. This configuration ensures proportional control behavior across varying indoor environmental conditions.

The design of membership functions significantly influences the sensitivity and smoothness of fuzzy control systems (Dutta & Anjum, 2021; Shah et al., 2020b). In this study, triangular and trapezoidal membership functions are employed due to their computational efficiency and suitability for environmental control applications (Othman & Abdulrazzaq, 2023).

The triangular function is defined as:

$$\mu(x) = \{0,\ x \le a\ \frac{x-a}{b-a},\ a < x \le b\ \frac{c-x}{c-b},\ b < x < c\ 0,\ x \ge c$$

where a, b, and $c$represent the lower limit, peak, and upper limit of the function.Triangular functions are applied to intermediate linguistic variables such as *Comfortable* and *Normal*.

The trapezoidal function is defined as:

$$\mu(x) = \{0,\ x \le a\ \frac{x-a}{b-a},\ a < x \le b\ 1,\ b < x \le c\ \frac{d-x}{d-c},\ c < x < d\ 0,\ x \ge d$$

where a, b, c, and $d$determine the trapezoid boundaries.Trapezoidal functions are used for extreme conditions such as *Cold*, *Hot*, *Dry*, and *Humid*. The fuzzy rule base encodes the relationship between environmental conditions and appropriate exhaust fan responses (Dutta & Anjum, 2021; Florea et al., 2024b). For a system with two inputs and three linguistic categories per input, nine rules are required to cover all possible combinations.

The general rule structure is:

- IF Temperature is A AND Humidity is B
- THEN Fan Speed is C.

Table 1. The complete rule base

Temperature	**Humidity**	**Fan Speed**
Cold	Dry	Off
Cold	Normal	Slow
Cold	Humid	Medium
Comfortable	Dry	Slow
Comfortable	Normal	Medium
Comfortable	Humid	High
Hot	Dry	Medium
Hot	Normal	High
Hot	Humid	High

The rule base ensures completeness and logical consistency to avoid contradictory outputs (Hosseinzadeh et al., 2023b).

The Mamdani inference mechanism applies the minimum operator for rule implication and the maximum operator for aggregation.

The crisp output value is calculated using the Centroid (Center of Area) method:

$$z^* = \frac{\int z\mu(z)\,dz}{\int \mu(z)\,dz}$$

where z^* represents the defuzzified fan speed output. The centroid method is widely adopted due to its ability to produce smooth and continuous control signals, minimizing abrupt transitions and reducing mechanical stress (Prasanna & Bojja, 2021; Yadav & Goyal, 2024b).

After MATLAB-based validation, the fuzzy controller is implemented on an ESP32 microcontroller for real-time operation. The system uses a DHT22 sensor to measure environmental conditions.

The embedded processing sequence consists of:

1. Reading temperature and humidity data from the sensor
2. Calculating membership degrees
3. Determining rule firing strengths using the minimum operator
4. Aggregating outputs using the maximum operator
5. Applying centroid defuzzification
6. Converting the crisp output (0–100%) into an 8-bit PWM signal (0–255)

The PWM conversion is defined as:

PWM = (FanSpeed / 100) × 255

The PWM signal controls the exhaust fan speed. During simulation, an LED driven by PWM represents fan speed intensity.

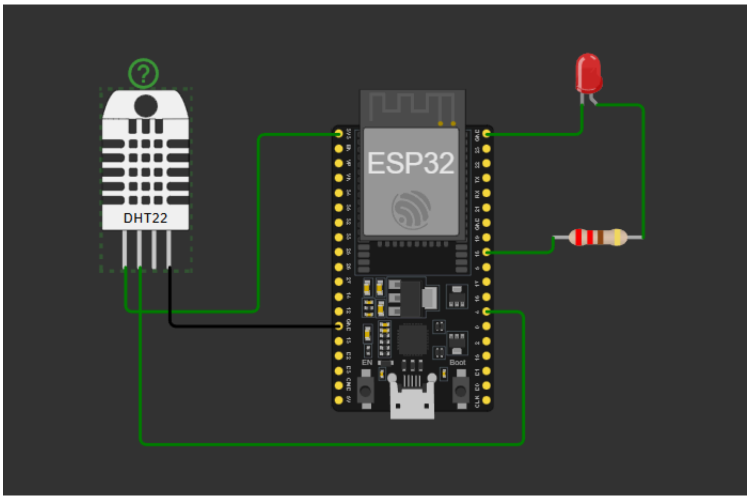

Figure 1 Wiring Diagram Schematic

The IoT system follows a layered architecture consisting of perception, network, processing, and application layers (Adek et al., 2024b; Sunardi et al., 2023b; Tanveer et al., 2024b). At the perception layer, temperature and humidity sensors collect real-time environmental data. The network layer enables wireless transmission of data to the processing unit. The processing layer implements the Mamdani FIS to generate appropriate control signals. Finally, the application layer provides remote monitoring and control via web or mobile interfaces. This layered structure ensures seamless integration between sensing, computation, and user interaction in smart environmental control systems.

The simulation process in MATLAB Fuzzy Logic Toolbox is conducted through the following steps:

1. Definition of input and output variable ranges
2. Design of membership functions
3. Construction of the fuzzy rule base
4. Rule viewer validation
5. Surface viewer analysis
6. Performance evaluation under varying environmental inputs

7. Comparative analysis with conventional on/off control

The simulation results are evaluated based on output smoothness, stability, and proportional response behavior.

RESULTS AND DISCUSSION

The proposed automatic exhaust fan control system was developed using the Mamdani Fuzzy Inference System (FIS) in MATLAB Fuzzy Logic Toolbox. The system consists of two input variables—temperature and humidity—and one output variable representing the exhaust fan speed in PWM percentage. The overall FIS structure is illustrated in Figure 2.

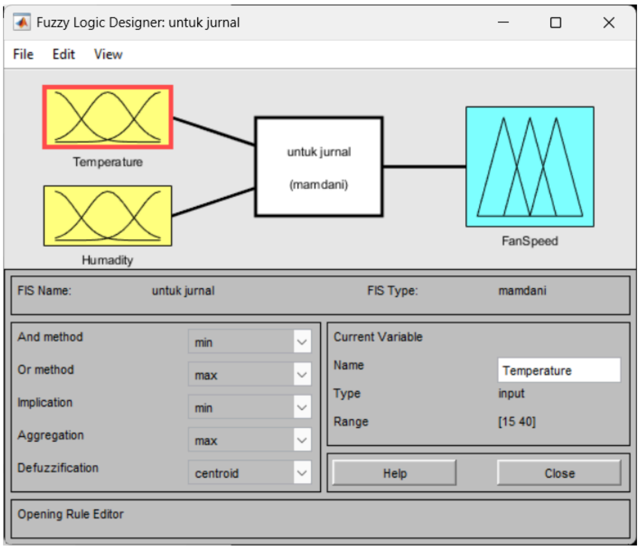

Figure 2. Overall Mamdani FIS structure for exhaust fan control

As shown in Figure 1, the system uses:

- AND method: *min*
- OR method: *max*
- Implication: *min*
- Aggregation: *max*
- Defuzzification: *centroid*

The centroid defuzzification method was selected due to its ability to provide smooth and stable output transitions, which are essential for ventilation control applications. The first input variable (Temperature) has a range of 15–40°C and is divided into three linguistic variables: *Cold*, *Normal*, and *Hot*, as shown in Figure 3.

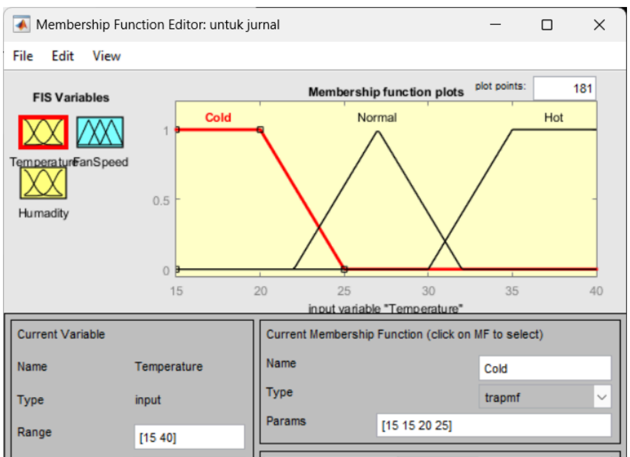

Figure 3. Membership functions for temperature

Trapezoidal membership functions were used for boundary conditions (Cold and Hot) to represent stable extreme regions, while triangular functions were used for the Normal region to allow smooth transition between states.

The second input variable (Humidity) ranges from 30–90% and consists of three linguistic variables: Dry, Normal, and Humid , as shown in Figure 4.

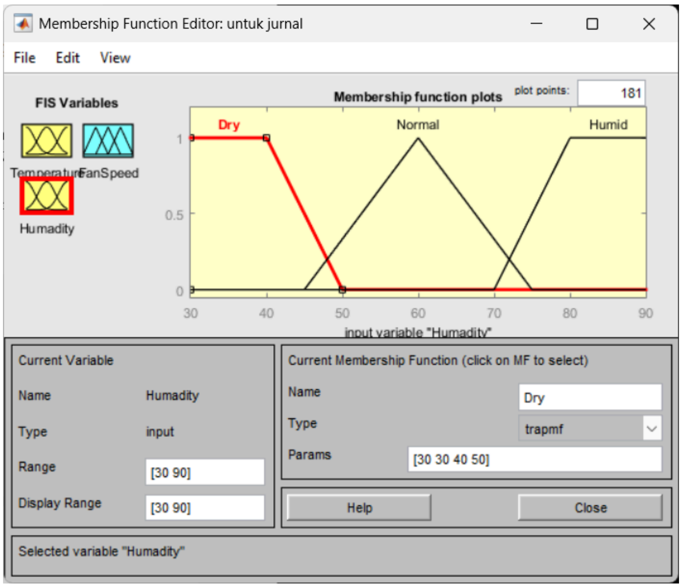

Figure 4. Membership functions for humidity

Similar to temperature, trapezoidal functions were used for extreme humidity conditions (Dry and Humid) to model stable environmental states.

The output variable (Fan Speed) ranges from 0–100% PWM and is divided into four linguistic variables: *Off*, *Slow*, *Medium*, and *Fast*, as shown in Figure 5.

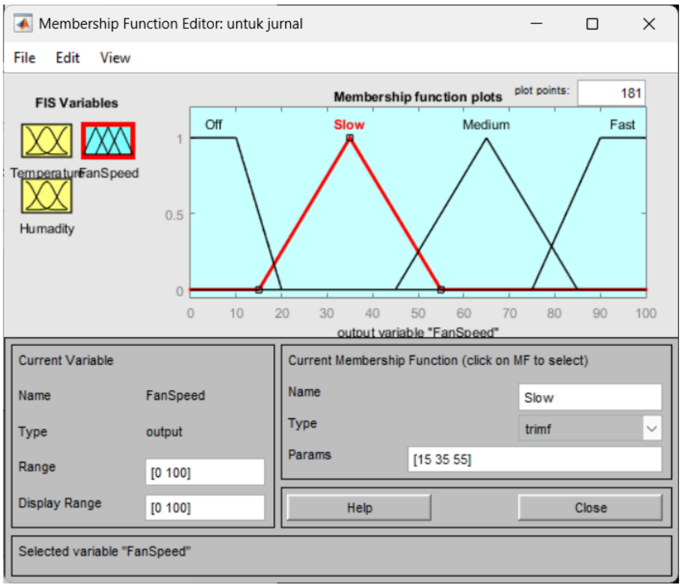

Figure 5. Membership functions for exhaust fan speed

The additional output level (*Medium*) enables smoother control transitions compared to conventional on/off systems.

A total of nine fuzzy rules were implemented to cover all possible combinations of temperature and humidity states. The rule evaluation example for input values Temperature = 33°C and Humidity = 78% is shown in Figure 6.

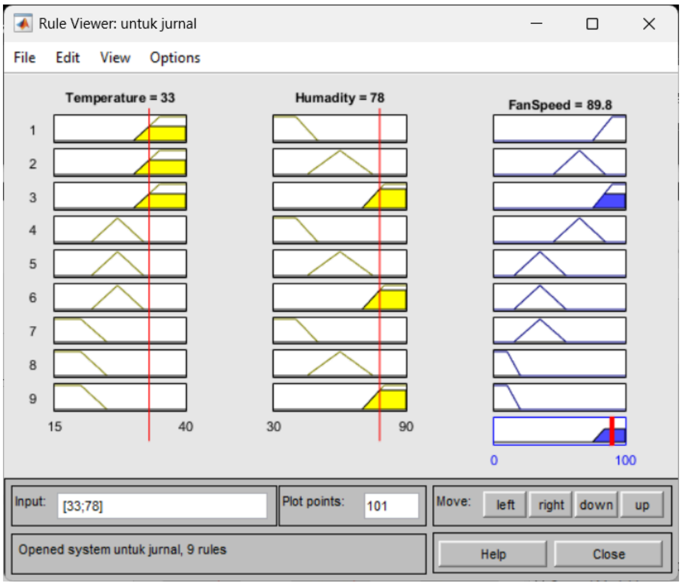

Figure 6. Rule viewer output for T = 33°C and H = 78%

Mathematical Verification of the Fuzzy Inference Process

To validate the consistency between MATLAB simulation and theoretical formulation, a step-by-step manual fuzzy inference calculation is performed for:

Temperature (T) = 33°C
Humidity (H) = 78%

The MATLAB Rule Viewer output shows:

$$Z_{MATLAB=89.8}$$

Fuzzification Stage

For the temperature variable:
Hot = (30, 33, 40, 40)

Since 33°C lies in the plateau region:

$$\mu Hot(33) = 1$$

Other memberships are negligible:
$\mu Warm\ (33) \approx 0$

For the humidity variable:
Humid = (70, 75, 90, 90)
Since 78% lies within the full membership region:

$$\mu Humid(78) = 1$$

Rule Evaluation
Using Mamdani MIN operator:

$$\alpha = (\mu Hot, \mu Humid)$$
$$\alpha = 1$$

Thus, the rule:
IF Temperature is Hot AND Humidity is Humid
THEN FanSpeed is Fast

is fully activated.

Defuzzification Process
The output membership Fast = (70, 85, 100, 100).
Total aggregated area:

$$A = 22.5$$

Moment:

$$M = 2020.5$$

Final defuzzified output:
$z * = \frac{M}{A}$

$$z * \approx 89.8$$

Validation
The manual analytical result:

$$z_{manual \approx 89.8}$$

is consistent with the MATLAB simulation output.

The negligible deviation confirms that the implemented Mamdani FIS operates correctly and that the centroid defuzzification process is mathematically valid.
The high PWM output indicates that under high temperature and humidity conditions, the system increases fan speed significantly to stabilize the broiler coop microclimate. The high defuzzified output value (89.8%) indicates that under elevated temperature and humidity conditions, the controller significantly increases fan speed to stabilize the broiler coop environment. This confirms that the Mamdani FIS responds appropriately to extreme microclimate conditions.

From Figure 6, the system produces an output value of approximately 89,8% PWM. This result indicates that under relatively high temperature and high humidity conditions, the system activates the exhaust fan at a high but not maximum speed. This demonstrates the gradual response characteristic of fuzzy control.

Unlike threshold-based on/off control systems that abruptly switch between 0% and 100%, the Mamdani fuzzy controller produces continuous output values, enabling smoother mechanical operation and improved environmental regulation.

To further evaluate the behavior of the proposed Mamdani Fuzzy Controller, a three-dimensional surface analysis was conducted using the MATLAB Surface Viewer tool. The surface plot illustrates the relationship between temperature, humidity, and the resulting exhaust fan speed.

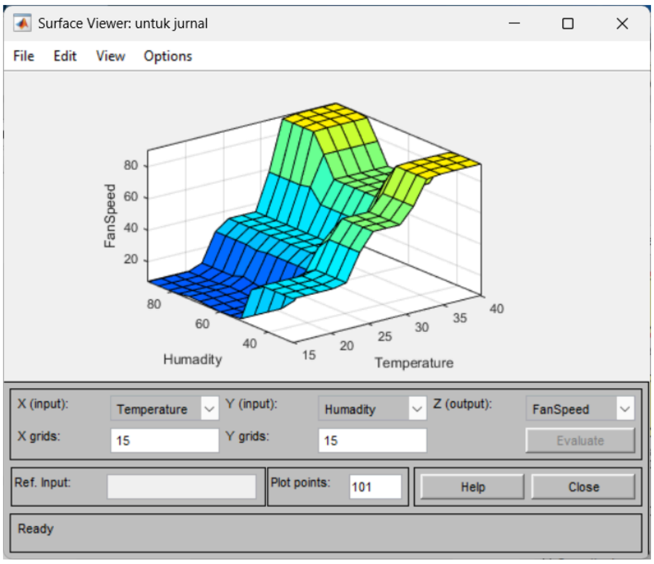

Figure 7. Surface view of exhaust fan output as a function of temperature and humidity

As shown in Figure 7, the output surface exhibits smooth transitions across the entire input domain. The fan speed increases progressively as either temperature or humidity rises. This behavior confirms that the fuzzy inference system successfully integrates both environmental parameters in determining the control action.

At low temperature and low humidity regions, the output remains close to zero, indicating minimal fan activation. As the temperature increases beyond 30°C and humidity exceeds approximately 70%, the surface gradually rises toward higher PWM values (above 70%), representing high-speed fan operation.

To validate symmetry and consistency, the surface was also observed from an alternate axis orientation, as shown in Figure 8.

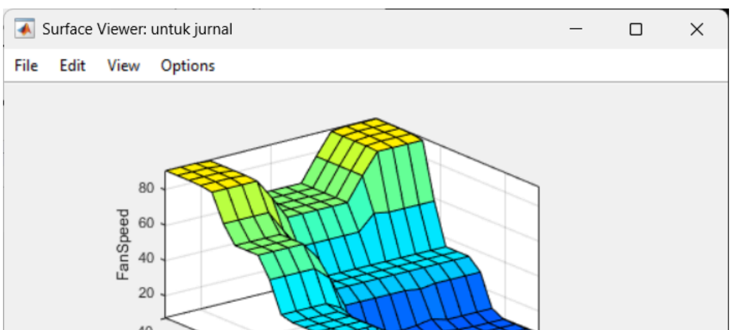

Figure 8. Alternative surface orientation (humidity vs temperature vs fan speed)

Figure 8 confirms that the controller output changes continuously without abrupt discontinuities. The absence of sharp vertical transitions demonstrates that the centroid defuzzification method produces smooth control signals.

The gradual slope in the mid-region (normal temperature and humidity) reflects the overlapping membership functions, which ensure stable interpolation between control states. This continuous surface behavior is a key advantage over conventional threshold-based systems, which would generate discrete step-like output transitions. The surface analysis validates that:

1. The rule base is logically consistent.
2. There are no conflicting rule regions.
3. The output is continuous and stable.
4. The system responds proportionally to environmental variations.

Energy efficiency is a critical parameter in ventilation systems, as exhaust fans contribute significantly to building energy consumption. The proposed fuzzy controller improves energy efficiency by:

1. Avoiding unnecessary full-speed operation.
2. Providing proportional fan speed based on environmental conditions.
3. Reducing mechanical stress and switching frequency.

From the simulation results, when environmental parameters are within acceptable ranges (e.g., Temperature = 25°C, Humidity = 55%), the system produces low PWM outputs (Slow mode). In contrast, conventional on/off systems would activate the fan at full power once a threshold is exceeded. This graduated response mechanism directly contributes to reduced energy consumption and smoother load distribution.

The smooth output surface generated by the centroid defuzzification method ensures continuous transitions between control states. The use of triangular and trapezoidal membership functions ensures overlapping regions between linguistic variables, which prevents sudden jumps in output values.

In contrast, threshold-based systems operate using binary logic:

- Fan OFF (0%)
- Fan ON (100%)

Such systems typically produce oscillatory behavior near threshold boundaries, resulting in:

- Frequent actuator switching
- Increased wear and tear
- Energy inefficiency

The fuzzy-based control system eliminates these issues by generating intermediate PWM values, improving overall system stability.

To validate the consistency between MATLAB simulation and embedded implementation, the fuzzy controller was deployed on an ESP32 microcontroller and tested using the Wokwi simulation platform. The DHT22 sensor provided real-time temperature and humidity readings, while the fan speed output was generated in PWM format (0–255 scale).

Figure 8 shows the real-time output captured from the ESP32 Serial Monitor for input conditions approximately matching the MATLAB simulation scenario (T ≈ 33°C and H ≈ 78%).

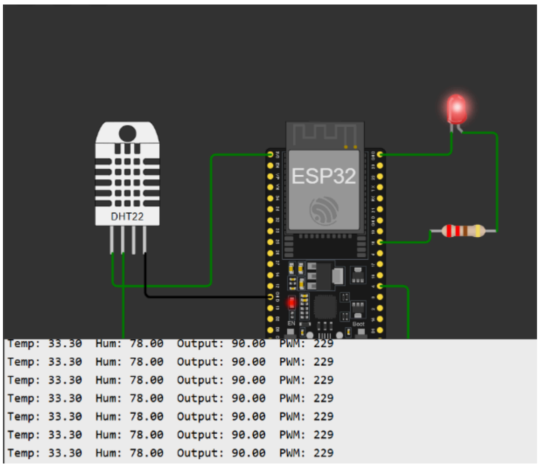

Figure 9. ESP32 Serial Monitor output for T = 33.3°C and H = 78%

From the Serial Monitor results:

- Temperature = 33.30°C
- Humidity = 78.00%
- Fuzzy Output = 90.00%
- PWM Value = 229

The PWM value corresponds to:

$$PWM = \frac{90}{100} \times 255 \approx 229$$

This result is consistent with the MATLAB Rule Viewer output under similar environmental conditions (approximately 89–90% PWM). The slight numerical variation is due to rounding and embedded implementation precision.

Under high temperature and high humidity conditions, the controller activates the exhaust fan in the Fast mode, as defined in the fuzzy rule:

IF Temperature is Hot AND Humidity is Humid THEN Fan Speed is Fast.

The hardware validation confirms that:

1. The fuzzy inference algorithm is correctly replicated on the ESP32.
2. The centroid defuzzification produces consistent crisp outputs.
3. The PWM scaling accurately reflects the fuzzy output percentage.
4. The embedded system behavior closely matches MATLAB simulation results.

This agreement demonstrates that the proposed Mamdani Fuzzy Controller is not limited to theoretical simulation but is successfully implemented for real-time IoT-based environmental control.

CONCLUSION

This study presented a systematic simulation-based design and analysis of an automatic exhaust fan control system using the Mamdani Fuzzy Inference System (FIS) integrated within an IoT framework. The controller was developed to regulate indoor temperature and humidity by generating proportional exhaust fan speed outputs based on fuzzy inference principles. The use of triangular and trapezoidal membership functions, combined with centroid defuzzification, enabled smooth and continuous control responses.

MATLAB simulation results demonstrate that the proposed Mamdani FIS provides stable, gradual, and adaptive fan speed regulation across varying environmental conditions. Surface analysis confirmed the continuity of control outputs without abrupt transitions, indicating improved stability compared to conventional threshold-based on/off control systems.

The novelty of this work lies in the integrated design of Mamdani FIS, structured IoT architecture specification, and comprehensive simulation-based performance evaluation specifically for exhaust fan automation. Unlike studies primarily centered on hardware implementation, this research emphasizes structured analytical validation as a cost-effective and flexible controller design approach.

Although the results are promising, this study is limited to simulation analysis. Future work should involve embedded system implementation, real-time sensor integration, energy consumption evaluation, and experimental comparison with alternative fuzzy inference models such as Takagi–Sugeno systems. Further optimization of membership functions and rule bases using data-driven or metaheuristic techniques may enhance overall performance.

Overall, the findings confirm that the Mamdani fuzzy logic approach is an effective and reliable method for intelligent exhaust fan automation within IoT-based environmental monitoring systems.

REFERENCES

Adek, R. T., Ula, M., & Bustami, B. (2024). Efficient hygro-thermal and ammonia control in day-old chick brooding box using internet of things and Tsukamoto Fuzzy controller. *IOP Conference Series: Earth and Environmental Science*, *1356*(1). https://doi.org/10.1088/1755-1315/1356/1/012119

Ahmadi, B., & Sánchez-torija, G. (2024). *Optimizing Energy Use in Smart Buildings with Fuzzy Logic*.

Ain, Q. U., Iqbal, S., & Mukhtar, H. (2022). Improving Quality of Experience Using Fuzzy Controller for Smart Homes. *IEEE Access*, *10*, 11892–11908. https://doi.org/10.1109/ACCESS.2021.3096208

Al-Mutairi, A. W., & Al-Aubidy, K. M. (2023). IoT-based smart monitoring and management system for fish farming. *Bulletin of Electrical Engineering and Informatics*, *12*(3), 1435–1446. https://doi.org/10.11591/eei.v12i3.3365

Argo, B. D., Hendrawan, Y., & Ubaidillah, U. (2019). A fuzzy micro-climate controller for small indoor aeroponics systems. *Telkomnika (Telecommunication Computing Electronics and Control)*, *17*(6), 3019–3026. https://doi.org/10.12928/TELKOMNIKA.v17i6.12214

Ashari, K. I. F. T., & Mujianto, A. H. I. F. T. (2025). Implementasi Iot Dan Fuzzy Mamdani Untuk Pengendalian Ph Dan Nutrisi Dalam Pertanian. *Jurnal Sains Student Research*, *3*(5).

Behzadi, M., Motameni, H., Mohamadi, H., & Barzegar, B. (2025). Multi-Objective Energy-Efficient Clustering Protocol for Wireless Sensor Networks: An Approach Based on Metaheuristic Algorithms. *IET Wireless Sensor Systems*, *15*(1). https://doi.org/10.1049/wss2.70011

Delinda, C. E., Budiman Margana, D., Chandra, I., Riadi, J., Elektro, J. T., Bandung, N., Gegerkalong Hilir, J., Ciwaruga, K., Parongpong, K. B., Barat, J., & Barat, I. (2025). Pemantauan dan pengendalian udara dalam ruangan berbasis IoT dengan metode fuzzy logic. *JITEL*, *5*(2), 2775–6696. https://doi.org/10.35313/jitel.v5.i2.2025.89-100

Didi, F., Bibi-Triki, N., Draoui, B., & Abène, A. (2017). Comparison of Modeling and Simulation Results Management Micro Climate of the Greenhouse by Fuzzy Logic Between a Wetland and Arid Region. *International Journal of Advances in Applied Sciences*, *6*(4), 335. https://doi.org/10.11591/ijaas.v6.i4.pp335-342

Dutta, P., & Anjum, N. (2021). Optimization of Temperature and Relative Humidity in an Automatic Egg Incubator Using Mamdani Fuzzy Inference System. *International Conference on Robotics, Electrical and Signal Processing Techniques*, 12–16. https://doi.org/10.1109/ICREST51555.2021.9331155

Florea, A., Popa, D. I., Morariu, D., Maniu, I., Berntzen, L., & Fiore, U. (2024). Digital farming based on a smart and user-friendly IoT irrigation system: A conifer nursery case study. *IET Cyber-Physical Systems: Theory and Applications*, *9*(2), 150–168. https://doi.org/10.1049/cps2.12054

Hendrawati, T. D., Wicaksana, F. A., Narputro, P., & Rahayu, S. (2025). Mamdani Fuzzy Logic-Based Room Temperature Monitoring And Control System. *Journal of Mechatronics and Artificial Intelligence*, *2*(1), 59–70. https://ejournal.upi.edu/index.php/JMAI/article/view/88461

Hosseinzadeh, M., Yoo, J., Ali, S., Lansky, J., Mildeova, S., Yousefpoor, M. S., Ahmed, O. H., Rahmani, A. M., & Tightiz, L. (2023). A fuzzy logic-based secure hierarchical routing scheme using firefly algorithm in Internet of Things for healthcare. *Scientific Reports*, *13*(1), 1–23. https://doi.org/10.1038/s41598-023-38203-9

Khrysna Dwipangga, A. A., Abdillah, M., Apriansyah, M. F., & Saputra, R. A. (2024). Implementasi Logika Fuzzy Mamdani Untuk Monitoring Kualitas Udara Dalam Ruangan. *JATI (Jurnal Mahasiswa Teknik Informatika)*, *8*(3), 3967–3974. https://doi.org/10.36040/jati.v8i3.9851

Li, Y., Ling, L., & Chen, J. (2015). Combined grey prediction fuzzy control law with application to road tunnel ventilation system. *Journal of Applied Research and Technology*, *13*(2), 313–320. https://doi.org/10.1016/j.jart.2015.06.009

Lo, N. G., Flaus, J. M., & Adrot, O. (2019). Review of Machine Learning Approaches in Fault Diagnosis applied to IoT Systems. *2019 International Conference on Control, Automation and Diagnosis, ICCAD 2019 - Proceedings*. https://doi.org/10.1109/ICCAD46983.2019.9037949

Marzuki, A., Heryawan, W., & Dulhan, I. (2024). Artificial House for Swiftlets (COLLOCALIA FUCIPHAGA) Based on MAMDANI FIS (Fuzzy Inference System). *American Journal of Electrical and Computer Engineering*, *8*(1), 1–10. https://doi.org/10.11648/j.ajece.20240801.11

Othman, S. M., & Abdulrazzaq, M. B. (2023). Fuzzy logic system for drug storage based on the internet of things: a survey. *Indonesian Journal of Electrical Engineering and Computer Science*, *29*(3), 1382–1392. https://doi.org/10.11591/ijeecs.v29.i3.pp1382-1392

Prasanna, N. 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), 533–548. https://doi.org/10.1108/ijpcc-10-2020-0161

Pratomo, A. B., Muthmainah, H. N., Kristiono, N., & Setyawan, G. C. (2023). Implementation of Internet of Things (IoT) Technology in Air Pollution Monitoring in Jakarta: Quantitative Analysis of the Influence of Air Quality Change and Its Impact on Public Health in Jakarta. *West Science Nature and Technology*, *1*(01), 40–47. https://doi.org/10.58812/wsnt.v1i01.225

Qomaruddin, M., Riansyah, A., & Hermawan, H. M. (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

Raju, S. K., Varadarajan, G. K., Alharbi, A. H., Kannan, S., Khafaga, D. S., Sundaramoorthy, R. A., Eid, M. M., & Towfek, S. K. (2024). Estimating best nanomaterial for energy harvesting through reinforcement learning DQN coupled with fuzzy PROMETHEE under road-based conditions. *Scientific Reports*, *14*(1). https://doi.org/10.1038/s41598-024-72194-5

Rizal Hanafi, M., Purnama Adjhi, D., & Adiwilaga, A. (2024). Prototype Implementation of Exhaust Fan Control Using Mamdani Fuzzy Logic to Minimize LPG Concentration. *Journal of Applied Information and Communication Technologies*, *1*(9), 293–300.

Shah, Z. A., Sindi, H. F., Ul-Haq, A., & Ali, M. A. (2020). 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, Y. K., Ahmed, G., & Saini, D. K. (2025). Comparative Performance Analysis of Mamdani and Sugeno Fuzzy Inference Systems for Sustainable Cluster Formation in WSNs. *Journal of*

Intelligent & Fuzzy Systems Applications in Engineering and Technology, *49*(5), 1306–1332. https://doi.org/10.1177/18758967251340448

Sunardi, Yudhana, A., & Furizal. (2023). Tsukamoto Fuzzy Inference System on Internet of Things-Based for Room Temperature and Humidity Control. *IEEE Access*, *11*(December 2022), 6209–6227. https://doi.org/10.1109/ACCESS.2023.3236183

Susilo, S., & Lalay, A. A. (2025). ANALYSIS OF ENERGY EFFICIENCY PERFORMANCE USING THE MEMBERSHIP FUNCTION (MF) METHOD IN A FUZZY LOGIC CONTROL SYSTEM FOR RESIDENTIAL SPLIT AIR CONDITIONERS (AC). *Multidisciplinary Indonesian Center Journal (MICJO)*, *2*(4), 4682–4695. https://doi.org/10.62567/micjo.v2i4.1381

Tanveer, S., Ahmad, M. I., & Khan, T. (2024). Technological Progression Associated With Monitoring and Management of Indoor Air Pollution and Associated Health Risks: A Comprehensive Review. *Environmental Quality Management*, *34*(1). https://doi.org/10.1002/tqem.22236

Yadav, A. L., & Goyal, S. K. (2024). An Efficient and Intelligent System for Controlling the Speed of Vehicle using Fuzzy Logic and Deep Learning. *International Journal of Advanced Computer Science and Applications*, *15*(3), 96–106. https://doi.org/10.14569/IJACSA.2024.0150311

Zhang, Y., Su, J., & Chen, M. (2020). Research on Adaptive Iterative Learning Control of Air Pressure in Railway Tunnel with IOTs Data. *IEEE Access*, *8*, 5481–5487. https://doi.org/10.1109/ACCESS.2019.2960638