# Prototype Implementation of Exhaust Fan Control Using Mamdani Fuzzy Logic to Minimize LPG Concentration

Mohamad Rizal Hanafi[1], Dhimaz Purnama Adjhi.[2], and Anugrah Adiwilaga[3,]
[1,2,3)] *Computer Engineering, Universitas Pendidikan Indonesia*

Abstract—This research aims to design and build a prototype of LPG gas leak detection system using fuzzy logic Mamdani method based on ESP32 with MQ-2 and DHT11 sensors as input and exhaust fan as output or action taken to prevent gas concentration. This research methodology includes literature study, identification and analysis, data collection, design implementation, software and hardware testing, and experiments to verify system performance. The results show that the system can detect LPG leaks and then provide preventive action by adjusting the speed and turning on the exhaust fan. This research is a prototype LPG gas leak detection system using fuzzy logic can be a solution to prevent hazards due to leaking gas. The contribution of this research is to provide alternative data processing methods that can improve the performance of gas sensors and provide responses that are in accordance with environmental conditions.

Index Terms—Adaptive System, Fuzzy Logic, Leak Detection, Control System,

## 1. Introduction

In general, people use LPG (Liquefied Petroleum Gas) as fuel for daily needs, especially for cooking [1]. However, this LPG also has several risks, one of which is a gas leak that can cause a fire or explosion. Data obtained from [2] and shown in Figure 1, from 2020 to 2022 there were 1037 fire incidents where 9.4% were caused by gas. Gas leaks can occur due to various factors, such as damage to the cylinder, hose, or regulator, errors in use or storage, or environmental factors such as temperature or air pressure. Therefore, a system is needed that can detect LPG leaks early and provide warnings or precautions to users.

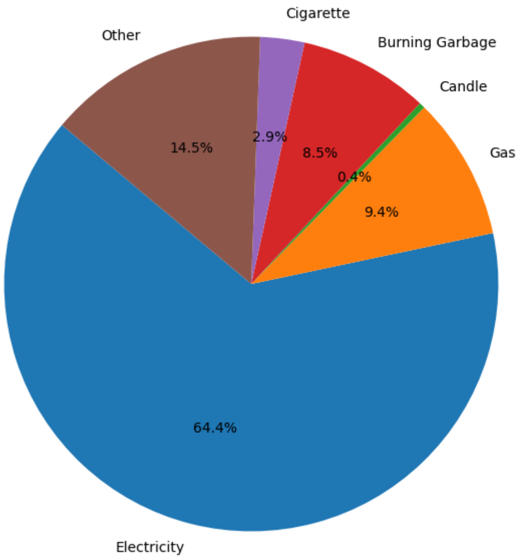


Figure 1. Causes of Fire.

The threshold of LPG is the concentration of LPG in the air that can cause a fire or explosion if exposed to a source of ignition. This threshold is also referred to as the explosion limit or the burnability limit. According to [3], the threshold of an LPG/air mixture is between 2% and 8% by volume of LPG. Below or above this range, the LPG/air mixture will not explode because it is either too little or too much.

One way to detect LPG leaks is by using an MQ-2 gas sensor. This sensor can measure the concentration of LPG in the air by producing an output voltage that is directly proportional to the gas concentration [4] [5] [6].

In addition to the MQ-2 sensor, a DHT-11 sensor is also needed, which is a sensor that can measure air temperature and humidity. The DHT-11 sensor can produce a digital signal containing measured air temperature and humidity data. This air temperature and humidity data is important to know, because research [7][8][6] shows that air temperature and humidity have an influence because the higher the air temperature, the greater the possibility of fire. Conversely, the higher the air humidity, the less likely a fire will occur. Therefore, a data processing method is needed that can improve the performance of this sensor.

Data from both sensors will be processed using fuzzy logic. This logic can perform data processing that can handle uncertainty and data complexity. Fuzzy logic can represent fuzzy knowledge using fuzzy sets and fuzzy rules, fuzzy logic can also perform fuzzy inference, which is the process of drawing conclusions from fuzzy data. One of the popular fuzzy inference methods is the Mamdani method. This method uses implication functions, rule composition, and defuzzification to produce fuzzy outputs. This method is applied in several fields of science such as agricultural technology [9], renewable energy technology [10], and also management systems [11] [12].

## 2. Literature Review

Several related studies have been conducted to apply fuzzy logic in detecting LPG leaks. For example, [13] This research developed an LPG gas leak detection device using an MQ-2 sensor, which can send SMS, LED, and buzzer notifications. The MQ-2 sensor can detect increasingly concentrated gas levels faster, but is affected by distance, time, and type of cellular network. This tool can help prevent hazards due to LPG gas leaks at home. Research [14] This study developed a prototype of an air quality control system in a smoking area room using fuzzy logic and an Arduino microcontroller. This system can measure air conditions with temperature sensors and smoke / gas sensors, then adjust the fan speed with fuzzy rules, and display air condition information on the web. This system can help improve the health and comfort of smokers and people who are around the room. Research [15] shows a gas leak detection device using an MQ2 sensor, buzzer, and nodeMCU connected to the blynk application. This tool can provide notifications and alarms when the gas exceeds a certain threshold. The research method used is the design, assembly, and testing of the tool. The results showed that this tool can work well and effectively in detecting gas leaks. The conclusion of this research is that a gas leak detection device with the blynk application can be a solution to prevent fires due to leaking gas. Research [16] discusses the design of a prototype to detect LPG gas leaks automatically using the MQ-2 sensor, Arduino Uno microcontroller, and SMS service as information media. This research was conducted in three different room conditions (open, semi-open, and closed) by measuring the detection distance and sensor characterization. The results show that the prototype can work optimally at a distance of 3 cm from the leak source and has good accuracy and repeatability. This prototype is expected to overcome and anticipate the risk of accidents due to LPG gas leaks early and in real time. [17] Study compares the performance of two types of fuzzy inference systems, namely Mamdani and Sugeno, to control the speed of computer cooling fans based on CPU temperature. This research shows that the Mamdani fuzzy inference system has advantages in terms of accuracy, speed, and stability compared to the Sugeno fuzzy inference system. Research [18] designed and implemented a water level control system using a Mamdani fuzzy inference system. This research uses two input variables, namely error and rate of change of error, and one output variable, namely valve position. [19] This research also compares the performance of the fuzzy control system with the conventional PID control system. The results show that the fuzzy control system has advantages in terms of overshoot, steady state error, and stabilization time compared to the PID control system. This research develops an exhaust fan speed control system using fuzzy logic to regulate room temperature. This research uses three input variables, namely room temperature, outside temperature, and humidity, and one output variable, namely the exhaust fan speed. This research [20] also conducted simulations and field tests to evaluate the performance of the fuzzy control system. The results show that the fuzzy control system can control the exhaust fan speed well and save energy.

Based on the literature review, it can be seen that the LPG gas leak detection system using fuzzy logic has the potential to be further developed by paying attention to several aspects, such as the type and number of gas sensors used, the type and number of input and output variables considered, the type and number of fuzzy rules created, the type and parameters of membership functions and fuzzy implications chosen, the type and method of defuzzification used, the type and way of communication between the system and the user, and the type and way of prevention carried out by the system. In addition, the LPG gas leak detection system using fuzzy logic also needs to be tested and evaluated.

The purpose of this research is to design and build a prototype LPG gas leak detection system using the ESP32-based Mamdani fuzzy logic method with MQ-2 and DHT11 sensors as inputs and exhaust fans as outputs or actions taken to prevent gas concentration. This system is expected to accurately detect LPG leaks and provide preventive action by adjusting and turning on the exhaust fan and providing warnings aimed at providing situation awareness to users.

## 3. Methods

A series of pre-planned steps formed the basis of this research. The flowchart shown in Figure 2 represents the sequence of activities carried out from start to finish in the research. Each step shows the process performed, such as literature study, identification and analysis, data collection, design implementation, software and hardware testing, and experiments to verify that the idea of the system built is correct.

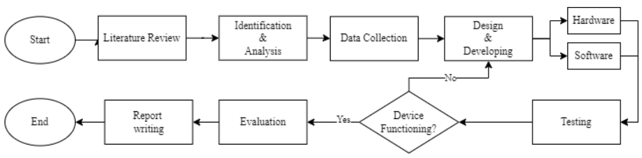

Figure 2. Methodology.

This basis will be used to create a research flow so that if the reader wants to replicate what has been done in this research.

### 3.1. Fuzzy Logic Design

Figure 3 is a graph displaying the gas leakage level on the X-axis (0 to 1000) and the membership level on the Y-axis (0 to 1). The red line represents "No Leakage" with high membership at low gas leakage levels that decreases sharply as the level increases. The light blue line represents "Small Leak" with increasing membership at medium gas leakage levels. The dark blue line represents "Large

Leakage" with high membership at higher gas leakage levels.

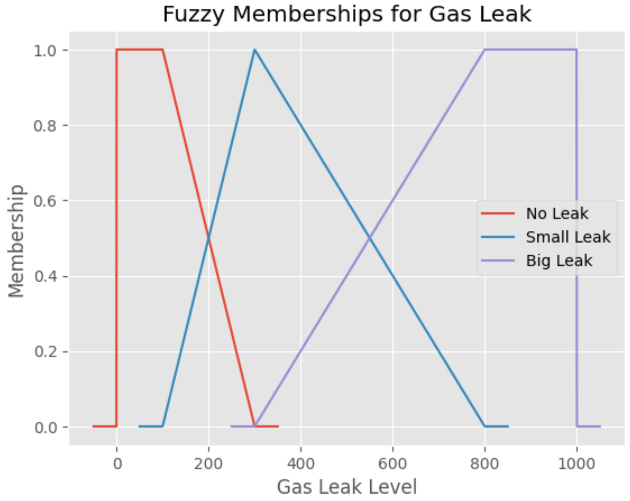


Figure 3. Fuzzy Memberships for Gas Leak.

Figure 4 is a graph displaying the temperature on the X-axis (20 to 30) and the membership level on the Y-axis (0 to 1). The red line represents "Cold" with high membership at low temperatures that decreases as the temperature increases. The blue line represents "Warm" with membership increasing as the temperature increases until it reaches the middle range, then decreases. The purple line represents "Hot" with low membership at low temperatures and increases as the temperature increases.

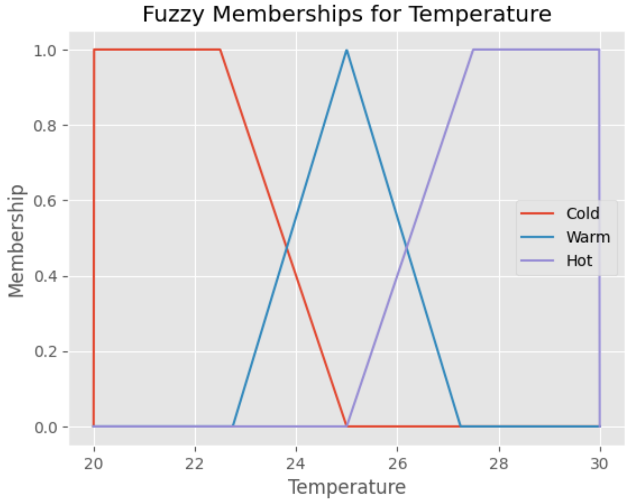


Figure 4. Fuzzy Memberships for Temperature.

Figure 5 is a graph displaying the PWM level on the X-axis (0 to 250) and the membership level on the Y-axis (0.0 to 1.0). The red line represents "Low PWM" with membership decreasing from 1.0 at PWM level 0 to 0 at around PWM level 100. The blue line represents "Medium PWM" which forms a triangular shape with a membership peak of 1.0 around the center of the graph (125 on the x-axis). The purple line represents "High PWM" with membership increasing from 0 at around 150 on the x-axis until it reaches a membership of almost one towards the end of the axis.

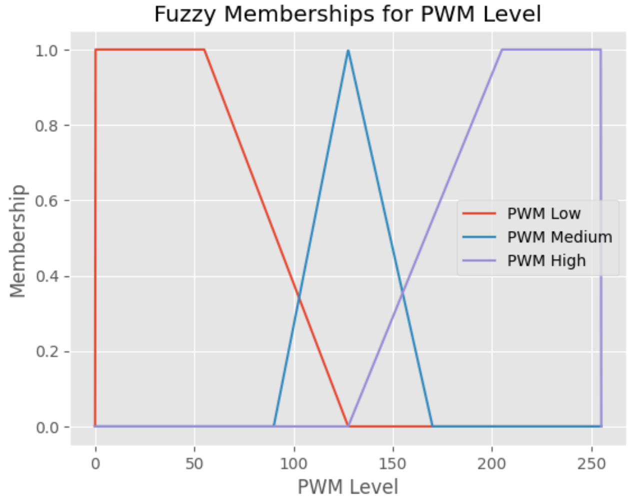


Figure 5. Fuzzy Memberships for Exhaust Level.

3.2. Block Diagram

Figure 6 shows the prototype of the system design which aims to apply fuzzy logic to the prototype device so that nature can determine the speed of the exhaust fan so that there is no concentration of LPG that can trigger LEL and EUL using the ESP32 microcontroller.

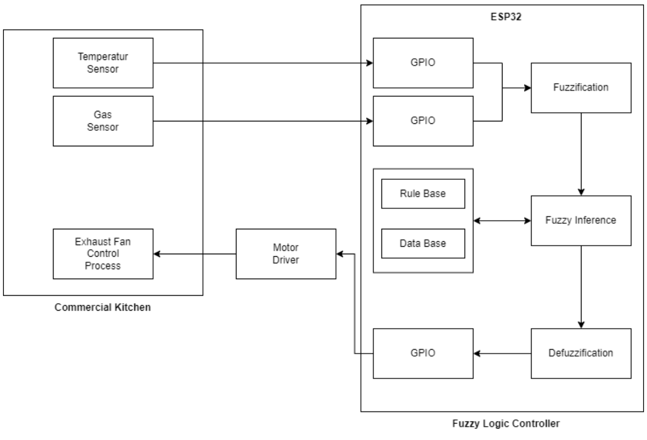


Figure 6. Block Diagram.

The ESP32 will work as a controller to receive input from the MQ-2 and DHT-11 sensors and input into fuzzy logic to adjust the speed of the exhaust fan and send warning notifications.

3.3. Flowchart System

The workflow of the program from the built prototype is explained through Figure 7. In general, the program is executed starting from the setup process then continued into a non-recurrent loop where this loop will only stop.

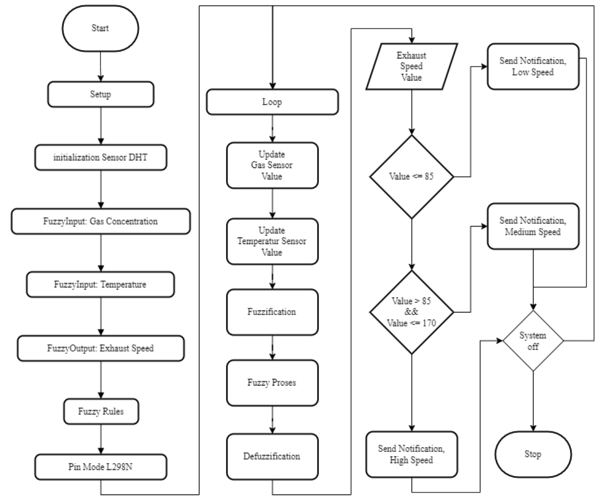


Figure 7. Flowchart.

After the setup process is complete the program will run into a loop, in this loop there is a process of updating the sensor values, in this process the gas and temperature sensor values are updated then enter the fuzzy fication process which is forwarded into the fuzzy process which after defuzzification the value resulting from the fuzzification process is then entered into a condition that will be adjusted into the condition and adjusted according to the value that has been set. Finally, this program will enter the process of sending notifications and adjusting the speed of the air fan rotation so that the gas concentration value reaches the LEL or EUL value which can cause an explosion.

3.4. Wiring Diagram

Figure 8. Shows the Wiring Diagram used in this study, for the hardware components used consisting of exhaust fans, motor drivers, DHT11 sensors, temperature sensors, and ESP32.

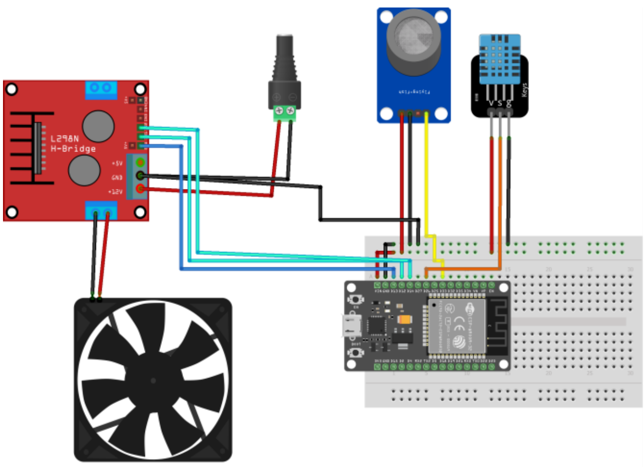


Figure 8. Wiring Diagram.

## 4. Result and Discussion

4.0. Fuzzy Logic Design

Figure 9 shows the configuration of the gas variables according to the capabilities of the MQ-2 sensor. In the fuzzy inference system and membership plot which has a range from 0 to 1000 values which are classified into 3 categories, namely 0 to 300 as non-leaking, 100 to 800 as medium leaking, and 300 to 1000 high leaking.

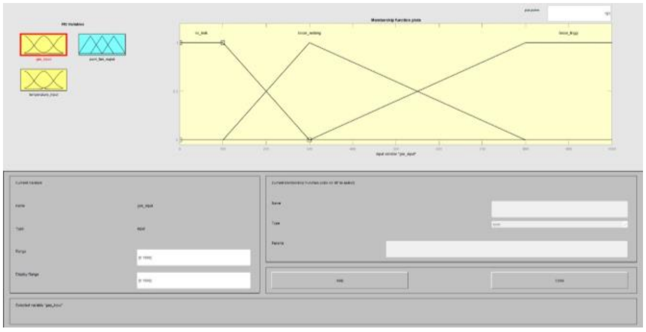

Figure 9. Membership input gas.

Figure 10 shows the configuration of the temperature variable according to the capabilities of the DHT11 sensor. The fuzzy inference system and membership plot are set in the range of 0 to 30 which is classified into 3 categories: 0 to 25 as cold, 22.5 to 27.25 as warm, and 25 to 30 as hot.

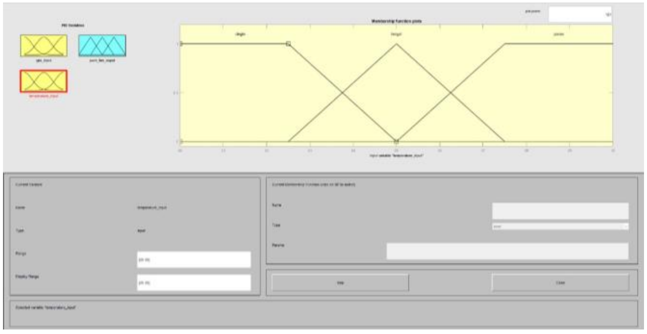

Figure 10. Temperature input membership.

Figure 11 shows the configuration of the fuzzy logic output which is set in the range of 0 to 255 based on PWM (Pulse Width Modulation) capabilities. This output will be used to determine the exhaust fan rotation speed with categories 0 to 127.5 as low rotation, 90 to 170 as medium rotation, 127.5 to 255 as high rotation.

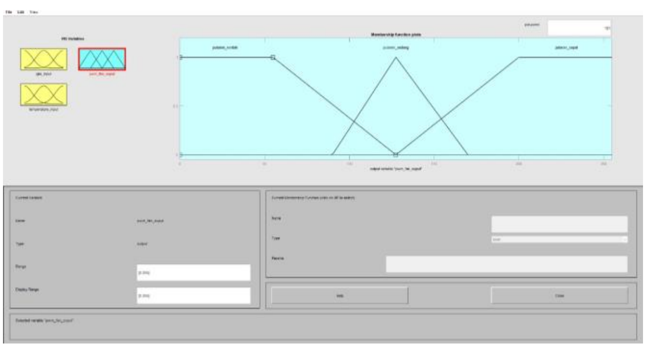

Figure 11. PWM output membership.

The determination of the crip value, obtained from the input control and the rules shown in Table 1.

Table 1. Membership Function.

| **Gas \ Temperature** | **Cold** | **Warm** | **Hot** |
|---|---|---|---|
| **No Leakage** | Low speed | Medium Speed | High Speed |
| **Medium Leakage** | Medium Speed | Medium Speed | High Speed |
| **Big Leak** | High Speed | High Speed | High Speed |

The fuzzy logic design will be used in the process of applying fuzzy logic to the software so that the exhaust fan speed can be adjusted.

4.1. MQ-2 Testing

Table 2 shows the test results of the MQ-2 sensor, the system is run for 5 minutes at each test, the data taken includes the analog value and PPM value. After testing the total overall average of the PPM values is 88 while the average analog value is 102.4.2.

Table 2. MQ-2 test results.

| No | Analog Value (Average) | PPM Value (Average) |
|---|---|---|
| 1 | 100 | 98 |
| 2 | 100 | 98 |
| 3 | 105 | 103 |
| 4 | 105 | 103 |
| 5 | 100 | 98 |

4.2. DHT11 test results

As for the DHT11 test results obtained at 29.28 with detailed data obtained shown in Table 3. Where the data is in the form of degrees Celsius.

Table 3. DHT11 test result.

| No | Average temperature (℃) |
|---|---|
| 1 | 29,10 |
| 2 | 29,10 |
| 3 | 29,30 |
| 4 | 29,30 |
| 5 | 29,60 |

4.3. Comparison of Fuzzy Logic in Simulation and System

The fuzzy simulation data in MATLAB shows the relationship between temperature, PPM, and PWM. In this simulation, temperature and PPM are used as inputs for the fuzzy system, which then produces an output in the form of a PWM value. From the given data, it can be observed that initially, when the temperature is constant at 24.1℃ and PPM at 106, the PWM value remains at 88.3. However, as the temperature rises, especially at line 6, there is a significant increase in both PPM and PWM values, indicating the sensitivity of the system to temperature changes. Furthermore, it is seen that although the temperature continues to increase, the PWM value then settles at the range of 202-206, which may reflect the stability or limit point of the system. Therefore, Table 4 of this simulation provides an overview of how the fuzzy system responds to temperature and PPM variations to produce the output represented by the PWM value.

Table 4. Simulation of fuzzy programs.

Fuzzy calculation during simulation

| No | Input | | Output |
|---|---|---|---|
| | Temperature | PPM | PWM |
| 1 | 24,1 | 106 | 88.3 |
| 2 | 24,1 | 106 | 88.3 |
| 3 | 24,1 | 107 | 88.3 |
| 4 | 25,4 | 107 | 151 |
| 5 | 25,5 | 108 | 155 |
| 6 | 25,9 | 180 | 169 |
| 7 | 26,0 | 214 | 172 |
| 8 | 26,1 | 263 | 174 |
| 9 | 27,0 | 297 | 197 |
| 10 | 27,5 | 348 | 206 |
| 11 | 28,0 | 400 | 205 |
| 12 | 28,0 | 450 | 204 |
| 13 | 29,1 | 480 | 203 |
| 14 | 29,1 | 516 | 202 |
| 15 | 29,0 | 591 | 202 |

Table 5 shows that when the fuzzy program in ESP32 is executed, with a constant temperature at 24.10℃ and PPM at 106, the PWM value stabilizes at 88, indicating the initial stability of the system under these conditions. However, as the temperature and PPM increase, especially in lines 4-5, the system shows a significant response, reflecting the high sensitivity to input changes. Furthermore, it is seen that the system response to temperature is not always linear, indicating the nonlinear characteristics of the fuzzy system.

The peak PWM value occurs at an ambient temperature of 27.50℃ with a PPM of 348, where the value reaches 206. Although the temperature continues to increase, the PWM value tends to remain stable within the 200 range, indicating the existence of a limit or stability point of the system at a certain temperature range. These data provide valuable insights into the dynamic response of fuzzy systems to input variables, including sensitivity, nonlinearity, and potential optimal points in the system.

Table 5. Fuzzy program fuzzy pada system.

| Fuzzy program on the system | | | |
|---|---|---|---|
| No | Input | | Output |
| | Temperature | PPM | PWM |
| 1 | 24,1 | 106 | 88 |
| 2 | 24,1 | 106 | 88 |
| 3 | 24,1 | 107 | 88 |
| 4 | 25,4 | 107 | 151 |
| 5 | 25,5 | 108 | 155 |
| 6 | 25,9 | 180 | 168 |
| 7 | 26,0 | 214 | 172 |
| 8 | 26,1 | 263 | 174 |
| 9 | 27,0 | 297 | 198 |
| 10 | 27,5 | 348 | 206 |
| 11 | 28,0 | 400 | 205 |
| 12 | 28,0 | 450 | 203 |
| 13 | 29,1 | 480 | 202 |
| 14 | 29,1 | 516 | 201 |
| 15 | 29,0 | 591 | 201 |

Table 6 shows the comparison between the fuzzy results carried out in MATLAB and the fuzzy results carried out on the system, the results show the difference in the error obtained is 1 while if in percentage the error obtained is in the range of 0.5% to 0.6%. The mean absolute error is 0.2%.

Table 6. Comparation Results.

| Output on simulation | Output on System | Error difference | Error (%) |
|---|---|---|---|
| 88 | 88 | 0 | 0,0% |
| 88 | 88 | 0 | 0,0% |
| 88 | 88 | 0 | 0,0% |
| 151 | 151 | 0 | 0,0% |
| 155 | 155 | 0 | 0,0% |
| 169 | 168 | 1 | 0,6% |
| 172 | 172 | 0 | 0,0% |
| 174 | 174 | 0 | 0,0% |
| 197 | 196 | 1 | 0,5% |
| 206 | 206 | 0 | 0,0% |
| 205 | 205 | 0 | 0,0% |
| 204 | 203 | 1 | 0,5% |
| 203 | 202 | 1 | 0,5% |
| 202 | 201 | 1 | 0,5% |
| 202 | 201 | 1 | 0,5% |
| | | mean absolute error | 0,2% |

## 5. Conclusion

Based on the test results, the MQ-2 sensor shows a sensitive response to variations in PPM concentration with an average value ranging from 98 to 103, while the analog value is in the range of 100 to 105. Overall, the average PPM during the test reaches 88, while the analog value is stable at 102. In addition, testing of the DHT11 temperature sensor gave an average value of about 29.28℃.

The initial response of the system at a constant temperature of 24.1℃ and a PPM of 106 results in a PWM value stable at 88.3. As the temperature increases, especially on the 6th line, there is a significant increase in the PPM and PWM values, indicating the sensitivity of the system to temperature changes. Although the temperature continues to increase, the PWM value then stabilizes in the range 202-206, indicating the stability or potential limit point of the system. Nonlinear characteristics are seen in the system's response to temperature changes. Table 5 shows that the system reaches a peak PWM value at an ambient temperature of 27.50℃ with a PPM of 348, where the value reaches 206. Although the temperature continues to increase, the PWM value tends to remain stable within the 200 range, indicating the existence of a limit or stability point at a certain temperature range. Comparative analysis between the fuzzy results in MATLAB simulation and the results in the real system shows a generally small error difference, with a mean absolute error of 0.2%. The system shows good agreement between simulated and actual results, indicating reliable translation of fuzzy logic from simulation to actual system.

Thus, the test results present a comprehensive picture of the performance of the MQ-2 sensor, the DHT11 sensor, and the fuzzy logic system to regulate the PWM. The data provided provides an understanding of the system's response to variations in temperature and PPM concentration, as well as illustrates system characteristics such as sensitivity, nonlinearity, and potential optimum points within the range of conditions tested.

Corresponding author. Tel.: 085171627381
Email: dhimaz@upi.edu

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