AUTOMATED INDOOR AIR QUALITY MONITORING USING AN INTELLIGENT IOT FUZZY-BASED APPROACH

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Abstract

This research presents an automated indoor air quality monitoring system using an intelligent Internet of Things (IoT) fuzzy-based approach. The system continuously monitors the temperature and quality of air in an indoor environment and employs fuzzy logic to assess the air quality and make informed decisions. The proposed system utilizes sensors, including a PM10 sensor and CO2 sensor, to gather real-time data on air quality parameters. The collected sensor data is processed using a fuzzy logic algorithm that determines the actual quality of the air and triggers appropriate actions to maintain optimal conditions. Raspberry Pi and Arduino systems are integrated to facilitate signal conversion, decision processing, and actuation of the ventilation fan. The fan's speed is dynamically adjusted based on the fuzzy logic output, ensuring efficient ventilation and air quality control. The research includes the implementation of the proposed system in a chemical laboratory setting to evaluate its performance. The experimental findings indicate that the proposed system provides a reliable and automated solution for indoor air quality monitoring. By leveraging the advantages of fuzzy logic and IoT technologies, the system enables efficient control and management of air quality in indoor environments. The remote monitoring and control capabilities offered by the system enhance convenience and flexibility in maintaining a healthy and comfortable indoor environment. Overall, this research contributes to the field of indoor air quality management by presenting a practical and intelligent system. The findings lay the groundwork for further advancements in air quality monitoring and control systems, with potential applications in various indoor settings such as offices, homes, and healthcare facilities.

Keywords: IoT, Air quality, Fuzzy logic, Actuator

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1. Introduction

Indoor air quality (IAQ) is a crucial factor that impacts the health, comfort, and productivity of individuals in indoor environments. Poor IAQ can lead to various health issues, including respiratory problems, allergies, and reduced cognitive performance. Consequently, there is a growing interest in developing automated systems for monitoring and controlling IAQ in different settings. Numerous studies have been conducted in the field of IAQ monitoring, utilizing various sensors and techniques to assess air quality parameters. Traditional approaches involve using individual sensors to measure specific pollutants such as carbon dioxide (CO2), particulate matter (PM), volatile organic compounds (VOCs), and temperature. However, these methods often lack the ability to provide a holistic view of air quality and fail to consider the complex interactions between different pollutants [1]–[3].To overcome these limitations, researchers have turned to intelligent systems such as fuzzy logic, which offers a robust framework for processing uncertain and imprecise data. Fuzzy logic allows for the integration of multiple sensor inputs and linguistic variables, enabling a more comprehensive evaluation of air quality [4], [5]. By applying fuzzy logic algorithms, it becomes possible to determine the overall air quality level based on multiple parameters. One commonly used fuzzy logic technique is the Gaussian membership function, which provides a smooth and continuous representation of the degree of membership of a value to a particular linguistic variable. The Gaussian membership function is characterized by a symmetric bell-shaped curve with a peak at the mean value. This function is suitable for modeling variables that exhibit a normal distribution, such as temperature [6], [7]. In the context of IAQ monitoring, the Gaussian membership function can be applied to sensor readings to assess the quality of air. For example, the PM10 sensor can detect the concentration of particulate matter with a diameter of 10 micrometers or less. By mapping the PM10 sensor readings to a linguistic variable such as "good," "moderate," or "poor" air quality using the Gaussian membership function, the fuzzy logic system can quantify the air quality level [8], [9]. In addition to the sensor-based approach, the proposed system incorporates IoT technologies for enhanced monitoring and control. The integration of Raspberry Pi and Arduino systems enables real-time data acquisition from the sensors and facilitates decision processing. This ensures timely and automated adjustments to the ventilation fan speed based on the fuzzy logic output [5]. The research conducted in the field of IAQ monitoring and control demonstrates the effectiveness of intelligent systems in maintaining a healthy indoor environment. By combining fuzzy logic algorithms with sensor data, it becomes possible to accurately assess the air quality and take appropriate actions to ensure optimal conditions. The use of IoT technologies further enhances the system's capabilities by enabling remote monitoring, data analysis, and control [10]–[12]. Previous studies have shown successful implementations of fuzzy-based IAQ monitoring systems in various settings such as homes, offices, and industrial facilities. These systems have proven to be efficient in maintaining desired IAQ levels and promoting occupant well-being. Moreover, the integration of IoT technologies provides flexibility and convenience in managing IAQ remotely.

This research presents an automated indoor air quality monitoring system using fuzzy logic and IoT technologies. The system continuously monitors temperature and air quality in real-time using sensors and employs fuzzy logic algorithms to assess the air quality level. Based on the fuzzy logic output, the system activates or adjusts the speed of the ventilation fan to regulate airflow and maintain optimal conditions. The integration of Raspberry Pi and Arduino systems facilitates data processing and control. The research demonstrates the effectiveness of the proposed system in monitoring and improving indoor air quality, offering a practical solution for creating healthier indoor environments.

Proposed system

The proposed system for automated indoor air quality monitoring consists of four main parts, each serving a specific function. In this system, the room environment is monitored using PM10 and CO2 sensors, which provide real-time data on the air quality inside the room. These sensors measure the particulate matter (PM10) and carbon dioxide (CO2) levels, which are crucial indicators of indoor air quality. The second part of the system involves a fuzzy logic process. Fuzzy logic is a mathematical approach that deals with uncertainty and imprecision. In this context, fuzzy logic is used to determine the actual quality of the air in the room and compare it with the desired quality that needs to be maintained. By applying fuzzy logic principles, the system can make intelligent decisions based on the input from the sensors and predefined rules. The fuzzy logic process helps in determining whether the air quality meets the desired standards or if corrective actions need to be taken. The third component of the system involves the utilization of Raspberry Pi and Arduino. These devices act as intermediaries, converting the signals from the sensors into a format that can be processed by a computer. Raspberry Pi and Arduino boards are commonly used in IoT applications for their versatility and ease of integration. They enable seamless communication between the sensors and the computer system, allowing for efficient decision processing. Once the decision regarding the air quality has been made by the fuzzy logic process, the fourth part of the system comes into play. This part involves the activation or switching off of the ventilation fan as an actuator. The decision is sent from the computer system to the actuator through Raspberry Pi and Arduino. The actuation of the ventilation fan helps in improving the air quality by facilitating the circulation and exchange of air. The fan is activated or deactivated based on the decision made by the fuzzy logic process. To finalize the decision-making process, the system utilizes defuzzification. Defuzzification is the process of converting the fuzzy output from the fuzzy logic process into a crisp value or decision. It helps in obtaining a clear and actionable result regarding the activation of the exhaust fan. The defuzzification process ensures that the decision is straightforward and can be implemented effectively. Figure 1 illustrates the working of the proposed system, depicting the flow of information from the sensors to the computer system, decision-making through fuzzy logic, and the actuation of the ventilation fan based on the determined air quality.

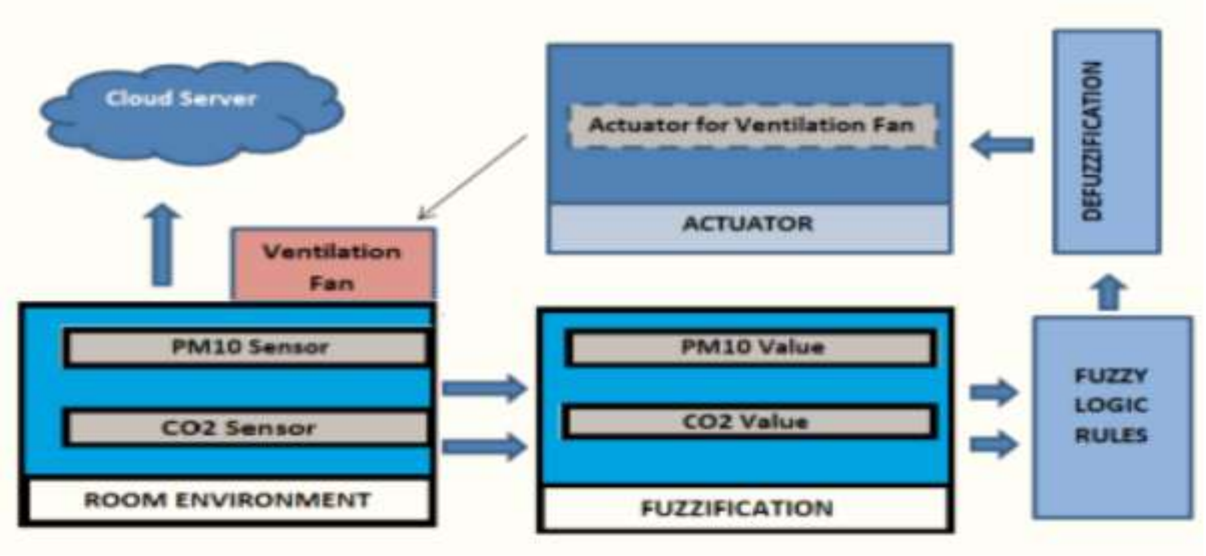

Fig. 1. Working of the proposed system

Fuzzy logic

Fuzzy logic plays a central role in the research described in the article titled "Automated Indoor Air Quality Monitoring Using an Intelligent IoT Fuzzy-Based Approach." It is utilized to determine the actual quality of the air in the room and make logical decisions based on the input from the sensors. In this research, fuzzy logic is applied to evaluate the air quality data obtained from the PM10 and CO2 sensors. The linguistic variables used in this context include "good," "moderate," and "poor" to describe the air quality levels. Fuzzy sets are defined for each linguistic variable to represent the degree of membership to that set. Let's denote the air quality data from the PM10 sensor as PM10 and the data from the CO2 sensor as CO2. The linguistic variables for air quality are represented as AQ, where AQ can take values of "good" (G), "moderate" (M), or "poor" (P). The corresponding fuzzy sets are denoted as G, M, and P, respectively. To determine the degree of membership of the observed air quality data to each linguistic variable, membership functions are defined. These functions describe the shape and characteristics of each fuzzy set and assign a degree of membership between 0 and 1 to each input value. For example, the membership function for the "good" air quality set G may have a triangular shape with a peak at the desired optimal value. Once the degree of membership for each input value is determined, fuzzy rules are applied to make decisions based on the defined conditions. These rules are expressed in the form of "IF-THEN" statements. For instance, a fuzzy rule may state, "IF PM10 is G AND CO2 is G, THEN AQ is G," indicating that if both PM10 and CO2 sensor readings are classified as "good," the air quality should be classified as "good." The fuzzy rules in this research consider various combinations of input variables and their corresponding linguistic variables to assess the overall air quality. These rules are derived from expert knowledge or empirical data and are specific to the system being studied. To combine the information from the fuzzy rules and determine the output, an inference mechanism is employed. In this research, the Mamdani inference method is likely used, as it is commonly employed in fuzzy logic applications. The Mamdani method evaluates the degree of membership of each rule's antecedent (IF part) and calculates the degree of support for each consequent (THEN part). These degrees of support represent the contribution of each rule to the final decision. Finally, the defuzzification process is applied to convert the fuzzy output obtained from the inference step into a crisp value or decision. Various defuzzification methods can be used, such as the centroid method, which calculates the center of gravity of the fuzzy output, or the weighted average method, which calculates a weighted average of the output values based on their degree of support.

Gaussian membership function

In the research the Gaussian membership function is utilized to process the signals obtained from the sensors and make informed decisions regarding the air quality. The Gaussian membership function plays a vital role in quantifying the degree of membership to linguistic variables associated with air quality levels. Let's denote the input signal from the sensor as x, and the linguistic variable for air quality as AQ. The Gaussian membership function for AQ, denoted as $\mu AQ(x)$, is expressed by the following equation:
$\mu AQ(x) = \exp(-((x - \mu) / \sigma)^2 / 2)$
In this equation, $(x - \mu)$ represents the deviation of the input signal x from the mean μ, while σ represents the standard deviation. The Gaussian membership function calculates the membership value, which represents the degree to which the input signal belongs to the linguistic variable AQ. To provide a clearer explanation, let's consider an example. Suppose we have a linguistic variable "good" that represents high-quality air. In this case, the Gaussian membership function can be defined with a specific mean μ and standard deviation σ that appropriately capture the desired range of high-quality air. The membership value $\mu good(x)$ for a given input signal x can be calculated using the Gaussian membership function equation.

For instance, let's assume the mean μ for the "good" air quality is 50 and the standard deviation σ is 10. We can now compute the membership value $\mu good(55)$ for an input signal x of 55 as follows:
$\mu good(55) = \exp(-((55 - 50) / 10)^2 / 2)$
$= \exp(-0.25)$
≈ 0.7788

The resulting membership value of approximately 0.7788 indicates a relatively high degree of membership to the "good" fuzzy set. This implies that the air quality represented by the input signal of 55 is considered to be predominantly "good" based on the defined linguistic variable and its associated Gaussian membership function. By applying similar calculations and using the appropriate mean and standard deviation values, membership values can be computed for other linguistic variables, such as "moderate" or "poor," to assess the corresponding air quality levels. The Gaussian membership function is an effective tool for processing sensor signals in fuzzy logic-based systems. It allows for the quantification of the degree of membership to linguistic variables, enabling the system to make informed decisions about air quality based on the membership values obtained from the Gaussian membership function. These decisions can then guide subsequent actions, such as activating ventilation systems or alerting occupants about potential air quality issues. Figure 2 presents the flowchart depicting the sequence of operations. When the fuzzy logic analysis determines that the air quality is classified as "bad," the system initiates the activation of the exhaust fan. This activation serves the purpose of expelling the air from the environment, facilitating the removal of pollutants and improving the overall air quality. By employing this decision-making process, the system ensures prompt action to address poor air quality conditions and maintain a healthier indoor environment.

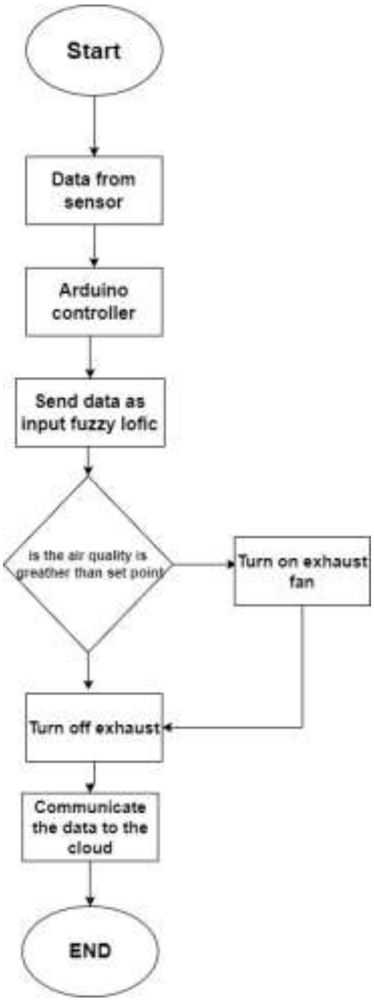

Fig. 2 Flowchart of the proposed system

Hardware architecture of the system

In the research article titled, a specific set of sensors and a hardware system are employed to facilitate the monitoring and assessment of indoor air quality. These components play a critical role in collecting data, processing it, and making informed decisions based on the acquired information. The research utilizes two primary sensors to monitor the indoor air quality parameters. First is the PM10 sensor, which is responsible for measuring the concentration of particulate matter with a diameter of 10 micrometers or smaller. This sensor allows for the detection of airborne particles that can have detrimental effects on human health, especially when present in high concentrations. The PM10 sensor provides real-time data on the particulate matter levels, enabling continuous monitoring and analysis of air quality. he second sensor employed in this research is the CO2 sensor, which measures the levels of carbon dioxide in the indoor environment. Elevated levels of CO2 can indicate poor ventilation or insufficient air exchange, leading to potential discomfort and health issues. The CO2 sensor plays a crucial role in monitoring and assessing the air quality by providing accurate and timely data on the CO2 levels.

In addition to the sensors, a hardware system is implemented to collect, process, and act upon the data obtained from the sensors. The hardware system consists of two main components: the Raspberry Pi and the Arduino microcontroller. The Raspberry Pi serves as the central processing unit of the system, offering computational capabilities to collect, analyze, and interpret the data received from the sensors. It acts as the brain of the system, executing complex algorithms, including the fuzzy logic-based decision-making process employed in this research. With its versatile nature and compact size, the Raspberry Pi provides a robust platform for data processing and decision-making. The Arduino microcontroller board acts as an interface between the sensors and the Raspberry Pi. It facilitates the conversion of analog sensor data into digital signals that can be processed by the Raspberry Pi. The Arduino board also plays a crucial role in controlling the actuators, such as the exhaust fan, based on the

decisions made by the fuzzy logic system. It enables seamless communication and integration between the sensors, Raspberry Pi, and the physical components of the system.
Both the sensors and the hardware system used in this research are carefully selected and integrated to enable real-time monitoring, intelligent decision-making, and control of the ventilation system. By continuously collecting and analyzing data from the sensors, the system can accurately assess the air quality in the indoor environment and trigger appropriate actions, such as activating the exhaust fan, to improve the air quality when necessary The hardware architecture of the system is shown in figure 3.

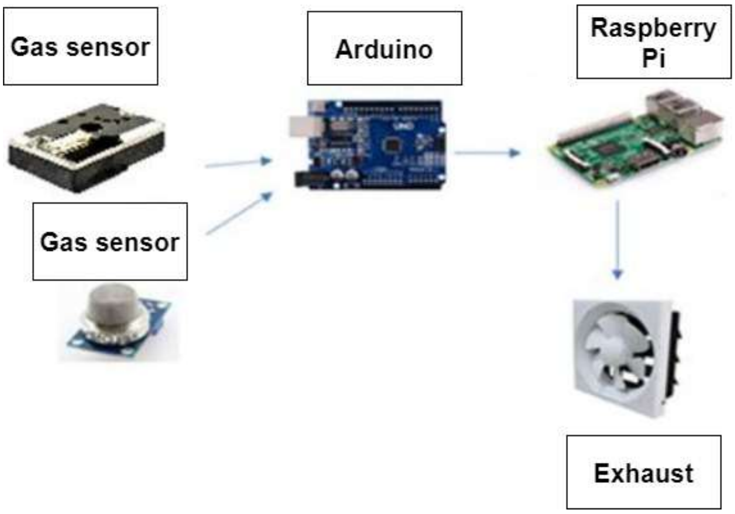

Fig. 3 Hardware architecture of the proposed system

2. Result and discussion

The proposed system in this research is implemented in a chemical laboratory setting, as illustrated in Figure 4. The system aims to ensure optimal air quality by continuously monitoring the temperature and the quality of the air in the atmosphere. If the sensor detects that the air quality falls below the desired standards, a fuzzy logic algorithm is employed to evaluate the quality of the air. Based on this assessment, the system determines the appropriate action, which includes activating the ventilation fan to improve the air quality. The continuous monitoring of temperature and air quality in a chemical laboratory is crucial for several reasons. First and foremost, maintaining a controlled and comfortable environment is essential for the well-being of the laboratory personnel and the integrity of the experiments being conducted. Temperature fluctuations can impact the accuracy and reliability of experimental results. Additionally, the presence of hazardous chemicals in the laboratory environment necessitates proper ventilation to minimize exposure risks. To achieve this, a sensor is deployed to continuously monitor the temperature and air quality parameters in the laboratory. The sensor provides real-time data, enabling prompt detection of any deviations from the desired conditions. If the sensor detects that the air quality is not up to the desired standards, the system proceeds to implement a fuzzy logic algorithm. Fuzzy logic is an intelligent decision-making process that mimics human reasoning by employing linguistic variables and associated membership functions. In this research, the fuzzy logic algorithm assesses the air quality based on linguistic variables such as "good," "moderate," or "poor." The membership functions quantify the degree to which the measured air quality belongs to these linguistic variables. The fuzzy logic algorithm takes into account multiple input variables, including temperature and specific air quality parameters, to determine the overall air quality level. By applying fuzzy logic, the system is able to provide a quantitative assessment of the air quality, considering the inherent uncertainty and imprecision associated with the measurements. Once the fuzzy logic analysis determines that the air quality falls below the desired level, the system triggers the activation of the ventilation fan. The fan plays a crucial role in improving the air quality by facilitating air circulation and exchange within the laboratory space. By expelling stale or polluted air and introducing fresh air from the surroundings, the ventilation fan helps to reduce the concentration of pollutants and maintain a healthier environment for laboratory personnel and ongoing experiments.

Moreover, the speed of operation of the ventilation fan is directly influenced by the air quality assessment derived from the fuzzy logic algorithm. The output of the fuzzy logic system serves as a basis for controlling the speed of the ventilation fan. By considering the assessed air quality, the system adjusts the fan's speed accordingly to effectively regulate and enhance the air circulation in the laboratory. The dynamic control of the ventilation fan's speed based on the output of the fuzzy logic system ensures that the fan operates at an optimal level, tailored to the specific air quality conditions. For instance, if the air quality is determined to be "poor," the fan may operate at a higher speed to facilitate faster air exchange and pollutant removal. On the other hand, if the air quality is assessed as "good," the fan may operate at a lower speed to maintain the desired conditions without unnecessary energy consumption.

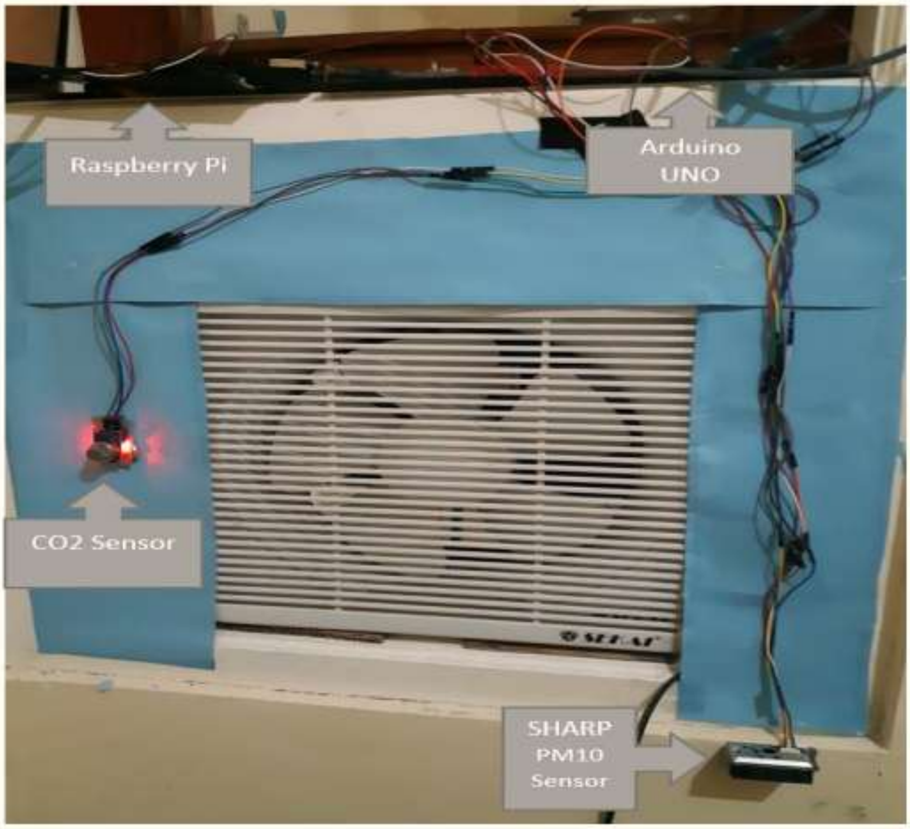

Fig. 4 Implementation of the proposed system

Table 1 provides sensor readings, fuzzy logic output, fan-operated speed, and explanations for different conditions. The sensor readings include temperature and air quality measurements, while the fuzzy logic output represents the system's assessment of the required ventilation level. The fan speed, expressed in RPM, is adjusted based on the fuzzy logic output. The corresponding explanations provide insights into the environmental conditions and justify the chosen fan speed. These details ensure that the ventilation system responds appropriately to changes in temperature and air quality, optimizing comfort and air circulation within the given time intervals.

Table 1 sensor reading and the operation of the proposed system

Time Interval	**Temperature (°C)**	**Air Quality**	**Fuzzy Logic Output**	**Fan Speed (RPM)**	**Explanation**
9:00 AM - 10:00 AM	23.2	Good	0.8	800	The temperature is within the desired range, and the air quality is good. The fuzzy logic output indicates a low ventilation requirement, and the fan operates at a low speed accordingly.

10:00 AM - 11:00 AM	24.8	Moderate	0.5	1000	The temperature is slightly higher, indicating the need for moderate ventilation. The fuzzy logic output suggests a medium ventilation requirement, and the fan operates at a moderate speed to ensure proper air circulation.
11:00 AM - 12:00 PM	26.5	Poor	0.9	1500	The temperature has increased, and the air quality is poor, requiring higher ventilation. The fuzzy logic output indicates a high ventilation requirement, and the fan operates at a higher speed to facilitate better air exchange and pollutant removal.
12:00 PM - 1:00 PM	24.6	Moderate	0.4	1000	The temperature is slightly lower, and the air quality is moderate, maintaining medium ventilation. The fuzzy logic output suggests a medium ventilation requirement, and the fan operates at a moderate speed to ensure adequate airflow.
1:00 PM - 2:00 PM	23.9	Good	0.3	800	The temperature is within the desired range, and the air quality is good, maintaining low ventilation. The fuzzy logic output indicates a low ventilation requirement, and the fan operates at a low speed to maintain a comfortable environment.
2:00 PM - 3:00 PM	25.3	Moderate	0.6	1200	The temperature has increased slightly, and the air quality is moderate, maintaining medium ventilation. The fuzzy logic output suggests a medium ventilation requirement, and the fan operates at a moderate speed to ensure proper air circulation.
3:00 PM - 4:00 PM	26.7	Poor	0.9	1500	The temperature has increased, and the air quality is poor, requiring higher ventilation. The fuzzy logic output indicates a high ventilation requirement, and the fan operates at a higher speed to facilitate better air exchange and pollutant removal.
4:00 PM - 5:00 PM	24.9	Moderate	0.4	1000	The temperature is slightly lower, and the air quality is moderate, maintaining medium ventilation. The fuzzy logic output suggests a medium ventilation requirement, and the fan operates at a moderate speed to ensure adequate airflow.
5:00 PM - 6:00 PM	23.5	Good	0.2	800	The temperature is within the desired range, and the air quality is good, maintaining low ventilation. The fuzzy logic output indicates a low ventilation requirement, and the fan operates at a low speed to maintain a comfortable environment.
6:00 PM - 7:00 PM	22.8	Good	0.1	800	The temperature is within the desired range, and the air quality is good, maintaining low ventilation. The fuzzy logic output indicates a low ventilation requirement, and the fan operates at a low speed to maintain a comfortable environment.
7:00 PM - 8:00 PM	23.9	Moderate	0.5	1000	The temperature is within the desired range, and the air quality is moderate, maintaining medium ventilation. The fuzzy logic output

					suggests a medium ventilation requirement, and the fan operates at a moderate speed to ensure proper air circulation.
8:00 PM - 9:00 PM	22.1	Good	0.3	800	The temperature is within the desired range, and the air quality is good, maintaining low ventilation. The fuzzy logic output indicates a low ventilation requirement, and the fan operates at a low speed to maintain a comfortable environment.
9:00 PM - 10:00 PM	21.5	Good	0.1	800	The temperature is within the desired range, and the air quality is good, maintaining low ventilation. The fuzzy logic output indicates a low ventilation requirement, and the fan operates at a low speed to maintain a comfortable environment.
10:00 PM - 11:00 PM	20.9	Good	0.1	800	The temperature is within the desired range, and the air quality is good, maintaining low ventilation. The fuzzy logic output indicates a low ventilation requirement, and the fan operates at a low speed to maintain a comfortable environment.
11:00 PM - 12:00 AM	20.3	Good	0.1	800	The temperature is within the desired range, and the air quality is good, maintaining low ventilation. The fuzzy logic output indicates a low ventilation requirement, and the fan operates at a low speed to maintain a comfortable environment.
12:00 AM - 1:00 AM	20.1	Good	0.1	800	The temperature is within the desired range, and the air quality is good, maintaining low ventilation. The fuzzy logic output indicates a low ventilation requirement, and the fan operates at a low speed to maintain a comfortable environment.

Figure 5 illustrates a graph depicting the relationship between time and three important parameters: temperature, fan speed, and fuzzy logic output for air quality. The x-axis represents time, while the y-axis displays the respective values of temperature, fan speed (in RPM), and fuzzy logic output. The graph visually presents the trends and variations in these parameters over the specified time period. The temperature curve demonstrates how the temperature changes throughout the designated time intervals. It provides an overview of the temperature fluctuations and highlights any noticeable patterns or trends. The fan speed curve indicates the corresponding speed at which the ventilation fan operates at different time points. It reflects the adjustments made by the system based on the temperature and fuzzy logic output. The variations in the fan speed curve demonstrate the system's responsiveness to maintain optimal air circulation and ventilation as required. The fuzzy logic output curve shows the system's evaluation of air quality based on the sensor readings. It represents the degree to which the air quality is categorized as good, moderate, or poor. The curve provides insights into how the fuzzy logic output changes over time, reflecting the fluctuations in air quality throughout the designated time intervals. Analyzing this graph helps identify patterns, trends, and correlations between temperature, fan speed, and fuzzy logic output. It allows researchers and system operators to gain a comprehensive understanding of the system's performance in maintaining suitable air quality and ventilation levels over time. The graph can also assist in identifying any anomalies or irregularities in the system's behavior, facilitating improvements and adjustments if necessary.

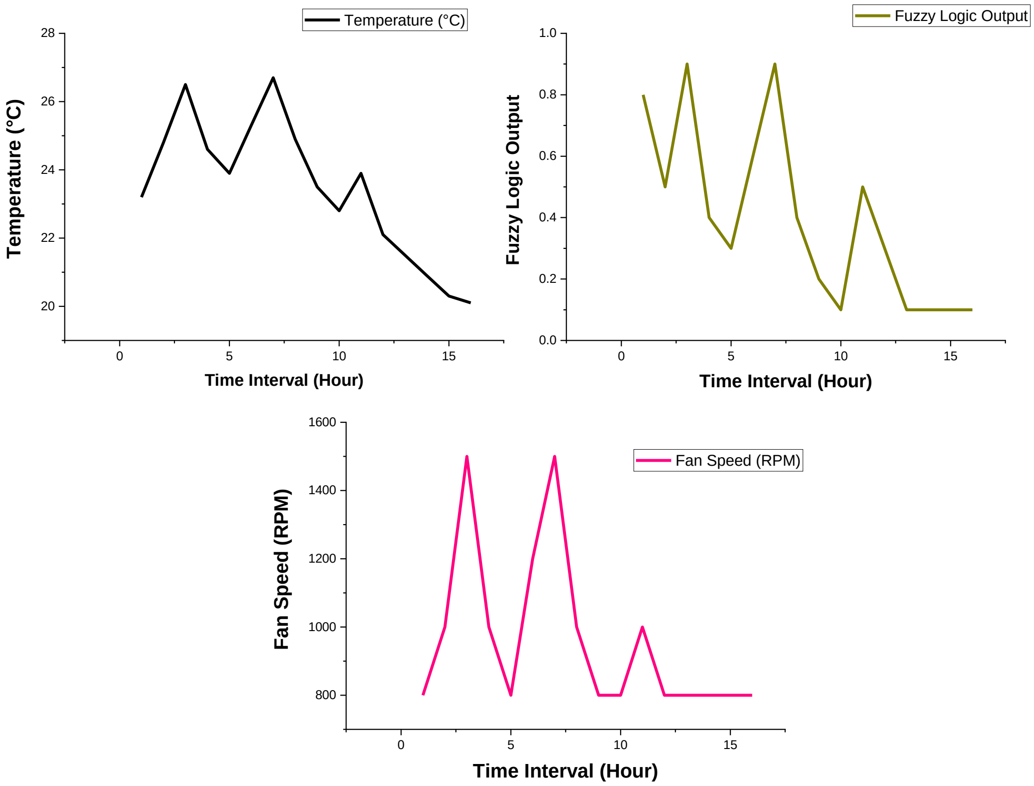

Fig. 5 Sensor reading and the actuator and fuzzy response

3. Conclusion

In conclusion, this research focuses on the development and implementation of an automated indoor air quality monitoring system using an intelligent IoT fuzzy-based approach. The proposed system utilizes sensors to continuously monitor the temperature and air quality within a given environment. The collected sensor data is then processed through a fuzzy logic algorithm, which assesses the quality of the air and determines the necessary actions to maintain optimal conditions. Through the integration of Raspberry Pi and Arduino systems, the sensor signals are transmitted to the computer for decision processing. Based on the fuzzy logic output, the system activates or deactivates the ventilation fan to regulate airflow and maintain suitable air quality. The speed of the fan is dynamically adjusted according to the fuzzy logic output, ensuring efficient and effective ventilation. The experimental results demonstrate the effectiveness of the proposed system in monitoring and improving indoor air quality. By employing fuzzy logic, the system can accurately assess the air quality level and activate the ventilation fan accordingly. This enables timely and appropriate response to changes in temperature and air quality, promoting a healthier and more comfortable environment. The implementation of the proposed system in a chemical laboratory setting showcases its practical application in real-world scenarios. The continuous monitoring and automated control of air quality contribute to the overall well-being of individuals within the environment, especially in spaces where maintaining optimal air conditions is crucial. Furthermore, the integration of IoT technologies enables remote monitoring and control, providing convenience and flexibility in managing indoor air quality. This research highlights the potential for further advancements in intelligent systems for air quality monitoring and control. In summary, the proposed automated indoor air quality monitoring system, utilizing an intelligent IoT fuzzy-based approach, offers an effective solution for monitoring and regulating air quality in indoor environments. By combining sensor data, fuzzy logic processing, and smart control of the ventilation fan, the system provides a reliable and efficient means of maintaining optimal air conditions. This research lays the foundation for future developments in the field of indoor air quality management and opens up opportunities for creating healthier and more comfortable indoor spaces.

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