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Indoor Air Quality Monitoring and Control System using Fuzzy Logic Controller

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Abstract
As more time is spent indoors due to increase in indoor activities, monitoring indoor air quality becomes increasingly important for maintaining a healthy environment. This study presents an integrated system that combines data acquisition, fuzzy logic control, and a mobile application to provide comprehensive air quality monitoring. Utilizing DHT11, MQ2, MQ9, and MQ135 sensors with an ESP32 microcontroller, the system measures key parameters such as humidity, temperature, CO, CO_2, and VOC levels. The ESP32 processes this data and transmits it to a MySQL database, where it is further analysed. The core of the system is the fuzzy logic controller, which uses a Mamdani approach to assess the air quality based on predefined rules. This analysis is then relayed to the mobile application, offering users real-time insights into their indoor air quality. The app not only presents this data but also provides personalized health and safety recommendations, making it a practical tool for everyday use. Our system was evaluated against the Nigeria Air Quality Index, revealing clear patterns where Good air quality corresponds to CO levels up to 5 ppm, CO_2 below 500 ppm, and VOC levels under 300 ppb. As these levels increase, the air quality shifts from moderate to unhealthy, then to very unhealthy, and eventually to hazardous condition. By integrating both hardware and software components, the system offers a proactive solution for indoor air quality management hence empowering the users to maintain healthier indoor environments through making informed decisions.

Keywords: *Air quality, Data acquisition, Fuzzy logic, MySQL database, ESP32*

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1. Introduction

Nigeria is known as the "giant of Africa" because of its substantial presence on the continent, particularly in terms of population. As a result of this significant population growth and other human activates which includes the use of smoke emission engines, cooking with fire wood and kerosene, etc. air pollution has noticeably and dangerously increased. The air in Nigeria is contaminated by a variety of substances, some of which are released into the atmosphere by cars and other vehicles. These pollutants include sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and black carbon, which is the primary component of soot and a powerful carcinogen when inhaled. Others would come from open burn sites and companies, where synthetic materials, organic matter, and fossil fuels are all burned. They consist of contaminants such as furans, dioxins, polychlorinated biphenyls, and volatile organic compounds (VOC).

For many years, environmental specialists and scientists concentrated on the health hazards that urban residents faced as well as ambient (outdoor) air pollution. But as people spend more of their time indoors, attention has also been focused on indoor air pollution due to its substantial health implications (Carslaw, 2024) as the well-being and comfort of people in residential, commercial, and industrial environments are impacted by indoor air quality (IAQ), which is an important component of environmental health. According to a report by WHO (2023), incomplete combustion of solid fuels and kerosene used for cooking results in household air pollution, which causes 3.2 million premature deaths from illnesses each year. Particulate matter and other pollutants in household air pollution inflame the airways and lungs, impair immune response, and lower the blood's ability to carry oxygen. This has given rise to numerous health concerns, such as respiratory disorders, allergies, and even chronic diseases that can be caused by constant exposure to poor air quality. Air quality has an index that represents the quality of air with values from 0 to 500 called Air quality index (AQI). To combat the impact of poor indoor air quality, (Sung et al, 2021) had developed an indoor air quality monitoring system based on the architecture of the Internet of Things (IoT), emphasizing the importance of real-time data report and integration of advanced technologies. Similarly, (Shamila, et al 2022) proposed an indoor air quality monitoring and controlling system, focusing on maintaining healthy indoor environments through constant monitoring and control mechanisms and (Cynthia et al 2018) proposed a proactive indoor air quality monitoring system leveraging IoT. The system uses gas senor (mq135) to detect harmful gases and compounds and transmit the data to a PIC16F877A micro-controller for processing and transmission. Alternatively, Field-Programmable Gate Arrays (FPGA) is also been utilized for air quality monitoring as (Babu et al, 2024) presented a solution utilizing FPGA for air quality monitoring. This system employs multiple sensors to monitor various contaminants in urban, rural, and industrial environments.

As people spend more time indoors and as knowledge about the negative health effects of air pollution increases, there is a growing need for accurate and dependable indoor air quality monitoring. The design and implementation of an indoor air quality detector and monitoring system using fuzzy logic controllers and multiple sensors represent a systematic approach to addressing this need. This paper aims to develop a system capable of continuously monitoring various air quality parameters, such as temperature, humidity, carbon dioxide (CO_2), volatile organic compounds (VOC), and other pollutants. By utilising fuzzy logic controllers, the system can provide a nuanced assessment of air quality, making informed decisions that can be used to maintain optimal indoor environments.

Fuzzy logic can handle imprecise and uncertain data, making it useful when binary logic might not be sufficient. Fuzzy logic controllers can combine data from many sensors, interpret the data in a more human-like way, and deliver real-time feedback and control actions to enhance indoor air quality. This paper will involve the design and construction of the hardware components, including the selection and integration of suitable sensors, as well as the development of the software algorithms for the fuzzy logic controllers and a mobile application to display the air quality and also show detailed information regarding different air quality parameters which includes temperature, humidity CO, CO_2 and VOC and also send air quality alert with safety tips to the user.

2. Materials and methods

The proposed system has been divided into three main sections which include the Data acquisition subsystem, the Fuzzy logic controller and the Mobile Application. The data acquisition module covers the hardware phase of the system which includes the DHT11, Mq2, and Mq9, Mq135 sensors and an ESP32 microcontroller / Wi-Fi board. The DHT 11 sensor was used to sense the humidity and temperature of the environment under surveillance while the Mq sensors were used to sense the CO, CO_2 and the VOC in the air. The ESP32 microcontroller / WiFi board serves as the microcontroller and the transmitter as it collects and processes the data from the microcontroller and then sends it to the MySQL database. The fuzzy logic process takes as input the data from the data acquisition subsystem and determines the air quality based on the set of fuzzy rules. Finally, the mobile application displays the result of the fuzzy process as the air quality also based on the result, the mobile application suggests health and safety tips.

2.1 System block diagram

The system block diagram represented by Fig. 1 shows the interconnection of the various modules that makes up the entire system which includes.

i. **The Power supply:** The power supply module consists mainly of a 5v power adapter which supplies the system with a constant 5v DC power required to effectively power the microcontroller module and the sensors.
ii. **The Sensors:** The sensor module consists if the DHT11 sensor which is used to sense the Temperature and Humidity of the environment, MQ2 which is used to sense the CO level, MQ9 which is used to sense the CO_2 level and MQ135 which is used to sense the VOC level.
iii. **The Control unit:** The Control unit which is the Esp32 Microcontroller board with a built in Wi-Fi module is responsible for processing the data collected by the sensors, processing the data and then uploading the data to the online MySQL database.
iv. **Database:** The Database was created using MySQL and hosted on AWARDSPACE. The MySQL Datable allows for easy storage, accessibility and retrieval of the data collected by the system.

v. **Fuzzy Logic System:** The fuzzy logic system is the Python program which is responsible for handling the fuzzy logic functionalities of the device. The fuzzy logic system utilizes the data stored in the Database to make Fuzzy based decisions.

vi. **Mobile application:** The mobile Application is a custom cross-platform Mobile application with a user-friendly user interface developed on Flutter. The mobile application allows the user to real-time information on indoor air quality and also provides custom health tips based on the air quality.

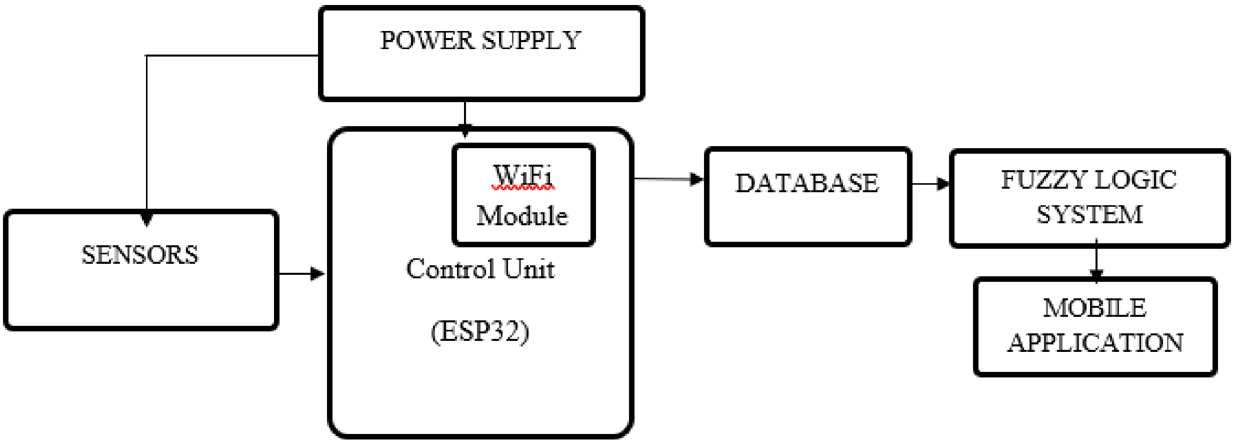

Fig. 1: Block diagram of the system

2.2 System flow chart

The flowchart of the Indoor Air Quality Monitoring and Control System using Fuzzy Logic Controller is shown in Fig. 2. the flow chart illustrates the flow of flow of process within the system. The system starts by taking the senor reading, this reading is then sent to the MySQL data base from which the Fuzzy logic program accesses the data and uses the data to complete the fuzzy logic process. The fuzzy result is then sent to the mobile application for display. Also, the mobile application suggests health and safety tips based on the fuzzy logic result.

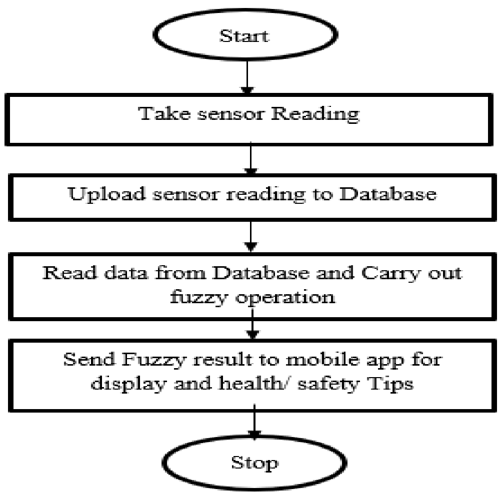

Fig. 2: Flow chart of the system

2.3 Hardware system design

The hardware subsystem consists of the hardware components that makes up the system which includes the Esp32 Microcontroller/ Wifi board, the DHT11 sensor, Mq2 sensor, Mq9 sensor and Mq135 sensor. Figure 3 below shows the system circuit diagram which is a diagrammatic representation of the interconnection of the hardware materials that makes up the system. The Esp32 is responsible for collecting, processing and also uploading the sensor reading to the database while the DHT 11 sensor is used for sensing the temperature and relative humidity of the environment. On the other hand, the Mq2 sensor as a good CO_2 sensor to senses the CO_2 level, the Mq9 is used to sense CO level and the Mq135 is used to sense VOC level.

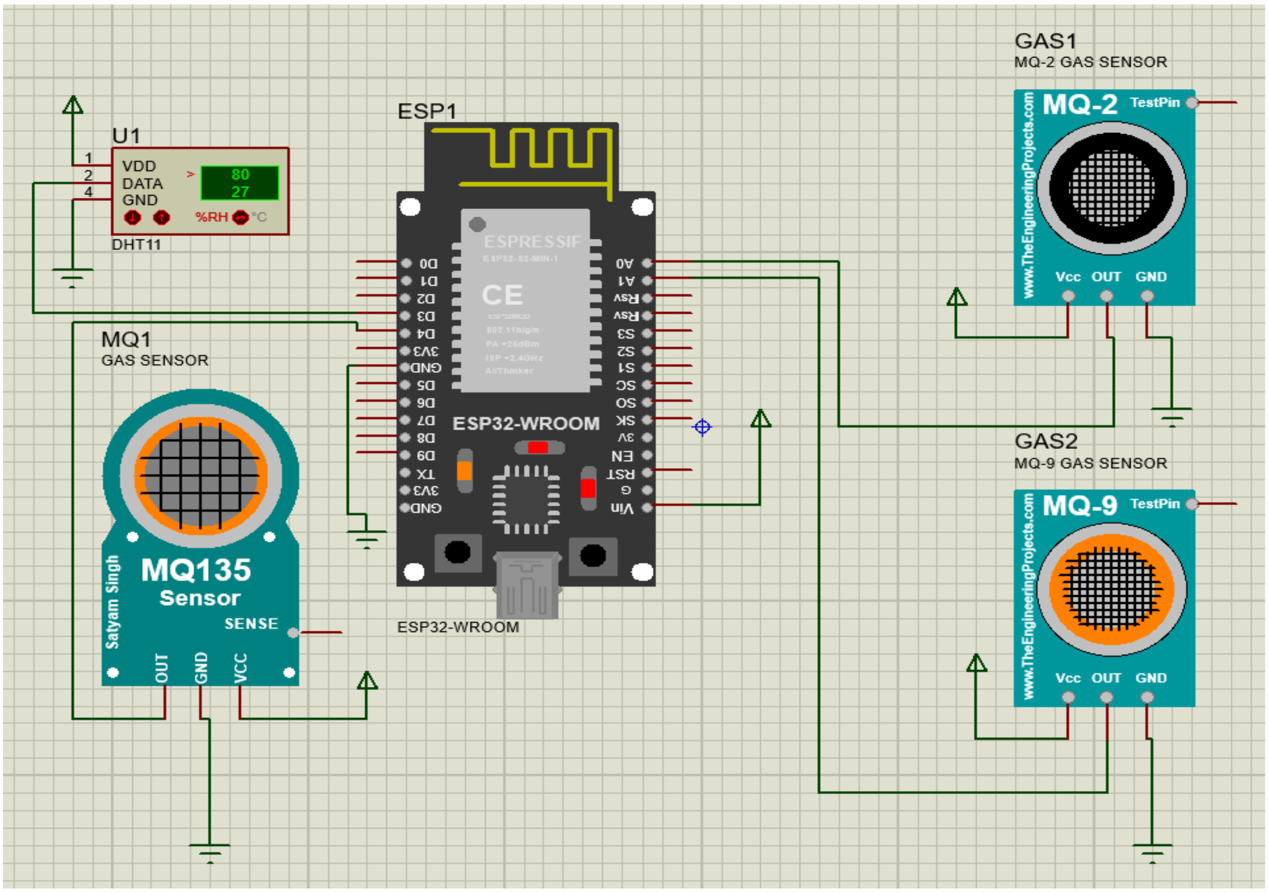

Fig. 3: System circuit diagram

2.4 Fuzzy logic controller

The fuzzy logic controller phase involves three main sections which are fuzzification, fuzzy processing, defuzzification. Fuzzification is the first step in the fuzzy logic system. It involves taking transforming the sensor readings which are crisp input values into fuzzy sets that can be processed by the fuzzy logic system. The fuzzy processing on the other hand is the core of the fuzzy logic system. It involves applying a set of rules to the fuzzy sets generated during fuzzification, to produce fuzzy output sets while defuzzification involves converting the fuzzy output sets generated by the inference engine into a single crisp value, which can be used as the system's output.

2.4.1 Fuzzy membership

To define how each point in the input space is mapped to a degree of membership between 0 and 1 fuzzy membership of Low, Medium and High has been created for each of the fuzzy inputs. From the fuzzy logic program which was implemented in Python programing language using Pycharm integrated development environment (IDE) a fuzzy membership chart was obtained which is a visual representation of the fuzzy membership of the fuzzy inputs. Figure 4 shows a snippet of the fuzzy logic implementation on Pycharm.

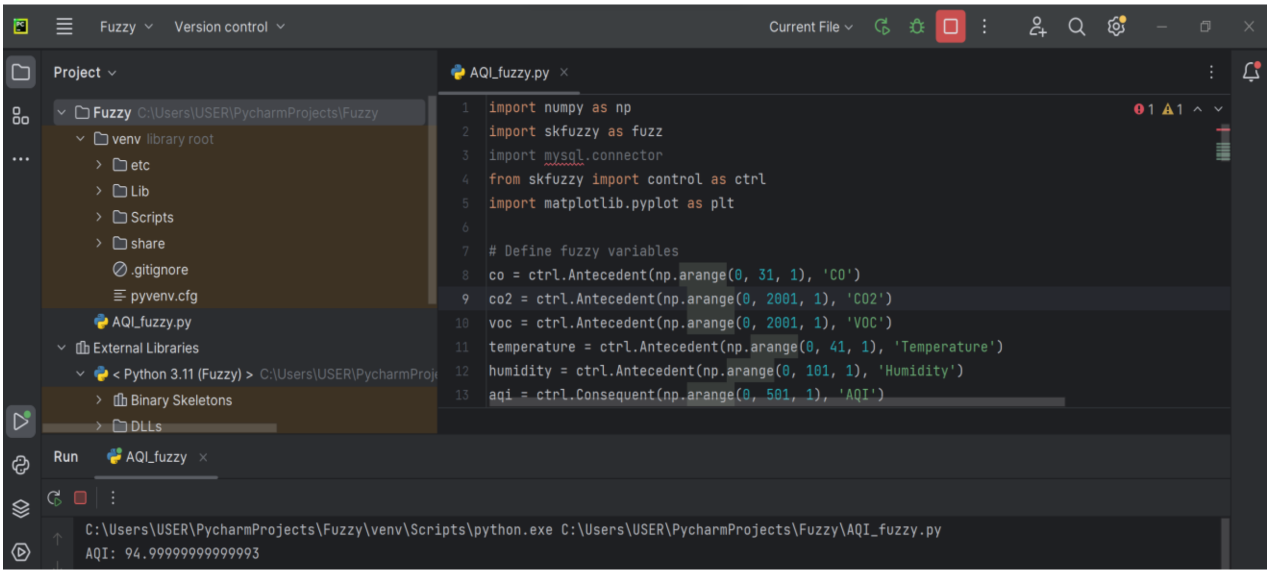

Fig. 4: Fuzzy logic code implementation on Pycharm IDE

i. Temperature (T)

In the implementation of the system, the temperature range from 0ºC to 40ºC has been considered. Where Low membership of temperature ranges from 0 - 15 °C. For medium membership it has range 15 - 30°C. And for high membership it has range from 30 - 40°C. Fig. 5 shows membership input diagram of temperature in °C with type trapezoidal

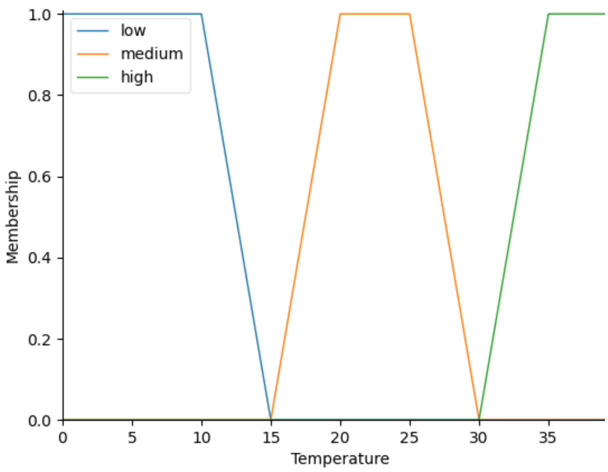

Fig. 5: Membership of temperature

ii. Humidity (H)

For the humidity value rang from 0% to 100%, the Low membership of humidity has a range from 0 – 30%, for medium membership it has range 30 – 70% and for high membership it has range from 70 – 100%. Fig. 6 shows the membership input diagram of humidity in % with type trapezoidal.

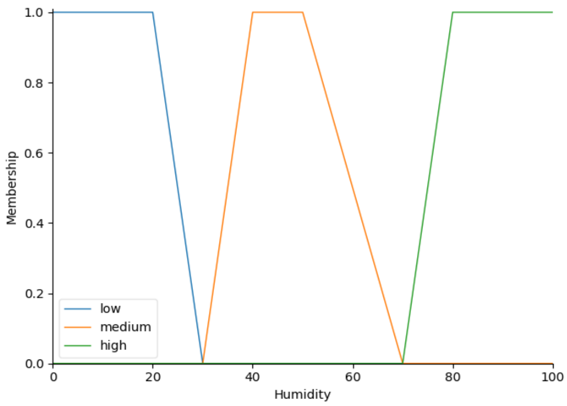

Fig. 6: Membership of humidity

iii. Carbon Monoxide (CO)

Considering the CO range from 0ppm to 30ppm, Low membership of CO has a range from 0 – 5 ppm for Medium membership it has range 4 –12 ppm and for high membership it has range from 11 – 30ppm. Fig. 7 shows the membership input of carbon monoxide (CO) in ppm with type trapezoidal.

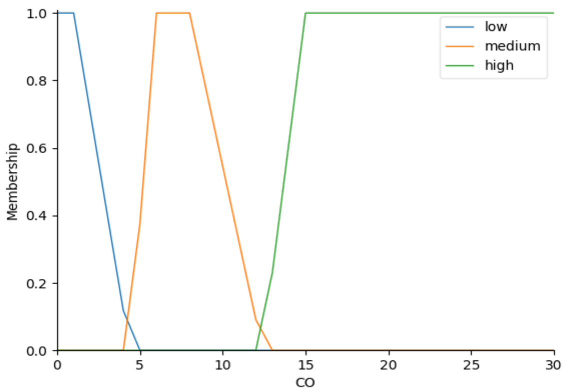

Fig. 7: Membership of carbon monoxide (CO)

iv. Carbon dioxide (CO_2)

For CO_2 range from 0 ppm to 5000 ppm, Low membership of CO_2 has a range from 0 – 600 ppm for Medium membership it has a range of 600 – 1500 ppm and for High membership, it has range from 1500 – 5000ppm. Fig. 8 shows the membership input of Carbon dioxide (CO_2) ppm with type trapezoidal.

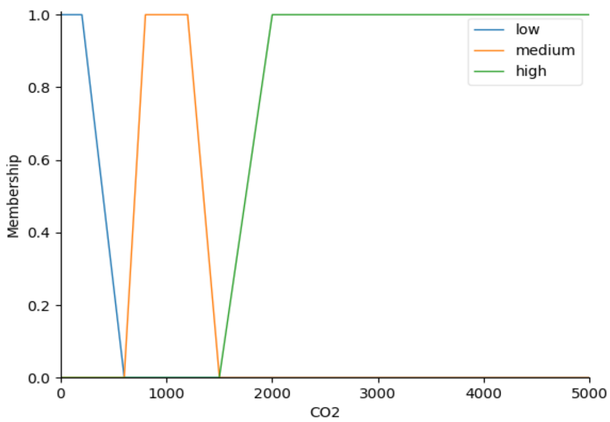

Fig. 8: Membership of carbon dioxide (CO_2)

v. Volatile organic compounds (VOC)

For VOC ranging from 0 ppb to 2000 ppb Low membership of VOC ranges from 0 – 300 ppb for Medium membership it has range of 300 –1000 ppb and for High membership it has range from 1000 – 2000 ppb. Fig. 9, shows the membership input of Volatile Organic Compounds (VOC) in ppb with type trapezoidal.

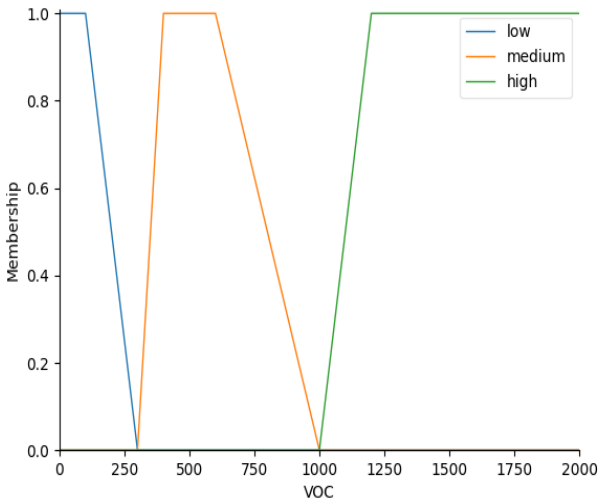

Fig. 9: Membership of volatile organic compounds (VOC)

vi. Membership fuzzy output

The membership fuzzy output refers to as the fuzzy result it used to determine the air quality report and health safety tip the user will receive. For the range of 0 ppb to 500 ppb, it has a Low membership of range from 0 – 50 for Good air quality, 51 –150 for moderate air quality, 151 to 300 for unhealthy air quality, 301 – 400 for very unhealthy air quality and 401 to 500 for hazardous air quality. Fig. 10, is membership input of Volatile Organic Compounds (VOC) in ppb with type Triangular.

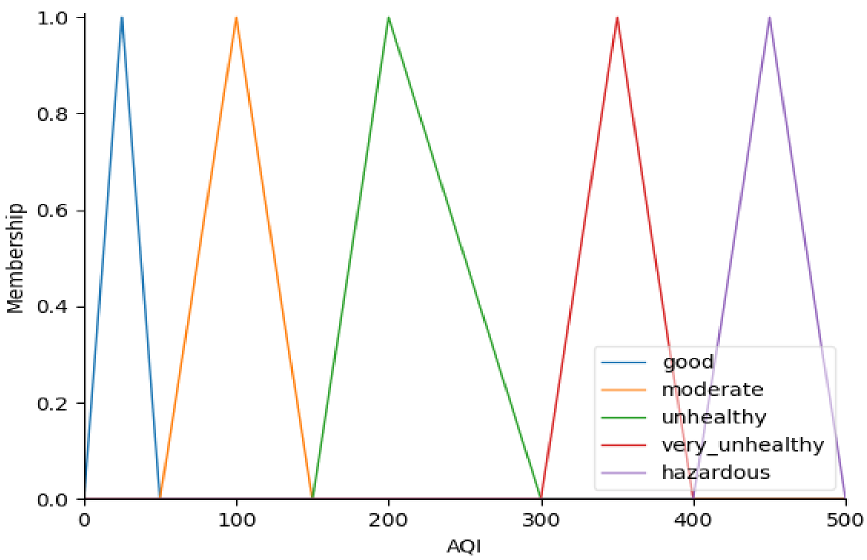

Fig. 10: Membership fuzzy output

2.4.2 Fuzzy rules

For the implementation of the fuzzy logic controller, nine fuzzy based rules were created. The following rules allows the fuzzy controller grade the air quality as good, moderate, unhealthy, very unhealthy or hazardous.

i. IF temperature is comfortable AND humidity is comfortable AND CO is low AND CO_2 is low AND VOC is low THEN air quality is good.

ii. IF temperature is hot OR humidity is humid OR CO is high OR CO_2 is high OR VOC is high THEN air quality is hazardous.

iii. IF temperature is cold AND humidity is dry AND CO is Moderate AND CO_2 is moderate AND VOC is moderate THEN air quality is moderate.

iv. IF temperature is comfortable AND humidity is comfortable AND CO is moderate AND CO_2 is low AND VOC is low THEN air quality is moderate.

v. IF Temperature is comfortable AND humidity is comfortable AND CO is high AND CO_2 is moderate AND VOC is moderate THEN air quality is unhealthy.

vi. IF temperature is hot AND humidity is humid AND CO is moderate AND CO_2 is high AND VOC is high THEN air quality is Very unhealthy.

vii. IF temperature is comfortable AND humidity is comfortable AND CO is moderate AND CO_2 is moderate AND VOC is high THEN air quality is unhealthy.

viii. IF temperature is cold AND humidity is comfortable AND CO is low AND CO_2 is low AND VOC is moderate THEN air quality is moderate.

ix. IF temperature is comfortable AND humidity is comfortable AND CO is low AND CO_2 is moderate AND VOC is low THEN air quality is good.

2.5 Mobile application

The mobile application is meticulously engineered to display data from various sensors on a detailed, user-friendly dashboard. The interface was developed using Flutter, a cross platform framework based on Dart. A JavaScript APIs was also written to collect sensor data from the MySQL database and the Fuzzy controller which is based on Phython programing Language, and transmit it to the mobile application for real-time display. The application is designed to present comprehensive real-time information on the fuzzy result and the sensor data which includes the temperature, humidity, CO level, CO_2, and VOC level. Also, utilizing the data gathered from the fuzzy controller, the mobile application intelligently suggests safety and health tips to users through an integrated in-app notification feature. Fig. 10a and 10b shows the screen shoot of the mobile application showing the carbon dioxide (CO_2) and carbon monoxide (CO) readings respectively while Fig. 11a is the screen short of the air quality index (AQI) dashboard which shows the result of the fuzzy logic process and Fig. 11b is the screen shot of the safety and health tips notification from the mobile application.

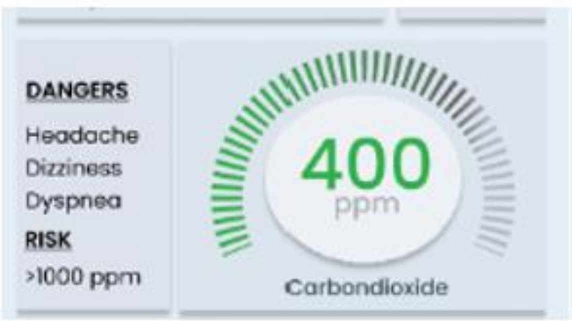

Fig. 10a: CO_2 reading

Fig. 10b: CO reading

Fig. 11: Air quality index dashboard

Fig. 11b: Health and safety alert screen

3. Results and discussion

The system proposed in this paper focuses on three major air contaminates namely CO, CO_2, and VOC and has been designed to align with the air quality evaluation standards set by Nigeria Air Quality Index to ensure that the system gives the right air quality warning and health/ safety suggestion which includes a proper ventilation approach. Fig. 12, 13 and 14 shows the effect of CO, CO_2 and VOC respectively on air quality. The results conform to the Nigeria Air Quality Index standard as the figures shows that when CO levels are less than or equal to 5 ppm, CO_2 levels are below 500 ppm, and VOC levels are under 300 ppb, the air quality is good. For CO levels between 4 and 12 ppm, CO_2 levels between 600 and 1500 ppm, and VOC levels between 300 and 1000 ppb, the air quality is moderate. Conversely, CO levels from 11 to 20 ppm, CO_2 levels between 1500 and 1750 ppm, and VOC levels from 1000 to 1500 ppb correspond to unhealthy air quality. When CO levels rise to between 20 and 25 ppm, CO_2 levels range from 1750 to 1850 ppm, or VOC levels are between 1500 and 1750 ppb, the air quality becomes very unhealthy. Finally, for CO levels above 25 ppm, CO_2 levels exceeding 1850 ppm, and VOC levels above 1750 ppb, the air quality index is hazardous.

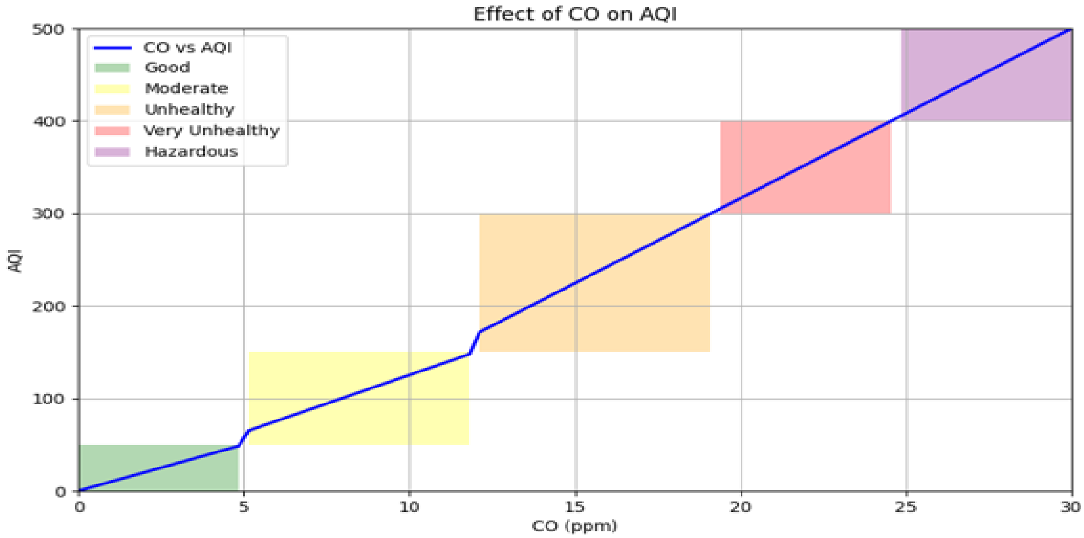

Fig. 12: Effect of CO on air quality

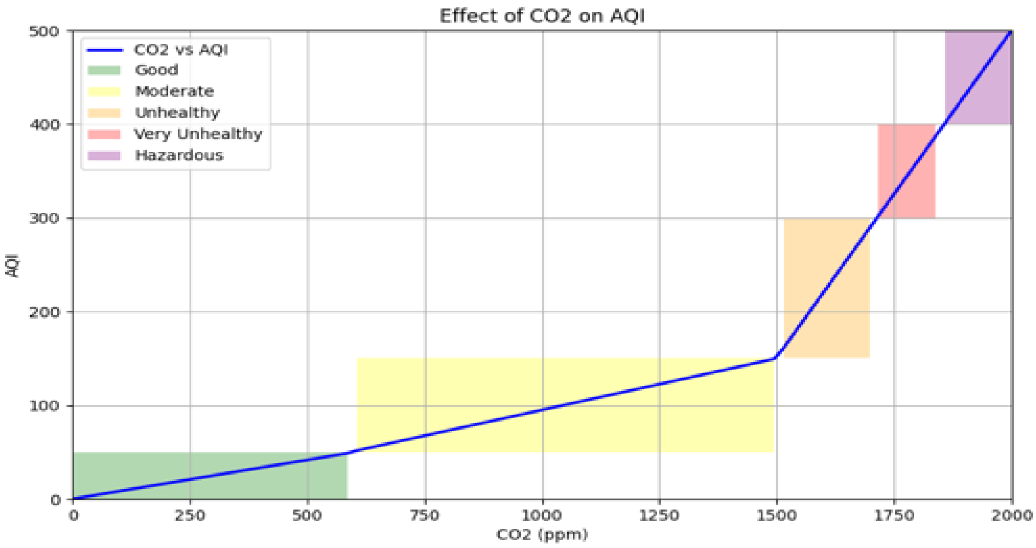

Fig. 13: Effect of CO_2 on air quality

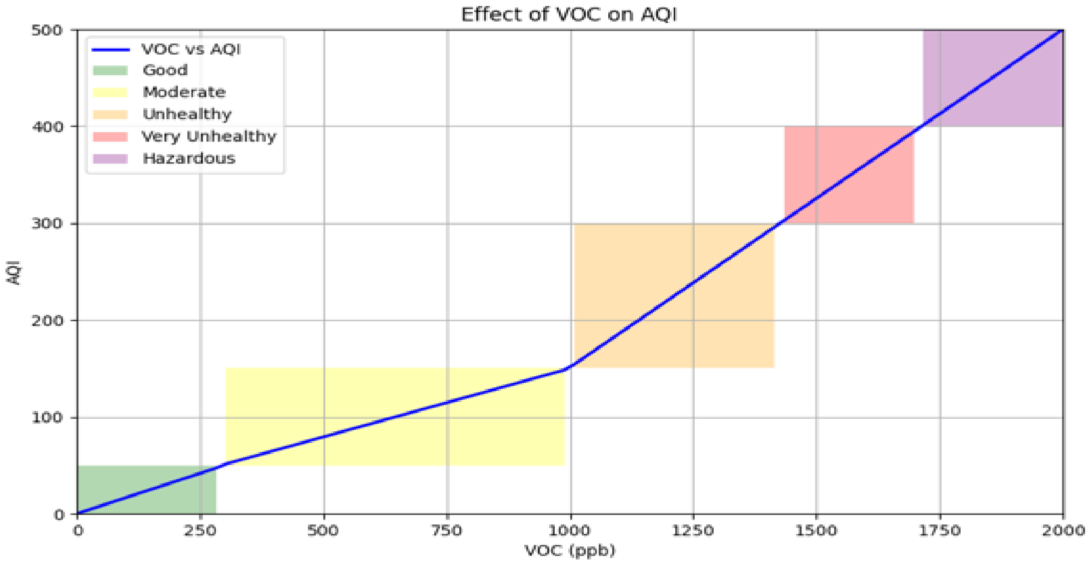

Fig. 14: Effect of VOC on air quality

4. Conclusion

In view of the result obtained from the indoor air quality monitoring and control system using fuzzy logic controller presented in this paper, a reliable solution for monitoring and notification of indoor air quality has been achieved. As a complete real-time air quality assessment and notification system, hardware and software components were integrated to create the system. The system uses a fuzzy logic controller to process the data and assure accurate air quality evaluation utilizing the data collected by the network of sensors, deployed to measure important air quality factors such as CO, CO_2, VOCs, humidity, and temperature**.** The integration of a mobile application as a user interface enhances user interaction by providing actionable insights and health recommendations, empowering users to make informed decisions about improving their indoor environment. The system's results align with Nigeria Air Quality Index standards as the test result shows that good air quality is defined as having CO levels of less than or equal to 5 ppm, CO_2 levels below 500 ppm, and VOC levels under 300 ppb. The air quality is moderate when CO_2 level is between 600 and 1500 ppm, VOC levels are between 300 and 1000 ppb, and CO levels are between 4 and 12 ppm. On the other hand, bad air quality is associated with CO levels between 11 and 20 ppm, CO_2 levels between 1500 and 1750 ppm, and VOC levels between 1000 and 1500 ppb. The air quality becomes extremely unhealthy when CO levels increase to 20–25 ppm, CO_2 levels range from 1750–1850 ppm, or VOC level is between 1500 and 1750 ppb. Lastly, the air quality index is dangerous for CO concentrations over 25 ppm, CO_2 levels over 1850 ppm, and VOC levels over 1750 ppb.

References

Babu, Y.A., Pallavi, V., Vagdevi, S. and Poojitha, N. (2024) Design and implementation of air quality monitoring system using FPGA.

Carslaw, N. (2024) September 16). Indoor Air Quality: Should we be worried? Retrieved from The York Policy Engine: https://www.york.ac.uk/policy-engine/news-and-blogs/indoor-air-quality/

Cynthia, B.B., Dharani, B.P., Nandhini, R., Sindhuja, P., Senthilkumar, A. and Raja, S. (2018) Proactive indoor air quality monitoring system. International Journal on Recent and Innovation Trends in Computing and Communication, 6(3): 133-138.

Household air pollution (2024, December 15). Retrieved from World Health Organization: https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health

Shamila, A., & Unni, D. (2022). An indoor air quality monitoring and controlling system. International Journal of Engineering Research & Technology, 11(06).

Sung, W.-T., & Hsiao, S.-J. (2021). Building an indoor air quality monitoring system based on the architecture of the Internet of Things. Journal of Wireless Communications and Networking, 2021(153).