AN IMPROVED AIR QUALITY MONITORING SYSTEM FOR INDUSTRIALIZED AREAS

Mohammed, S.H.[1*], Aliu, D.[2] and Idakwo, M.A.[3]

[1]Department of Operations Engineering, Nigerian National Petroleum Company, KRPC limited, Kaduna, Nigeria

[2]Department of Computer Engineering, Faculty of Engineering, Edo State University Uzairue, Nigeria

[3]Department of Computer Engineering, Faculty of Engineering, Federal University Lokoja, Nigeria

*Corresponding email: sali2k10@gmail.com

ABSTRACT

Air pollution is now a major contributor to mortality worldwide and this has become a burden to highly industrialized areas. Substances like ozone (O3), carbon monoxide (CO), nitrogen dioxide (NO2), sulfur dioxide (SO2), and particulate matter as experienced in Kogi State Nigeria poses significant threats to the health of the citizens, leading to both long-term and short-term conditions such as cardiovascular diseases, lung cancer, and respiratory infections. Therefore, monitoring these dangerous chemicals and airborne pollutants in industrialized areas is essential for alerting the public about the health dangers linked to elevated levels of these key pollutants. Thus, this paper developed an improved air quality monitoring system with the capability of detecting air pollution levels and transmitting real time data to the users. Leveraging IoT technology, the system connects to the cloud using NodeMcu ESP32 microcontroller for real-time online monitoring of carbon monoxide (CO) and liquefied petroleum gas (LPG) using MQ135 and MQ2 respectively and issues alerts when air quality reaches predefined thresholds. The developed system is engineered for high efficiency, reliability, and durability, in line with environmental and engineering standards.

Keywords: Air pollution, Internet of Things, Microcontrollers, Sensors, Pollution

1 INTRODUCTION

Air pollution regularly releases unpleasant odors, particles, and harmful gases into the environment. Depending on the type of pollutant and its concentration, the effect could be deleterious to humans who live or work near the polluted area over time [1]. Although, industrialization, deforestation, and rapid transportation growth have been attributed as the major causes of pollution in the developing countries, nevertheless, the level of awareness and control has remained low. This has significantly increased the citizens to respiratory illnesses [2]. The financial burden on the Governments may be enormous if the air quality continues to deteriorate. Hence, conventional air quality monitoring equipment are being deployed. pivotal tool. The conventional methods often rely either on manual handheld devices (that are inefficient and labor-intensive), or on wired systems (that are difficult to scale, bulky, and expensive). These systems often overlook factors like adaptability to certain industries and environmental factors, space constraints and the technical expertise of operators, thus limiting their wider adoption [3]. As the harmful effects of physical, chemical, biological, and radioactive pollutants on human health become more pronounced alongside economic growth and material advancement, there is an increasing demand for effective, affordable indoor air quality monitoring solutions. This need is driving the creation of innovative, wireless systems that can address these issues effectively. Hence, this paper developed an improved air quality monitoring system that can effectively monitor in real time carbon oxide (CO) and liquefied petroleum gas and alert the subscribers instantly.

2 LITERATURE REVIEW

Extensive research has been conducted in this area. For instance, [4] have critically evaluated the impact of cement industry air pollutant on the environment. [4] developed low power wireless area network for effective monitoring of air quality [3]. The system leverage on the internet of things to effectively measure the changes in the air quality. Ionascu (2024) proposed the calibration of nitric oxide, sulfur dioxide, and particulate matter for an improved detection of air pollution [5].

2.1 Air Quality Index

The air quality index (AQI) [3] is a widely accepted scale used to evaluate the air quality in a region by measuring the levels of various pollutants, including particulate matter, ozone, nitrogen dioxide, sulfur dioxide, and carbon monoxide. Each pollutant is assigned a numerical value, which is then categorized into a specific level of air quality, ranging from 'Good' to 'Hazardous'. These categories are represented by distinct colors, indicating the degree of health risk associated with the air quality, providing a clear and concise way to communicate air quality information to the public. An AQI value of 100 corresponds to the national standard for protecting public health, and values at or below 100 are considered satisfactory. However, when AQI values exceed 100, air quality becomes unhealthy, initially posing risks to sensitive groups, and eventually to everyone as the values continue to rise. The AQI provides valuable information for public awareness, policymaking, and implementing measures to protect public health during periods of poor air quality. The range of the AQI is described in Table 1.

Table 1. Air Quality Index Scale for Ozone and Particles Pollution [6]

AQI Color	Color Level	Index Values	Description of Air Quality
Green	Good	0 - 50	Air quality is satisfactory, and air pollution poses little or no risk.
Yellow	Moderate	51 - 100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.
Orange	Unhealthy for Sensitive Groups	101- 150	Members of sensitive groups may experience health effects. The general public is less likely to be affected.
Red	Unhealthy	151- 200	Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects.
Purple	Very Unhealthy	201- 300	Health alert: The risk of health effects is increased for everyone.
Maroon	Hazardous	301-Higher	Health warning of emergency conditions: everyone is more likely to be affected.

2.2 Internet of Things (IoT)

Internet of things as a transformative technology that simplifies human tasks by seamlessly integrating various devices and communication technologies [7]. It connects physical (sensors, communication devices wired/wireless) and virtual objects (virtual machines, web applications,), allowing for the collection and analysis of various data types from diverse applications through the Internet. Increasingly, organizations in a variety of industries are using IoT to deliver enhanced customer service, operate more efficiently, improve decision-making and increase the value of the business [8]. Overall, IoT technology is the foundation of modern pollution monitoring, allowing for efficient and effective environmental management.

2.3 Sensors

A sensor is a device designed for the detection of changes in its surroundings and producing a response in another system. It converts physical phenomena into a measurable signal, either as a digital signal or an analog voltage, which are displayed for further processing or human interpretation [9]. Sensors are majorly found in everyday devices, such as lamps that adjust brightness through touch, touch-sensitive elevator buttons, and as well as in numerous other applications often unnoticed by users. Sensor are in various types, like those that detect gases, particulate matter, temperature, and sound. These sensors provide essential real-time data, supporting informed decision-making and effective pollution control strategies, thereby safeguarding public health and the environment.

2.4 Environmental Health and Air pollution

Air pollution refers to the contamination of the air by harmful substances, known as pollutants. The pollutant can negatively impact the environment, human health, and other living organisms [1]. It has remained a significant environmental issue that poses major challenge in modern societies. The adverse effects of air pollution extend to natural ecosystems, human health, man-made structures, and wildlife. Furthermore, it contributes to climate change by intensifying the greenhouse effect, depleting the ozone layer, and causing acid rain which are global environmental problems of paramount concern. Air pollution can occur both outdoors and indoors, resulting from natural processes and human activities. While the deterioration of air quality poses a worldwide threat to human wellbeing, it is closely linked to environmental inequality. Differences in air pollution exposure and its effects are evident across countries, with developing nations facing more severe indoor air pollution. In these regions, organic fuels like wood and coal are commonly used for cooking and heating, and their combustion releases harmful pollutants, especially particulate matter, into homes.

3 SYSTEM DEVELOPMENT

The proposed smart pollution monitoring system comprises of hardware and software components. The hardware segment consists of various components like: Microcontrollers that process and analyze data. A lithium battery that provides backup power. An OLED display that shows real-time data. A power module that ensures reliable energy supply. Sensors that detect and measure pollutant levels. These hardware components work together to collect and transmit data.

3.1 Arduino UNO

The Arduino Uno R3 Microcontroller was adopted as the brain of the smart walking stick. The different sensors were attached to the board as it has fourteen (14) digital input and output (I/O) pins attached to the board. This ease scalability as more sensors can be added. Furthermore, it has six (6) analogue inputs, a USB connection, an ICSP reset button, and a power jack as shown in Figure 1 [10]. The Arduino Uno processes all the inputs from the different sensors and uses the programmed logic for decisions before sending signals to actuators like the buzzers and LEDs as feedback mechanisms to the user.

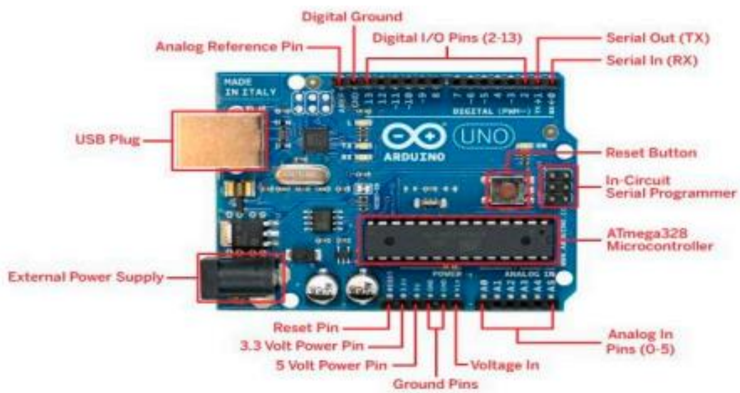

Figure 1. Arduino Uno R3

3.2 NodeMCU ESP8266

The NodeMCU ESP8266 shown in Figure 2 is an affordable and popular development board widely used for IoT projects [11]. It features a built-in Wi-Fi-enabled ESP8266 microcontroller, making it ideal for connecting to devices and networks. Its compact size and versatility allow it to interface with sensors, actuators, and peripherals through GPIO pins. Supporting multiple programming languages, including Lua, Arduino IDE, and Micro Python, it caters to developers of varying skill levels. Its strong community support and powerful features make it a top choice for this research.

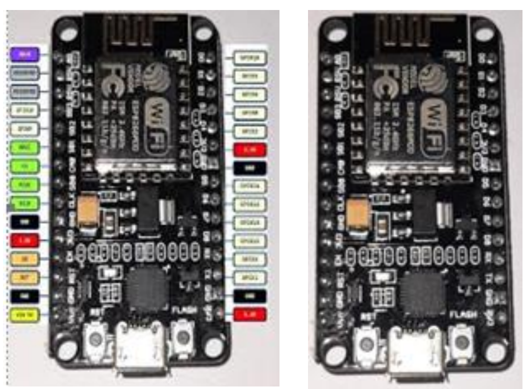

Figure 2. ESP8266 Node MCU 1st generation Development Board and Pin

3.3 MQ-135, MQ-7, and MQ-2 sensors

The MQ-135, MQ-7, and MQ-2 sensors shown in Figure 3 are essential components in this research as there play a critical role in detecting harmful gases. The MQ-135 sensor is a versatile air quality monitoring tool, capable of detecting a wide range of gases, including benzene, nitrogen oxides, and ammonia for both outdoor and indoor environments [11]. It provides valuable insights into pollution levels and enabling measures to maintain healthy living conditions and environmental sustainability. The MQ-7 sensor on the other hand, specifically designed for carbon monoxide detection. The MQ-2 sensor offers versatility by detecting combustible gases such as propane, methane, and hydrogen. Their unique ability various gases make it ideal for leakage and pollutant detection. These sensors detect gases by measuring changes in resistance, which directly correlates with the concentration of the gas. When connected to electronic devices or microcontrollers, they can monitor gas levels, automate control, and trigger alarms.

Figure 3. MQ2 and MQ135 Sensor [12]

3.4 Lithium Battery

A lithium battery as shown in Figure 4 provides a reliable backup power source, offering consistent and efficient energy during outages or critical situations. Its key features, including high energy density, long shelf life, and low self-discharge rates, make it an ideal choice for the developed system

Figure 4. Lithium Battery [13]

3.5 OLED Portable Display Unit

Organic Light Emitting-diode (OLED) screens [14] represented in Figure 5, offers a visual experience characterized by broad viewing angles, high contrast, and rich colors. It belongs to the display technology using organic compounds to generate light when electrified. Contrarily to the conventional liquid crystal display displays, OLEDs do not require a backlight, thus, enabling more flexible, thinner, and energy-efficient designs. These unique features make OLEDs a popular choice for various applications, including wearable devices, TVs, and smartphones where exceptional image quality and versatility are essential. The Software segment, on the other hand, comprises programming tools like Arduino IDE and the Blynk IoT application that facilitates remote monitoring and analysis of real-time data.

Figure 5. Organic Light Emitting-diode Display

3.6 Arduino IDE

The Arduino integrated development environment is a user-friendly software tool for programming Arduino microcontroller boards as shown in Figure 6. It simplifies development by allowing users to easily write, compile, and upload code. Featuring C/C++-based syntax, the IDE includes helpful tools like syntax highlighting, code auto-completion, and error checking to support efficient, error-free coding.

Figure 6. Arduino IDE

3.7 Proteus

Proteus [15] is a powerful software suite designed for electronic circuit design, simulation, and PCB layout, offering a comprehensive platform for creating, testing, and refining circuits in a virtual environment. By enabling digital design and simulation, it helps users save time and resources by reducing the need for physical prototypes and minimizing errors. Furthermore, it has an extensive library of components and an intuitive interface as shown in Figure 7.

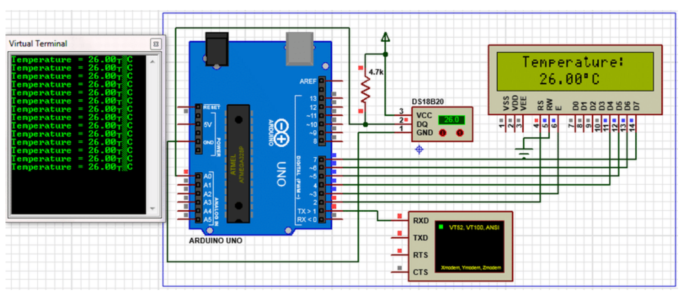

Figure 7. Circuit Simulation in Proteus

3.8 Blynk IoT

Blynk IoT is an innovative platform designed to simplify the creation of Internet of Things projects, accommodating users of all skill levels [16]. Its user-friendly drag-and-drop interface as shown in Figure 8 allows for easy development of custom control panels, while its cloud-based system enables real-time data monitoring, analysis, and visualization. Blynk seamlessly integrates with popular hardware like Arduino and Raspberry Pi, offering compatibility with a wide range of IoT devices. With features such as remote device management, data analytics, and alert systems, Blynk empowers users to develop advanced IoT applications with ease, making it ideal for this research.

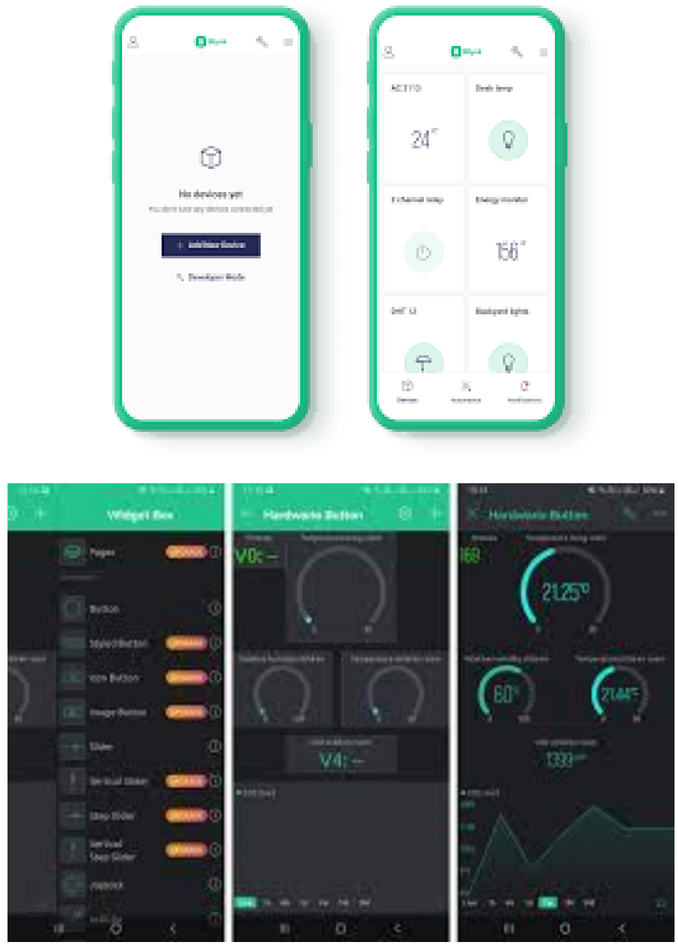

Figure 8. Blynk IoT Interface

3.9 Power Consumption by the Developed System

The system was design with a dual power source, from an AC-DC adapter and a battery bank. Each working independently and simultaneous providing the system an all-round -the-clock operation. The voltage of the supply is selected to be above the system operating voltage; hence it can be enough to power the system. The power demand for the proposed system is shown in Table 2.

Table 2. Power Demand by the Proposed System

Sn	Component	Voltage	Current	Power	Source
1	Esp 32 Wi-fi Module	5	0.206	1.03	Mouser Electronics
2	Mq 135	5	0.15	0.75	Elveta
3	Mq 2	5	0.15	0.75	Elveta
4	IC2 Backpack	5	0.05	0.25	Addicore
5	LCD 16x2	5	0.102	0.51	Addicore
6	LED	2	0.02	0.04	Stream light
		Total	0.678	3.33	

The total current and power drawn by the system is 0.678A and 3.33w respectively. Two lithium battery of 3.6v each were connected to meet the voltage supply requirement using equation (1) during the system design.

$$BatteryVoltage = E_s > D_v \tag{1}$$

Where Vs is the Supply Voltage, Dv is the Device Operating Voltage. The electromagnetic force in series was evaluated using equation (2).

$$E_s = \sum_{k=1}^{n} E \tag{2}$$

To evaluate the backup-time by the lithium battery (3.6v, and 3.6A from the lithium battery description) equation (3) was adopted.

$$B_T = \frac{B_C(AmpsHour)}{I(Amps)} \tag{3}$$

Where B_T is the Battery Backup-Time, B_C is the Battery capacity, I is the current Load. Therefore, the estimated operating time of the system is 5.3hours provided all physical condition remain constant. Recall that the circuit demand 3.33W of power. Hence, it is expedient to select an effective transformer for the ac-dc conversion. The transformer is the center hub of power for any AC-DC conversion circuit power reliance system. Using a tolerance of 20% to account for heat and other physical conditions, the transformer required was evaluated using equation (4).

$$P_{Transformer} = P_{circuit}(1+T) \tag{4}$$

A transformer with a power rating greater than 3.995w is required. The voltage selection of the transformer is determined by the battery voltage. The transformer voltage must exceed the battery voltage to ensure efficient charging. Given the battery bank voltage of 7.6V and considering market availability, a step-down transformer from 220VAC to 12VAC was selected. Considering factors such as size, cost, availability, and reliability, a transformer rated at 12W, which exceeded the required 3.995W was chosen.

Selecting Voltage Regulator

Given the required voltage of the regulator: The current requirement is calculated using the mathematical expression given by equation (5).

$$I = \frac{P_{transformer}}{V_r} \tag{5}$$

The available regulator in the market is rated at 1A, which is greater than 0.799A, and thus, it was selected for the design.

Selection of Smoothing Capacitor

To select the smoothing capacitor for the AC-DC converter, equation (6) was used.

$$C = \frac{I}{2 \times f \times Vpp} \tag{6}$$

Where: I = load current in amperes. F is the frequency = 100Hz (Full wave rectifier), Vr is the maximum ripple voltage in volts = 1v. The nearest to this in the market is 2200uf thus it was chosen for the work. From the values obtain from equation (1) to (5) the matching components value where select from the proteus library to design the circuit prototype as shown in Figure 9.

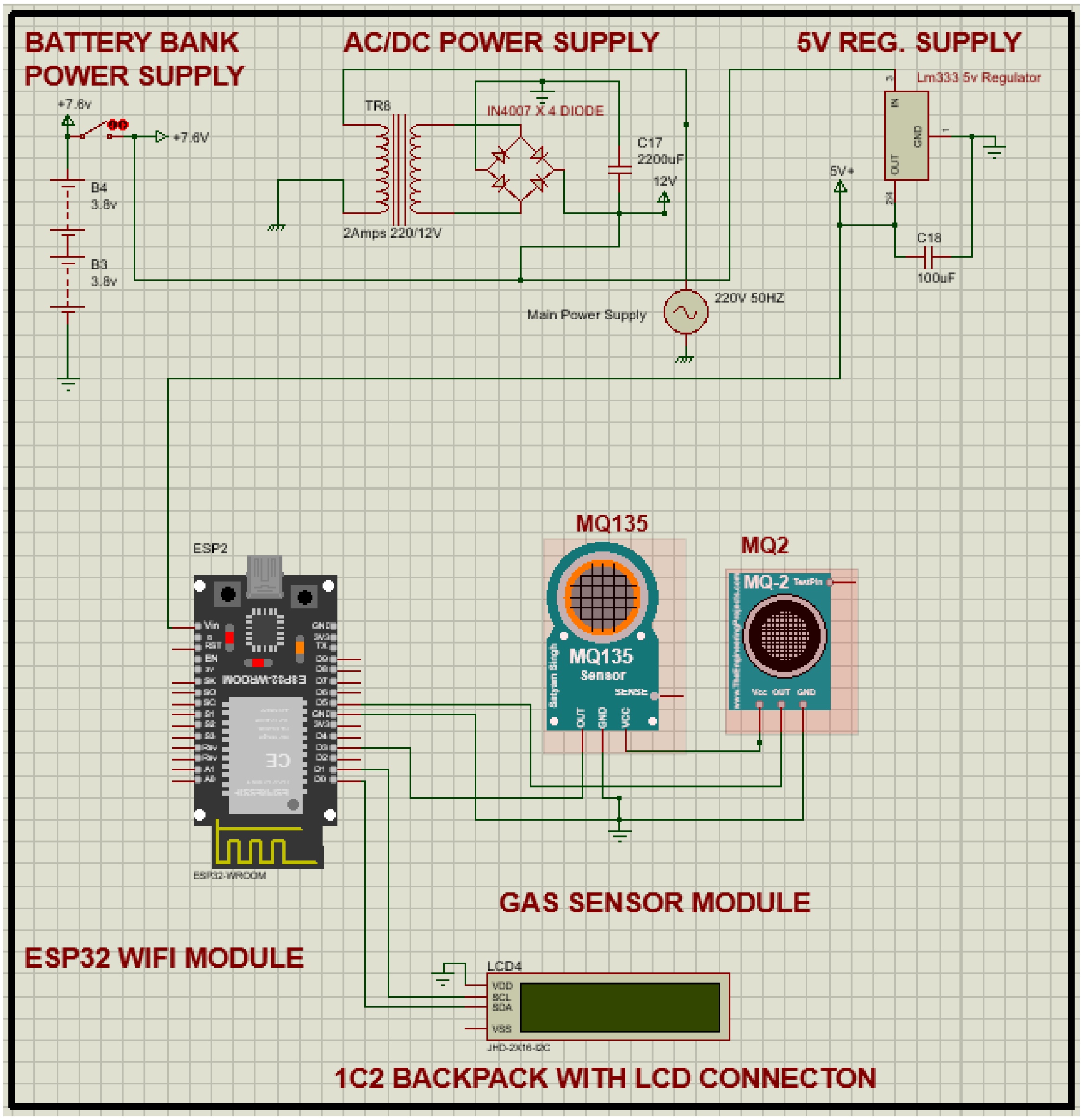

Figure 9. Circuit Design Using Proteus Software

Packaging

To ensure that the developed circuits are well fit into a portable package, the casing dimension were first designed before printing using a 3D printer. The step-by-step design showing the detailed isometric view (left, right, back, front, south-west and north-east) is presented in Figure 10.

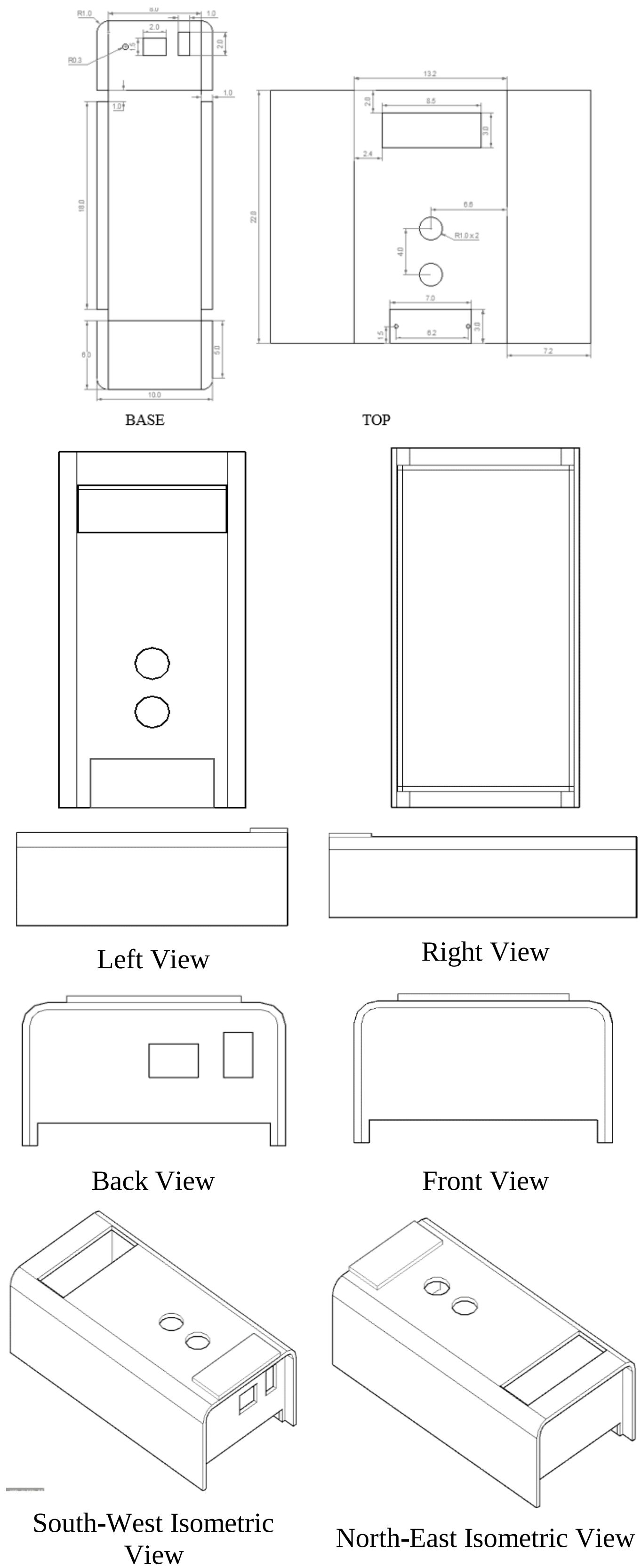

Figure 10. Orthographical Projection

4 RESULTS AND DISCUSSION

The designed circuit was neatly enclosed within the 3D-printed casing, as illustrated in Figure 11. From Figure 11, the developed system casing is compact and portable, making it highly convenient for housing the circuit. This design facilitates easy deployment in industrial areas while allowing remote access to environmental pollutant readings.Hence, ensuring practicality and efficiency.

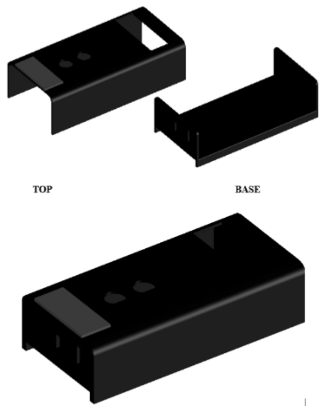

Figure 11. Developed System Casing

4.1 Proximity Sensor Evaluation

To ascertain the developed system sensitivity to pollutant, MQ135, and MQ2 sensors distance were varied from a LNG pollutant sources. The results obtained from the variation of the MQ135, and MQ2 sensors to the LNG pollutant sources are prensented in Table 3 and Table 4 respectivly. From Table 3 and Table 4, it is seen that as the LNG source moves closer to the sensing element, indicating a higher concentration of gas, the sensor's resistance decreases. This inverse relationship causes an increase in voltage, in line with Ohm's Law, which states that voltage across a conductor is directly proportional to the current flowing through it, given a constant resistance. Therefore, a lower resistance results in a higher voltage for a given current. This behavior confirms the sensors' effectiveness in detecting gas concentrations. Hence,the closer the pollutant source to the sensor, the more significant the reduction in resistance, thereby enhancing the sensor's ability to detect and respond to gas presence accurately.

Table 3. MQ135 Sensor Proximity to Gas Pollutant

Gas Proximity (cm)	Resistance (r)	Voltage (v)
1	2.1	3.1
5	3.8	1.2
10	4.19	0.88
20	4.29	0.67
30	4.47	0.58

Table 4. MQ2 sensor distance variation with LNG

Gas Proximity (cm)	Resistance (r)	Voltage (v)
1	1.8	4.3
5	5	2.6
10	6.25	2
20	6.6	1.7
30	7	1.5

4.2 Cabon Monoxide Detection

The developed system was further subjected to the fluctuations in carbon monoxide (CO) levels over a 40-minute period during wood combustion. The response of the system with measurements taken at 5-minute intervals is presented in Figure 12. From Figure 12, at the 5-minute mark, CO concentration begins at 10 ppm, just before the burning wood was placed into an enclosed space, allowing smoke to accumulate. After enclosure, CO levels gradually rise, eventually reaching hazardous levels, indicating the increase in pollutants and making the air unsafe for breathing. The graph also suggests a temporary clearing of the air as the smoke density decreases but shows a subsequent increase due to continued burning.

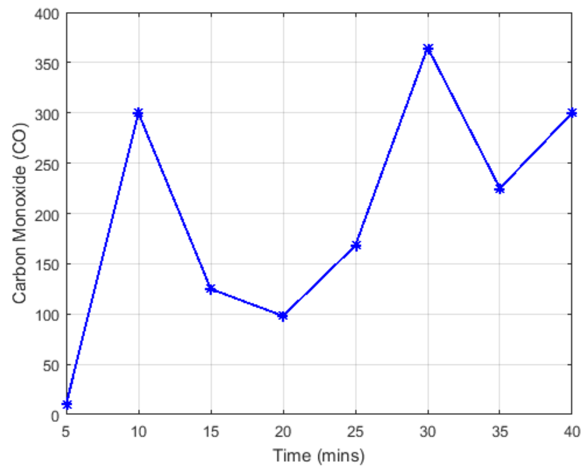

Figure 12. Carbon monoxide detection

4.3 Air Qualiity Index

To ensure adequate air quality measurement, the sensor was placed in an enclosed space and exposed to a container of petroleum. The observation from the experimental setup is shown in Figure 13. Figure 13 shows the changes in the Air Quality Index (AQI) over a 40-minute period, with measurements recorded at 5-minute intervals. Initially, at the 5-minute mark, the AQI is 24, indicating good air quality and safe conditions. However, after placing the sensor in an enclosed space and exposing it to a container of petroleum, the AQI steadily rises, eventually reaching dangerous levels, signaling an increase in pollutants and making the air hazardous to breathe. After 10 minutes, the petroleum container was closed, and as time passed, the AQI began to decrease. This consistent drop, observed in 5-minute intervals, reflects the dispersion of pollutants, leading to an improvement in air quality over time.

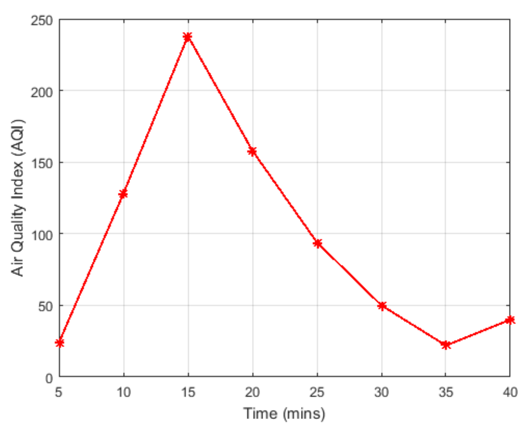

Figure 13. Air quality index measurement

4.4 Developed System Graphical User Interface

The developed improved air quality measurement graphical user interface allows users to monitor the air quality remotely as shown in Figure 14. The system features a user-friendly interface that enables real-time monitoring of environmental pollutants. The developed module can be accessed and controlled remotely via an intuitive frontend interface. This interface seamlessly integrates with the ESP32-WiFi module, which continuously transmits real-time readings to ensure up-to-date data. This design provides a reliable and robust solution for efficient environmental management.

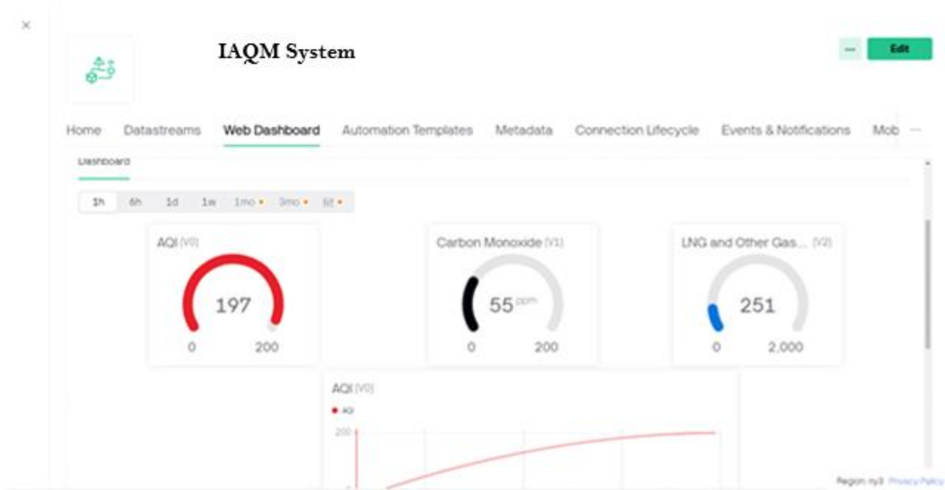

Figure 14. Developed Graphical User Interface

5 CONCLUSIONS

This paper presented the design and implementation of an improved air quality monitoring system equipped with a user-friendly interface for industrialized environments. The proposed system demonstrates high efficiency in accurately detecting and measuring key air pollutants, coupled with real-time data acquisition and cloud-based visualization through IoT integration. Its ability to issue alerts when pollutant concentrations exceed predefined safety thresholds enhances environmental awareness and facilitates prompt decision-making by users and relevant authorities. In addition to its precision and responsiveness, the system is optimized for low power consumption, cost-effectiveness, and reliable long-term operation making it suitable for continuous deployment in industrial zones and urban centers. The design ensures compliance with environmental monitoring standards while maintaining durability and scalability. Overall, this work contributes to advancing smart environmental monitoring solutions that promote healthier, safer, and more sustainable living conditions.

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