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LOW POWER CONSUMPTION FOR O_2 AND CO GASES MEASURING BASED IoT SYSTEM AT CONFINED SPACE AREA

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Abstract:

Confined spaces such as tanks pose significant risks to workers due to limited airflow and hazardous gas accumulation. Occupational Safety and Health Administration OSHA in confined space requirement mentioned the oxygen (O_2) concentration for confined spaces is typically between 19.5% and 23.5%, while carbon monoxide (CO) levels should remain below 5 ppm to ensure a safe working environment. The absence of real-time monitoring increases the potential for accidents and threats to worker safety based on. With real-time monitoring, the standby person (SP) can stay more alert to gas concentrations in the confined space and helping to respond quickly to any dangerous changes. This study aims to develop a portable device for low power consumption gas measurement system for O_2 and CO using Internet of Things (PCGIoT) technology that providing remote monitoring capabilities to ensure safety. The system's performance was analysed of its power consumption and demonstrating its ability to deliver accurate, real-time data. The results demonstrate the system's ability to effectively monitor gas levels in confined spaces to ensuring safety by detecting changes in carbon monoxide (CO) and oxygen (O_2) concentrations. The findings demonstrate that by detecting variations in CO and O_2 concentrations, the system can efficiently monitor gas levels in tight places to guarantee safety. O_2 concentrations often fall as CO levels rise. This has a track record of using the Internet of Things. Additionally, because PCGIoT devices use very little current, batteries last for around 40 hours, making it a good option for continuous monitoring while reducing exposure to hazardous gas levels and all the hazards that come with it. With data accessible remotely, the device provides the most practical way to continually monitor gas safety for workers in restricted spaces.

Keywords:

IoT, Confined Space, Gas Detector, ESP32, E-Paper Display

Introduction

Confined spaces are areas with restricted access and egress, partially restricted ventilation, and potentially toxic atmospheres that can pose serious risks to workers in the majority of industries. Tanks, ships, silos, sewers, and subterranean chambers are a few examples of the habitats. A worker is exposed to many dangers when working in a restricted environment. Because of the restricted air exchange in the tight environment, oxygen depletion is one of the most significant dangers. Hypoxia is caused by concentrations below 19.5%; a sufferer will experience light headedness and confusion, lose consciousness, and eventually death. (Lakshmipriya et al., 2019; Stefana et al., 2021; Figueiredo et al., 2020). Additionally, hazardous atmospheres that may include dangerous gases like carbon monoxide, hydrogen sulphide, and methane can be found in confined places. These harmful compounds can cause poisoning, respiratory issues, and even death when breathed. (Akano et al., 2024; Arifin et al., 2024; Selman et al., 2019) . Furthermore, there is a significant risk of fire and explosion when combustible gases and vapours are present in small areas. Combining an ignition source (such as welding equipment or electrical sparks) would cause these catastrophic occurrences, which would expose personnel to the air and have extremely deadly end effects. (Wang et al., 2024; Li et al., 2021). Safe entrance and working procedures inside confined spaces are particularly crucial because of the severe type of injuries, deaths, or considerable financial loss. All this

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requires deep knowledge in understanding the possible hazards; introduction of various safety precautions by using advanced technology for real-time monitoring will be able to mitigate all these risks. Traditional methods in confined space safety have, by and large, utilized either manual monitoring or portable gas detectors where the observations can only be made by entry people. The major flaws present within the two approaches include: human error, inability to offer timely monitoring, and inaccessibility of remote or dangerous site. For measuring carbon monoxide (CO) and oxygen (O_2), conventional gas detectors typically use three broad classes of sensors: electrochemical, metal oxide semiconductors (MOS), or infrared (Kong et al., 2023; Buček et al., 2023).

Electrochemical sensors function through an electrochemical reaction between the target gas and the electrode inside the sensor. Such sensors are very sensitive to and accurate with regard to certain gases, making them most applicable to low levels of CO and O_2, for instance (Williams, 2020). It can interfere with other gases, as well as drift problems which require periodic recalibration (Alam et al., 2024).

Metal Oxide Semiconductor (MOS) sensors perform through changes in electric conductivity in metal oxide semiconductor materials when exposed to target gases. Such advantages of cost-effectiveness and multisensory detection can be found with these sensors. Nevertheless, it offers less specificity and so is swayed by other gases as well as environmental factors such as temperature and humidity (Magar et al., 2023; Goel et al., 2023).

Infrared sensor (IR) works via the absorption of infrared light by the target gas; such sensors are typically more selective and not much influenced by interference with other gases compared to the case of MOS sensors (Hao et al., 2023). This went further to say that these IR sensors are also due to a very complex calibration procedure justified with the reason that other sensors will use differently lower costs than those expensive IR sensors (Ou et al., 2022; Zhang & Wu, 2004). This elaborates the merits and demerits of each type of sensor to measure CO and O_2 gas detection.

These conventional gas detectors only give localized measurements because the sensor is located at the entry point of the confined space. This limited location would not cover much of the confined space area where there might be hazardous gas concentrations. Further, the reliance on manual reading and absence of real-time data monitoring can lead to an increase in accident risk. Not having real-time data means that the Standby Person (SP) will not be able to immediately adapt to changes in gas concentrations within the confined space, affecting the early response for what could be life-threatening events. In recent years, great steps have been made by innovations toward developing sophisticated modern systems that have improved gas monitoring systems. For example, fixed gas detection systems that continuously monitored hazardous gases from fixed-location sensors installed in the confined space have been developed. However, there is limited real-time data for mobile workers within the space (Suhendar et al., 2024; Spandana & Devi, 2023; Abdalla et al., 2018). Revolutionized by the advent of IoT technology, confined space safety has dramatically changed due to real-time data collection, remote monitoring, and improved decision-making. Thus, an IoT-based system uses a network of interconnected sensors, actuators, and gateways that get parameter data from the field such as gas concentrations, temperature, humidity, and worker location. The data can be wirelessly sent to a central monitoring station for real-time analysis and intervention (Guerrón et al., 2023; Zong et al., 2025).

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The Internet of Things has many uses in cramped areas. Wireless sensor networks can serve as data carriers and collectors, as demonstrated by the development of an Internet of Things-based system for real-time gas level monitoring in a limited environment (Ayyappan et al., 2024; Ali et al., 2022). Another preliminary study details the use of wearable sensors to monitor workers' vital signs and position in a restricted area in order to guarantee worker safety and enable prompt emergency response. Advanced levels of sophistication and efficacy in confined space monitoring solutions have been made feasible by the quick development of several IoT technologies (Chaudhari et al., 2022; Praveen Sharma et al., 2023; Mohamad et al., 2023; Ali et al., 2014). The modern-day confined space monitoring systems face a host of challenges. The earlier approaches often used a single point measurement at the entry point of the confined space. The restricted position makes it unable to cover the entire area or zone within the confinement; thus, areas surrounding the confined space may have unnoticed hazardous gas concentrations. Also, real-time data is not available for closed spaces, making the workplace a potential site of accidents regarding the safety of the workers. Without real-time data, the SP may not be able to react fast to a hazardous situation since he may not know what is happening inside the confined area and the gas concentrations involved. Moreover, dependency on older gas measurement instruments causes high-power consumption, which reduces the life span of these devices and increases the capital and operating costs. The obstacles to be dealt with include proposing and implementing a new monitoring system with an expanded range, the capacity to be accessed remotely, to allow real-time data monitoring at very low power consumption rates. Such a solution would address the aforementioned problems, ensuring that very highly increased efficiency and security are achieved in critical operations within limited spaces. The objective of this research is to bring about something new completely by developing and evaluating an IoT-based system for increased safety and effectiveness, overcoming the shortcomings of the existing confined space monitoring systems. To be specific, the research and development of a portable O_2 and CO gas monitoring system emphasizes the design of a small, portable device that could accurately detect the amounts of both gases in restricted environments. The incorporation of an IoT platform becomes possible with the gas measurement system availing real-time data transmission and remote monitoring, and analysis. The data is accessible for the real-time monitoring of O_2 and CO gas levels, as well from remote access as well. To assess the power consumption characteristics of the built IoT system as well as for maximizing energy efficiency and operational lifespan, the power consumption of this system can be analysed based in time operation under the limited area. This study will enhance confined space safety by enabling a more practical and efficient mode of keeping track of dangerous environments and reducing the associated hazards.

Methodology

Block Diagram PCGIoT

Portable gas detector devices are wise safety equipment in a confined environment like cities, restricted spaces, and industrial sites where toxic gases may occur. These devices help users monitor the presence of gases and notify unsafe situations, such as low oxygen or explosive gases, that may lead to accidents or health hazards. Due to continuous technological changes in recent years, portable very reliable, compact, and simple devices have been developed. Sensors typically interfaced into IoT systems also make possible real-time monitoring and quick actions, especially in high-risk places. This chapter reviews the progress made recently in portable gas detection, including sensor types, the Internet of Things' involvement in monitoring, and strategies for maximizing power consumption for longer operation. This

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section explains about developments in portable gas detection, including types of sensors, the role of IoT in monitoring, and methods to optimize power usage for extended operation. Development of system consist of three part which is input, processing and output. The input including are oxygen and carbon monoxide sensors that functioning for measurement the quantity of gases at surrounding. The second part is processing where the ESP32 chip is use. Lastly, the buzzer for alert alarm and E-ink display as the output was use in displaying the current value of oxygen and carbon monoxide gas. Figure 1 shows the block diagram of PCGIoT system.

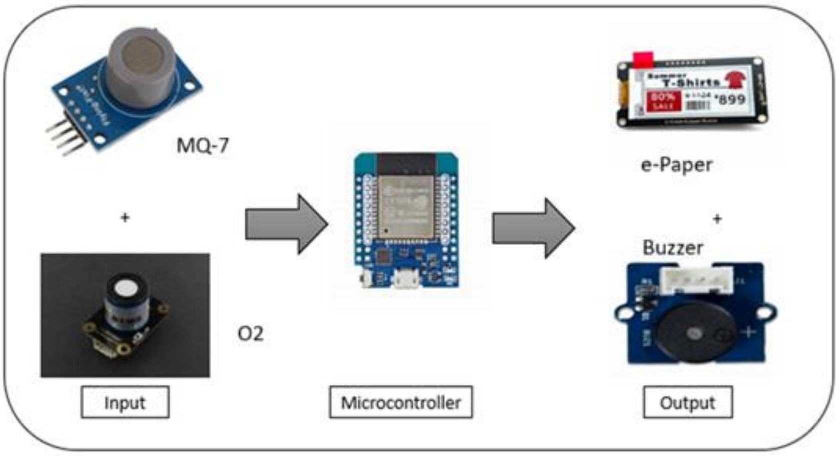

Figure 1: Block Diagram for PCGIoT

As the input, the MQ-7 Gas Sensor and the Electrochemical Oxygen sensor are used in measuring the level of O_2 and CO. These sensors are indeed fundamental to collecting information for monitoring safety conditions as well as for assessing environmental pollutants. MQ-7 Gas Sensor has been ideally suited for various applications ranging from domestic areas to industrial facilities but specializes in detection of CO with utmost sensitivity. The device works on the principle of a tin dioxide layer that changes resistance in response to CO enabling precise measurement of CO. Robust construction of MQ-7 sensor consists of micro-AL2O3 ceramic tube, stainless steel mesh for explosion avoidance, and a nickel-chrome alloy heater that maintains ideal operating conditions, which allows it to detect CO in the range of 20 to 2000 ppm. It provides very high precision and stability when measuring the oxygen level, the Electrochemical O2 Sensor is ideally suited for places like mines and warehouses with requirements for air circulation. It uses the inter-inter communication (I2C) interface for communication, and its rugged construction ensures reliability even when used for long periods. Together, these sensors provide vital information for ensuring a safe and healthy environment. It is sensitive up to 0.15% Vol and has a range from 0 to 25% Vol, with upper limit measurement of 30% Vol. The sensor works condensation free from -20°C to 50°C, between 0 and 99% RH. It is applicable for any atmospheric pressure conditions and tolerably used up to ±10%.

Micro-Processor Circuit: The ESP32 D1 Mini board is really tiny and compact; it is multifunctional and quite close to being the complete wireless communication module with Bluetooth and wi-fi that would serve for wireless communication applications and Internet of Things (IoT) projects. Being neat and small makes it well-engineered for extensive features to be packed into a practical solution for limited areas. Major functions of this board include Dual

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Mode Bluetooth (Classic and BLE) with standard interference-free 2.4 GHz transmission capabilities. This is the ideal hardware for smooth data transfer and cross-platform networking. The ESP32 D1 Mini board has implementation of the ESP8266 microcontroller, which makes it a great board in terms of connectivity for Wi-Fi applications; to be precise, it's useful in 802.11 b/g/n standard applications on 2.4 GHz bands. This particular board has a dual-mode Bluetooth, as it supports Bluetooth Low Energy (BLE) and Classic connections. In addition, it houses 4MB of flash memory built in for better data storage. Operating voltage is 3.3 V. GPIO, which is meant for general purpose input/output operations has several such pins, thus making it amendable to a variety of uses. The board can be supplied by an external power source or by 5V supply through USB, making it widely used. Its small size, indeed, makes it possible for work in areas which-prevent the larger devices.

Lastly the 2.13-inch e-Paper display is used as the output display. It is a low-power, high-contrast screen ideally suited for applications such as electronic shelf labels, IoT displays, and other battery-powered devices where long-term visibility and minimal energy use are priorities. This Active-Matrix Electrophoretic Display (AMEPD) utilizes bi-stable technology, allowing the last displayed image to remain visible even after power is removed, thus reducing energy consumption significantly. Operating in a pure reflective mode with no need for backlighting, the display provides a clear, high-contrast view that can be comfortably read even in bright light conditions. With a 122x250 pixel resolution, the display can be used in both landscape and portrait orientations, which is valuable for displaying flexible content. Its anti-glare, hard-coated surface further enhances readability from wide viewing angles, making it adaptable to indoor and outdoor environments alike.

Architecture System for PCGIoT

The architecture system for PCGIoT begins with the initialization of the system. When the system is powered on, the sensors O_2 and CO will start working with reading the surrounding gases and display data at e-paper display in percentage for O_2 and ppm for CO. If the value of CO and O_2 sensor reading exceed the limit then a buzzer will sound continuously until the sensor data returns to the normal value (O_2 19.5% until 23.5%) and (CO 5ppm). The data also being transmit to the Thinger IO platform, where it will be displayed on a dashboard Thinger IO and also the data will be record on the cloud. Figure 2 shows flow of architecture system for PCGIoT.

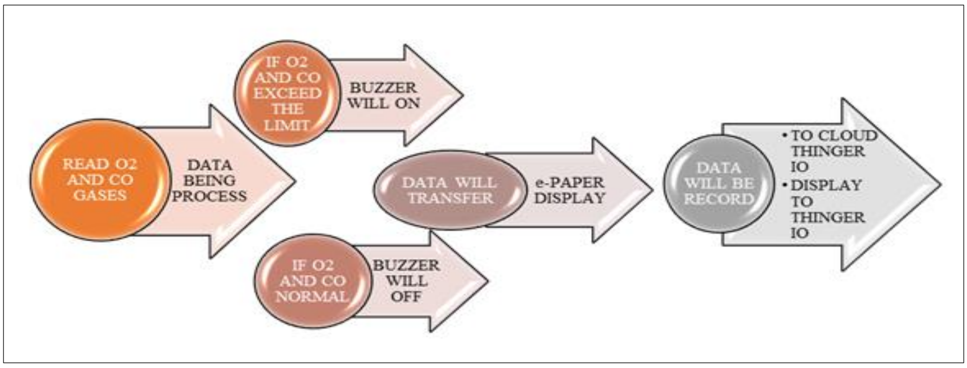

Figure 2: Architecture System PCGIoT

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Schematic Design PCGIoT

The schematic design had created using fritzing software. Fritzing is an open-source hardware initiative that make electronics accessible as a creative material for anyone. In Figure 3 show the components connected to microcontroller ESP 32 for *PCGIoT* system. The two gases sensor are used on this system where the O_2 and CO as the input. ESP 32 will be processing the data from sensors and the result will be transfer to Thinger IO. The buzzer is functioning as indicator when the sensors measuring exceed the limit. Lastly e-Paper is used as the display because of low power consumption and the graphic display will remaining when the power off.

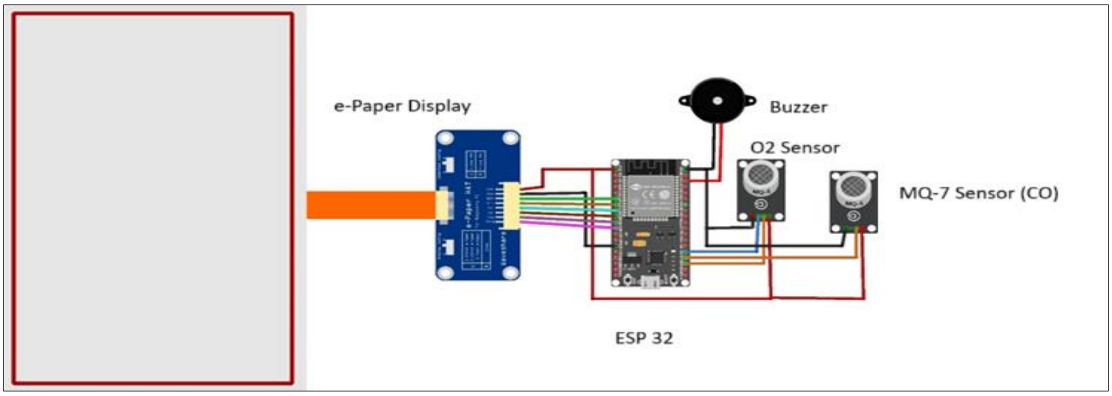

Figure 3: Schematic Design

Final Assembly and Testing PCGIoT

The final assembly took place when each assembly condition had been satisfied in a proper fit and wiring. The casing was closed carefully and secured by screws to ensure that nothing came jiggling loose-Such openings were lined with sensory holes-conscious display windows. Once assembled, the configuration was put through performance checks and functional tests. A 5000mAh battery bank was then used to power the siting of the system where the entire intended power source operation was assessed. The 2.13-inch e-Paper display was also found to be capable of presenting clear outputs for real-time results, while measuring accurately for both O_2 and CO sensors.

Figure 4: Final Assembly and Testing PCGIoT System

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Thus, it is guaranteed how much efficient INA219 current sensor helps monitor the power consumed in the system. If he buzzed the gas levels that were above normal levels, it was easy to find out if it worked. General durability of housing also checked just to ensure that there are literally no cracks or misalignments after sealing. The finish is completed with minor touch, like adjusting screw tightness and component alignment, for a neat and polished finish. The final assembly and testing of the PCGIoT system are shown in Figure 4. Concisely, the last hardware settings were fine-tuned to full operation, and this permitted the establishment of a software system for monitoring and data analysis in real-time.

Thinger.IO Integration and Remote Monitoring PCGIoT

As part of their security assurance towards perfection in restricted areas, Thinger.io integration with the portable gas detection system facilitates real-time monitoring and data visualization. Some of these parameters include oxygen (O_2) concentration readings, carbon monoxide (CO) levels during times of running, total voltage, total current, and total power, among the many excellent scores viewed by a Thinger.io dashboard. At the side of oxygen concentration is a graph showing changes overtime in the voltage readings from the oxygen sensor. This imparts stability and accuracy to the data from this sensor. Similarly for carbon monoxide levels, it will be displayed besides an accompanying graph of the voltage deviations from the CO reading sensor, thus enabling monitoring changes in gas concentration.

The dashboard here would enable us to see how well the system performed on the fuel consumed. It has separate graphs which show how total voltage and total current fluctuate through time. This information becomes vital when one needs to track the stability of the power supply and to spot any irregular fluctuations. There is also provided a total energy consumption graph that enables one to keep an eye on the entire energy consumption by the system and analyse the efficiency of the machine from its operation. Consolidated into a single display is all this data as shown in the Thinger.io dashboard in Figure 5. The data-wise simplicity and transparency within dashboard data visualization enable remote monitoring of gas levels, power consumption, and sensor performance.

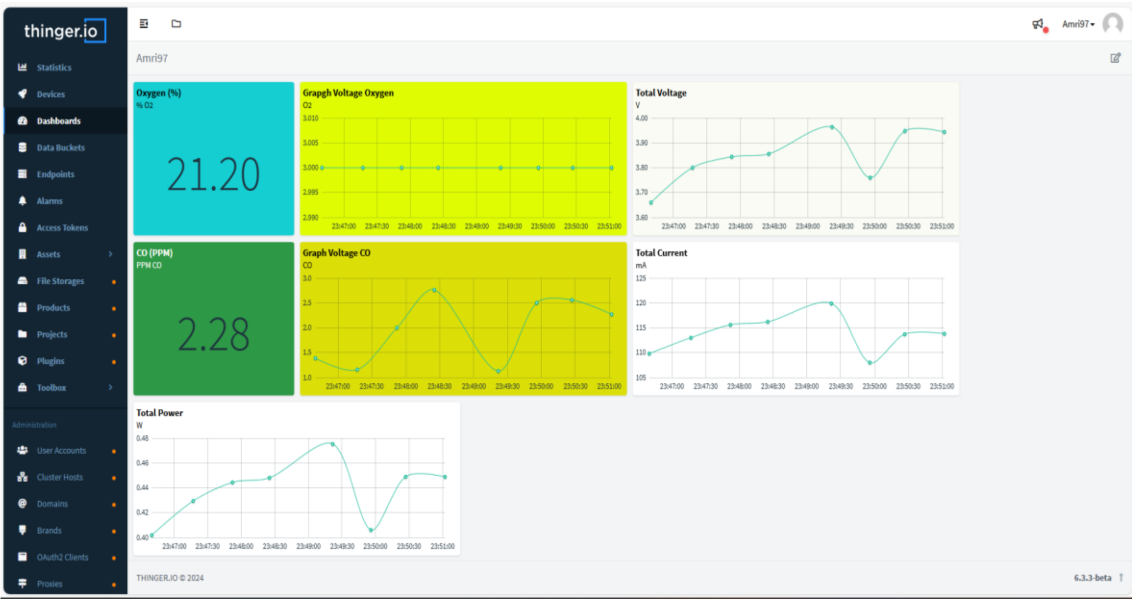

Figure 5: Thinger.IO Dashboard

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Results

Commercial Portable Gas Detectors (MSA Altair 4XR) and PCGIoT System Comparison

This comparison was done to analyse the total variations (+/- values) in carbon monoxide (CO) and oxygen (O_2) measurements between commercial device MSA Altair 4XR and PCGIoT system. Result measurement show, the betterment seems to be on the side of the PCGIoT having an average offset of approximately +/- 0.6% as compared to MSA Altair 4XR as per 10 readings taken. This indicates that more or less, increased oxygen values were always recorded by the improved methodology. The total difference in carbon monoxide (CO), however, varied relative to concentration. At CO low levels, the recorded results from the PCGIoT were slightly lower than average at +/-0.6 PPM. However, as CO levels increased, it resulted into closely resembling results, reaching approximately +/- 0.2-0.6 PPM at maximum level. The PCGIoT system was reliable, having only slight variations as compared to the commercial device MSA Altair 4XR. More calibration will reduce the differences and increase the accuracy of the system developed. A comprehensive comparison of the data reported between the two methods is presented in Table 1.

Table 1: Commercial Portable Gas Detectors (MSA Altair 4XR) vs PCGIoT System

Bil	PCGIoT System		MSA Altair 4XR	
	Oxygen (O_2)	Carbon Monoxide (CO)	Oxygen (O_2)	Carbon Monoxide (CO)
1	21.23 %	0.04 PPM	20.8 %	0 PPM
2	21.37 %	0.19 PPM	20.9 %	0 PPM
3	21.81 %	0.24 PPM	`21.3 %	0 PPM
4	20.24 %	2.89 PPM	19.7 %	3 PPM
5	20.40 %	3.69 PPM	20.0 %	4 PPM
6	20.5 %	4.59 PPM	20.1 %	4 PPM
7	20.3 %	5.16 PPM	19.8 %	5 PPM
8	19.99 %	5.80 PPM	19.5 %	6 PPM
9	19.98 %	5.96 PPM	19.5 %	6 PPM
10	19.99 %	6.01 PPM	19.5 %	6 PPM

Sensor Response and Voltage Behaviour

In this section, attention is given to the response of the sensor and the related voltage behaviour to oxygen (O_2) and carbon monoxide (CO) measurements. Resulting Table 2 depicts the correlation of voltage for the CO and O_2 sensors with corresponding gas concentration. The CO sensor voltage increased steadily as the increased concentration of CO increased, suggesting an intimate correlation between increasing CO concentration and sensor voltage in its sample readings. For instance, the voltage was recorded at 0.22 V when the concentration was 0.02 PPM. However, the value increased to 1.70 V at higher concentrations, for instance, at 6.01 PPM. These signs point towards the expected functional measure that with increased gas levels, CO sensors detected increased sensitivity and accuracy in measured linear response.

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Table 2: Sensor Response and Voltage Behaviour

Bil	Carbon Monoxide (CO)	Carbon Monoxide (CO) Voltage	Oxygen (O_2)	Oxygen (O_2) Voltage
1	0.02 PPM	0.22 V	21.31 %	3 V
2	0.40 PPM	0.66 V	21.32 %	3V
3	1.05 PPM	0.95 V	21.29 %	3V
4	2.89 PPM	1.35 V	20.24 %	3V
5	3.69 PPM	1.46 V	20.40 %	3V
6	4.59 PPM	1.56 V	20.5 %	3V
7	5.16 PPM	1.62 V	20.3 %	3V
8	5.80 PPM	1.68 V	19.99 %	3V
9	5.96 PPM	1.69 V	19.98 %	3V
10	6.01 PPM	1.70 V	19.99 %	3V

The O_2 sensor consistently provided a voltage output of 3V across all measured O_2 levels. The voltage did not vary even when oxygen levels changed from 21.31% to 19.99%. Such performance shows that the O_2 sensor is capable of measuring the concentration of oxygen well within that range, and it works reliably with a constant voltage output. Figure 6 shows a plot of CO (PPM) versus O_2 (%) exhibiting that stable behaviour in O_2 and CO and intersection between both sensors measuring.

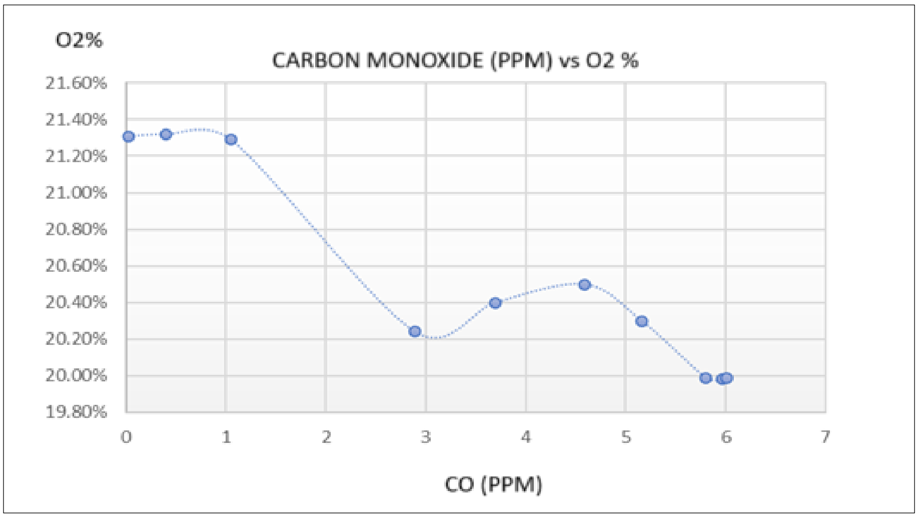

Figure 6: CO (PPM) vs O_2 (%)

Data Gas Measuring in Confined Spaced Area

Here, the readings for carbon monoxide (CO) and oxygen (O_2) gas were taken at distances of one, two, and three meters from the opening of an enclosed space. The sensor is to be placed farther away from an opening that may affect ventilation to monitor carbon monoxide and oxygen concentration variations. All appropriate ventilation systems were installed in the restricted space area to provide air circulation and preserve safe gas concentrations. An

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intensive inspection was conducted by the Authorised Gas Tester (AGT) to determine gas concentrations and to secure the area before granting any authorized entrance (AE). To ensure that the levels of gas did remain at safe ranges during the time that the work was being carried out, the AGT checked every four hours. In normal circumstances, the permissible level of carbon monoxide in the air for a working environment is up to 0.15 PPM-0.25 PPM, while the permissible level for oxygen is about 21.14%-21.31%. The carbon monoxide levels ranged from 0.15 PPM to 0.20 PPM, while oxygen differed from 21.08% to 21.30% at a distance of one meter from the entrance, when the sensor is placed. At this distance, it was also found that levels of carbon monoxide measurement differed from 0.13 PPM at two meters from the door to 0.17 PPM, while equal concentration of oxygen remained at a minimum of 21.30% to a maximum of 21.37% within the range. Similarly, carbon monoxide levels are still within acceptable levels of 0.14 PPM to 0.17 PPM; moreover, oxygen levels three meters from the door is also stable and varied from 21.29%-21.43%.

These results indicate that varying the distance from the door does not affect oxygen and carbon monoxide concentrations significantly. The ventilation system apparently does a good job in space maintenance to keep air quality constant. Through constant AGT inspections, it is clear that gas levels have generally remained at safe levels while ensuring any risks from gases were found out and fixed in time. It clearly states that measurements in the enclosed space initial distance from the door were made and quite consistent levels of carbon monoxide and oxygen were found to be within acceptable limits for atmospheric air as they have been recorded. This, therefore, is representative of good safety standards in place with efficient ventilation and systematic checks by the AGT to ensure a safe working environment for its employees. Gas concentrations at different distances from the entrance into the confined area are summarized in Table 3.

Table 3: Data Gas Measuring in Confined Spaced Area

Condition	Oxygen (O_2)	Carbon Monoxide (CO)
Normal Condition	21.14 %	0.25 PPM
	21.31 %	0.17 PPM
	21.24 %	0.20 PPM
1 Metre	21.08 %	0.20 PPM
	21.09 %	0.17 PPM
	21.30 %	0.15PPM
2 Metre	21.30 %	0.13 PPM
	21.30 %	0.14 PPM
	21.37 %	0.17 PPM
3 Metre	21.36 %	0.15 PPM
	21.29 %	0.14 PPM
	21.43 %	0.15 PPM
	21.42 %	0.17 PPM

Battery Lifetime and Power Consumption

This segment presents the power consumption and the battery life of the PCGIoT system. For every hour, across a duration of ten hours, the voltage, current, and power consumption of the

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system were recorded for measurement. For a part of the time during the test run, the power consumption remained fairly constant, ranging from 0.48 watts to 0.51 watts. Like most rechargeable batteries, the reduction in voltage and current was observed when the battery depleted. The measurements performed with the power bank were carried out at 25% charge level down to 0% battery life. From the Table 4 below, it was observed that when the battery was at 25% charge, it lasted for approximately 10 hours. Based on this, we can estimate that with a fully charged 100% battery, the system could operate for approximately 40 hours, assuming the power consumption remains consistent. To confirm this estimation, the average load current was calculated to be approximately 121.69 mA. Using the battery lifetime formula (Kong et al., 2023):

$$Battery\ Lifetime = \frac{Battery\ Capacity\ (mAh)}{Load\ Current\ (mA)} \quad (1)$$

With a 5000 mAh battery capacity, the theoretical battery lifetime is approximately 41.1 hours. This indicates that under ideal conditions, the system could operate for about 41.1 hours on a full charge, assuming constant power consumption. However, during testing, the system operated for about 10 hours before the battery reached 0%. This difference can be attributed to practical factors such as power losses, battery efficiency, and environmental conditions, which can affect the actual battery performance.

Table 4: Battery Lifetime and Power Consumption

Hour	Voltage (V)	Current (mA)	Power (W)
1	4.06	121.95	0.50
2	4.11	123.48	0.51
3	4.07	122.82	0.50
4	4.09	123.28	0.50
5	4.07	122.66	0.50
6	4.08	122.82	0.50
7	4.03	120.70	0.49
8	4.01	120.59	0.48
9	4.00	119.80	0.48
10	4.06	122.29	0.50

The voltage and current for power consumption data was also visualized in Figure 7(a) and Figure 7(b) that showing the relationship between voltage and current measuring in real time. These graphs indicated fluctuating values of voltage and current, with increases and decreases throughout the test period. The trend of graph is decreasing by time linearly, reflecting the expected behaviour as the battery approached depletion. This trend suggests that the power consumption gradually decreases as the battery's charge diminishes. The linear line equation as mention below for voltage (2) and current (3). Where *ya* and *yb* for hour and *xa* and *xb* for voltage and current measuring.

$$ya = -0.0075xa + 4.0993 \quad (2)$$

$$yb = -0.2511xb + 123.42 \quad (3)$$

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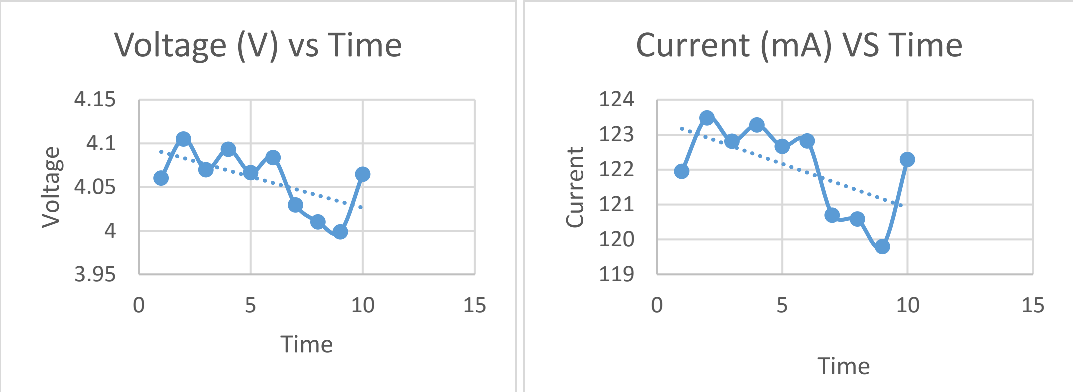

Figure 7: (a)Voltage vs Time and (b) Current vs Time

Conclusion

The findings give crucial information related to the success of the system in monitoring carbon monoxide (CO) and oxygen (O2) levels inside closed spaces. This was first demonstrated by showing that the system's accuracy in detecting O2 and CO levels was only limited compared to that of a commercial gas detector, the MSA Altair 4XR. For practical purposes, these variations were approximately ±0.6% for oxygen and ±0.6 ppm for carbon monoxide. Another advantage of this system was its capability for real-time monitoring. It made remote data access and continuous monitoring possible through integration into the Thinger.io platform. This ensures that hazardous gas levels are detected early, enhancing safety because employees and managers are provided with more time for intervention to be taken. Monitoring gas level changes over time also improves decision-making for work in confined spaces. Of its many impressive features, the system's energy economy is perhaps the best. At an average power consumption of just 0.5 W, the entire system could run for nearly 40 hours from a 5000mAh fully charged battery. The primarily responsible for this energy efficiency is the use of an E-Ink display typically consuming a negligible amount of energy. Therefore, the system is suited for use over an extended period without having to be recharged frequently. The conclusions of the study are consistent with previous studies and with safety regulations. Safety regulations indicate that levels of carbon monoxide should be less than 5 ppm and levels of oxygen should be between 19.5 and 23.5 percent. The system demonstrated compliance with the adopted industry safety standards by operating within the specified parameters. Moreover, the real-time and remote monitoring features offer significant advantages over older approaches, which, more often than not, do not have such capabilities. The findings indicate the system's ability to deal with the major challenges associated with gas monitoring in confined spaces. As such, the systems can be in use for workplace safety enhancement as they guarantee accurate detection, real-time monitoring, and efficient operations.

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