

AirGuard : Smart IoT-Based Environmental & Confined Space Air Safety System

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Abstract—AirGuard: Smart IoT-Based Environmental & Confined Space Air Safety System is a smart monitoring solution developed to ensure safe air conditions in indoor environments and confined spaces such as storage rooms, tanks, laboratories, and industrial areas. In such places, improper levels of oxygen (O₂) and carbon dioxide (CO₂) can lead to breathing difficulties, health hazards, and life-threatening situations. This project focuses specifically on monitoring CO₂ and O₂ levels in real time to maintain a safe and breathable atmosphere.

The AirGuard system uses IoT-based sensors to continuously measure the concentration of carbon dioxide and oxygen in the air. These sensors are connected to a microcontroller that processes the data and transmits it to a display or mobile device through wireless communication. When oxygen levels drop below safe limits or carbon dioxide levels rise beyond acceptable levels, the system immediately provides alerts through buzzers, indicators, and digital notifications, allowing quick action to prevent accidents.

The main aim of this project is to provide a reliable, low-cost, and real-time air safety system for workplaces and confined spaces where proper ventilation is critical. By using Internet of Things (IoT) technology, AirGuard improves safety awareness, reduces risks related to poor air quality, and helps protect human health by ensuring a balanced level of oxygen and carbon dioxide in the environment.

Keywords—Smart IoT Monitoring, CO₂ Detection, O₂ Monitoring, Air Quality Monitoring, ESP-8266, MQ-135 Sensor, AO-03 Oxygen Sensor, Wireless Sensor Network, Real-Time Monitoring, Threshold-Based Alert System, Buzzer Alert Mechanism, Mobile Application Integration, Wi-Fi Communication, Environmental Safety, Confined Space Monitoring.

I. INTRODUCTION

Air is one of the most essential elements required for human survival. Every living being depends on a balanced mixture of gases in the atmosphere to breathe and function properly. Among the many gases present in air, oxygen (O₂) and carbon dioxide (CO₂) play a crucial role in maintaining life and environmental stability. Oxygen is necessary for respiration, energy production, and proper functioning of the human body, while carbon dioxide is a natural by-product of breathing and various industrial processes. A safe and breathable environment requires a proper balance between these two gases. When this balance is disturbed, especially in enclosed or poorly ventilated areas, it can lead to serious health risks and dangerous situations.

In many workplaces and environments such as laboratories, factories, storage tanks, basements, underground facilities, and confined industrial spaces, the concentration of oxygen and carbon dioxide can change quickly due to human

activity, machinery, or lack of ventilation. If oxygen levels fall below the normal safe range, people may experience fatigue, dizziness, confusion, or even unconsciousness. Similarly, an increase in carbon dioxide levels can lead to headaches, breathing difficulty, and in extreme cases, suffocation. These risks make it extremely important to monitor the levels of O₂ and CO₂ continuously, especially in areas where air circulation is limited and people work for extended periods of time.

Traditional air monitoring methods often rely on manual checks or simple detection devices that provide limited information and may not offer continuous monitoring. In many cases, workers or users become aware of dangerous air conditions only after experiencing physical discomfort. This delay in detection can increase the chances of accidents and reduce the time available for taking preventive action. There is a strong need for a modern, intelligent system that can monitor air quality in real time and provide early warnings before conditions become harmful.

With the advancement of technology, the Internet of Things (IoT) has emerged as a powerful solution for real-time environmental monitoring. IoT technology allows sensors, microcontrollers, and communication modules to work together to collect and share data continuously. Smart sensors can measure specific environmental parameters and send the data to a central system for analysis and display. This technology makes it possible to create automated systems that monitor air quality at all times and instantly alert users if unsafe conditions are detected. IoT-based systems are highly efficient, reliable, and capable of providing remote monitoring through mobile devices or cloud platforms.

The project titled AirGuard: Smart IoT-Based Environmental & Confined Space Air Safety System is designed to address the problem of unsafe air conditions by continuously monitoring oxygen and carbon dioxide levels. The system uses specialized gas sensors to detect the concentration of O₂ and CO₂ in the surrounding air. These sensors are connected to a microcontroller that processes the collected data and displays it in real time. The system can also transmit data wirelessly to a connected device, allowing users to monitor air conditions from a distance. If oxygen levels drop below the safe threshold or if carbon dioxide levels increase beyond acceptable limits, the system activates alerts such as buzzers, indicator lights, or notifications. This

immediate warning helps users take necessary action, such as improving ventilation or leaving the area, to avoid dangerous situations.

The use of IoT technology in this project ensures that air quality monitoring becomes continuous, accurate, and automated. Unlike traditional systems, this smart solution does not require constant manual supervision. It can operate continuously and provide real-time updates, making it highly useful in industries, laboratories, classrooms, storage areas, and even smart homes.

By focusing specifically on oxygen and carbon dioxide monitoring, the project highlights the importance of maintaining a safe and breathable environment for human health and safety.

This project also emphasizes the importance of preventive safety measures. Rather than reacting to accidents after they occur, the system works to detect potential hazards in advance and provide early warnings. Such a proactive approach helps in reducing risks, improving workplace safety, and protecting lives. The system is designed to be cost-effective, easy to install, and scalable so that it can be implemented in different environments according to the need. It can be used for small indoor spaces as well as larger industrial areas where continuous monitoring of air composition is required.

By combining environmental sensing with modern IoT technology, the AirGuard system demonstrates how smart monitoring solutions can improve safety and awareness in confined and indoor spaces. Continuous observation of oxygen and carbon dioxide levels ensures that people are always aware of the air conditions around them. This not only improves safety but also promotes better environmental management and responsible use of technology in everyday life.

II. RELATED WORK

A. *IoT-Based Air Quality Monitoring System*

In recent years, several IoT-based air quality monitoring systems have been developed to track environmental conditions in real time. These systems typically use gas sensors to measure the concentration of gases such as carbon dioxide and oxygen and connect them to microcontrollers like Arduino, NodeMCU, or ESP32. The collected data is transmitted wirelessly to cloud platforms or mobile applications where users can monitor air quality remotely. These systems are especially useful in classrooms, offices, and public buildings where maintaining good indoor air quality is important for health and productivity. Real-time alerts and continuous data logging help users take preventive measures before air conditions become harmful.

However, many of these systems are designed for general air quality monitoring and focus mainly on comfort and pollution levels rather than life-threatening situations in confined spaces. The AirGuard project takes inspiration from these systems but focuses specifically on maintaining a safe balance between oxygen and carbon

dioxide in enclosed environments where rapid changes in air composition can be dangerous.

B. *Industrial Confined Space Safety Monitoring*

Confined spaces such as underground chambers, storage tanks, tunnels, and industrial containers can quickly become hazardous due to reduced oxygen levels or increased carbon dioxide concentration. To address this problem, industries commonly use gas detection devices that measure oxygen levels before allowing workers to enter these areas. Some advanced systems include continuous monitoring with alarms that activate when gas levels exceed safe limits. These systems have significantly improved worker safety by reducing accidents related to suffocation and toxic air exposure.

Despite their usefulness, many traditional confined space monitoring systems are portable and provide only local alerts. They may not store data for long-term analysis or provide remote notifications to supervisors. Modern IoT-based approaches are now being introduced to improve these systems by enabling real-time data transmission and centralized monitoring. The AirGuard project is related to these developments, as it combines gas sensing with IoT communication to provide continuous monitoring, instant alerts, and improved safety awareness in confined environments.

C. *Smart Ventilation and Indoor Safety Systems*

Smart ventilation systems in modern buildings use carbon dioxide sensors to monitor indoor air quality and automatically adjust airflow. These systems help maintain a comfortable and healthy environment by ensuring that CO₂ levels remain within safe limits. When carbon dioxide concentration increases due to human presence or poor ventilation, the system activates fans or ventilation units to restore air balance. Some advanced systems used in laboratories and healthcare facilities also monitor oxygen levels to ensure safe breathing conditions.

While these systems are effective in maintaining comfort and energy efficiency, they are often expensive and designed for large buildings with complex infrastructure. They may not be suitable for small-scale industrial spaces or temporary confined environments. The AirGuard project aims to provide a simpler and more cost-effective solution that can be used in various settings, including classrooms, small industries, and storage areas. By focusing on both oxygen and carbon dioxide monitoring, the system ensures not only comfort but also safety.

D. *Wireless Sensor Networks for Environmental Monitoring*

Wireless sensor networks (WSNs) have been widely used in environmental monitoring projects to collect data from multiple locations. These systems consist of several sensor nodes that communicate wirelessly with a central unit. Each node measures environmental parameters such as temperature, humidity, and gas concentration. The collected data is transmitted to a monitoring station where it is analyzed and displayed. WSN-based systems are useful for monitoring large industrial areas, research facilities, and smart city environments. Although some of these systems include gas sensors for oxygen and

carbondioxide detection, their primary focus is large-scale environmental observation rather than confined space

safety. They are often complex and require multiple sensor nodes and advanced communication infrastructure. The AirGuard system is inspired by these technologies but is designed to be simpler and more focused. It provides accurate monitoring of O₂ and CO₂ levels in specific areas and delivers immediate alerts when unsafe conditions are detected.

E. Portable Gas Monitoring and Safety Devices

Portable gas monitoring devices are commonly used by workers in hazardous environments. These handheld devices can detect oxygen deficiency and elevated carbon dioxide levels and provide immediate audio or visual warnings. They are easy to carry and useful for short-term monitoring. Many industries rely on such devices to ensure worker safety before entering confined spaces.

However, portable devices require manual handling and may not provide continuous monitoring once they are removed or turned off. They also do not always support remote data sharing or long-term tracking. The AirGuard project improves upon this concept by offering a fixed, automated system that continuously monitors gas levels and sends real-time alerts. This reduces dependence on manual checks and ensures that air safety is maintained at all times.

F. IoT-Based Safety Alert Systems

IoT-based safety alert systems have been developed for various applications such as fire detection, gas leakage monitoring, and environmental hazard detection. These systems use sensors to detect unsafe conditions and send alerts through mobile notifications, alarms, or cloud platforms. The integration of IoT technology allows users to monitor conditions remotely and respond quickly to potential hazards.

These systems demonstrate the effectiveness of combining sensors with communication technology for improved safety. The AirGuard project follows a similar approach but focuses specifically on monitoring oxygen and carbon dioxide levels in confined and indoor environments. By providing real-time monitoring and automated alerts, it ensures that users are always aware of air conditions and can take immediate action when necessary.

III. PROPOSED METHODOLOGY

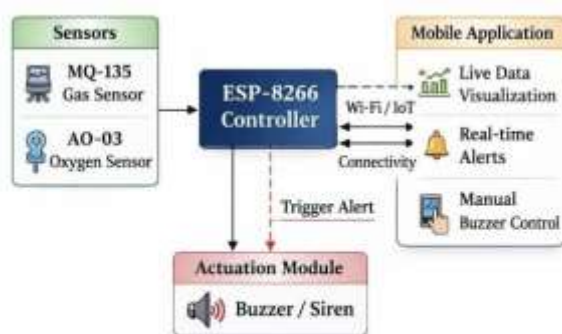


Fig. 1. Workflow diagram of the Smart IoT-based Emission Monitoring System.

a. System Overview

The proposed Smart IoT-Based Emission Monitoring System is designed to continuously monitor air quality parameters and provide real-time alerts in hazardous environments such as tunnels, wells, industrial areas, and enclosed spaces. The system integrates gas sensing technology with IoT-based communication to ensure early detection of harmful gases and oxygen level variations. By combining sensing, processing, communication, and actuation modules, the system enhances safety through automated and remote monitoring.

The sensing unit consists of the MQ-135 gas sensor, which detects harmful gases such as ammonia, nitrogen oxides, benzene, smoke, and CO₂, and the AO-03 oxygen sensor, which measures oxygen concentration in the surrounding environment. These sensors continuously collect environmental data and send analog signals to the ESP-8266 controller. The controller acts as the central processing unit, converting sensor readings into digital values and comparing them with predefined safety thresholds.

The ESP-8266 microcontroller, equipped with built-in Wi-Fi capability, enables IoT connectivity by transmitting real-time data to a mobile application through a cloud or local network. The mobile application provides live data visualization in graphical format, allowing users to monitor gas concentration and oxygen levels remotely. Additionally, the application generates real-time alerts when abnormal or hazardous conditions are detected, ensuring immediate awareness and response.

An actuation module consisting of a buzzer or siren is integrated into the system for on-site alert generation. When sensor readings exceed the safety limits, the controller automatically triggers the buzzer to warn nearby individuals. The mobile application also provides manual buzzer control, enabling users to activate or deactivate the alarm remotely if required.

Fig. 1 illustrates the overall workflow of the Smart IoT-based Emission Monitoring System, showing the interaction between sensors, the ESP-8266 controller, the mobile application, and the actuation module for efficient environmental monitoring and alert management.

a. Module Descriptions

• Sensor Module

The Sensor Module is responsible for detecting carbon dioxide (CO₂) and oxygen (O₂) levels in the environment. It consists of the MQ-135 gas sensor for measuring CO₂ concentration and the AO-03 oxygen sensor for monitoring oxygen percentage. These sensors continuously sense environmental conditions and generate analog output signals proportional to gas concentration.

The module ensures uninterrupted real-time monitoring of CO₂ and O₂ levels. The collected sensor data is transmitted to the ESP-8266 controller for processing and analysis. This module forms the foundation of the system by enabling early detection of increased CO₂ levels or decreased oxygen concentration in enclosed environments.

- Controller Module

The Controller Module uses the ESP-8266 as the central microcontroller unit. It receives real-time data from the MQ-135 (CO₂) and AO-03 (O₂) sensors and converts analog signals into digital values for analysis. The controller compares these values with predefined safety thresholds.

If CO₂ concentration increases beyond safe limits or oxygen levels drop below the permissible range, the controller automatically triggers the buzzer to alert nearby individuals. Additionally, using its built-in Wi-Fi capability, the ESP-8266 transmits processed data to the mobile application for remote monitoring and alert management.

- Mobile Application Module

The Mobile Application Module is developed using Flutter for cross-platform compatibility. It provides real-time visualization of CO₂ concentration and oxygen levels in graphical and numerical formats. Users can continuously monitor environmental conditions through the application.

The app generates instant notifications when unsafe CO₂ or O₂ levels are detected. It also allows users to manually control the buzzer through the interface. This module enhances remote accessibility, user interaction, and overall system effectiveness.

- Actuation Module

The Actuation Module consists of a buzzer or siren used to provide immediate alerts during hazardous conditions. The ESP-8266 controller activates the buzzer automatically when CO₂ levels exceed safe limits or oxygen levels decrease below the threshold.

The system also supports manual override through the mobile application. This ensures immediate safety action in critical environments such as tunnels, wells, or confined spaces.

b. Use-Case Illustration

The proposed Smart IoT-Based CO₂ and O₂ Monitoring System is primarily used in enclosed environments such as tunnels, wells, basements, and industrial rooms where air quality monitoring is critical. In a typical scenario, the system is installed at the monitoring location, and the MQ-135 sensor continuously measures carbon dioxide (CO₂) levels while the AO-03 sensor monitors oxygen (O₂) concentration. These readings are sent to the ESP-8266 controller for real-time processing and threshold comparison.

Under normal environmental conditions, the controller transmits the sensor data via Wi-Fi to the mobile application, where the user can view live CO₂ and O₂ levels in graphical and numerical formats. This enables the safety personnel or operator to remotely monitor air quality without being physically present at the site. The system ensures continuous and uninterrupted monitoring of environmental parameters.

When CO₂ concentration exceeds the predefined safe limit or oxygen levels fall below the acceptable threshold, the controller immediately identifies the unsafe condition. In

response, the system automatically activates the buzzer or siren to alert nearby individuals. Simultaneously, a real-time notification is sent to the mobile application, informing the user about the hazardous situation.

After receiving the alert, the user can take appropriate safety measures, such as evacuating the area or improving ventilation. Additionally, the mobile application provides manual control over the buzzer, allowing the user to activate or deactivate the alarm if necessary. Thus, the system ensures early detection, immediate warning, and remote supervision, enhancing safety in confined environments.

IV. DESIGN ANALYSIS AND DISCUSSION

The Smart IoT-based Emission Monitoring System is designed as an integrated solution for real-time environmental safety. The system architecture bridges the gap between raw hardware sensing and user-accessible software through a robust four-layer methodology: Sensing, Processing, Connectivity, and Actuation.

1. Hardware Architecture & Sensing Strategy

The core of the hardware design relies on the MQ-135 and AO-03 sensors to monitor air quality. MQ-135 Gas Sensor: Chosen for its sensitivity to a wide range of harmful gases, specifically CO₂, benzene, and NH₃. It provides an analog output proportional to the gas concentration. AO-03 Oxygen Sensor: This electrochemical sensor is critical for safety monitoring, ensuring that O₂ levels remain within breathable limits. Signal Conditioning: As seen in the circuit diagram, an LM358 Op-Amp is utilized to amplify the low-voltage signals from the sensors before they reach the controller. This ensures that the data processed by the ESP-8266 is accurate and less susceptible to noise.

2. Controller Logic and Processing

The ESP-8266 (NodeMCU) serves as the central brain. It was selected for its integrated Wi-Fi capabilities and low power consumption. Threshold-Based Logic: The controller is programmed with predefined safety limits. If CO₂ levels rise or O₂ levels drop beyond these limits, the controller triggers a GPIO pin to activate the alarm. Data Conversion: The controller converts analog signals from the sensors into digital values that can be transmitted over the internet, facilitating the transition from hardware "events" to software "data."

3. IoT Connectivity & Software Integration

The integration of a Flutter-based Mobile Application transforms the device from a simple alarm into a smart monitoring tool. Real-time Visualization: Using IoT protocols, data is sent from the ESP-8266 to a cloud backend, which the mobile app fetches to display live graphs. Remote Management: Unlike traditional hardware-centric systems, this design allows for Manual

Buzzer Control. Users can silence an alarm or test the system remotely through the app interface. Notifications: The software layer ensures that even if a user is not looking at the app, push notifications provide immediate awareness of hazardous conditions.

4. Actuation and Safety Mechanisms

The system employs an Actuation Module consisting of a high-decibel buzzer/siren. Redundancy: The circuit utilizes BC547 transistors and Relays to drive the actuators. This separation of the low-power controller circuit from the higher-power buzzer circuit ensures system stability and protects the ESP-8266 from electrical back-EMF. Immediate Response: The buzzer is hardwired to respond to the controller's logic locally, ensuring that the alarm sounds even if the Wi-Fi connection is lost.

V. CONCLUSION AND FUTURE WORKS

The proposed Smart IoT-Based CO₂ and O₂ Monitoring System presents an effective and reliable solution for monitoring air quality in confined and hazardous environments such as tunnels, wells, and industrial spaces. By integrating the MQ-135 CO₂ sensor and AO-03 oxygen sensor with the ESP-8266 microcontroller, the system ensures continuous and real-time detection of carbon dioxide concentration and oxygen levels. The wireless communication capability allows seamless data transmission to a mobile application for remote monitoring.

The implementation of threshold-based analysis enables the system to identify unsafe environmental conditions instantly. When CO₂ levels exceed permissible limits or oxygen concentration drops below safe levels, the controller automatically activates a buzzer and sends real-time notifications to the mobile application. This immediate alert mechanism enhances safety and helps prevent potential health risks in enclosed environments.

The mobile application further improves system usability by providing live data visualization and manual control over the buzzer. Users can remotely monitor environmental parameters and take timely action when required. Overall, the system is cost-effective, easy to deploy, and scalable, making it suitable for both small-scale and industrial applications.

In future developments, the system can be enhanced by integrating additional sensors such as temperature and humidity sensors to provide a more comprehensive environmental analysis. Cloud-based storage can be implemented to maintain historical data records and perform trend analysis for better decision-making.

Further improvements may include adding GSM-based alert systems to ensure notifications even without internet connectivity and incorporating AI-based predictive analytics to forecast hazardous conditions before they reach critical levels. These enhancements can improve the system's intelligence, scalability, and practical applicability in real-world industrial safety management.

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