CoalMine Sentinel: A wireless air quality monitoring and alarming device for coal mining industry

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Abstract: *Each year, numerous miners lose their lives in accidents, with the majority occurring in underground coal mines. Due to the high-risk environment, continuous monitoring of critical parameters—such as methane (CH_4), carbon monoxide (CO), carbon dioxide (CO_2), temperature, and potential fire hazards—is essential to ensure worker safety. This project presents a wireless monitoring system designed to detect hazardous gas levels, including CH_4 , CO, and CO_2 , in real-time. The system also includes a temperature sensor to aid in early fire detection. In the event of abnormal readings, the device triggers an alert that is immediately transmitted to the control room, enabling quicker decision-making and more efficient rescue efforts.*

Keywords: *Coal, Mining industry, air quality, Arduino UNO, ESP8266 wifi module*

1. INTRODUCTION

Maintaining air quality in coal mines is essential to safeguard workers' health and ensure smooth operations. Gases such as methane (CH_4) and carbon monoxide (CO) are commonly present in mining environments and can lead to life-threatening situations, including explosions and toxic exposure. Risk factors of coal mining are mainly due to the presence of toxic gases, explosive hazards and respiratory issues due to long-term exposure to suboptimal air quality. A real-time air quality monitoring and alert system can play a vital role in identifying hazardous gas levels before they reach critical limits. This system employs gas sensors like the MQ135, MQ4, and MQ7—each tailored to detect CO_2, methane, and CO—to continuously track gas concentrations. If the measured levels surpass predefined safety thresholds, the system activates alarms, prompting immediate action to mitigate risks. Implementing such a solution in coal mining operations greatly enhances safety measures, minimizes the potential for accidents, and supports the well-being of personnel.

2. OBJECTIVE

The objective of an air quality monitoring and alarm system for coal mining is to ensure the safety and health of miners by continuously monitoring the levels of hazardous gases and particulates in the mine's atmosphere. The system aims to detect dangerous levels of gases such as methane (CH_4), carbon monoxide (CO), and carbon dioxide (CO2), as well as dust particles, which can pose risks of explosion, poisoning, and respiratory diseases. To prevent accidents related to gas explosions and suffocation by providing real-time detection of hazardous gas concentrations and triggering alarms when levels exceed safe thresholds. To collect and store data on air quality over time, facilitating analysis to identify patterns, improve safety protocols, and optimize the working environment.

2. LITERATURE REVIEW

Sl no	Author(s)	Year	Focus Area	Remarks
1.	Sujata Upgupta & Prasoon Singh	2017	Environmental impacts in Indian coal mining	Emphasized need for holistic, interdisciplinary studies
2.	Kalisz & Małachowska	2022	Geology of coal seams	Showed how regional geology influences mining practices
3.	Muralidhara Rao & B.D. Deebak	2022	Technological advancements	Focused on mining digitization and automation
4.	Bhanu Pandey & Madhoolika Agrawal	2018	GHG emissions and carbon footprint	Advocated for emission accountability in coal projects
5.	Bhattacharyya & Liu	2023	Historical evolution of coal mining	Highlighted need for continuous technological innovation

3. IMPLEMENTATION USING ARDUINO UNO

The prototype for the indoor air quality monitoring system involves integrating multiple gas sensors with a microcontroller, enabling. This implementation involves the integration of three gas sensors—MQ-135 (for CO_2 and general air quality), MQ-7 (for carbon monoxide), and MQ-4 (for methane) with an Arduino microcontroller for real-time environmental monitoring. The system also includes an LCD display to visualize gas concentration levels detected by the sensors. The MQ-series sensors produce analog voltage signals that vary according to the concentration of specific gases. These signals are read through the Arduino's analog input pins. As each sensor has distinct calibration requirements and response characteristics, the system's firmware includes logic to interpret and convert raw analog data into meaningful gas concentration values using calibrated response curves.

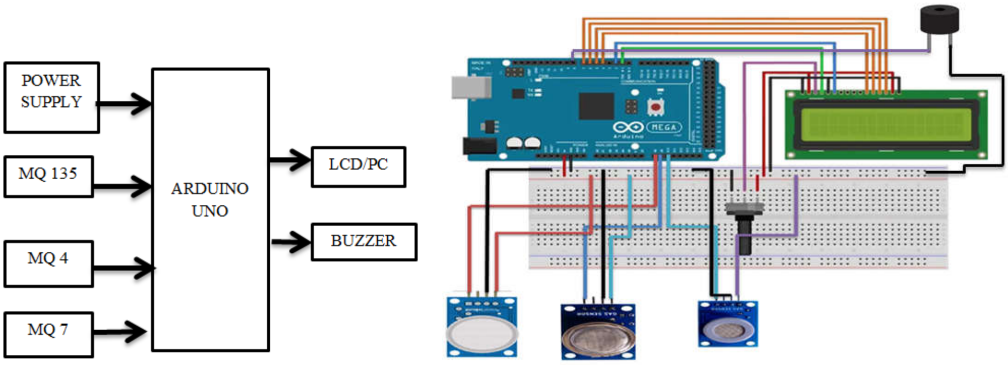

Fig: Block diagram and circuit diagram using Arduino Uno module

A standard 16×2 LCD is used to display the gas readings. This display is connected to the Arduino via multiple digital pins, which handle data and command inputs. A potentiometer is included in the circuit to adjust the contrast of the display, allowing for optimal readability under various lighting conditions. During operation, the Arduino continuously samples data from all three sensors and updates the LCD in real time. MQ sensors operate by detecting changes in their internal resistance when exposed to specific gases. These resistance changes result in variations in output voltage, which the Arduino measures and interprets. As gas concentrations fluctuate, the corresponding values are updated automatically on the LCD, providing an effective and low-cost solution for ambient air quality monitoring. A buzzer is integrated into the system to emit an audible alarm when gas concentrations exceed a predefined hazardous threshold.

4. IMPLEMENTATION USING ESP8266 WIFI MODULE

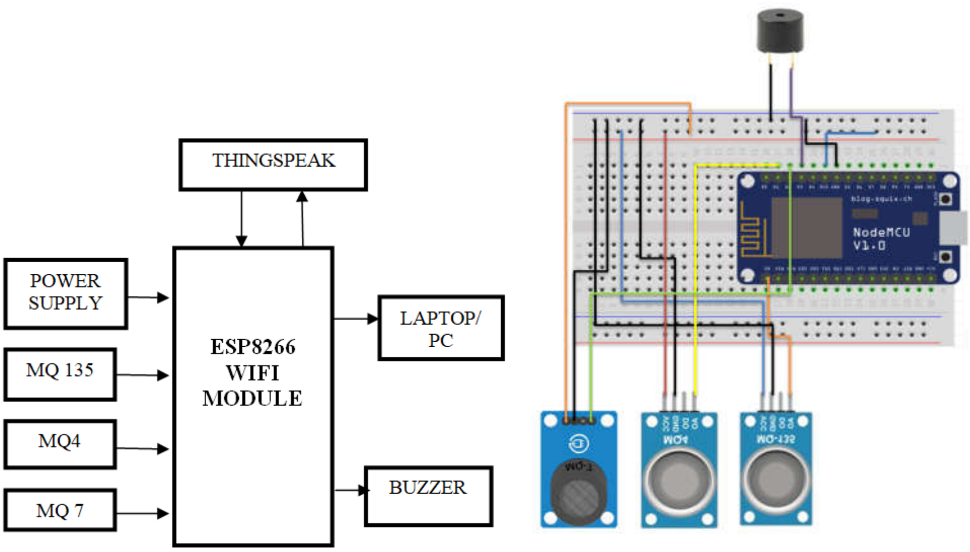

Fig: Block diagram and Circuit Diagram using ESP8266 Wi-Fi module

The gas detection system initiates with a power-on sequence, activating the ESP8266 module, which subsequently establishes a Wi-Fi connection and configures the connected gas sensors—MQ-135, MQ-4, and MQ-7. Upon successful initialization, the system enters a continuous monitoring cycle, where it collects real-time gas concentration data from the environment. The ESP8266 processes this data and transmits it to the ThingSpeak cloud platform, where it contributes to a centralized sensor database for ongoing analysis. If all gas levels remain within safe limits, the system proceeds with uninterrupted monitoring. However, if any gas concentration exceeds the predefined safety threshold, the ESP8266 promptly triggers a buzzer to emit an audible warning and simultaneously sends an alert signal to the server. This enables users to access live data and alerts through the ThingSpeak dashboard on their PC, ensuring timely awareness of potential hazards. The system then seamlessly resumes its monitoring loop, maintaining continuous environmental surveillance.

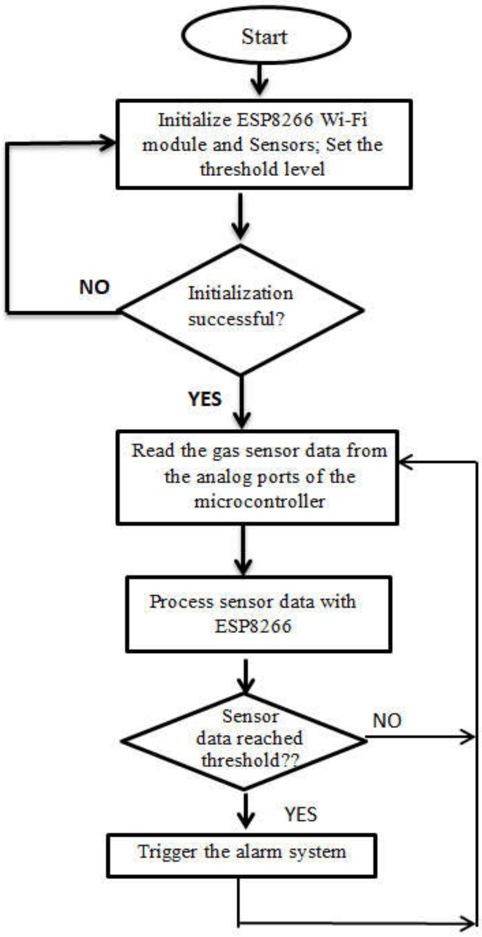

Fig: flow chart of the proposed system using ESP8266 Wi-Fi module

5. RESULT AND DISCUSSION

a) **Results using Arduino UNO**: The first set of experiments was conducted using the Arduino UNO board, with data captured and logged directly onto a laptop. Three distinct experiments were performed, each designed to measure and record gas concentration levels under varying conditions. Data from each trial was transmitted via serial communication at a baud rate of 9600, ensuring stable and accurate data transfer between the Arduino UNO and the laptop throughout the experimentation process.

Experiment no. 1: All the sensors are tested and recorded at normal temperature inside the room.
Experiment no. 2: Experiment using incense sticks
Experiment no. 3: Experiment using gas lighter

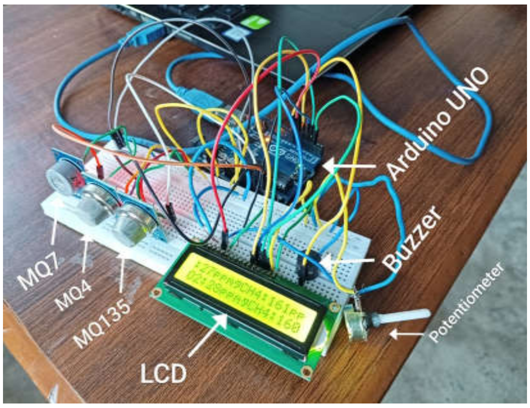

Fig: Hardware model using Arduino UNO

Table 1: Partial record of sensor data at after room temperature (experiment 1)

MQ135(CO2,ppm)	MQ4(CH4,ppm)	MQ7(CO,ppm)
34ppm	164ppm	140ppm
34ppm	164ppm	140ppm
34ppm	164ppm	139ppm
33ppm	164ppm	139ppm
35ppm	163ppm	140ppm
34ppm	163ppm	139ppm
34ppm	163ppm	139ppm
35ppm	163ppm	139ppm
33ppm	162ppm	139ppm
34ppm	162ppm	138ppm
33ppm	162ppm	138ppm
34ppm	161ppm	137ppm
35ppm	160ppm	138ppm
35ppm	159ppm	137ppm
35ppm	158ppm	138ppm
35ppm	158ppm	136ppm

Table 2: Partial record of sensor data after 15min of incense stick exposure (experiment 2)

MQ135(CO2,ppm)	MQ4(CH4,ppm)	MQ7(CO,ppm)
32ppm	187ppm	135ppm
32ppm	185ppm	135ppm
32ppm	183ppm	134ppm
32ppm	182ppm	134ppm
32ppm	180ppm	134ppm
31ppm	178ppm	133ppm
31ppm	177ppm	133ppm
31ppm	176ppm	133ppm
40ppm	188ppm	132ppm
51ppm	292ppm	133ppm
53ppm	305ppm	134ppm
54ppm	315ppm	134ppm
55ppm	299ppm	135ppm
59ppm	272ppm	135ppm
54ppm	252ppm	135ppm
45ppm	237ppm	134ppm

Table 3: Partial record of sensor data after gas lighter exposure (experiment 3)

MQ135(CO2,ppm)	MQ4(CH4,ppm)	MQ7(CO,ppm)
44ppm	289ppm	133ppm
45ppm	291ppm	132ppm
43ppm	263ppm	132ppm
45ppm	261ppm	131ppm
51ppm	251ppm	131ppm
49ppm	270ppm	131ppm
48ppm	296ppm	132ppm
53ppm	288ppm	132ppm
54ppm	297ppm	131ppm
53ppm	296ppm	132ppm
51ppm	297ppm	135ppm
48ppm	302ppm	138ppm
48ppm	311ppm	135ppm
50ppm	313ppm	137ppm
48ppm	318ppm	135ppm
47ppm	316ppm	133ppm
50ppm	310ppm	134ppm

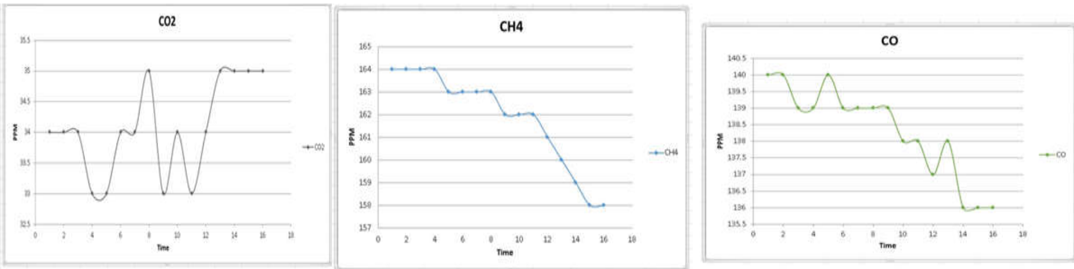

Fig: Graphical representation of sensor data collected through three sensors for experiment no. 1

The observed data trend for the gas concentration demonstrates three distinct phases. Initially, the gas levels remain stable, averaging around 34 PPM for CO_2, indicating a period of equilibrium. This is followed by noticeable fluctuations, characterized by periodic dips and peaks in the readings, likely influenced by changing environmental conditions or dynamic factors affecting gas concentration. Toward the end of the observation period, the gas levels stabilize once more, settling at approximately 35 PPM for CO_2 . This pattern suggests a system responsive to external variations, yet capable of returning to a steady state over time.

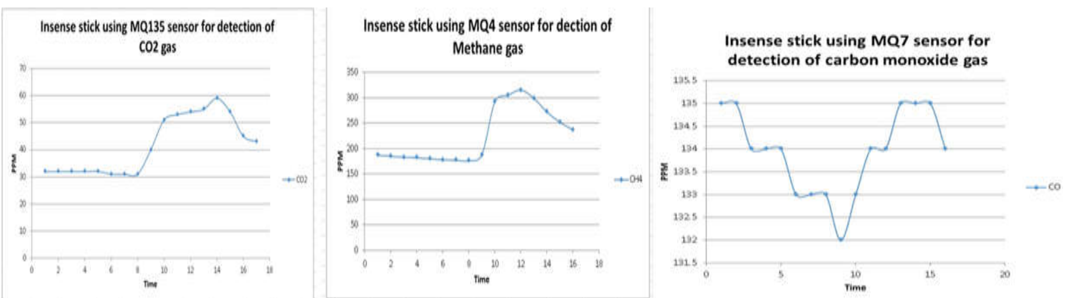

Fig: Graphical representation of sensor data collected through three sensors for experiment no. 2

The first graph indicates a stable initial concentration of CO_2 around 30-35 PPM for the first 7 minutes. At around 8 minutes, there is a sharp rise in CO_2 levels, peaking at approximately 65 PPM near the 13th minute. After the peak, the levels gradually decrease, stabilizing at around 40 PPM by the 18th minute. The CH_4 (second graph) shows a stable baseline period from time 0 to around time 9, where methane levels remain steady at approximately 180-190 PPM. A sudden sharp increase is seen at around time 9-10, where the concentration jumps dramatically. A peak concentration of around 300-320 PPM between time 11min -13min. Then a gradual decline in concentration is observed from time 13min onwards, trending back down towards 240 PPM by time 16min. The CO concentration graph displays noticeable fluctuations over time, beginning with initial readings near 135 PPM. The trend includes several step-wise decreases, indicating gradual reductions in CO levels. Around the 10min-time mark, there is a significant dip to approximately 132 PPM, followed by a recovery as the levels rise back toward 135 PPM. Toward the end of the observation period, the CO readings stabilize, settling around 134 PPM, suggesting the system's tendency to return to equilibrium after transient changes.

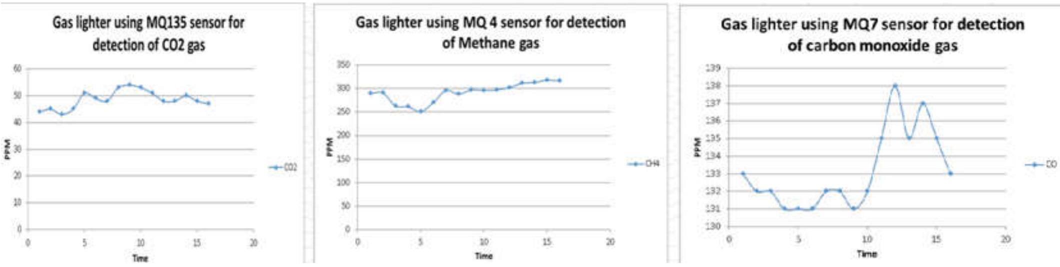

Fig: Graphical representation of sensor data collected through three sensors for experiment no. 3

Graph 1 depicts the fluctuation of CO_2 levels between approximately 40-55PPM over the course of the measurement period. The data shows a gradual increase in concentration, reaching a peak of about 53–54PPM around the 10th time point. After this peak, the levels decline steadily and eventually stabilize around 47–48PPM, indicating the system's tendency to return to a stable state following initial variations. Graph 2 shows a different pattern, where initial CO_2 readings lie between 290PPM and 300 PPM. A brief dip is observed, bringing the concentration down to approximately 250PPM. This is followed by a gradual and continuous rise in levels, ultimately reaching around 310–315 PPM by the end of the period. This trend suggests a temporary reduction followed by a progressive accumulation of CO_2 in the environment. Graph 3 illustrates the behavior of CO concentrations. The graph begins with a relatively stable baseline of about 131–132 PPM. A sharp spike then occurs, peaking at approximately 138 PPM, followed by a second, smaller peak. After these fluctuations, the CO levels gradually decline and return to near-baseline values. This pattern reflects short-term disturbances, possibly from transient environmental factors, and highlights the system's ability to recover and stabilize over time.

b) **Results using ESP8266 Wi-Fi Module:** Experiments are done in ESP8266 Wi-Fi module and data are recorded in laptop. Two different experiments are done and data are recorded accordingly. For serial transmission 9600 baud rate is used.

Experiment 1: Experiment with incense stick using ESP8266 Wi-Fi module
Experiment 2: Experiment with gas lighter using ESP8266 Wi-Fi module

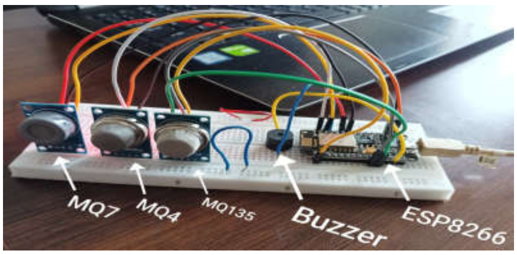

Fig: Hardware model using ESP8266

Fig: MQ135 output from incense stick after 15mins (experiment 1) in Thingspeak

Fig: MQ4 output from incense stick after 15mins (experiment 1) in Thingspeak

Fig: MQ7 output from incense stick 15mins (experiment 1) in Thingspeak

The MQ135 (CO_2) sensor starts with a relatively high gas concentration. This is due to sensor exposure to pollutants. The sensor reading gradually decreases as the air is becoming cleaner over time (e.g., better ventilation). The graph shows two sharp dips, likely due to sensor anomaly or noise; however, since each is followed by a quick recovery, they can be considered negligible. The MQ4 (methane) gas sensor graph demonstrates a general downward trend, starting around 320ppm and declining to about 290ppm, where it stabilizes with some minor fluctuations. The MQ7 (CO) graph shows a gradual decrease in carbon monoxide concentration over time, with some minor fluctuations and a few notable dips in the readings. The combined sensor data confirms the presence of multiple gases—specifically methane, carbon monoxide, and carbon dioxide or other pollutants—which appear to be dissipating over time, likely due to environmental changes such as increased ventilation.

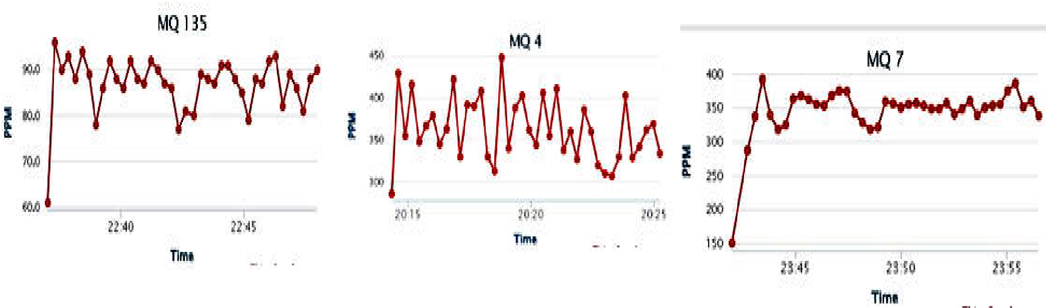

Fig: Graphical representation of sensor data collected through three sensors for experiment no. 2

The data from the three sensor graphs indicate varying gas concentration patterns over time. The first graph shows an initial sharp spike from ~60 PPM to over 90 PPM, likely due to the sudden introduction of a gas source (e.g., a gas lighter). This is followed by fluctuating levels between 80–90 PPM and eventual stabilization, suggesting a settling of gas concentration in the environment. The second graph displays fluctuations between 300 and 450 PPM, with periodic peaks that suggest intermittent exposure to a gas source, possibly methane or natural gas. The pattern indicates dynamic changes influenced by environmental factors like airflow. The third graph begins with a steep rise from ~150 PPM to nearly 400 PPM, followed by consistent fluctuations between 300–400 PPM. The presence of multiple peaks and troughs points to rapid and frequent changes in gas concentration, indicating an unstable gas environment. Across all three graphs, the recurring spikes, fluctuations, and elevated PPM levels suggest the presence and varying concentration of a combustible gas—likely methane—within the monitored area.

6. CONCLUSION

The proposed system can significantly enhance safety by enabling early detection of hazardous gases such as carbon monoxide (CO), carbon dioxide (CO_2), and methane (CH_4), thereby reducing the risk of explosions and health hazards. The system offers real-time monitoring, ensuring continuous updates on air quality and allowing for timely interventions. It plays a crucial role in protecting worker health by maintaining safe atmospheric conditions and minimizing long-term respiratory issues. With automated alerts, it quickly notifies personnel when gas levels become dangerous, facilitating immediate response and evacuation if needed. Additionally, the system supports regulatory compliance, helping mining operations meet essential safety and environmental standards.

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