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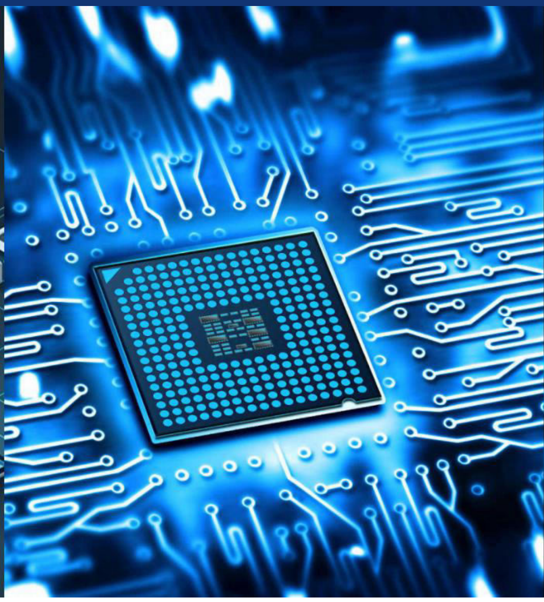

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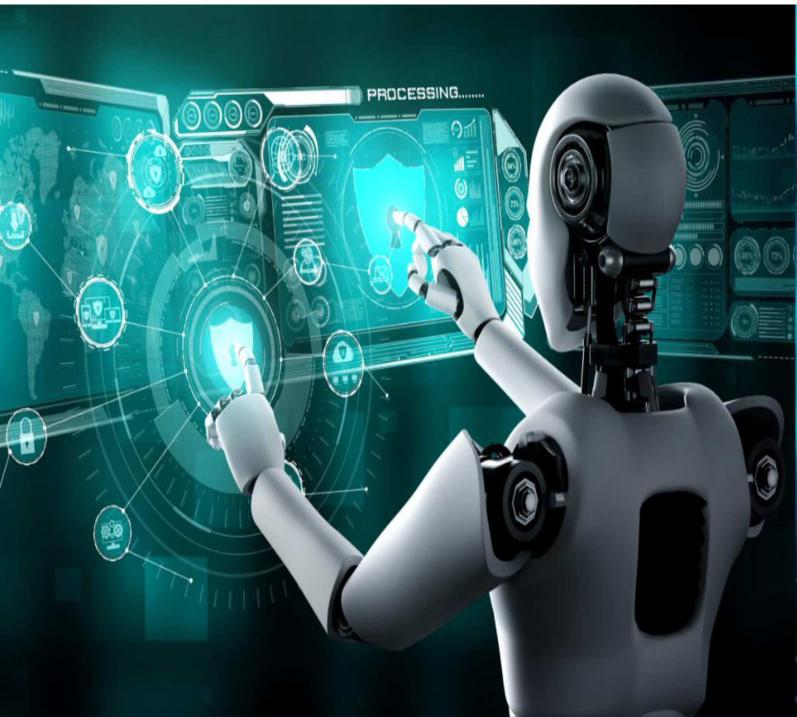

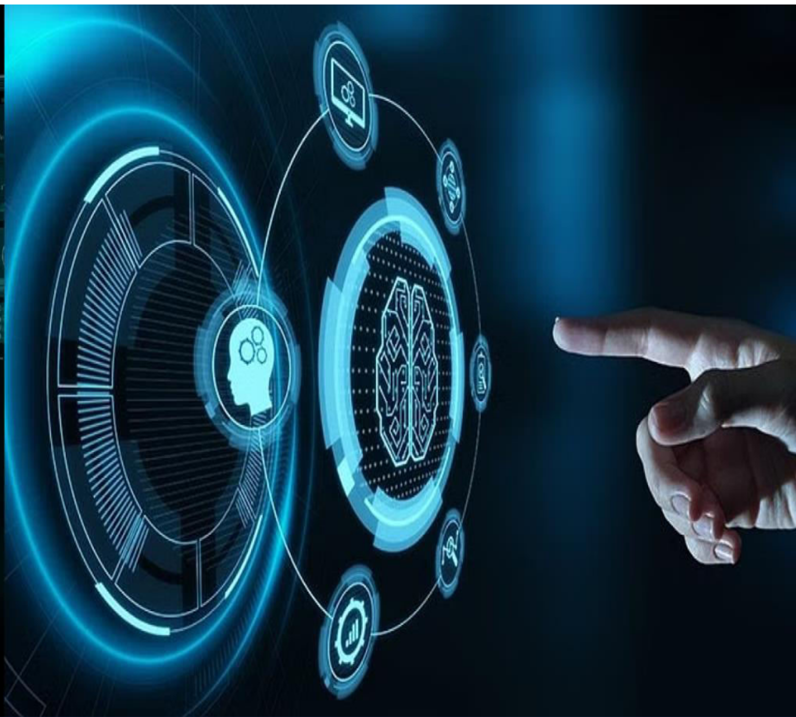

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Smart Coal Mine Safety Monitoring and Alerting System

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ABSTRACT: The Smart Coal Mine Safety Monitoring and Alerting System project is designed to enhance safety practices in coal mining environment through an innovative approach by integrating multiple sensors to a microcontroller and interfacing a cloud platform and a user-friendly app for data visualization and real-time monitoring. The System uses multiple sensors to monitor smoke, Methane, Carbon Monoxide levels. The acquired data from the multi-sensor fusion is then processed by a microcontroller and transmitted to a cloud platform for graph and gauge visualization. Experimental evaluation confirmed that the system reliably identifies hazardous conditions and provides an effective solution for safety monitoring in mining and industrial environments.

KEYWORDS: ESP32; MQ2 Sensor; MQ4 Sensor; MQ7 Sensor; BME280 Sensor; DS3231 RTC Module; ThingSpeak; MIT App Inventor.

I. INTRODUCTION

Coal mining plays a vital role in energy production, but it also comes with serious safety challenges, especially in underground environments where ventilation is limited. In such conditions, harmful gases can build up over time without immediate notice, making the environment unpredictable and dangerous. Even small delays in identifying these changes can lead to accidents that affect both workers and infrastructure.

Most existing safety methods rely either on manual inspection or simple threshold-based systems. These approaches work to some extent; these aren't that reliable considering the harsh environment of coal mines and the presence of hazardous and toxic gases. Fixed thresholds may either trigger unnecessary alerts or fail to respond at the right time, which reduces overall reliability.

To overcome these limitations, our work focuses on developing a monitoring system that can observe environmental conditions continuously and respond in real time. By using multiple sensors together instead of relying on a single parameter, the system provides a clearer picture of the surroundings. The collected readings are processed in a way that adapts to variations, making the detection more dependable. In addition, integrating cloud monitoring through ThingSpeak and a mobile interface built using MIT App Inventor allows the user to check conditions remotely. This combination of continuous tracking and remote access helps in making quicker and more informed decisions in critical situations.

II. PROPOSED ALGORITHM

The Proposed system of Smart Coal Mine Safety Monitoring and Alerting System is a developed model designed to keep a track of coal mine environment, i.e. the toxic gases, environmental temperature and air pressure are all monitored simultaneously and remotely. As illustrated in the Fig. 1 and Fig. 2 the overall work flow of the proposed system follows a step-by-step path from data acquisition to real-time monitoring.

At the initial stage, a multi-sensor fusion is used to track the environment and sense the changes in the gas levels such as methane, smoke, carbon monoxide alongside temperature and air pressure. The data is then acquired and processed

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by ESP32 microcontroller which converts raw analog readings to digital data and also implements other features such as dynamic thresholding, risk score calculation and predictable logic. The processed data is then transmitted to a cloud platform "ThingSpesk" via built-in Wi-Fi in the ESP32 for data visualization and analysis. And, simultaneously the same data is interfaced with a user-friendly app "MIT App Inventor" used for remote monitoring. And alert mechanism starts working if the thresholds are increased and rapid gas change detected.

III. COMPONENTS USED

- **ESP32 Microcontroller:** ESP32 is a dual-core, 32-bit Microcontroller which has built-in Wi-Fi feature, 12 bits ADC and also a low power processing capability which makes this to be the ideal microcontroller for our proposed system. The microcontroller reads analog signals from MQ Sensors and digital data from BME280 and DS3231 RTC. It is ground and power railed with the sensor suite and took a delay of 5 seconds due to heat period and provide stable output. The microcontroller acts as the core unit that links sensing, analysis, and communication into a single workflow.
- **Sensor Suite (MQ2, MQ4, MQ7):** Sensor Suite incorporates a combination of gas sensors to ensure comprehensive monitoring of hazardous conditions. The MQ2, MQ4, MQ7 sensors analog inputs are connected to 34, 35, 32 pins of ESP32 respectively. The MQ2 sensor is employed to identify smoke and combustion-related changes, enabling early detection of fire risks. The MQ4 sensor focuses on detecting methane accumulation, which is critical for identifying explosion-prone conditions. The MQ7 sensor is used to track carbon monoxide levels, providing early warnings of toxic exposure. The thresholds of MQ2, MQ4, MQ7 sensors are set to 3000, 5000, 1500 respectively and once the levels of the sensor readings exceed the threshold levels, the alert mechanism starts working and alert buzzers turns on.
- **BME 280 Sensor (Temperature and Pressure**): BME280 sensor is integrated to provide contextual environmental data, including temperature and atmospheric pressure. The BME280 sensor is used in the project to provide a supportive structure to the sensor suite by reducing false alarms i.e. if the multi sensor fusion levels are exceeding the thresholds but the environmental temperature levels are stable, then the risk of a hazardous situation is very low. So, BME280 sensor plays a crucial role in reducing unwanted alarms in the coal mine environment which can lead to disturbance in mining activity.
- **DS3231 RTC Module:** To maintain precise timing for data logging and analysis, the DS3231 module is used. It ensures that all sensor readings are accurately time-stamped, which is important for tracking trends and understanding the sequence of environmental changes. It is mostly used in the Data Visualization in cloud platforms for actively monitoring the conditions of coal mine environment. This capability enhances the reliability of the monitoring system, especially during long-term operation.
- **Buzzer:** An audio alert mechanism is implemented using a buzzer to provide immediate feedback when unsafe conditions are detected. It is connected to the analog pin 26 of ESP32 microcontroller and also provided an alternate pin 26 if using the second circuit wiring. The buzzer is triggered based on the evaluated risk level, ensuring that alerts are generated only when necessary. This real-time notification system supports quick response and improves overall safety.

IV. WORKING METHODOLOGY

- **Data Acquisition:** Coal mine environment is constantly sensed and detected by the sensors MQ2, MQ4, MQ7, BME280. These sensors continuously detect smoke, methane, carbon monoxide levels in the environment, and acquired by the microcontroller ESP32.
- **Data Processing:** Acquired data from sensor suite and environmental parameter detectors is the processed using Esp32 microcontroller. The ESP32 digitizes analog sensor signals, formatting the data for real-time visualization on the ThingSpeak cloud platform.
- **Multi-Sensor Data Fusion:** Multi sensor data fusion approach is based on a machine learning like algorithm where the sensor readings are all combined and verified as a single output. This approach reduces the chances of false alarms and improves detection accuracy. The system reads and analyses all the sensor readings and provide alert mechanism only when two or more sensor readings exceed the threshold.
- **Dynamic Thresholding:** Dynamic thresholding is a technique to continuously change the thresholds of the detected gas ranger instead of relying on fixed thresholds or manually entered thresholds. The thresholding is adapted according

to the environmental changes. The previous changes in the sensor readings are verified and dynamic thresholds are generated using them.

- **Risk Level Assessment**: The fusion score and dynamic thresholding are further calculated to generate risk score. The risk score then classifies the environment in coal mine as either Safe or Warning or Danger. The processed sensor data is used to determine the safety condition of the environment.
- **Cloud-Based Monitoring:** The processed data from the microcontroller is then transmitted to cloud platform ThingSpeak through Wi-Fi Connectivity by API based communication. This data is then analyzed and visualized as graphs, gauges, and numerical values in ThingSpeak. This supports real-time monitoring of the system and data logging.
- **Experimental Setup:** The system was implemented using sensors and an ESP32 microcontroller assembled on a breadboard. A stable power supply ensured continuous operation during testing. All the components are power railed and ground riled to ESP32 reducing complex connections. The setup allowed easy modification and flexible connections. This made it suitable for experimental evaluation under different conditions. And the whole setup is incorporated into a hardware housing for better presentation and protection of the components.
- **Testing Under Normal Conditions:** The overall system is first tested in room temperature and under normal conditions to evaluate the correctness of the system and to ensure that there are no false alarms or warning provided under safe conditions in the coal mine environment.
- **Smoke Detection Performance:** When exposed to Smoke, the MQ2 sensor detected the rapid change in the environment and provide rapid spike that indicates gas increase in the system with a 5 second's delay. Though the smoke levels increased, our system did not produce any alerts due to multi sensor data fusion technology i.e. it only produce alerts once more than two sensors exceed their threshold levels.
- **Methane Detection Performance**: The MQ4 sensor's threshold is set at 5000ppm for prototyping and evaluating the system performance, and when methane was released in the environment the MQ4 sensor detected and responded to it gradually with a delay of 5 seconds and provided a "Rapid gas Increase" warning once the detected value exceeded the threshold.
- **Carbon Monoxide Detection:** The MQ7 sensor's threshold is set at 1500ppm, and it detected gradual changes in carbon monoxide levels during testing. And once all the sensors detected the immediate increase in the gas levels a warning signal is produced and later by calculating the fusion score and dynamic thresholding a danger signal is produced with a 7 seconds delay between the results.
- **Environmental Monitoring:** The BME280 sensor provided stable and accurate measurements of temperature and pressure. Minor variations were observed during testing, reflecting environmental changes. These parameters help in understanding gas behavior. They improve the system's adaptability and accuracy.
- **Real-Time Output Display:** Sensor data and processed values were displayed on both the serial monitor and the cloud platform ThingSpeak. Users can observe both real-time values and trends. It enhances usability and analysis.
- **System Performance:** The system demonstrated reliable performance across all testing conditions. It successfully detected variations in gas concentration and environmental parameters. Alerts were generated accurately based on the conditions. This confirms the effectiveness of the proposed system.

V. RESULTS

Figure 3 and 4 shows the graphical visualizations from the cloud platform ThingSpeak, demonstrating real-time monitoring of environmental conditions. Under normal conditions, all parameters remained stable, indicating safe operation. During testing, smoke and methane levels showed sharp increases, while carbon monoxide changed gradually. Temperature and pressure exhibited minor variations, supporting overall analysis.

Figure 5 illustrates the mobile application developed using MIT App Inventor for real-time monitoring. The app displays both graphical trends and numerical values of gas concentrations, where methane levels were higher, carbon monoxide moderate, and smoke showed fluctuations. Environmental parameters remained stable, and the calculated risk score indicated a safe condition.

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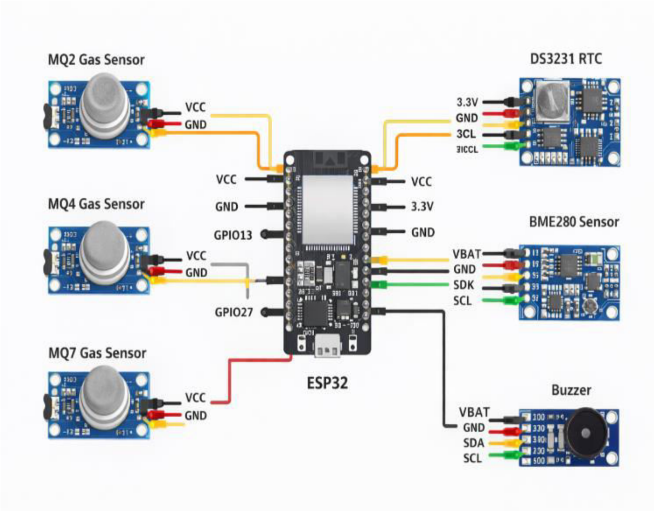

Fig. 1. System Architecture of the proposed system

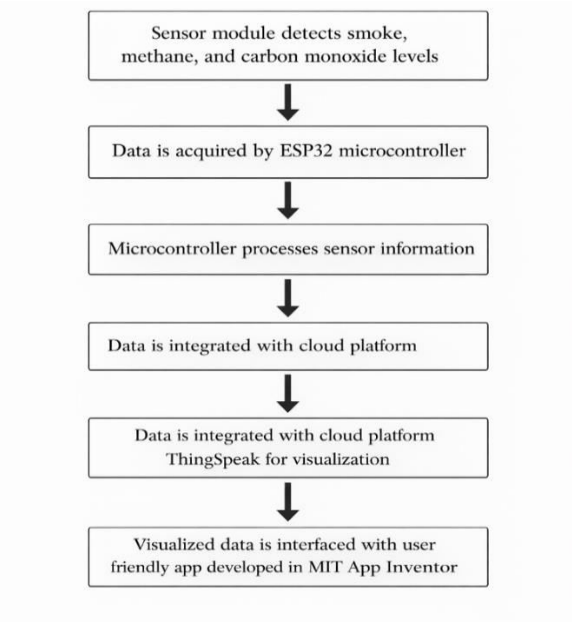

Fig. 2. Data flow of the proposed system

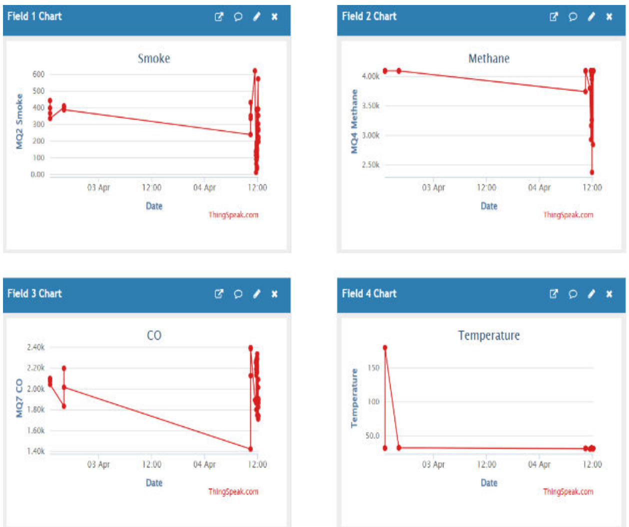

Fig. 3. Graph Visualization of data

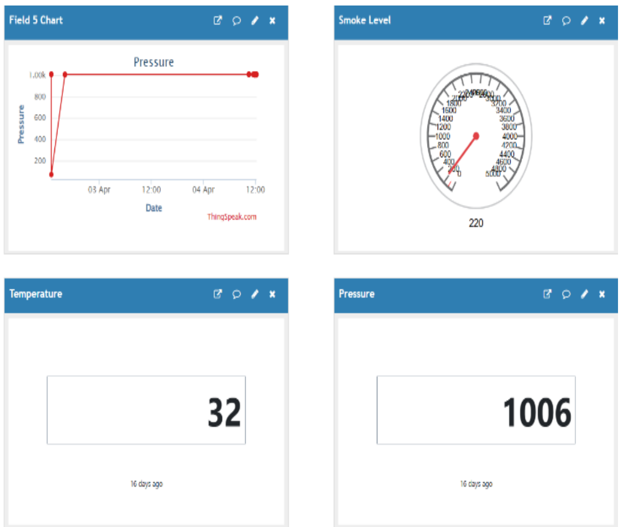

Fig. 4. Gauge Visualization of data

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Fig. 5. MIT App Inventor Output

VI. CONCLUSION

The developed monitoring system provides a practical approach for improving safety in coal mining environments.By combiningmultiple sensors and processing their outputs together, the system is able to detect hazardous conditions more reliably than traditional methods. The addition of cloud monitoringand mobile access makes the system more flexible and easier to use. Based on the testing carried out, the system was able to identify changes in environmental conditions and respond accordingly. This work demonstrates that integrating simple hardware with intelligent processingcan significantly enhance safety monitoringin real-world applications.

VII. FUTURE SCOPE

The system can be further enhanced by integrating additional sensors for detecting other hazardous gases and environmentalparameters. Advanced technologies such as machine learningcan be incorporated to predict potential hazards and improve decision-making capabilities. The communication system can also be upgraded using advanced wireless technologies for better reliability in underground environments.In addition,the system can be expanded to support large-scale industrial deployment with centralized monitoringsystems and improved user interfaces.These enhancements can further increase the efficiency,scalability,and reliability of the system.

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