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SMART IOT BASED ODOURLESS GAS DETECTION SAFETY MONITORING AND ALERTING SYSTEM FOR COAL MINES USING LORA AND AI

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Abstract: Coal mining involves toxic gases, fire hazards, poor ventilation, and harsh underground conditions, where methane and carbon monoxide are especially dangerous as they are invisible and difficult to detect. This project proposes a Smart IoT-Based Odourless Gas Detection, Safety Monitoring, and Alerting System for coal mines using LoRa and Artificial Intelligence. Multiple sensors monitor methane, carbon monoxide, temperature, humidity, and smoke in real time, while a GPS module tracks miner locations. Sensor data is transmitted through LoRa for long-range, low-power communication. A Random Forest–based AI model analyzes real-time and historical data to classify mine conditions as safe or hazardous. When hazardous conditions are detected or when sensor values exceed permissible limits, the system immediately triggers audible and visual alerts and sends real-time notifications with location details to supervisors and control centers. Enabling early detection of dangerous situations, reducing response time, and significantly improving overall safety for coal mine workers**.**

Index Terms: IoT, Coal Mine Safety, Odourless Gas Detection, LoRa, Artificial Intelligence, Random Forest Algorithm, Real-Time Monitoring, Hazard Prediction, Safety Alert System.

I. INTRODUCTION

Coal mines are inherently dangerous working environments due to poor ventilation, confined underground spaces, and the continuous release of invisible and odourless toxic gases. Among these gases, methane and carbon monoxide are particularly hazardous as they cannot be detected by human senses and may accumulate rapidly without warning, leading to explosions, suffocation, and serious health risks. Traditional gas monitoring systems often depend on manual inspection or basic alarm mechanisms with limited communication range. Such approaches may delay critical safety responses, increasing the likelihood of accidents and loss of life in underground mining operations.

With the advancement of Internet of Things (IoT) technologies, real-time environmental monitoring has become more reliable and efficient in industrial safety applications. IoT enables continuous data collection from multiple sensors and supports automated data processing for timely decision-making. However, underground coal mines pose unique challenges for IoT deployment due to signal attenuation, power constraints, high humidity, and harsh environmental conditions. Conventional wireless technologies such as Wi-Fi and Bluetooth are often ineffective in these environments because of their limited range and high power consumption, making reliable communication a major challenge in underground safety systems.

To address these challenges, the proposed system adopts LoRa (Long Range) communication technology due to its low power consumption, extended communication range, and strong signal penetration capabilities, making it well suited for underground mining applications. In addition, the integration of Artificial Intelligence (AI) enhances system intelligence by enabling predictive safety analysis rather than simple threshold-based detection. AI algorithms analyze real-time and historical gas concentration data to identify abnormal patterns and predict hazardous conditions in advance. This proactive approach allows mine operators to take preventive actions early, enabling faster emergency response, timely evacuation, and improved protection of human lives in coal mine environments. By incorporating low-power communication, intelligent data processing, and automated alerting, advanced monitoring systems can significantly enhance emergency preparedness and support safer and more sustainable mining operations.

II. RELATED WORKS

With the advancement of smart mining technologies and industrial automation, several systems have been developed to improve safety, monitoring, and hazard detection in underground coal mines. Researchers have proposed various solutions using sensors, microcontrollers, Internet of Things (IoT), and wireless communication technologies to monitor environmental conditions and prevent accidents caused by toxic gases. This section reviews some of the significant works related to gas detection systems, IoT-based mine safety monitoring, LoRa communication systems, and AI-based predictive safety models.

Many IoT-based coal mine monitoring systems focus on detecting hazardous gases such as methane and carbon monoxide using sensor networks. These systems continuously collect environmental data and transmit it to remote monitoring stations for analysis. While such systems improve real-time monitoring, most of them rely on fixed threshold values and lack predictive capabilities, limiting their effectiveness in early hazard detection. Several embedded system-based solutions using microcontrollers like Arduino and ESP32 have also been developed for gas detection and alert generation. These systems provide local alerts through buzzers and display units when unsafe conditions are detected. However, they are generally limited to short-range communication and do not support reliable data transmission in deep underground environments.

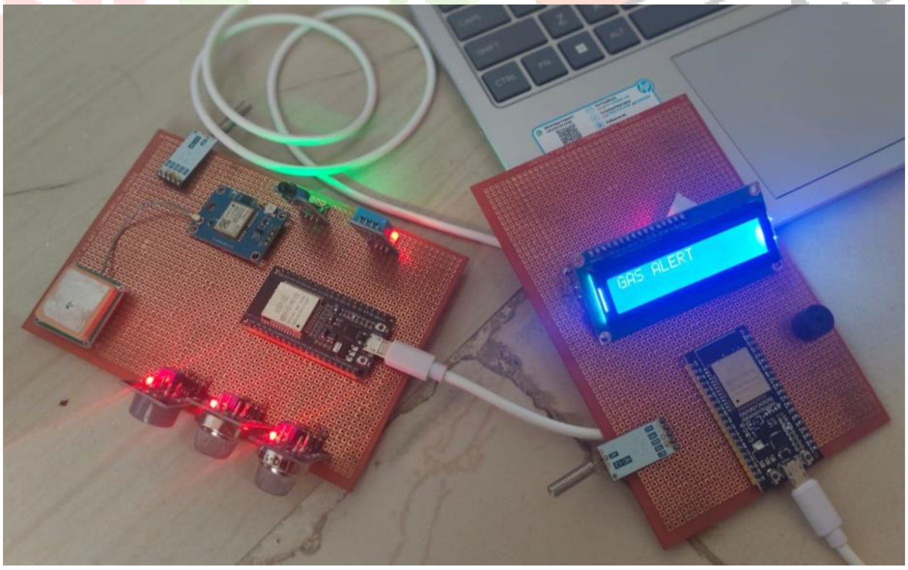
Wireless communication technologies such as Zigbee and Wi-Fi have been used in mine safety systems for data transmission. Although these technologies are suitable for short-range communication, they face challenges such as signal attenuation, limited coverage, and high power consumption in underground mines. To overcome these issues, LoRa-based systems have been introduced, offering long-range and low-power communication. These systems improve connectivity but often focus only on data transmission without integrating intelligent analysis.

In recent years, Artificial Intelligence and Machine Learning techniques have been applied to enhance safety systems by enabling predictive analysis. AI-based models analyze historical and real-time sensor data to identify patterns and predict hazardous conditions. However, many existing systems do not fully integrate IoT sensing, LoRa communication, and AI-based prediction into a single unified framework. Therefore, the proposed system aims to overcome these limitations by integrating real-time IoT-based sensing, reliable LoRa communication, and AI-based predictive analysis into a comprehensive safety monitoring and alerting system for coal mines. This integrated approach enhances early hazard detection, improves response time, and ensures better safety for miners.

Energy-efficient system design has become an important focus in recent mine safety research. Since underground monitoring devices are often battery-powered, several studies have proposed low-power sensor networks and communication protocols to extend system lifetime. Techniques such as duty cycling and energy-aware data transmission are used to reduce power consumption. However, many of these systems compromise on data transmission frequency or real-time performance to save energy. Multi-sensor data fusion is another area that has gained attention in improving the accuracy of hazard detection. Instead of relying on a single sensor, these systems combine data from multiple sensors such as gas, temperature, and humidity sensors to provide a more reliable assessment of environmental conditions. This approach reduces false alarms and improves decision-making. Nevertheless, effective integration and processing of multi-sensor data remain a challenge in many existing systems.

Several researchers applied machine learning models such as decision trees, support vector machines, and neural networks to predict gas leakage and fire hazards in mining environments. These models use historical and real-time sensor data to classify safety conditions. Although these approaches improved prediction accuracy, many were implemented independently of real-time monitoring systems or relied heavily on cloud processing. Cloud-based AI-enabled mine safety systems offer advanced analytics and data storage capabilities. However, their dependence on continuous internet connectivity introduces latency and reliability concerns, especially in underground environments where connectivity is unstable. Delays in processing or communication can significantly impact emergency response effectiveness.

SAMPLE OUTPUT IMAGE



III. METHODOLOGY

The methodology of the proposed system focuses on designing and implementing a smart mine safety monitoring platform that enhances worker safety through real-time environmental monitoring, intelligent analysis, and reliable communication. The system integrates multiple gas and environmental sensors, a microcontroller, LoRa communication technology, and an AI-based model to continuously monitor underground coal mine conditions and detect hazardous situations. The development process includes sensor data acquisition, data processing, long-range data transmission, AI-based analysis, alert generation, and remote monitoring.

3.1 Power Supply

This module is responsible for collecting real-time environmental data inside the coal mine using various sensors. Gas sensors such as MQ-series sensors (MQ-2, MQ-7, MQ-135) are used to detect hazardous gases like methane (CH_4), carbon monoxide (CO), and other toxic gases. Additionally, temperature and humidity sensors monitor environmental conditions within the mine. These sensors continuously sense variations in gas concentration and environmental parameters. The collected data is transmitted to the microcontroller for further processing and analysis.

3.2 Data Processing and Decision Making

In this module, the microcontroller acts as the central processing unit of the system. The sensor data collected from various sensors is received and processed by the controller. The system compares real-time sensor readings with predefined threshold values to determine safety levels. If gas concentrations exceed safe limits, the system identifies it as a hazardous condition. Basic decision-making is performed at the microcontroller level to ensure immediate response.

3.3 AI-Based Analysis and Prediction

This module enhances the system by incorporating Artificial Intelligence techniques for intelligent monitoring. The collected sensor data is analyzed using machine learning algorithms to predict potential hazardous situations before they occur. AI models can identify patterns in gas concentration changes and detect abnormal trends. This helps in early warning generation, reducing the risk of sudden accidents such as gas leaks or explosions in coal mines.

3.4 LoRa Communication System

The LoRa (Long Range) communication module is used for transmitting data over long distances in underground environments where traditional communication methods are ineffective. The sensor data processed by the microcontroller is sent through a LoRa transmitter to a remote receiver unit located outside the mine. LoRa ensures low power consumption and reliable communication even in harsh underground conditions.

3.5 Alert and Warning System

This module provides immediate alerts to miners and supervisors when unsafe conditions are detected. The system uses buzzers, LEDs, and display units to notify workers inside the mine. When gas levels exceed safe limits, the system triggers an alarm and displays warning messages. This helps miners take quick action, such as evacuating the area or using protective equipment.

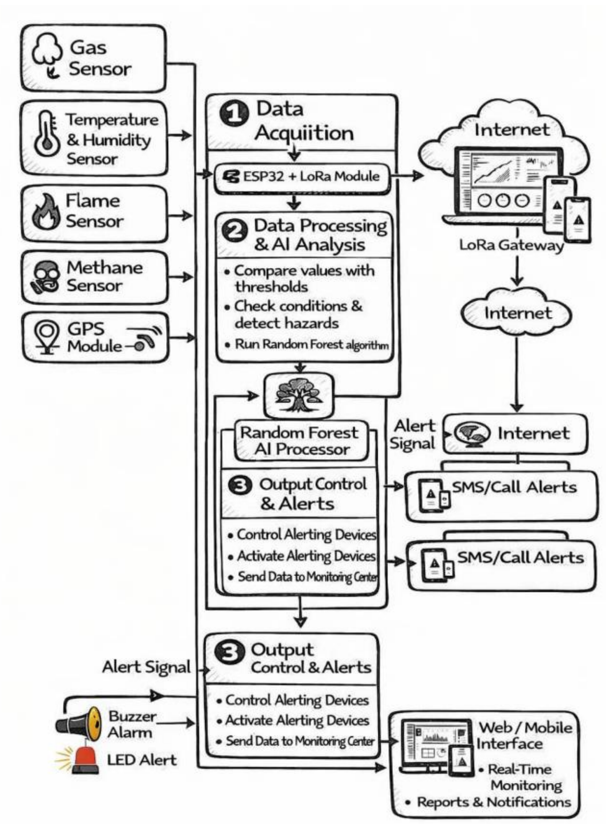
IV. SYSTEM ARCHITECTURE

We have developed a smart IoT-based odourless gas detection safety monitoring and alerting system for coal mines, which is designed to significantly enhance worker safety and environmental monitoring in hazardous underground conditions. This system integrates advanced sensing technologies, IoT communication using LoRa, and machine learning algorithms to provide real-time monitoring, intelligent decision-making, and immediate alert generation. The architecture diagram illustrates the overall structure and working of the system, highlighting its key components such as sensor units, data acquisition module, processing unit with AI analysis, communication network, and alerting system.

Each component in the architecture performs a specific function to ensure efficient and reliable operation. The sensor unit consists of multiple sensors including gas sensors, methane sensors, flame sensors, temperature and humidity sensors, and a GPS module. These sensors continuously monitor environmental parameters inside the coal mine such as gas concentration, temperature variations, presence of fire, and location tracking. The collected data is real-time in nature and is transmitted to the central processing unit for further analysis.

The data acquisition module is built using an ESP32 integrated with a LoRa communication module. This unit acts as the interface between sensors and the processing system. It gathers data from all sensors and ensures efficient long-range transmission using LoRa technology, which is highly suitable for underground mining environments where conventional communication methods may fail. The data processing and AI analysis module plays a crucial role in the system. The collected sensor data is analyzed by comparing it with predefined safety threshold values. In addition, a machine learning model based on the Random Forest algorithm is implemented to intelligently detect hazardous conditions such as gas leakage, fire risks, or abnormal environmental changes. This AI-based approach improves accuracy and reduces false alarms by considering multiple parameters simultaneously.

Once a potential hazard is detected, the output control and alert system is activated. The system generates alert signals and triggers warning devices such as buzzers and LED indicators to immediately notify nearby workers. At the same time, alert messages are sent through SMS or call notifications to responsible authorities for quick action. The system also includes a LoRa gateway connected to the internet, which transmits the processed data to cloud platforms. This enables remote monitoring through a web and mobile interface, where users can view real-time data, receive notifications, and analyze reports. This feature ensures continuous supervision even from distant locations, improving overall safety management.



In critical environments like coal mines, uninterrupted operation is essential. The system is designed to handle sensor failures or communication issues by implementing redundancy and continuous health monitoring of devices. If any sensor stops functioning or provides inconsistent data, the system can identify the fault and notify the monitoring center. This ensures that safety is not compromised due to hardware malfunction. Additionally, the use of robust communication protocols helps maintain stable data transmission even in challenging underground conditions.

The system also supports real-time decision support and automation, reducing the dependency on manual intervention. Based on the analyzed data, the system can automatically trigger predefined safety actions such as activating alarms, isolating affected areas, or sending emergency alerts. This rapid response capability minimizes the time between hazard detection and action, which is crucial in preventing accidents. By assisting mine operators with accurate and timely insights, the system enhances overall operational efficiency and ensures a safer working environment for miners.

V. RESULTS AND DISCUSSION

The proposed Smart IoT-based Odourless Gas Detection System was tested under different environmental conditions to evaluate its performance in detecting hazardous gases and ensuring safety. The system continuously monitored parameters such as methane levels, gas concentration, temperature, humidity, and flame presence using multiple sensors. When the sensor values exceeded predefined limits, the system accurately detected the hazard using threshold comparison and AI analysis. It immediately generated alerts through buzzer, LED, and SMS/call notifications. The results show that the system provides fast, reliable detection with improved accuracy, ensuring early warning and enhanced safety in coal mine environments**.**

The performance of the system under different conditions is summarized in Table 1.

Table 1: System Performance Analysis

S.No	Parameter Monitored	Normal Range	Observed Condition	System Response	Result
1	Methane Gas Level	0-250 ppm	266 ppm	Alert + Alarm Activated	Potential Gas Risk Identified
2	Carbon Monoxide(CO)	0 – 30 ppm	265 ppm	Warning Alert	Dangerous Level Detected
3	Temperature	20° C - 40°C	Above 50° C	Alert Generated	Prevent Overheating Risk
4	Flame Detection	No flame	Flame Detected	Immediate Alarm	Fire Hazard Prevented
5	Communication (LoRa)	Stable transmission	Data Transmitted Successfully	Real-time update	Reliable Communication
6	System Response Time	< 3 sec	Immediate	Automatic Action	High Performance

From the above observations, it is clear that the system performs effectively in detecting hazardous conditions and responding in real time. The integration of multiple sensors ensures continuous monitoring of gas levels, temperature, humidity, and fire presence inside the coal mine. The system accurately detects abnormal conditions when the values exceed safe limits and immediately generates alerts through alarms and notifications. The use of LoRa communication enables reliable long-range data transmission, even in underground environments. Overall, the system demonstrates high reliability, quick response time, and efficient performance in ensuring safety and early hazard detection in coal mine operations.

VI. CONCLUSION

The proposed Smart IoT-based Odourless Gas Detection Safety Monitoring and Alerting System for Coal Mines provides an efficient and reliable solution for ensuring safety in hazardous underground environments. The system continuously monitors critical parameters such as methane concentration, toxic gases, temperature, humidity, and flame presence using multiple sensors. By utilizing ESP32 and LoRa communication, the collected data is transmitted effectively even in long-range and low-signal mining areas. This real-time monitoring enables early detection of dangerous conditions, reducing the risk of accidents and ensuring the safety of workers.

The integration of IoT and Artificial Intelligence enhances the system's capability to make accurate and intelligent decisions. The sensor data is analyzed using both predefined threshold values and a Random Forest algorithm, which helps in identifying abnormal patterns and minimizing false alarms. The system quickly responds to hazardous conditions by activating buzzer alarms, LED indicators, and sending SMS or call alerts to authorities. Additionally, the use of a LoRa gateway and cloud connectivity allows remote monitoring through web and mobile interfaces, improving supervision and emergency response.

Overall, the system demonstrates high performance, reliability, and cost-effectiveness. The use of low-cost components and energy-efficient communication makes it suitable for large-scale deployment in coal mines. The system not only ensures immediate hazard detection and alerting but also supports data logging and analysis for future improvements. It can be further enhanced by integrating advanced AI models and predictive analytics, making it a strong foundation for developing intelligent and safer mining systems.

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