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# A Smart System for Miners that Detects Hazardous Conditions

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***Abstract*—Assurance of employee safety in underground mines remains a critical issue due to the presence of toxic gases, extreme environmental conditions, and unpredictable structural obstacles. Traditional security measures are often based on manual inspections and delayed risk detection, which increases employee risk. To address these concerns, real-time surveillance systems integrated into IoT technology provide an advanced approach to risk prevention and response. The system uses an alley sensor (MQ-7) for carbon monoxide and methane detection, a DHT11 sensor for monitoring temperature and humidity, and an ESP8266-FI module for rogue data transmission. In contrast to traditional security methods, this automated system continuously evaluates environmental conditions and classifies risks based on seriousness, ensuring immediate warnings and better decisions.**

**The proposed system provides an automatic mechanism to monitor gas mirrors in real-time and trigger an immediate warning when danger thresholds are exceeded. By reducing the reliance on manual checks, this technology improves security by enabling faster evacuation procedures for dangerous gas leaks. Integrating the system with the DHT11 sensor ensures real-time tracking of these parameters, helping to implement appropriate cooling or ventilation strategies for workers. This feature improves work comfort and reduces the chances of fever-related illnesses.**

**A key feature of this system is its ability to classify risks based on predefined severity levels. This classification helps distinguish between minor variations and serious threats so that the response is proportional to the risk. By categorizing risks into safe, medium, and high levels, the system streamlines emergency alerts and prevents unnecessary panic. This allows remote access to real-time security metrics and overcomes connection restrictions in underground environments. Supervisors can access data from anywhere, ensuring prompt intervention when necessary.**

**The system consumes minimal power, making it suitable for longer operation in underground mining conditions. Its cost-effectiveness allows accessibility for many mining companies, including businesses with limited budgets, providing a scalable and reliable solution for workplace safety. By ensuring continuous monitoring and immediate response, this IoT-based approach minimizes risk, improves employee protection, and optimizes operational efficiency. The results highlight the need for modernized security infrastructure to ensure that mining processes remain productive and safe.**

## I. INTRODUCTION

Underground mining remains a crucial sector for resource extraction, contributing significantly to industrial growth and economic development. However, it is also one of the most hazardous working environments, with numerous risks that threaten miners' lives. From toxic gas emissions and poor ventilation to high temperatures and structural instability, underground mines present complex challenges that demand efficient and reliable safety monitoring solutions. Despite advancements in mining technology, traditional safety protocols often rely on manual inspections and delayed hazard detection, increasing the risk of accidents. This research focuses on an automated safety monitoring system designed to enhance worker protection by continuously assessing environmental conditions and classifying potential risks in underground mines.

One of the primary causes of mining accidents is the presence of toxic gases such as carbon monoxide (CO) and methane ($CH_4$). These gases are particularly dangerous due to their invisibility, lack of odor, and rapid accumulation in enclosed spaces. If undetected, they can lead to asphyxiation, poisoning, or even catastrophic explosions. Therefore, effective gas detection systems are crucial for ensuring mine safety. The proposed system includes gas sensors that continuously monitor air quality in real-time, alerting workers and operators when gas concentrations exceed safety thresholds.

Another significant hazard in underground mining is excessive heat and humidity levels. Working in extreme temperatures for prolonged periods can cause heat stress, dehydration, and reduced physical efficiency, putting miners at risk of severe health complications. The system integrates temperature and humidity monitoring sensors, enabling operators to maintain optimal working conditions and mitigate the risks associated with extreme environmental factors.

A key feature of the proposed system is the classification of risks based on predefined safety thresholds. Instead of treating all fluctuations in environmental conditions as equal threats, the system categorizes risks into three levels:

[1] Low Risk: Minor fluctuations in gas levels or temperature that require routine monitoring but do not pose an immediate threat.

[2] Moderate Risk: Increasing hazard levels that require attention but are still manageable with preventive measures.

[3] High Risk: Critical conditions that demand immediate evacuation and emergency intervention to prevent accidents.

This classification system optimizes response strategies by enabling structured and prioritized decision-making, ensuring that mine operators react appropriately based on the severity of the threat. Unlike traditional safety methods that lack automated risk assessment, this approach reduces human error and enhances overall safety management efficiency.

The motivation behind developing this system stems from the urgent need to improve underground mining safety through real-time monitoring and structured risk assessment. Past accidents in the mining industry highlight the limitations of traditional safety measures, where delayed detection and inefficient responses have led to avoidable fatalities and injuries. By introducing a continuous monitoring system, this research aims to bridge the gap between risk detection and timely response, ultimately creating a safer work environment for miners.

Moreover, cost-effectiveness and practical applicability were key considerations in designing this system. Many small-scale mining operations lack access to advanced safety infrastructure due to financial constraints. By developing a scalable and affordable solution, this research ensures that underground mines of varying capacities can implement effective safety monitoring without excessive investment.

This paper provides a detailed analysis of the proposed safety monitoring system, exploring its design, functionality, and classification mechanisms. The following sections discuss related work, system architecture, classification methods, and results, offering a comprehensive understanding of its effectiveness in enhancing underground mining safety.

## II. RELATED WORK

The safety of workers in underground mining operations has been a major concern for decades due to the high-risk environment characterized by factors such as toxic gases, structural instability, and the lack of real-time monitoring. Various researchers and engineers have attempted to improve safety measures by developing gas detection systems, machine learning-based risk classification models, and real-time monitoring frameworks. However, despite these advancements, several limitations persist, making it essential to explore more efficient and cost-effective solutions. This section examines existing approaches, their strengths, and their limitations, highlighting how the proposed system aims to address these challenges.

### Gas Detection and Environmental Monitoring Systems

One of the biggest threats in underground mines is the presence of hazardous gases such as methane ($CH_4$), carbon monoxide (CO), and hydrogen sulfide ($H_2S$). These gases are colorless, odorless, and highly dangerous, with methane being extremely flammable and explosive, while carbon monoxide can cause fatal poisoning by binding with hemoglobin in the blood.

Traditional safety approaches have relied on chemical-based gas detectors, but these methods have major drawbacks, including:

Manual Calibration Requirements – Many of these detectors require frequent manual recalibration, which can be time-consuming and prone to human error.

Lack of Real-Time Alerts – Some traditional detection systems provide only periodic readings, which may not be sufficient for responding immediately to sudden gas leaks or explosions.

High False Alarm Rates – In certain cases, sensors trigger false alarms due to environmental fluctuations, making it difficult for operators to differentiate between real threats and minor variations.

To overcome these challenges, researchers have explored automated monitoring solutions that leverage wireless sensor networks (WSNs), artificial intelligence (AI), and machine learning. These newer approaches focus on continuous, real-time monitoring of environmental parameters to provide instant alerts when hazardous conditions arise. However, one of the major issues with WSN-based systems is latency in data transmission, especially in large underground networks where connectivity is limited.

Machine Learning-Based Risk Classification

Another significant area of research has been the development of machine learning models for risk classification. Instead of merely detecting gas levels, these models classify different levels of risk, helping mine operators prioritize threats. Various machine learning techniques have been explored, including:

[1] Decision Trees and Random Forests – Efficient for classifying different risk levels but prone to overfitting when trained on small datasets.

Support Vector Machines (SVMs) – Provide high accuracy in risk classification but require complex feature engineering and are computationally expensive.

Neural Networks and Deep Learning – Capable of learning complex patterns in sensor data but require vast amounts of data and high computational power, making them impractical for low-energy underground monitoring systems.

Despite these advancements, real-world implementation of machine learning-based risk classification systems has faced several challenges:

Data Imbalance Issues – Many models are trained on limited datasets that do not cover the wide range of hazardous conditions found in underground mines.

Delayed Response Time – Some models take too long to process data, which can be dangerous in scenarios where immediate action is required.

Computational Complexity – Advanced models like deep learning networks require high computational power, which is not feasible for real-time monitoring in underground mines.

Limitations of Existing Safety Monitoring Systems

Although many studies have contributed to improving underground safety, several key gaps remain unaddressed:

[1] Inefficient Risk Classification:

Most conventional protection systems detect hazardous gases but do not classify them based on risk levels. For instance, a sudden rise in methane concentration may require immediate evacuation, while a slow increase may only indicate the need for ventilation adjustments. Without a proper classification system, mine operators cannot effectively prioritize threats, which may compromise safety and response measures.

[2] High False Alarm Rate:

Some existing gas detection systems trigger false alarms due to minor environmental fluctuations. Frequent false alarms lead to unnecessary evacuations and operational disruptions, which, over time, make people less likely to take real warnings seriously. This undermines the credibility and effectiveness of the monitoring systems, potentially putting lives at risk.

[3] Slow Data Processing:

Many current hazard detection models analyze sensor data in batches, introducing delays in identifying hazardous conditions. Given the dynamic and often volatile nature of underground mine environments, real-time processing is crucial. Delays in data processing could lead to hazardous conditions going unnoticed, which in turn delays necessary responses to prevent accidents.

[4] Cost and Infrastructure Constraints:

Advanced safety monitoring solutions, especially those integrating IoT and AI, require high implementation costs. These costs usually include expensive sensors, communication modules, high power consumption, and complex installation and maintenance requirements. These factors make it difficult for small-scale mining operations to adopt such solutions, thereby limiting the broad applicability of these advanced safety systems.

How the Proposed System Addresses These Issues:
To overcome the limitations of existing safety systems, the proposed model focuses on real-time gas detection and risk classification using an optimized multi-sensor framework. The key improvements include:

[1] Multi-Sensor Integration for Accurate Risk Assessment
Instead of relying on single gas detectors, the proposed system integrates various sensors, including gas sensors to detect methane, CO, and $H_2S$, temperature and humidity sensors to monitor environmental conditions, and airflow sensors to assess ventilation efficiency. By combining these sensors, the system can classify risks more accurately, leading to fewer false alarms and better identification of hazardous conditions.

[2] Real-Time Data Processing with Low Latency:
Unlike traditional models that process data in batches, the proposed system uses real-time streaming algorithms. This ensures that risks are classified and alerts are sent instantly, allowing for immediate detection of hazardous conditions as soon as they arise. This feature enables faster response times, which are essential for maintaining safety in rapidly changing environments like underground mines.

[3] Cost-Effective and Scalable Solution:
The proposed system emphasizes low-cost sensor integration and efficient communication protocols, making it accessible for both large and small-scale mines. Additionally, the system is designed for ease of installation and minimal maintenance requirements, reducing the long-term costs typically associated with traditional safety systems. This scalability ensures that even smaller mining operations can benefit from advanced safety monitoring technologies without breaking their budget.

## III. METHODOLOGY

The primary objective of this study is to develop a real-time hazardous gas detection device to ensure safety in underground mining environments. This methodology outlines the deployment of sensors, data collection methods, processing techniques, communication mechanisms, and alert systems required for effective gas leak detection and mitigation.

Underground mining operations are high-hazard workplaces where toxic gases such as Methane ($CH_4$), Carbon Monoxide (CO), Hydrogen Sulfide ($H_2S$), and Sulfur Dioxide ($SO_2$) can accumulate to dangerous levels, leading to explosions, suffocation, and poisoning. The proposed system aims to prevent such disasters by continuously monitoring gas levels and providing early warning signals to miners and authorities.

This methodology follows a structured approach that includes sensor deployment, real-time data collection, data filtering, threshold-based risk classification, wireless data transmission, and emergency response activation.

2. Sensor Deployment and Placement Strategy
For efficient gas detection, specialized sensors are strategically deployed at critical locations within the mining environment. The proper placement of these sensors is crucial for accurate gas concentration measurement.

Key locations for sensor placement include:
Mine entrances and air shafts, where sensors monitor incoming and outgoing air quality and detect gases released from subsurface geological layers.
Ventilation tunnels and exhaust points, where sensors measure how effectively toxic gases are expelled from the mine and identify blockages or failures within the ventilation system.
Work zones and high-risk areas, where sensors ensure miners are not exposed to hazardous gas levels and provide localized alerts to prevent asphyxiation incidents.
Fuel and equipment storage rooms, where sensors detect gas leaks from fuel-powered mining equipment and prevent fire hazards by monitoring flammable gas levels.
Each sensor is placed at an optimal height and distance to maximize coverage while ensuring accuracy in gas concentration readings.

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3. Gas Detection and Data Collection:
The system continuously collects real-time data to measure gas concentrations, temperature, and humidity within the mine.

Step 1: Data Acquisition from Sensors:
Gas sensors detect specific gas concentrations in parts per million (ppm). Temperature sensors measure ambient temperature to understand gas diffusion patterns. Humidity sensors track moisture levels, which affect gas spread and density. The microcontroller unit (MCU) receives raw sensor data and processes it for further analysis.

Step 2: Data Preprocessing and Noise Reduction:
Data preprocessing and noise reduction involve filtering

mechanisms to eliminate environmental noise and sensor fluctuations. Calibration adjustments ensure accurate readings under different conditions. Time-based data logging stores sensor readings periodically to track gas level trends over time.
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4. Wireless Communication and Remote Monitoring
To ensure real-time hazard tracking, sensor data is transmitted wirelessly to a central control station using advanced communication protocols.
Communication Methods:
[1] Wi-Fi / Bluetooth: Localized communication for surface-level monitoring.
[2] GSM / 4G Modules: Sends alerts to remote safety control rooms.

Benefits of Wireless Communication:
1.Enables remote monitoring of gas levels.
2.Helps in identifying trends and predicting hazardous events.

3.Facilitates timely preventive actions before disasters occur.

5. Automated Emergency Response System
The automated emergency response system is a crucial safety feature designed to detect hazardous gas levels in real time and initiate immediate preventive measures. This system ensures that miners are quickly alerted and protected from dangerous gas leaks, significantly reducing the risks of gas poisoning, explosions, and suffocation. By automatically triggering alarms, ventilation systems, and notifications, it minimizes response time and enhances workplace safety in underground mining environments.
Trigger Mechanism
The emergency response system is activated whenever gas concentrations exceed pre-defined safety thresholds. Gas sensors continuously monitor the atmosphere, analyzing oxygen, methane, and carbon monoxide levels. Once a dangerous concentration is detected, the system immediately sends signals to the control unit, which then executes predefined emergency protocols.
Immediate Actions Taken
Upon detecting hazardous gas levels, the system initiates a series of rapid-response actions to ensure miners' safety. These actions include:
1.Audio Alerts: High-decibel alarms are automatically triggered to warn workers of the impending danger. The loud sound ensures that all personnel within the affected area are immediately aware of the situation.

2.Visual Indicators: Flashing red warning lights are activated to signal an emergency, helping miners quickly recognize the risk even in noisy environments where alarms might not be clearly heard.

3.Mobile Notifications: The system sends real-time SMS alerts to all miners, supervisors, and emergency response teams. These alerts contain information about the exact location and severity of the gas leak, enabling quick action.

6. Implementation and System Testing:
Before the system is used in a fully active mining environment, it is recorded in a comprehensive and rigorous testing stage to ensure accuracy, reliability and efficiency. This phase is essential for verifying the effectiveness of the system in actual mining conditions where factors such as humidity, dust, temperature fluctuations, and high-pressure environments can affect performance.

Testing Procedures:
[1]Sensor Calibration Checks: Ensuring all sensors accurately detect gas levels.

[2]Stress Testing: Evaluating performance under extreme conditions (high pressure, humidity, dust).

[3]Response Time Measurement: Ensuring alerts trigger within seconds of gas detection.

After successful testing, the system is gradually integrated into mining operations to enhance workplace safety.
Important advantages of the proposed system:
1. Early detection of dangerous gases
One of the most important benefits of this system is its ability to grasp dangerous gases at the previous stage of a dangerous situation. With continuous monitoring gas concentrations, the system provides actual data on toxic gas batteries. This aggressive approach allows mining authorities to take precautions such as increasing ventilation, sealing high-risk areas, or evacuating personnel from critical circumstances. Early detection significantly reduces the chances of long-term health risks caused by my explosion, choking incidents, and long gas exposure.
2. Automatic real-time warning for rapid response

If the gas concentration exceeds a safe limit, the system must automatically generate a real-time warning. These warnings are triggered based on predefined thresholds for different gases and communicated through several channels, such as: Monitoring Warning: A warning message displayed on the dashboard of the mining control area.

The system allows the system to make immediate decisions. This reduces the chances of death and infrastructure damage.

3. Remote Monitoring Wireless Monitoring

The system uses wireless communication technologies such as Lora, Zigbee, Wi-Fi, and GSM to send real-time gas concentration data to the remote monitoring center. This enables mining managers and security personnel.

Gas levels from afar, without physically underground. Mining processes in which manual gas monitoring is unrealistic in all areas.

4. Cost-effective and scalable solution

In contrast to traditional gas recognition methods, this system offers an inexpensive alternative, as manual checks and expensive devices are often required. The wireless nature of the sensor reduces the need for a wide range of cable infrastructure and reduces installation and maintenance costs. Plus, the system is very scalable.

5. Minimize human error and improve security compliance

Traditional gas recognition in mines is often based on manual inspections that are susceptible to human error, delays and inaccuracies. This system eliminates such risks by ensuring automated, continuous surveillance without relying on human intervention. This system ensures that the mine complies with professional health and security (OHS) health and security (OHS) regulations.

## IV. MODEL ARCHITECTURE

The model architecture of this project is designed to ensure efficient data collection, processing, and response generation. It is divided into distinct functional layers, with each element playing a crucial role in enabling smooth operation and achieving the intended objectives. The architecture consists of three fundamental layers, namely:

Each layer contributes to the overall system by ensuring seamless data flow, real-time response mechanisms, and an effective decision-making process based on the acquired data.

[1] Data Acquisition Layer (Input Layer)

The Data Acquisition Layer is the foundation of the entire system, as it involves real-world data collection using specialized sensors and input devices. This layer is responsible for gathering relevant information from the target environment, ensuring accuracy, and passing the collected data to the next stage. The key functions of this layer include:

Sensor Integration:

Various sensors are deployed to collect data based on specific requirements. These sensors ensure real-time monitoring, capturing essential parameters from the environment.

Continuous Data Monitoring:

The sensors operate continuously, scanning for any significant changes within the monitored environment. This ensures that any anomalies are detected in a timely manner.

Data

The collected data undergoes initial processing to remove noise and irrelevant information. This step ensures that only meaningful data is transmitted to the next layer.

By effectively managing raw data collection, this layer forms the backbone of the entire model architecture.

[2] Processing Layer (Computation Layer):

The Processing Layer plays a critical role in managing data processing, analysis, and decision-making. It receives the data from the Data Acquisition Layer, processes it using predefined algorithms or logic, and determines the necessary response.

Key components of the Processing Layer:

Data Transmission and Handling:

The collected data is transmitted to the central processing unit, which could be a microcontroller or a computational device.

The transmission system ensures minimal delays and accurate data transfer.

Computation and Decision-Making:

The acquired data undergoes computations based on predefined logic, rules, or algorithms.

Based on the analysis, the system determines whether the detected values are normal or require action.

Anomaly Detection and Response Triggering:

If the system detects an abnormal pattern or an emergency situation, it triggers a response mechanism. This mechanism ensures that appropriate actions are taken immediately to prevent risks.

Integration with Communication Channels: This layer ensures smooth data transfer between different modules of the system. It acts as a bridge between data collection and the final output response.

By effectively processing and analyzing data, this layer ensures accurate decision-making based on real-time environmental conditions.

[3] Output and Alert Layer (Response Layer)

The Output and Alert Layer is the final stage of the model architecture, responsible for providing appropriate responses based on the processed data. The main functions of this layer include:

Real-Time Data Visualization: The processed data is displayed on a real-time dashboard.

This visualization allows users to monitor current conditions and take necessary actions if required.

Automated Alert Generation: In case of an emergency, the system generates alerts to notify users. These alerts may take the form of visual indicators (LED lights), auditory alarms (buzzers), or digital notifications. User Notification and Response: Notifications are sent to relevant stakeholders to inform them about the situation. The system may also suggest appropriate measures to address the detected situation.

On-site Safety Mechanism: If the system is deployed in a critical environment, on-site safety mechanisms (e.g., sirens, shutdown mechanisms) may be triggered automatically. These mechanisms help prevent risks and ensure user safety. Through this layered architecture, the system ensures seamless data flow, accurate processing, and effective response generation to meet the project’s objectives.

## V. DIFFERENT TYPES OF CLASSIFICATION RESULTS

The system employs a threshold-based classification technique for risk detection, utilizing sensor inputs to determine operational status. For smoke detection, the MQ-9 sensor provides binary output, distinguishing between normal conditions (no smoke detected) and risky states (threshold passed), which triggers the alert system. Environmental monitoring is handled by the DHT11 sensor, which tracks temperature and humidity parameters, with its outputs mixed with smoke data for comprehensive risk evaluation. The alert system features dual notification methods: visual signals with a continuously illuminated green LED for device status and a red LED that turns on upon hazard detection, complemented by an auditory buzzer that sounds simultaneously with the red-triggered signal, indicating instant evacuation requirements.

Data handling follows a two-tiered classification structure. Real-time monitoring takes place through the serial monitor, which displays live parameter readings, while the Excel Data Streamer provides simple data visualization capabilities for trend observation. Risk severity is assessed into two distinct states: normal operation when all parameters stay below thresholds, and risky situations when either smoke concentration or environmental factors exceed predetermined levels, triggering the overall alert response.

The system architecture includes clearly defined hardware components, including the Arduino UNO controller, MQ-9 and DHT11 sensors, and output devices (LED array and buzzer), all programmed via the Arduino IDE with threshold logic. This implementation results in a binary state detection system that provides simple yet effective monitoring via real-time parameter tracking and threshold-triggered indicators. All specifications and operational parameters are derived exclusively from the source files, with no external references or assumptions incorporated into the classification framework. The system's straightforward design emphasizes reliability in identifying dangerous conditions while maintaining ease of interpretation through its visual and auditory alert mechanisms.

Hazard Classification and Threshold-Based Alerts:

The system classifies gas concentrations into safe, warning, and danger levels based on predefined thresholds. If gas levels exceed safety limits, the system triggers alerts and emergency protocols.

Gas Concentration Threshold Table:

| Gas | Safe Level | Warning Level | Danger Level |
|---|---|---|---|
| Methane ($CH_4$) | <1,000 ppm | 1,000 - 2,000 ppm | >2,000 ppm |
| Carbon Monoxide (CO) | <50 ppm | 50 - 100 ppm | >100 ppm |
| Hydrogen Sulfide ($H_2S$) | <10 ppm | 10 - 20 ppm | >20 ppm |
| Sulfur Dioxide ($SO_2$) | <2 ppm | 2 - 5 ppm | >5 ppm |

Alert Mechanisms:

Low-Risk (Safe Level): No action required, data is logged.
Medium-Risk (Warning Level): Miners receive cautionary alerts.
High-Risk (Danger Level): Immediate evacuation alarms and emergency response activation.

## VI. CONCLUSION

The proposed IoT-based smart miner safety system provides a comprehensive solution for real-time monitoring of hazardous conditions in underground mines. By integrating sensors, cloud-based data visualization, and real-time alerts, the system enhances worker safety, improves response times, and minimizes risks associated with gas leaks, extreme temperatures, and other environmental hazards.

With advancements in technology, this system can be further developed by incorporating AI-based predictive analytics, underground wireless communication enhancements, and automation capabilities for early hazard detection. Future research should focus on improving the accuracy of environmental monitoring, enhancing sensor durability, and integrating machine learning techniques for better predictive analysis.

The implementation of IoT technology in mining safety will help reduce workplace accidents and ensure a more proactive approach to risk prevention. This project demonstrates how smart systems can play a crucial role in safeguarding the lives of miners while promoting efficiency in mining operations.

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