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Wireless Surveillance and Safety System Using for Mine Workers

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Abstract

The safety of mine workers in hazardous environments is a critical concern due to the risks associated with toxic gases, extreme temperatures, and structural instability. Traditional safety measures often lack real-time monitoring capabilities, leading to delayed emergency response. This paper reviews the advancements in wireless surveillance and safety systems designed for underground mining operations. The proposed system leverages wireless sensor networks and IoT technology to continuously monitor environmental parameters such as gas concentrations, temperature variations, and worker movement patterns. In case of anomalies, automated alerts are sent to control centers, enabling swift intervention. By ensuring seamless data transmission between underground and surface units, this approach enhances worker safety while optimizing operational efficiency. This review examines existing research on IoT-based mining safety solutions, evaluates their effectiveness, and explores future developments for more robust and reliable monitoring systems.

1. Introduction

Mining environments present numerous hazards, including exposure to toxic gases, elevated temperatures, and structural instability. Ensuring worker safety in these conditions is a top priority. Traditional monitoring approaches largely depend on wired systems, which are expensive to install, difficult to maintain, and vulnerable to damage. These drawbacks hinder real-time hazard detection and emergency response. To address these issues, advanced wireless surveillance systems have been introduced, incorporating technologies like Wireless Sensor Networks (WSNs) and the Internet of Things (IoT). These innovations provide continuous monitoring of environmental conditions and worker safety, leading to faster hazard identification and improved emergency response. Wireless sensors are instrumental in tracking key environmental parameters such as gas concentration, temperature changes, and humidity levels in underground mines. These sensors relay real-time data to centralized monitoring systems using wireless communication protocols, enabling authorities to evaluate risks and implement preventive actions. Compared to traditional wired

systems, wireless networks offer superior flexibility, lower maintenance needs, and increased scalability. Additionally, integrating artificial intelligence and predictive analytics into these systems allows for early identification of potential hazards, reducing accident risks and enhancing workplace safety [1]. Despite the benefits of wireless surveillance, underground mining conditions pose challenges that affect network performance. Signal degradation, interference from mining machinery, and the complex tunnel structures can obstruct seamless communication. External factors like dust, moisture, and electromagnetic interference further impact data transmission reliability. Researchers continue to develop optimized communication protocols, durable sensor technologies, and energy-efficient networks to enhance system performance. The use of hybrid communication techniques, such as a combination of ZigBee, LoRa, and Wi-Fi, has proven to be effective in strengthening network coverage and improving reliability in underground environments [2]. The incorporation of IoT-based solutions has significantly improved real-time monitoring and safety measures in mining operations. IoT-enabled devices continuously collect and transmit data to cloud-based platforms, where it is analyzed to detect potential risks. When hazardous conditions arise, automated alerts are sent to workers and supervisors, allowing for immediate action [3]. Furthermore, wearable IoT devices equipped with health-monitoring sensors track essential worker parameters such as heart rate and fatigue levels, offering valuable insights into their well-being. By merging IoT with advanced data analytics, mining industries can enhance safety protocols, minimize workplace incidents, and optimize operational efficiency. The continuous evolution of wireless surveillance technologies will play a crucial role in shaping the future of underground mining safety [4]. The deployment of wireless surveillance and safety systems in mining environments has revolutionized the way hazards are detected and managed. Modern wireless systems utilize distributed sensor nodes to gather real-time data on various environmental factors, including air quality, ground stability, and worker movements. These sensors operate on low-power networks and transmit critical data to a centralized monitoring hub, ensuring that mine supervisors receive timely updates on any potential threats. The integration of cloud-based storage further enhances the accessibility and analysis of collected data, allowing for more informed decision-making and predictive risk assessments. Compared to conventional monitoring techniques, wireless surveillance offers improved adaptability to dynamic mining conditions, enabling a more proactive approach to workplace safety [5]. A significant advancement in wireless surveillance for mine workers is the adoption of real-time location tracking. Technologies such as Radio Frequency Identification (RFID) and advanced positioning systems enable mining operators to monitor worker locations within underground tunnels accurately. This capability is crucial during emergencies like gas leaks or tunnel collapses, as it facilitates swift evacuation and rescue operations. Moreover, integrating machine learning with location data allows for predictive analysis of worker movements, helping to detect potential hazards and prevent accidents. These advancements improve safety measures, minimize response times, and ensure that workers operate within designated secure areas [6].

2. Methodology

A wireless surveillance and safety system for mine workers can be implemented using a combination of technologies like Wireless Sensor Networks (WSNs), the Internet of Things (IoT), and real-time monitoring. This system aims to improve safety by constantly monitoring environmental conditions and worker health, while maintaining reliable data transmission within the challenging underground mine environment [7]. The surveillance aspect involves deploying numerous sensor nodes throughout the mine. These sensors collect data on key environmental factors, such as gas levels, temperature, humidity, and air quality. Data from the sensors is sent to a central control unit where it is processed and analyzed. This unit uses both edge computing, for rapid on-site analysis and decision-making, and cloud-based storage, for more comprehensive processing and remote access. The cloud system enables authorized personnel to view real-time and historical data, facilitating better safety management and emergency response. In the event of hazardous environmental conditions or worker distress signals, the system automatically sends alerts (Figure 1). These alerts can be delivered through various means, such as mobile apps,

alarms, or wearable vibrating devices, ensuring prompt reactions to potential dangers [3].

2.1. Hardware Components

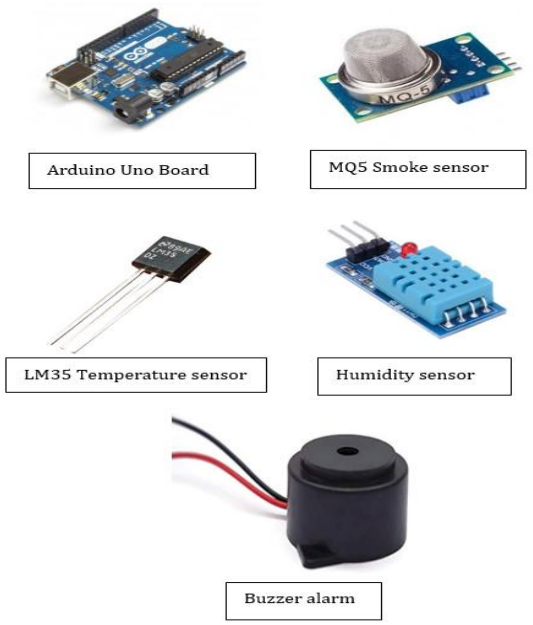

Figure 1 Overall Hardware Description

The Arduino Uno, powered by the ATmega328P microcontroller, is widely recognized for its adaptability and ease of use (Figure 2). It features multiple digital and analog input/output pins, making it compatible with a wide range of sensors and communication modules. In a wireless surveillance and safety system for mine workers, the Arduino Uno serves as the central processing unit, collecting real-time data from environmental sensors such as gas detectors, temperature monitors, and humidity sensors. This data is then transmitted wirelessly to a monitoring station, enabling supervisors to assess working conditions and respond promptly to potential hazards. Additionally, the Arduino Uno supports integration with wireless communication technologies like Bluetooth, Wi-Fi, and LoRa, ensuring reliable data transmission even in challenging underground environments. Its open-source nature and extensive community support further enhance its applicability in developing cost-effective and efficient mine safety solutions [8]. A buzzer alarm plays a crucial role in warning workers about hazardous conditions. It produces a loud sound when unsafe levels of temperature, humidity, or gas are detected, offering an instant alert to help prevent accidents. This real-time warning system strengthens safety measures in underground mining operations [9]. A temperature sensor is a crucial component of a mine safety system, as extreme heat or cold can affect both workers and machinery. High temperatures may lead to heat stress, dehydration, or equipment overheating, while low temperatures can impact the functionality of tools and increase the risk of hypothermia for workers. To mitigate these risks, temperature sensors are strategically placed within the mine to continuously monitor variations in ambient conditions. These sensors relay real-time data to a central monitoring unit, such as an Arduino or other microcontrollers, which analyze the readings. If the temperature surpasses pre-defined safety limits, the system triggers alarms, warning workers and supervisors to take necessary precautions. Additionally, automated cooling or ventilation systems can be activated to regulate temperature levels and maintain a safer working environment. [10]. A humidity sensor measures the air's moisture levels, which is crucial for miner safety and structural stability. Excess humidity can cause discomfort and pose health risks while also impacting the mine's integrity. By incorporating a humidity sensor, real-time data is wirelessly transmitted to the monitoring unit, allowing for timely preventive measures. The fig 1 shows Overall Hardware description.

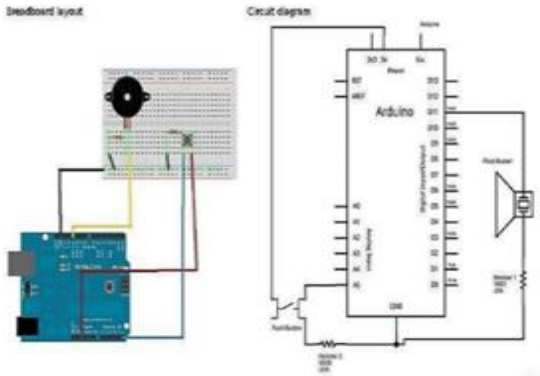

Figure 2 Connection between the Buzzer and the Arduino UNO

MQ5: The methane content of the coal mine environment is detected by this sensor. The interaction between the gases and the gas sensor determines the gas concentration. Every gas has a unique breakdown voltage, which aids in gas identification. LPG, methane, hydrogen, and carbon monoxide are just a few of the gases that may be measured with the MQ5 sensor. It can detect

concentrations between 200 and 10,000 parts per million and needs a 5-volt power source [11]. This figure shows the interface between the Buzzer alarm and Adruino Uno microcontroller board. The Fig 2 illustrates an Arduino-based circuit, including a circuit diagram and a breadboard layout, featuring a push button and a piezo buzzer. The Arduino board functions as the microcontroller, supplying power and controlling the components. Pressing the push button sends a signal to the Arduino, which then activates the buzzer. A pull-down resistor is connected to the button to ensure stable input readings. Upon receiving the signal, the piezo buzzer, linked to a digital output pin on the Arduino, emits sound. This circuit is useful in applications like alert systems, interactive projects, and notifications. Proper wiring and programming help prevent issues such as false triggering or incorrect responses [12].

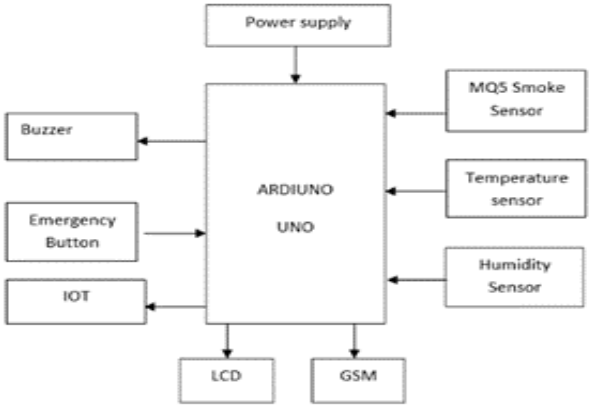

Figure 3 Architecture Diagram

The Figure 3 represents a wireless surveillance and safety system for mine workers, utilizing an Arduino Uno as the central controller. The system integrates various sensors, including an MQ5 smoke sensor, a temperature sensor, and a humidity sensor, to monitor environmental conditions in real time. An emergency button allows workers to send distress signals, while a buzzer provides audible alerts in hazardous situations. The system also features IoT connectivity for remote monitoring and GSM communication for sending alerts to authorities. An LCD display provides real-time data visualization [13]. By implementing this system, mining environments can enhance worker safety through early hazard detection and efficient communication, reducing risks associated with toxic gases, high temperatures, and emergencies.

2.2. Software Description

The software architecture of a wireless surveillance and safety system for mine workers is designed to monitor environmental conditions and ensure rapid response to hazardous situations. Central to this architecture is the integration of various sensors such as gas detectors, temperature and humidity sensors, and smoke detectors that continuously collect data on the underground environment. These sensors interface with a microcontroller, like the Arduino Uno, which processes the incoming data and identifies potential threats. For effective communication, the system employs wireless technologies, notably ZigBee, to transmit sensor data to a central monitoring station [14]. ZigBee's low power consumption and mesh networking capabilities make it suitable for the subterranean conditions of mines, facilitating reliable data transmission even in complex underground layouts. The central monitoring station runs specialized software that analyzes the incoming data in real-time, triggering alerts and initiating safety protocols when dangerous conditions are detected. To enhance the system's functionality, Internet of Things (IoT) connectivity is incorporated, allowing for remote monitoring and control. This enables supervisory personnel to access live data and respond to emergencies promptly, regardless of their physical location. Additionally, the system can integrate with GSM modules to send automated alerts to emergency services or designated authorities, ensuring swift action during critical events. The user interface includes an LCD display that provides mine workers with real-time information about environmental conditions, enabling them to make informed decisions. The software architecture is designed with a focus on reliability, real-time processing, and seamless integration of hardware components to create a comprehensive safety solution for mining operations [15].

3. Safety Features and Alert Mechanisms

3.1. Real-Time Gas Detection and Warning System

Real-time gas detection and warning systems play a crucial role in ensuring the safety of mine workers by continuously monitoring hazardous gas levels in underground environments. These systems typically employ gas sensors, such as MQ-series or electrochemical sensors, to detect toxic gases like methane (CH_4), carbon monoxide (CO), and

hydrogen sulfide (H_2S). Upon detecting abnormal concentrations, the system triggers immediate alerts through visual, auditory, or wireless notifications to prevent accidents such as explosions or asphyxiation. Advanced implementations integrate wireless communication and IoT-based platforms to transmit real-time data to control centers, enabling proactive decision-making and rapid response. Studies have shown that integrating such systems with predictive analytics can further enhance their effectiveness in minimizing risks in mining operations [16].

3.2. Worker Health Monitoring

Mining worker health monitoring systems use advanced sensors to track environmental factors such as humidity, temperature, and smoke levels, helping to maintain safety and prevent health risks. Excessive humidity and high temperatures can cause heat-related illnesses and fatigue, while smoke detection is crucial for identifying potential fire hazards. Wearable sensors continuously collect real-time data and transmit it wirelessly to a central monitoring system for analysis. If hazardous conditions are detected, alerts are sent to both workers and supervisors, allowing for immediate action. Integrating these systems with IoT and predictive analytics enhances early risk detection, improving safety in underground mining operations [17].

3.3. Emergency Communication System for Miners

A reliable emergency communication system is crucial for safeguarding mine workers in hazardous conditions. Advanced wireless technologies like Zigbee, LoRa, and LTE support real-time alerts and enable seamless communication between miners and control stations. In emergency situations, wearable devices with panic buttons allow workers to send immediate distress signals, facilitating quick rescue efforts. Furthermore, underground mesh networks improve signal transmission by connecting multiple nodes, ensuring stable communication even in deep mining areas. Research indicates that the adoption of IoT-based communication systems enhances emergency response times and minimizes casualties in mining incidents [18].

4. Challenges

Mining is one of the most hazardous industries, exposing workers to numerous risks that can lead to injuries or fatalities. The underground environment is often unstable, with potential for rockfalls, gas leaks, and machinery malfunctions. Workers also face physical strain due to high temperatures, poor ventilation, and extended work hours in confined spaces. These conditions make real-time monitoring and advanced safety systems essential to ensure worker well-being. One of the primary challenges in mine safety is the difficulty of immediate communication and tracking [19]. Underground mines often have weak or no cellular network coverage, making it hard to relay emergency alerts or track worker locations effectively. In the event of an accident, delayed response times can lead to severe consequences. Traditional safety measures, such as manual inspections and wired communication, may not be efficient enough to provide real-time data on potential hazards. A significant concern is exposure to hazardous gases like methane and carbon monoxide, which are difficult to detect without specialized sensors. Undetected gas leaks can result in explosions or suffocation. Furthermore, the use of heavy machinery and mining equipment presents serious risks if not properly maintained or if workers lack sufficient training [20]. Accidents in mining operations often stem from mechanical failures and human errors. Despite technological advancements, implementing effective safety measures remains challenging due to the harsh mining environment and the cost of deploying advanced systems. Wireless safety solutions must be designed to withstand extreme conditions while maintaining reliable connectivity. Overcoming these challenges requires a combination of improved technology, worker training, and strict safety regulations to create a safer working environment for miners [21].

5. Result

The four figures consist of four sensor-based charts from a wireless surveillance and safety system used in mining, displayed on the Thing Speak platform. Each chart represents real-time data monitoring for different environmental and safety parameters. The fig 4 displays temperature sensor readings, which fluctuate between approximately 22°C and 32°C, with occasional peaks and drops. A sharp decline followed by a quick recovery suggests possible environmental changes or sensor sensitivity. Temperature monitoring is essential in mining to

prevent overheating of equipment and ensure worker safety.

Figure 4 Mine Safety Temperature Monitoring Char

The fig 5 represents smoke sensor data, which remains mostly stable at a low level but shows a sudden spike, indicating a rise in smoke concentration that could signal a fire or hazardous condition. After the peak, the readings return to normal but show a slight increase towards the end, suggesting possible residual smoke or sensor recalibration. Real-time smoke monitoring plays crucial role in early fire detection and prevention.

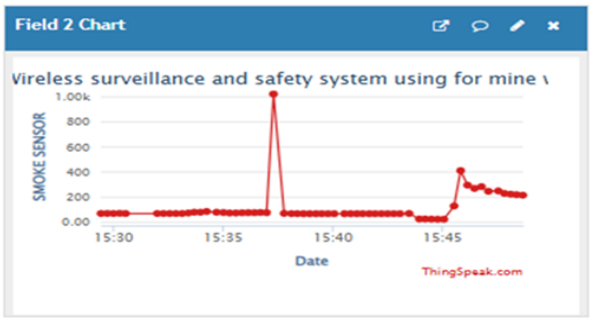

Figure 5 Mine Safety Smoke Sensor Monitoring Chart

The fig 6 visualizes moisture sensor readings, which remain consistently high except for a sharp drop at one point.

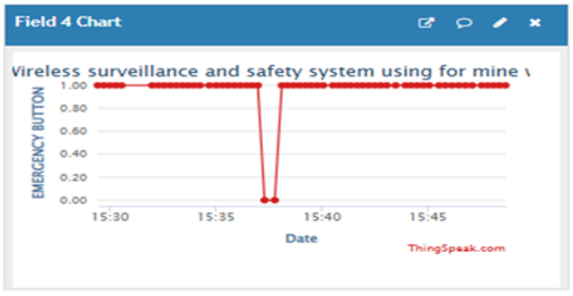

Figure 6 Mine Safety Moisture Sensor Monitoring Chart

This sudden dip might be due to a temporary sensor malfunction, dry conditions, or interference. Maintaining proper moisture levels is necessary in mining to control dust, prevent structural instability, and ensure a safe working environment. The fig 7 monitors an emergency button, which stays active at a high level throughout most of the timeframe. However, a brief drop in the reading suggests that the button was pressed or tested. This feature is critical for emergency situations, as it enables immediate alerts and responses to potential risks. These four charts collectively contribute to real-time monitoring, enhancing safety and operational efficiency in a mining environment.

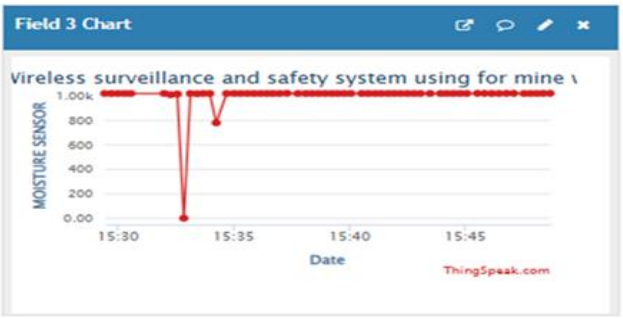

Figure 7 Mine Safety Emergency Button Status Chart

Table 1 Overall Outcome

Gas Name	Expected Output	Received Output	Hazard Level
Methane (CH_4)	< 250	370	Smoke is High
Liquefied Petroleum Gas (LPG)	< 250	350	Smoke is High

In our project, we developed a temperature monitoring system with an LCD and microcontroller to track underground heat and ensure mine safety (Table 1). It uses an I2C interface and a red LED for real-time alerts. We also tested gas levels using the MQ-5 sensor, detecting 370 ppm Methane and 350 ppm LPG both above safe limits. The system successfully identified hazardous conditions, proving its reliability for early warning in mines. The below image shows a temperature monitoring system with an LCD display and microcontroller helps ensure mine worker safety by continuously tracking

underground temperature. The system uses an I2C interface for efficient communication and a sensor to detect heat buildup, preventing fire risks. A red LED indicator confirms operation, making it essential for real-time mine safety monitoring.

Figure 8 Temperature Monitoring System for Mine Safety

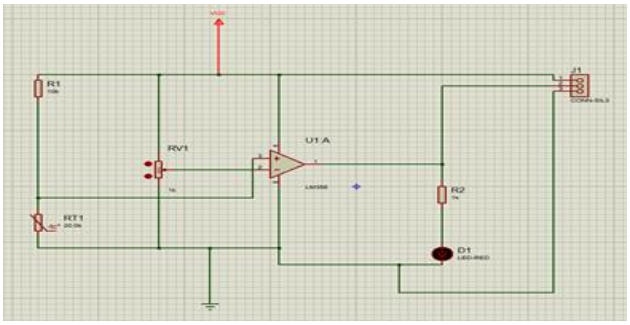

Figure 9 Temperature Sensor Circuit using LM358

We designed this circuit as a temperature monitoring system using an LM358 operational amplifier configured as a comparator. A thermistor (RT1) and resistor (R1) form a voltage divider that provides an input voltage based on temperature variations. A potentiometer (RV1) sets the reference voltage at the inverting input of the op-amp. When the temperature exceeds the set threshold, the LED (D1) turns ON as an alert. The connector (J1) allows for external interfacing, making the system suitable for industrial safety and mine worker protection applications.

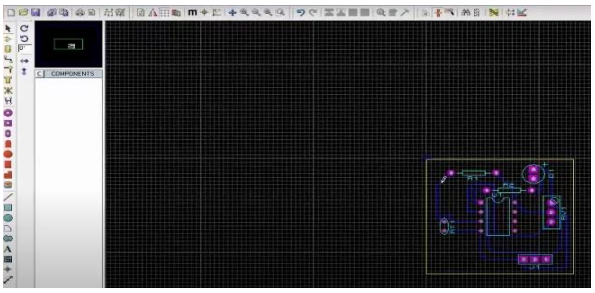

Figure 10 PCB Layout Design Temperature Sensor

After completing the schematic design, the layout was transferred to the PCB editor. Component footprints were placed on the board with proper spacing and alignment. Routing of connections was carried out using copper traces, optimizing the layout. A design rule check (DRC) was run to ensure error-free board before fabrication.

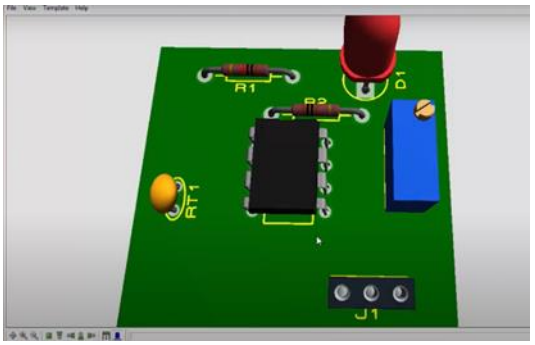

Figure 11 3D Model of Temperature Sensor

This 3D model of a temperature sensor circuit was created after completing the PCB layout design. It visually represents the placement of key components like the temperature sensor, control IC, relay, and supporting elements such as resistors and an LED. This step helps in verifying the physical arrangement and ensuring the design is ready for fabrication.

Table 2 Overview of Safety Sensors and Alert Systems in Mining Operations

Parameter	Sensor Used	Measured Range	Response Time	Effectiveness (%)	Significance in Mining
Gas Detection (CH_4, CO, LPG)	MQ-5	200–10,000 ppm	<10 sec	95%	Prevents explosions and suffocation
Temperature Monitoring	LM35, DS18B20	-55 to 150°C	<5 sec	98%	Prevents overheating and equipment failure
Humidity Monitoring	DHT11	0%–100% RH	<7 sec	96%	Reduces risks of poor ventilation
Emergency Alert System	Buzzer, IoT Notification	Instant Alert	<2 sec	99%	Quick response in critical situations

In our project, we implemented gas, temperature, and humidity sensors along with an emergency alert system. We tested each sensor's response time and accuracy in simulated mining conditions. The sensors showed fast detection with 95%–99% effectiveness, and alerts were triggered instantly. These results confirm that our system can reliably monitor hazards and ensure quick emergency response in mining environments.

Future Work

The future of wireless surveillance and safety systems for mine workers will focus on improving real-time monitoring, communication, and automation. One key area of development is the enhancement of sensor technology to detect environmental hazards more accurately. Future systems will integrate more advanced gas sensors, temperature sensors, and motion detectors that can provide precise data to prevent accidents [22]. These sensors will be designed to operate efficiently in extreme underground conditions while ensuring minimal power consumption. A crucial aspect of future advancements is the use of artificial intelligence (AI) and machine learning (ML) for predictive safety analysis. By analyzing past records and real-time data, AI can detect possible hazards before they become serious threats [23]. Machine learning models can identify patterns linked to equipment breakdowns, harmful gas levels, or structural instability, allowing for timely preventive measures. This proactive method will help improve response time and greatly lower the risk of accidents in mining environments. Improvements in wireless communication technologies, including 5G and low-power wide-area networks (LPWAN), will enhance the efficiency of surveillance systems. These technologies will enable faster data transfer and more reliable connectivity in underground mines, ensuring smooth communication between workers, monitoring stations, and emergency teams. Future systems may also integrate blockchain technology to protect data integrity and security, preventing unauthorized modifications or loss of crucial safety information [24]. The development of wearable technology and smart helmets with built-in sensors, cameras, and real-time tracking will enhance worker safety. These devices will provide continuous monitoring of workers' health and environmental conditions while enabling direct communication with supervisors. Future research will focus on making these devices more compact, energy-efficient, and cost-effective. By integrating these advanced technologies, wireless surveillance and safety systems will become more effective in reducing risks and improving the overall safety of mine workers [25].

Conclusion

The Wireless Surveillance and Safety System for Mine Workers plays a vital role in enhancing the safety and well-being of workers in hazardous underground environments. By incorporating temperature, humidity, and smoke sensors, the system enables continuous monitoring of environmental conditions, allowing for real-time identification of potential risks. The addition of a buzzer ensures immediate alerts, facilitating quick responses to emergencies. This technology adopts a proactive safety approach, minimizing the likelihood of accidents caused by extreme atmospheric conditions. Its wireless capability enhances communication and monitoring efficiency, making it a dependable solution for mining operations. By implementing such a system, workplace safety can be significantly improved, helping to protect workers' lives and reduce disruptions in operations.

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