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IoT-Driven Safety And Environmental Monitoring System For Coal Mining Workers

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Abstract:
The indispensable task of ensuring the safety of workers in coal mining is a crucial issue because of dangerous underground conditions such as toxic gas emissions, high temperatures and humidity, structural vibrations, etc. However, traditional monitoring technologies do not support real-time transmission, long-distance communication, and energy-efficient requirements, which cannot meet the needs of underground mining. In overcoming these shortcomings, this article proposes an IoT-based safety monitoring system equipped with Zigbee hardware, able to deliver continuous real-time monitoring of miners' environmental and physiological conditions. This contains three sensors; DHT11 (temperature & humidity), MQ2 (gas detection), SW-420 (vibration monitoring), and pulse sensor (heart rate tracking). These sensors are incorporated into a wearable device connected to a centralized control hub through Zigbee, ensuring long-distance, low-power, and anti-interference communication in underground scenarios. The data is uploaded to ThingSpeak, a cloud-based IoT analytics platform and real-time visualization, anomaly detection and historical trend analysis is done on the uploaded data. All sensor information is processed within the control unit and alert users as soon as possible as long as a measured parameter exceeds pre-defined limits. Also, the system can also track location in real time, helping emergency responders act quickly and rescue. Experimental results show that the system detects environmental hazards and worker health and anomalies, with low latency and high accuracy, with respect to the data transmission. This system improves the safety of workers, efficiency in operations, and preparedness for emergencies in the mining space by using the combination of IoT, Zigbee, and cloud-based analytics. We plan to build upon these results with AI-based predictive analytics and edge computing for optimum performance and scalability.

Keywords— *IoT, Coal Mine Safety, Zigbee, Worker Safety, Environmental Monitoring, Gas Detection, Temperature and Humidity Monitoring, Vibration Detection, Pulse Sensor, ThingSpeak, Cloud Computing, Real-Time Monitoring, Wearable Sensors, Emergency Alert System, Underground Mining.*

Introduction

Coal mining continues to play a vital role in meeting global energy demands, but it remains one of the most hazardous industrial occupations due to the presence of toxic gases, unstable geological conditions, excessive heat, humidity, and limited visibility. Underground workers are frequently exposed to life-threatening situations that require continuous observation of both environmental and physiological conditions. Conventional monitoring systems generally rely on manual inspections or isolated sensing units that provide limited coverage and delayed reporting of hazardous events. Such approaches often fail to provide timely warnings, reducing the effectiveness of emergency response measures. The increasing demand for safer mining operations has encouraged the adoption of advanced sensing technologies capable of continuously monitoring underground environments and transmitting data to centralized monitoring stations for rapid decision-making. [1]

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The Internet of Things (IoT) has emerged as a practical solution for industrial safety by enabling interconnected sensors, communication devices, and cloud platforms to exchange information in real time. In underground mining, IoT technology allows multiple environmental and health-related parameters to be monitored simultaneously, improving situational awareness and minimizing operational risks. Through wireless communication networks, sensor data can be collected from remote locations without requiring extensive cabling infrastructure. This capability not only improves monitoring efficiency but also supports preventive maintenance and emergency preparedness in hazardous working conditions. [5]

Wireless communication technologies have become an important component of modern mine safety systems. Among the available communication protocols, Zigbee has gained considerable attention because of its low power consumption, reliable transmission, mesh networking capability, and suitability for harsh underground environments. Zigbee-based communication enables wearable devices and sensor nodes to maintain stable connectivity even in locations where conventional wireless technologies experience signal degradation. As a result, miners' safety information can be transmitted continuously to control stations without significant communication delays. [6]

Continuous monitoring of environmental parameters is essential for preventing accidents inside coal mines. Sensors capable of measuring temperature, humidity, combustible gases, and structural vibrations provide valuable information regarding underground conditions. Abnormal changes in these parameters often indicate potential hazards such as gas leakage, fire outbreaks, equipment malfunction, or structural instability. Integrating multiple sensors into a unified IoT platform enables comprehensive environmental assessment while reducing the possibility of overlooking critical safety indicators. Such systems contribute significantly to improving worker protection and operational reliability. [3]

In addition to environmental monitoring, tracking the physiological condition of miners has become increasingly important. Wearable health monitoring devices equipped with pulse sensors can continuously observe workers' heart rates and identify abnormal physiological responses caused by stress, fatigue, or exposure to hazardous gases. Real-time health monitoring provides an additional layer of protection by allowing supervisors to detect medical emergencies before they become critical. Combining environmental sensing with physiological monitoring creates a comprehensive worker safety framework suitable for underground mining operations. [4]

Cloud-based IoT platforms have further enhanced industrial monitoring by enabling real-time data visualization, storage, and remote accessibility. Platforms such as ThingSpeak simplify the process of collecting sensor data, generating graphical representations, analyzing historical trends, and issuing automated alerts whenever predefined safety thresholds are exceeded. Cloud integration also facilitates remote supervision of mining activities, allowing authorized personnel to monitor safety conditions from centralized control rooms or mobile devices, thereby improving emergency coordination and operational management. [7]

The advancement of low-power embedded systems has encouraged the development of portable monitoring devices capable of operating for extended periods in underground environments. Modern IoT systems combine microcontrollers, environmental sensors, wearable devices, and wireless communication modules into compact monitoring units that are easy to deploy and maintain. Such integrated systems reduce installation complexity while increasing monitoring coverage throughout mining tunnels and work areas. Their modular architecture also allows future expansion with additional sensing capabilities and intelligent data processing techniques. [8]

Considering these developments, this work presents an IoT-driven safety and environmental monitoring system designed specifically for coal mining workers. The proposed system integrates DHT11, MQ2, SW-420 vibration sensor, and pulse sensor with Zigbee communication and ThingSpeak cloud analytics to provide continuous monitoring of environmental and physiological conditions. The objective is to improve worker safety by delivering real-time alerts, reliable wireless communication, cloud-based monitoring, and rapid emergency response support under challenging underground mining conditions. [14]

Literature Survey

S. Kumar, R. Gupta, and P. Sharma developed an IoT-based smart mine safety monitoring system that employed wireless sensor networks for continuously observing underground environmental conditions. Their work demonstrated that real-time sensing and wireless communication could significantly reduce response time during hazardous situations while improving operational safety. However, the proposed architecture mainly emphasized environmental monitoring and provided limited consideration for miners' physiological health parameters. [1]

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A. K. Mishra, S. Verma, and P. K. Singh presented an underground coal mine monitoring system based on IoT technologies for monitoring environmental parameters such as temperature and hazardous gases. Their system improved data collection efficiency and remote supervision through wireless communication. Although the proposed framework enhanced mine safety, it lacked integrated wearable health monitoring and cloud-based analytics for long-term performance evaluation. [2]

H. Zhang, Y. Li, and X. Wang introduced a real-time environmental monitoring framework using IoT technology to supervise underground mining conditions. Their study focused on collecting information related to temperature, humidity, and gas concentration through distributed sensing nodes. Experimental results showed improved monitoring accuracy and communication reliability, making the system suitable for early hazard detection in mining environments. [3]

S. S. Raut, V. B. Gaikwad, and P. R. Patil proposed a wearable IoT device capable of monitoring both environmental conditions and miners' physiological status. Their system incorporated wearable sensors to observe worker health while simultaneously collecting surrounding environmental information. The integration of wearable technology demonstrated considerable potential for improving occupational safety, although communication range remained a limiting factor in large underground mining areas. [4]

R. K. Singh and D. Sharma designed a Zigbee-based hazardous gas monitoring system intended for underground mining applications. Their research highlighted the advantages of Zigbee communication, including low energy consumption, reliable wireless connectivity, and efficient transmission over long distances. The proposed solution demonstrated stable performance under challenging mining conditions and confirmed Zigbee as a suitable communication technology for underground safety systems. [6]

M. A. Islam, T. Rahman, and M. S. Hossain proposed a cloud-based industrial safety monitoring framework utilizing the ThingSpeak platform for real-time visualization and storage of sensor information. Their architecture enabled continuous remote monitoring, graphical data representation, and automated alert generation. The study demonstrated that cloud integration greatly enhances decision-making capabilities while supporting historical analysis of safety-related parameters. [7]

P. K. Das, A. Roy, and S. Chatterjee developed a low-power IoT-based mine safety monitoring system using ESP32 and Zigbee communication modules. Their research focused on reducing power consumption while maintaining reliable wireless communication among distributed sensor nodes. The system achieved stable performance and demonstrated that low-energy IoT devices can effectively support continuous underground safety monitoring for extended operational periods. [8]

B. Prakash, K. Reddy, and N. Rao introduced an IoT-enabled wearable health monitoring system for industrial workers. Their work continuously monitored physiological parameters and transmitted health information to centralized monitoring units for immediate analysis. The study showed that wearable sensing technologies improve worker safety by enabling early detection of abnormal health conditions before they develop into serious emergencies. [10]

M. Chen, J. Wang, and Y. Zhao proposed an edge-enabled intelligent monitoring architecture for underground mine safety. Their framework combined IoT devices with edge computing to process safety information near the sensing location, thereby reducing communication latency and improving system responsiveness. The study demonstrated that edge computing enhances scalability and enables faster emergency response compared to conventional cloud-only architectures. [12]

Y. Liu, H. Sun, Z. Chen, and X. Zhao presented an AI-assisted IoT framework for predictive safety monitoring in underground coal mines. Their research utilized intelligent algorithms to analyze sensor information, predict hazardous situations, and support preventive safety management. The proposed framework demonstrated that integrating artificial intelligence with IoT significantly improves prediction accuracy, reduces false alarms, and provides a promising direction for future intelligent mining safety systems. [16]

Existing System:

In traditional coal mining industries, worker safety and environmental monitoring are mainly carried out through manual inspection methods. Supervisors regularly check gas levels, temperature, humidity, and underground conditions using separate measuring devices. These methods require human involvement and do not provide continuous real-time monitoring. In emergency situations such as toxic gas leakage, fire, or tunnel collapse, delay in identifying the problem may lead to serious accidents and loss of life. Existing systems are often costly, less efficient, and limited in communication capability.

Proposed System:

The proposed system continuously monitors mine conditions using sensors such as MQ gas sensor, DHT11 temperature and humidity sensor, vibration

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sensor, and pulse sensor.

All sensor data is processed by the Raspberry Pi Pico in real time. If any parameter exceeds the predefined safety limit, the system immediately activates a buzzer alarm and sends alerts through IoT communication. An OLED display is used to show live sensor values.

Block Diagram

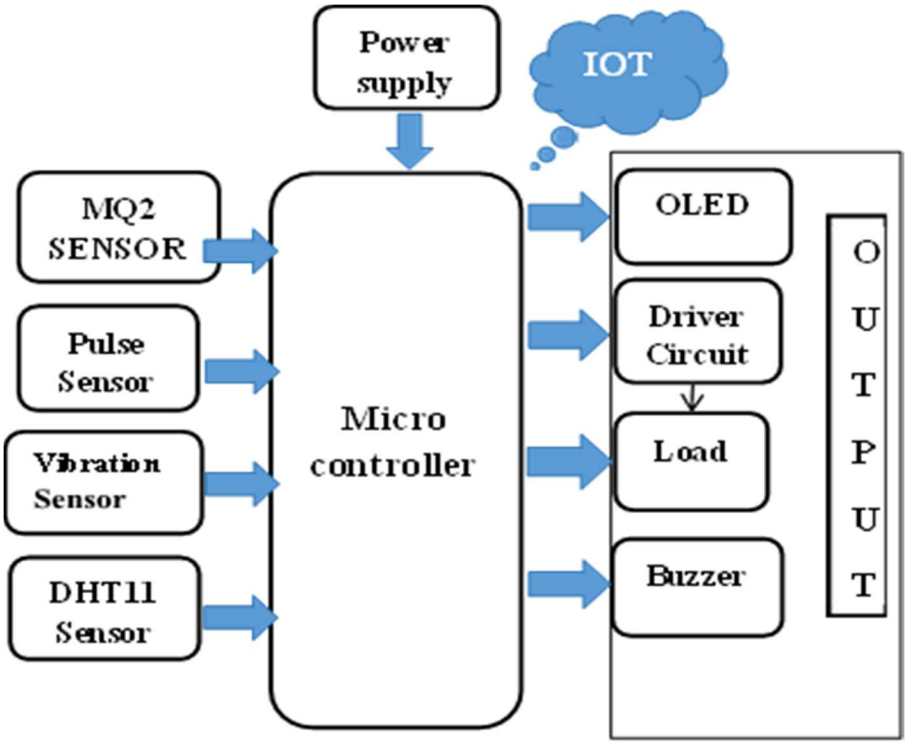

Fig 1: Iot-Driven Safety and Environmental Monitoring System for Coal Mining Workers

Block Diagram Description

The proposed IoT-Driven Safety and Environmental Monitoring System for Coal Mining Workers is designed to continuously monitor environmental conditions and the health status of miners working in underground coal mines. The system integrates multiple sensors, a microcontroller, IoT connectivity, and alert mechanisms to provide real-time safety monitoring and emergency notification.

At the core of the system is the microcontroller, which acts as the central processing unit. It receives input data from various sensors, processes the collected information, compares the measured values with predefined safety thresholds, and controls the output devices accordingly. The entire system is powered by a regulated power supply that provides stable voltage to all hardware components.

The MQ2 gas sensor is used to detect the presence of harmful and combustible gases such as methane, LPG, smoke, and carbon monoxide that are commonly found in mining environments. The sensor continuously monitors air quality and sends gas concentration data to the microcontroller. If the gas level exceeds the permissible limit, an immediate alert is generated to warn workers and supervisors.

The pulse sensor is incorporated to monitor the heart rate of miners in real time. Since underground mining involves physically demanding activities and exposure to hazardous conditions, continuous monitoring of heart rate helps identify abnormal physiological conditions such as stress, fatigue, or medical emergencies. The collected pulse data is transmitted to the microcontroller for analysis and storage.

The vibration sensor (SW-420) is employed to detect unusual vibrations and structural movements within

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the mining area. Excessive vibration may indicate equipment malfunction, rock instability, or the possibility of tunnel collapse. By continuously monitoring vibration levels, the system can provide early warning signals before a serious accident occurs.
The DHT11 sensor measures temperature and humidity inside the mine. Elevated temperatures and excessive humidity can negatively affect worker health and operational efficiency. The sensor provides real-time environmental data that helps maintain safe working conditions and enables corrective action when abnormal values are detected.
All sensor data is processed by the microcontroller and transmitted to the IoT platform through a wireless communication network. The IoT module enables remote monitoring, cloud data storage, and real-time access to safety information from any location. The collected data can be visualized on cloud platforms such as ThingSpeak, allowing supervisors to analyze trends and monitor underground conditions continuously.
The OLED display serves as a local monitoring interface by displaying real-time values of temperature, humidity, gas concentration, vibration levels, and pulse rate. This allows workers and operators to instantly view important safety information without requiring external devices.
The driver circuit acts as an interface between the microcontroller and the load. Since certain output devices require higher current than the microcontroller can provide directly, the driver circuit amplifies control signals and ensures reliable operation of connected loads.
The load represents external devices such as ventilation systems, emergency lights, exhaust fans, or other safety equipment that can be activated automatically when hazardous conditions are detected. This automated response helps minimize risks and improve worker protection.
A buzzer is included as an audible warning device. Whenever any monitored parameter exceeds the predefined safety threshold, the microcontroller activates the buzzer to immediately alert workers and nearby personnel about potential danger. This rapid alert mechanism enables timely evacuation and emergency response.
Overall, the proposed system combines environmental sensing, health monitoring, wireless communication, cloud analytics, and automated alert generation into a single integrated platform. The system enhances worker safety, improves hazard detection capabilities, supports emergency management, and contributes to safer and more efficient coal mining operations.

SCHEMATIC DIAGRAM:

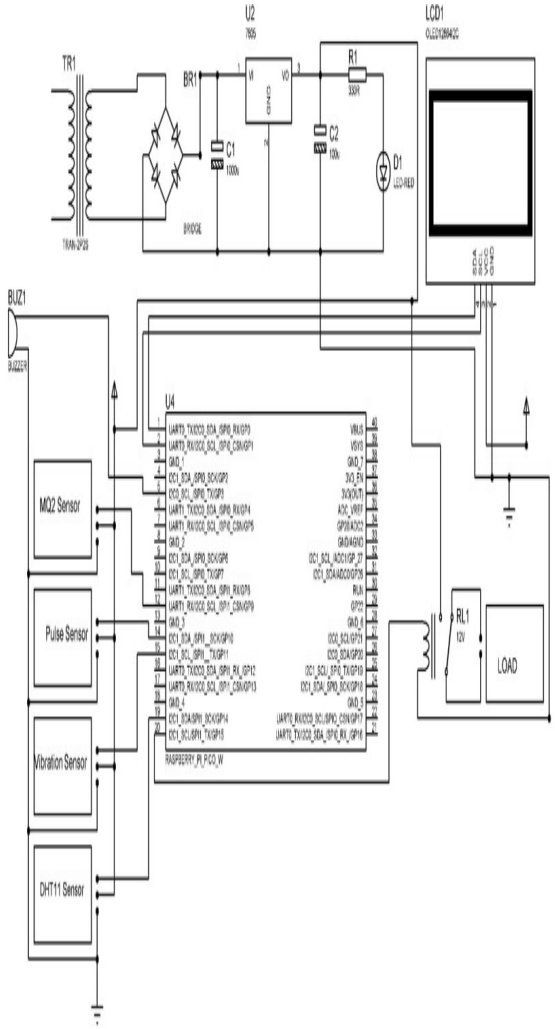

Fig 2: Schematic Diagram of Iot-Driven Safety

Explanation:
This circuit is like a small smart monitoring system built around the Raspberry Pi Pico W. Power comes from AC, gets stepped down, converted to DC, and stabilized using a 7805-voltage regulator. Several sensors—MQ2 gas sensor, pulse, vibration, and DHT11—act as the system's "eyes and ears," sending data to the Pico. An OLED display (I2C) shows readings clearly, while a buzzer warns of danger. When something goes wrong, the Pico activates a 12V relay module to switch off a connected load, helping protect people and equipment.

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Implementation

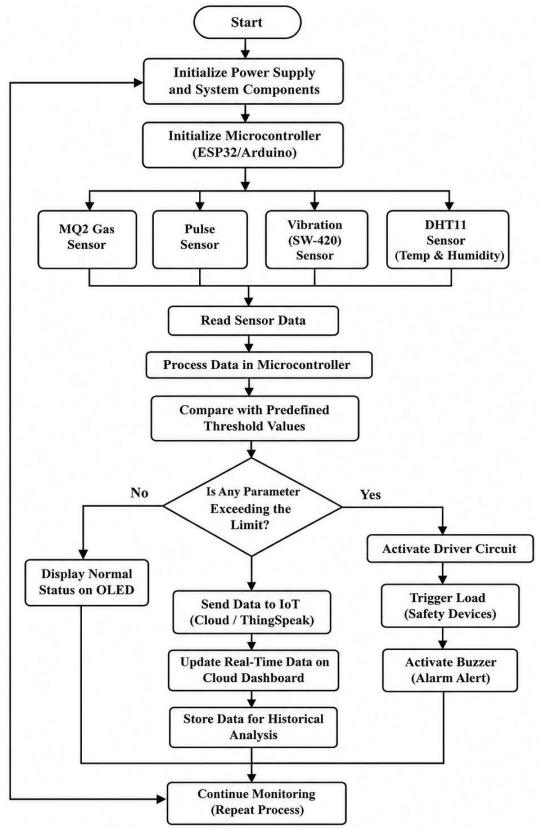

Fig 3: Workflow process

Results:

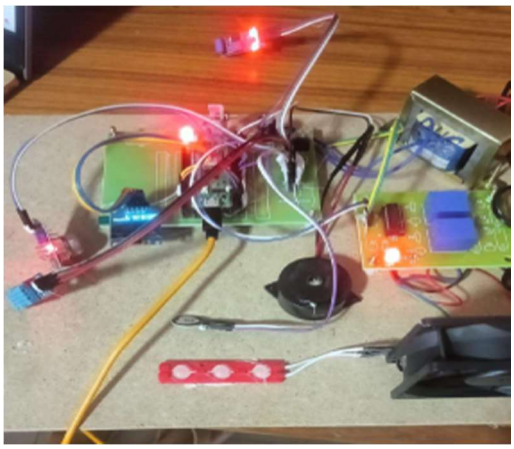

Fig 4: Hardware Kit in ON Condition

The kit is switched ON, and you can see it working through the glowing LEDs.
All the components are active and ready to sense and respond to signals.

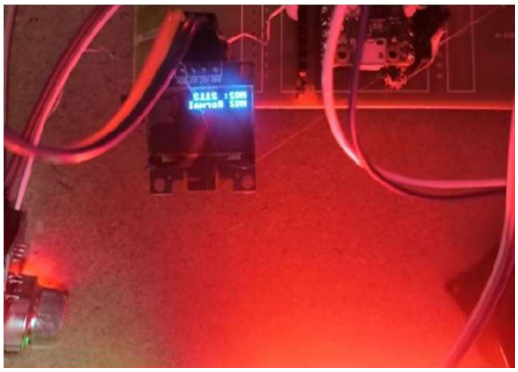

Fig 5: Gas Sensors

The gas sensor detects presence of gases in the air and sends signals to the system.
Based on the gas level, the system processes the data and shows the readings on the display.

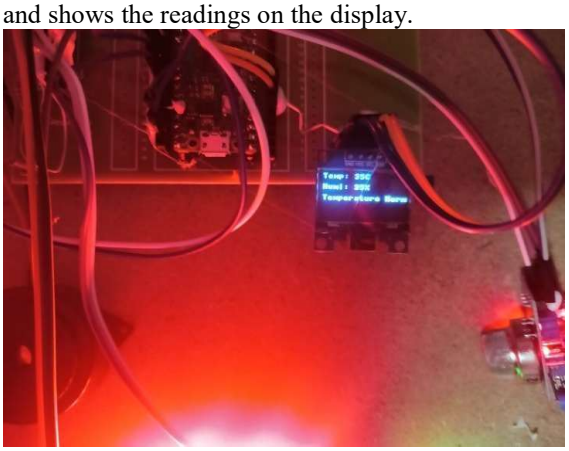

Fig 6: Temperature Values

The temperature sensor measures the surrounding heat and keeps track of changes in temperature.
It sends this data to the system, which then displays the current temperature on the screen.

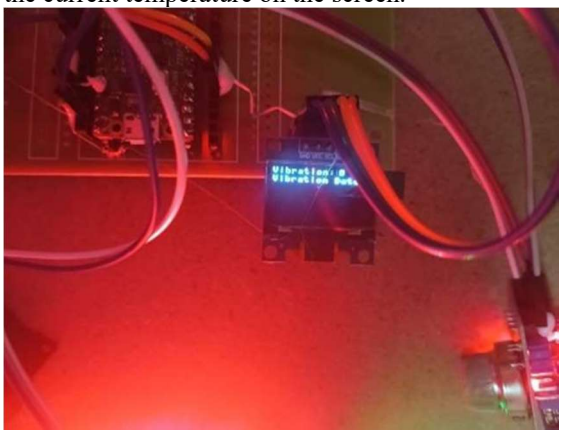

Fig 7: Vibration Sensor

The vibration sensor detects any movement or shaking in the surroundings.

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It sends this information to the system, which then shows the vibration status on the display.

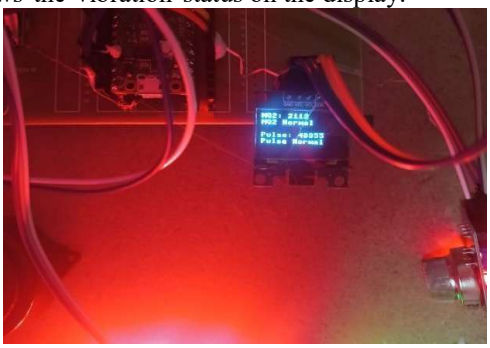

Fig 8: Pulse Sensor

The pulse sensor gently touches your skin and detects tiny changes in blood flow with each heartbeat. It then converts these signals into digital data, showing your pulse rate clearly on the display in real time.

Conclusion

The safety of underground mine workers is a global imperative that demands robust, real-time, and intelligent solutions. The proposed IoT-based safety monitoring system addresses the critical limitations of traditional approaches by integrating low-cost sensors, Zigbee wireless communication, and cloud-based analytics into a wearable, real-time, and scalable platform. By enabling real-time anomaly detection, physiological monitoring, and environmental assessment, this system significantly enhances operational safety, emergency preparedness, and health management in coal mining operations.

As mining operations become more automated and data-centric, such IoT systems will become essential not only for safety but also for optimizing workflows and reducing downtime. Looking ahead, incorporating machine learning algorithms, edge computing, and AI-based predictive maintenance will further enhance the system's intelligence and adaptability. The proposed framework lays the groundwork for a safer, smarter, and more sustainable mining industry.

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