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Monitoring of Mining Workers At High Altitude

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Abstract:
This work presents a compact and reliable system for monitoring the safety and environmental conditions of mining workers operating at high altitudes. The proposed prototype integrates multiple sensors with a NodeMCU microcontroller to continuously observe critical parameters that influence worker health and risk exposure. A flame sensor is employed to detect the presence of fire hazards, while a smoke sensor identifies harmful gases or particulate concentration in the surroundings. A vibration sensor is incorporated to recognize abnormal movements or ground disturbances that may indicate structural instability. Additionally, a DHT11 sensor measures temperature and humidity, which are essential factors in high-altitude environments.
All sensor data are processed in real time by the NodeMCU, enabling immediate analysis and response. When any parameter exceeds predefined safety thresholds, an alert is generated through a buzzer to notify nearby personnel. The system is powered through a stable supply unit, ensuring uninterrupted operation in remote locations. The design emphasizes low cost, ease of deployment, and adaptability to harsh mining conditions. This prototype demonstrates an effective approach to enhancing worker safety through continuous monitoring and early warning, thereby reducing the likelihood of accidents and improving overall operational reliability in mining environments.

Keywords: Mining safety, high-altitude monitoring, worker safety system, NodeMCU, flame detection, smoke detection, vibration sensing**.**

I.INTRODUCTION:

Coal mine accidents create conditions where human rescue becomes slow, risky, and often ineffective due to poor visibility and unstable surroundings. This drives the need for intelligent rescue systems that can operate safely while providing accurate environmental perception. Binocular vision offers a practical solution by enabling depth estimation and three-dimensional scene understanding without physical contact. Motivated by these advantages, this work examines how such vision systems can strengthen the sensing capability of rescue robots. It contributes by outlining key techniques, reviewing recent developments, and identifying existing limitations, thereby guiding future improvements in reliable, vision-based rescue operations [1]. Slope instability in open-pit mines poses a serious threat to worker safety and operational continuity, with failures often occurring without sufficient warning. This creates a strong need for reliable, wide-area monitoring systems that can detect early signs of ground movement and support timely decision making. Satellite interferometry, particularly using Sentinel-1 data, offers a valuable approach by enabling frequent, large-scale observation of surface deformation. Motivated by these capabilities, this study explores the use of interferometric techniques for identifying and analysing slope behaviour. It contributes by demonstrating deformation mapping, classifying instability types, and

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highlighting both the practical potential and current limitations of satellite-based monitoring in mining environments [9]. Unsafe and unmonitored worker behaviors on construction sites can reduce productivity and increase the risk of accidents, highlighting the limitations of traditional manual supervision methods. This creates a need for automated, accurate, and continuous monitoring solutions. Advances in computer vision provide an effective means to detect, track, and analyze worker activities in real time. Motivated by this potential, the study examines vision-based approaches for behaviour monitoring in construction environments. It contributes by reviewing detection, localization, and activity recognition techniques, analysing current research trends, and identifying key challenges, thereby offering direction for improving safety-focused, intelligent monitoring systems [7]. Underground mining environments are highly prone to hazardous gas accumulation and unstable conditions, making continuous monitoring essential for worker safety. Traditional portable detectors offer limited coverage and lack real-time communication, which can delay critical responses. This motivates the adoption of IoT-based systems with long-range wireless capabilities for efficient data transmission in challenging underground settings. The study focuses on integrating LoRa communication with environmental sensors to enable real-time monitoring of multiple parameters. It contributes by developing a portable monitoring system, validating its performance in mine conditions, and demonstrating its potential as a cost-effective solution for improving safety through timely alerts and continuous data analysis [3]. As mining operations extend to deeper geological layers, the risk of rock fracturing and seismic-related hazards increases, making safety management more complex. Conventional monitoring methods often lack the precision and real-time capability required to detect early signs of structural instability. This creates a need for advanced sensing systems that can accurately capture subsurface activities. Motivated by this challenge, the study focuses on micro seismic monitoring using high-precision distributed wireless acquisition stations. It contributes by developing a reliable data acquisition system, validating it through field experiments, and analysing fracturing behaviour, thereby supporting improved disaster prediction and enhancing safety in deep mining environments [5]. Remote operation in underground mining reduces direct human exposure to hazardous environments, but limited visual perception can affect operator efficiency and safety. Traditional camera views may lack depth accuracy and completeness, especially in complex and dynamic mining conditions. This creates a need for enhanced visualization techniques that provide reliable and real-time environmental understanding. Motivated by this challenge, the study explores the integration of camera and lidar data for improved scene representation. It contributes by developing a real-time view generation and rendering pipeline, enabling accurate depth perception and scene reconstruction, thereby supporting safer and more effective remote operation in mining applications [8]. Underground mining exposes workers to extreme environmental and health risks, while existing health monitoring practices remain infrequent and dependent on manual participation, limiting timely intervention. This highlights the need for continuous and reliable health sensing systems that can operate effectively in harsh conditions. Motivated by this requirement, the study explores wearable and wireless technologies for real-time monitoring of miners' physiological parameters. It contributes by proposing a health sensing system architecture, analysing communication reliability in underground settings, and identifying key challenges, thereby supporting the development of proactive safety measures and improved occupational health management in mining environments [2].

II.LITERATURE SURVEY:

Zhai et al. (2020) reviewed binocular vision-based rescue robots, emphasizing stereo matching and 3D reconstruction but noting limitations in robustness under low-visibility mine conditions. Earlier works by Zhang et al. (2018) and Hu et al. (2019) explored visual sensing and navigation for mining robots; however, their approaches showed reduced accuracy in dynamic and dust-prone environments. Ji et al.

(2017) investigated obstacle detection using vision systems, yet lacked real-time adaptability for emergency scenarios. Despite these contributions, a clear gap remains in developing reliable, real-time binocular vision systems that can perform consistently in harsh, unstructured mining environments with minimal computational delay [1]. Ranjan et al. (2021) examined wearable health sensing systems for underground miners, highlighting challenges in reliable communication and continuous monitoring. Earlier studies by Zhao et al. (2019) and Sahu et al. (2020) focused on wireless health data collection, but their approaches showed limitations in signal stability within complex mine geometries. Misra et al. (2018) explored IoT-based health monitoring frameworks, yet lacked real-world validation in harsh mining conditions. Although these works contribute to occupational health monitoring, a significant gap remains in developing robust, energy-efficient, and continuously reliable health sensing systems that can sustain accurate data transmission in extreme underground environments [2]. Naik et al. (2023) developed a LoRa-based real-time environmental monitoring system for underground mines, demonstrating effective long-range communication but with moderate data correlation for certain gases. Earlier work by Reddy et al. (2021) focused on IoT-based gas monitoring, though it faced limitations in scalability and continuous underground deployment. Raj et al. (2022) explored wireless sensor networks for mine safety, yet lacked comprehensive validation in real-time conditions. Despite these efforts, a key gap remains in achieving highly accurate, fully reliable, and scalable environmental monitoring systems that ensure consistent data precision and robust communication across complex underground mining environments [3]. Medina et al. (2022) proposed a safety-oriented wireless sensor network placement model for underground mines, achieving improved coverage and connectivity with reduced node deployment. Earlier studies by Ruiz et al. (2020) and Avendaño et al. (2019) focused on efficient WSN deployment but often relied on simplified assumptions that did not fully reflect real mining conditions. Céspedes et al. (2018) examined connectivity reliability, yet lacked integrated optimization for both coverage and fault tolerance. Despite these contributions, a clear gap exists in designing adaptive, real-time WSN deployment strategies that can dynamically respond to changing underground environments while maintaining consistent safety and communication reliability [4]. Qiao et al. (2022) developed a high-precision distributed wireless micro seismic acquisition system for monitoring mine fracturing, demonstrating effective data collection and analysis in deep mining conditions. Earlier work by Zhang et al. (2020) focused on micro seismic sensing techniques but lacked integrated wireless scalability for large areas. Zhang et al. (2019) also explored geophone-based monitoring, though with limited real-time processing capability. While these studies contribute to fracture detection and analysis, a key gap remains in achieving fully real-time, energy-efficient, and highly reliable micro seismic monitoring systems that can operate continuously and adapt to dynamic deep mining environments [5]. Hajizadehmotlagh et al. (2021) introduced a wearable resonator-based dust monitoring system for real-time measurement of respirable particles, offering improved sensitivity and compact design. Earlier studies by Fahimi et al. (2019) focused on particulate sensing techniques but lacked portability for continuous personal monitoring. Singhal et al. (2020) explored dust detection systems, though with limited accuracy across varying particle sizes. Paprotny et al. (2018) investigated resonator-based sensing, yet without full integration into wearable platforms. Despite these contributions, a gap remains in developing highly durable, energy-efficient, and fully field-deployable wearable systems capable of consistent long-term monitoring in harsh underground mining environments [6]. Dima and Sjöström (2021) proposed a camera and lidar-based system for real-time view generation in remote mining operations, improving scene understanding and operator awareness. Earlier work by Dima et al. (2019) explored vision-based remote monitoring but lacked accurate depth perception. Sjöström et al. (2020) investigated lidar integration, though with limited real-time rendering efficiency. Other studies on remote operation systems also faced challenges in handling occlusions and dynamic

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environments. Despite these advancements, a gap remains in developing highly efficient, low-latency fusion techniques that ensure precise, real-time visualization under complex and safety-critical underground mining conditions [8]. Li et al. (2021) proposed an improved safety helmet detection framework by integrating online hard example mining and multi-part combination, achieving higher accuracy under challenging conditions. Earlier studies by Lyu et al. (2019) and Xu et al. (2020) applied traditional object detection models, but their performance was affected by lighting variations and complex backgrounds. Wang et al. (2018) explored helmet detection using basic deep learning approaches, though with limited robustness to occlusion and scale variation. Despite these advancements, a gap remains in developing lightweight, real-time detection systems that maintain high accuracy across diverse and dynamic industrial environments [10].

III.PROPOSED METHODOLOGY:

The proposed system is designed to monitor the safety and environmental conditions of mining workers operating at high altitudes through an integrated sensor-based approach. The architecture consists of a NodeMCU microcontroller interfaced with multiple sensors, including a flame sensor, smoke sensor, vibration sensor, and DHT11 sensor for temperature and humidity measurement. Each sensor continuously collects real-time data related to environmental hazards and working conditions. The NodeMCU processes these inputs and compares them with predefined safety thresholds. In case of abnormal conditions such as fire presence, increased smoke levels, unusual vibrations, or extreme temperature and humidity variations, the system immediately triggers an alert using a buzzer to warn nearby workers. The system operates on a continuous monitoring cycle, ensuring timely detection of potential risks. Data acquisition, processing, and alert generation are carried out with minimal delay to enhance responsiveness. The design focuses on low power consumption and reliable performance, making it suitable for deployment in remote and harsh mining environments. This methodology provides a practical and efficient solution for improving worker safety by enabling early detection of hazards and supporting quick preventive action.

BLOCK DIAGRAM:

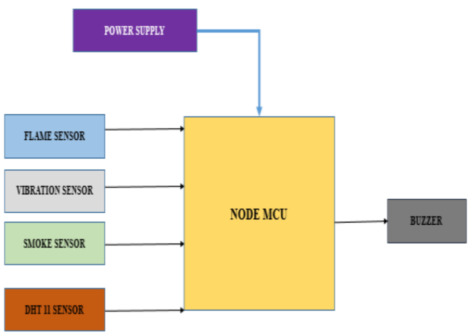

FIG 1: BLOCK DIAGRAM

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HARDWARE WORK FLOW
NODEMCU

FIG 2: NODEMCU

The NodeMCU serves as the central processing unit of the proposed system, coordinating data acquisition, processing, and response actions. It is built on the ESP8266 platform, which integrates a microcontroller with inbuilt Wi-Fi capability, making it suitable for IoT-based monitoring applications. In this system, the NodeMCU receives input signals from multiple sensors, processes the data based on predefined safety thresholds, and controls output devices such as the buzzer. Its low power consumption, compact size, and ease of programming make it ideal for deployment in remote mining environments where reliability and continuous operation are essential.

FLAME SENSOR

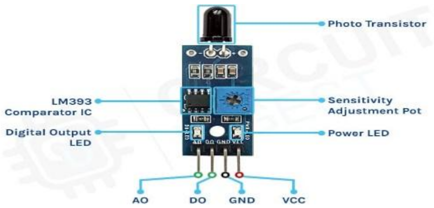

FIG 3: FLAME SENSOR

The flame sensor is used to detect the presence of fire or open flames within the mining environment. It operates by sensing infrared radiation emitted by flames within a specific wavelength range. When a flame is detected, the sensor generates a signal that is transmitted to the NodeMCU for further processing. This enables immediate identification of fire hazards, which are critical risks in mining operations. The sensor's fast response time and sensitivity to flame sources make it an effective component for early warning systems, helping to reduce the chances of fire-related accidents and ensuring prompt safety measures.

SMOKE SENSOR

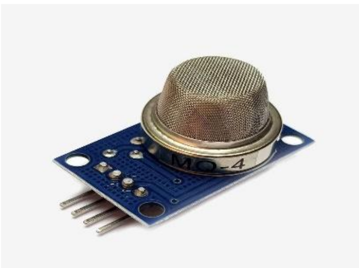

FIG 4: SMOKE SENSOR

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The smoke sensor is responsible for detecting the presence of harmful gases and airborne particles in the mining atmosphere. It typically operates based on changes in electrical resistance when exposed to gases such as carbon monoxide or smoke particles. In hazardous conditions, the sensor output increases, signalling the NodeMCU to initiate an alert. This component plays a vital role in identifying poor air quality and potential gas leaks, which are common in mining environments. Its continuous monitoring capability supports early detection of dangerous conditions, allowing workers to take preventive actions before exposure reaches critical levels.

VIBRATION SENSOR

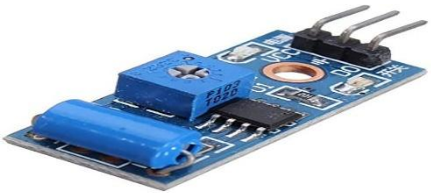

FIG 5: VIBRATION SENSOR

The vibration sensor is used to detect abnormal movements or disturbances that may indicate structural instability, equipment malfunction, or ground shifts within the mining area. It works by converting mechanical vibrations into electrical signals that can be analysed by the NodeMCU. Sudden or excessive vibrations are interpreted as potential warning signs of hazardous events such as collapses or machinery faults. By continuously monitoring vibration patterns, the system can provide early alerts, enabling timely intervention. This component enhances overall safety by addressing risks that are not always visible but can have serious consequences.

DHT11 SENSOR

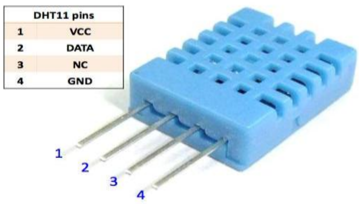

FIG 6: DHT11 SENSOR

The DHT11 sensor is employed to measure ambient temperature and humidity levels in the mining environment. It provides digital output data, which simplifies integration with the NodeMCU. Monitoring these parameters is essential in high-altitude and underground conditions, where extreme temperature or humidity can affect both worker health and equipment performance. The sensor operates with moderate accuracy and low power requirements, making it suitable for continuous monitoring applications. By tracking environmental variations, the system ensures that unsafe conditions are detected early, contributing to improved comfort, safety, and operational efficiency.

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BUZZER

FIG 7: BUZZER

The buzzer functions as an immediate alert mechanism in the system. It is activated when any monitored parameter exceeds predefined safety limits. Controlled by the NodeMCU, the buzzer produces an audible signal that can be easily recognized by nearby workers, even in noisy environments. This ensures that warnings are communicated instantly without relying on visual indicators alone. The simplicity and reliability of the buzzer make it an effective choice for real-time alerting. Its role is critical in enabling rapid response to hazardous situations, thereby reducing the risk of accidents and improving overall safety awareness.

POWER SUPPLY UNIT

FIG 8: POWER SUPPLY UNIT

The power supply unit provides the necessary electrical energy required for the operation of all system components. It ensures stable voltage and current levels for the NodeMCU and connected sensors, preventing fluctuations that could affect performance or data accuracy. In mining environments, where consistent power availability may be challenging, a reliable power source is essential for uninterrupted monitoring. The design typically includes voltage regulation to maintain safe operating conditions for electronic components. A stable power supply supports continuous system functionality, ensuring that safety monitoring remains active at all times.

IV.RESULT AND DISCUSSIONS:

The developed prototype was tested under controlled and semi-realistic conditions to evaluate its performance in detecting environmental and safety-related parameters. Each sensor responded effectively to its respective stimulus. The flame sensor successfully detected the presence of fire sources within a short response time, while the smoke sensor showed noticeable variation in output when exposed to smoke and gas conditions. The vibration sensor was able to identify abnormal movements, indicating its suitability for detecting ground disturbances or equipment-related vibrations. The DHT11 sensor provided

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consistent readings for temperature and humidity, reflecting environmental changes with acceptable accuracy.

The NodeMCU processed all incoming data reliably and triggered the buzzer whenever predefined threshold values were exceeded. The alert mechanism functioned without delay, ensuring immediate notification of unsafe conditions. The system demonstrated stable operation with minimal power consumption, making it suitable for continuous monitoring.
However, certain limitations were observed, including moderate sensitivity variations in gas detection and limited precision of the DHT11 sensor under extreme conditions. Despite these constraints, the overall system performance confirms its effectiveness as a low-cost and practical solution for enhancing safety in mining environments through real-time monitoring and early warning capabilities.

V.CONCLUSION:

The proposed system demonstrates an effective approach for monitoring mining workers by integrating multiple sensors with a microcontroller to detect environmental hazards in real time. It provides timely alerts, helping to reduce risks and improve safety in high-altitude mining conditions. The prototype highlights the feasibility of a low-cost and reliable monitoring solution suitable for harsh environments. Future work can focus on enhancing sensor accuracy, integrating advanced communication technologies for remote monitoring, and incorporating wearable health sensors for tracking worker conditions. Further improvements may also include data logging, predictive analysis, and the use of intelligent algorithms for better decision-making and automation.

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