COAL MINE MONITORING SYSTEM FOR ENVIRONMENTAL ENTITIES IN VIEW OF LANDSLIDE HAZARD DETECTION

Shriram Ganpatrao Kokat[1], Dr. S. D. Chede[2]

[1] *Student,M.Tech E&TC Engineering Dept.*
D.Y. PATIL College of Engineering & Technology Kolhapur, India.

[2] *Professor E&TC Engineering Dept.*
D.Y. PATIL College of Engineering Technology Kolhapur, India.

Abstract: *Coal mines, while serving as a backbone for global energy production, remain among the most hazardous workplaces. Unpredictable gas leaks, temperature fluctuations, and seismic vibrations create a volatile environment that can quickly escalate into life-threatening situations. Conventional safety systems often fall short, relying heavily on manual checks or limited-scope detectors. Addressing these challenges, this paper introduces a real-time monitoring framework based on the ESP32 microcontroller. The system is built around a network of MEMS-based sensors including gas, vibration, tilt, temperature, humidity, and moisture modules capable of gathering critical environmental data directly from the field. The innovative approach is the ability to monitor two distinct but interconnected threats: underground mine hazards and surface-level landslide risks. Data is processed locally on the ESP32 to reduce latency, and alerts are immediately transmitted via SMS and logged to a cloud-based dashboard for remote access. The compact design, wireless communication, and low power demands make it ideal for deployment in remote, infrastructure-scarce regions. By offering an affordable, scalable, and dual-purpose solution, this system not only enhances worker safety but also improves disaster preparedness in mining operations.*

Keywords: ***Coal mine safety, Landslide detection, ESP32, MEMS sensors, IoT monitoring, Real-time alert system, Environmental sensing, Edge computing***

1. INTRODUCTION

Coal continues to power a significant portion of the world's industries and households. From generating electricity to supporting steel production and heavy manufacturing, its role remains pivotal particularly in developing nations. However, beneath the productivity lies an equally pressing issue: the risk. Coal mines are among the most hazardous workplaces known today. With unpredictable geological conditions, exposure to toxic gases, sudden ground shifts, and poor visibility, miners are constantly vulnerable to life-threatening events. Despite advances in machinery and infrastructure, ensuring safety within these subterranean environments remains an ongoing challenge.

One of the core issues stems from the very nature of underground mining. Conditions can change rapidly. Methane leaks, temperature spikes, or unnoticed vibrations can indicate an impending collapse. Often, these signals are too subtle or go undetected until it's too late. Traditionally, mines have depended on isolated gas detectors, periodic inspections, and manual safety checks. While these approaches provide some degree of protection, they fall short in providing continuous, real-time environmental awareness. The lag between hazard development and its detection remains dangerously wide.

Regions surrounding mines particularly hilly or mountainous areas are prone to landslides. Heavy rainfall, unstable slopes, or accumulated soil moisture can trigger catastrophic collapses, damaging equipment, endangering lives, and halting operations.

Yet, much like underground hazards, these surface-level threats often go unmonitored or are tracked using costly, single-parameter systems that do not reflect the complex interplay of environmental factors that lead to slope failures. To address both domains underground and adjacent terrain this study introduces a comprehensive monitoring system based on the ESP32 microcontroller. Compact, affordable, and powerful, the ESP32 has emerged as a favorite in the embedded systems and IoT space. It features dual-core processing, integrated Wi-Fi and Bluetooth, low power consumption, and broad compatibility with a wide array of sensors. These capabilities make it uniquely suited for remote, real-time environmental monitoring in conditions where traditional communication systems might falter.

The system proposed in this paper leverages a suite of MEMS-based sensors to gather critical environmental data. Inside coal mines, it monitors temperature, humidity, gas concentration (especially methane and carbon monoxide), and ground vibration. Any deviation from safe thresholds can point to potential hazards like gas build-up or structural weakness. Meanwhile, on the surface, another set of sensors monitors rainfall, soil moisture, tilt, and vibrations factors strongly associated with landslide activity. The system is capable of detecting both gradual trends (like increasing moisture) and sudden events (like tremors), allowing for early warnings before full-scale disasters unfold.

Unlike many existing monitoring solutions, this system is decentralized. That means sensor data is processed at the “edge,” directly on the ESP32 module. This design offers several benefits. First, it reduces latency alerts are triggered immediately without needing to wait for a remote server’s response. Second, it increases resilience. In remote areas where internet connectivity is unreliable, critical decisions can still be made locally. Third, it minimizes the need for high-bandwidth data transmission, preserving both power and processing resources.

When hazardous readings are detected, the system springs into action. Alerts are issued in two parallel ways: locally, through audible buzzers and visual indicators, and remotely, via SMS notifications and cloud-based dashboards. The cloud platform not only displays real-time data but also logs historical trends, allowing for long-term analysis and pattern recognition. Safety personnel can also use mobile and web interfaces to update threshold settings, review alerts, and respond quickly to emergencies all from a remote location.

2. LITERATURE REVIEW

The increasing demand for intelligent monitoring systems in high-risk industries such as coal mining has driven extensive research into the use of embedded technologies and wireless sensor networks (WSNs) to improve real-time environmental awareness and automate safety protocols. Coal mining environments are particularly susceptible to hazards like gas leaks, underground fires, structural instability, and landslides, necessitating reliable, low-latency, and scalable safety monitoring systems.

Wang et al. (2014) introduced a coal mine safety system based on WSNs, utilizing the nRF2401 module for local communication and GPRS for long-range data transmission. Their architecture was centered around MSP430 microcontroller-based sensor nodes capable of monitoring key environmental parameters such as gas concentration, humidity, temperature, and wind speed. Notably, the system integrated an ARM9-based control console and an embedded Geographic Information System (GIS) interface, which enabled real-time visualization of underground conditions. The system also included a robust alert mechanism that used GPRS to transmit SMS notifications when hazardous thresholds were exceeded.

Zhu et al. (2019) developed a ZigBee-based coal mine environmental monitoring system structured around a tree-topology WSN. Their implementation involved CC2530 microcontrollers interfaced with gas, CO, humidity, and temperature sensors. The authors highlighted the limitations of wired networks, especially in terms of inflexibility and high maintenance, and proposed a reconfigurable wireless alternative capable of extending into previously inaccessible areas. ZigBee's low-power communication features, coupled with a hierarchical node structure, contributed to enhanced scalability and efficient data routing.

Yang et al. (2021) conducted a comprehensive review of coal mining hazards and the role of emerging technologies in mitigating risks. Their study categorized hazards into environmental, technical, and operational domains, and emphasized how IoT-enabled systems can enhance environmental awareness, trigger early warnings, and assist in rescue efforts. The review, however, also identified persistent challenges such as human error, insufficient training, and design flaws in existing safety systems.

Jawalkar et al. (2022) proposed an IoT-based landslide detection system using gyroscopes, soil moisture sensors, and embedded microcontrollers. Their work emphasized the need for fast-response, affordable solutions in regions prone to landslides. By evaluating various sensor technologies and detection methodologies, they concluded that cloud-enabled WSNs offer a reliable foundation for terrain monitoring and early-warning mechanisms.

Though later retracted, Sathishkumar et al. (2021) contributed a conceptual framework for an IoT-driven mine safety system integrating sensors for gas, temperature, and fire detection. The system aimed to prevent rescue personnel from entering dangerous zones by delivering early alerts, thereby contributing to the broader discourse on embedded safety monitoring.

Ramesh et al. (2025) presented an IoT-enabled coal mine safety system that combined ZigBee communication with cloud-based analytics. Their system featured multi-sensor modules capable of detecting harmful gases, pressure changes, and temperature spikes. The integration with cloud platforms allowed for centralized monitoring, data storage, and long-term safety trend analysis.

Savitha et al. (2021) proposed a real-time coal mine monitoring framework built on low-power sensor networks. Their system focused on modular sensor deployment to track gas emissions, fire hazards, and temperature variations. Data collected was sent to a cloud backend for analysis and visualization, enabling both real-time alerts and predictive insights.

In another innovative study, Vishnuvarthan et al. (2022) demonstrated the use of LoRa communication in underground mining environments. Their system featured Arduino-based sensor nodes collecting environmental data and transmitting it to the ThingSpeak cloud platform. LoRa's long-range, low-energy operation proved particularly effective in overcoming communication challenges in deep and interference-prone mining areas.

Zhang et al. (2014) proposed a hybrid monitoring architecture that combined traditional cable monitoring systems (CMS) with WSNs. Their system leveraged the reliability of CMS for backbone data transmission and utilized WSNs to cover narrower or less accessible regions. They also incorporated energy-efficient communication strategies and fault-tolerant topologies to enhance sensor node longevity and system robustness.

Together, these studies highlight a clear evolution in mining safety systems from static, wired solutions toward dynamic, wireless, and cloud-integrated platforms. Key trends include the miniaturization of sensors, the shift to decentralized edge computing, and the increasing use of scalable communication protocols like ZigBee and LoRa. Furthermore, the integration of cloud analytics and mobile access has enabled remote monitoring and responsive safety management.

The proposed ESP32 and MEMS sensor-based monitoring system draws upon these advances to deliver a lightweight, modular, and cost-effective solution. Designed for both underground coal mines and landslide-prone surface areas, it offers edge-level processing, dual alert mechanisms, and cloud connectivity, thereby addressing the critical need for reliable, real-time environmental surveillance in hazardous industrial environments.

3. METHODOLOGY

The development of a dual-purpose monitoring system for coal mine safety and landslide detection required a methodical and modular approach. The methodology adopted in this project is divided into clear stages ranging from component selection and sensor interfacing to data transmission, cloud integration, and alert system implementation. Each stage was designed to ensure reliability, scalability, and responsiveness under real-world environmental conditions.

3.1 System Architecture Overview

The complete system comprises two separate yet interconnected subsystems:

- Coal Mine Monitoring Unit
- Landslide Detection Unit

Each unit operates on an ESP32 microcontroller and is equipped with MEMS-based and environmental sensors. Both subsystems collect sensor data in real-time, process it locally using edge computing logic, and transmit relevant alerts through GSM (SMS) and Wi-Fi (cloud dashboard) interfaces. The architecture emphasizes decentralization, so both units can function independently even in the absence of stable internet connectivity.

3.2 Component Selection and Sensor Integration

A detailed component and literature survey was conducted to select suitable sensors for the target applications. The following criteria were used during selection: sensitivity, durability, power consumption, compatibility with ESP32, and reliability in harsh or unstable environments.

Coal Mine Monitoring:

- MQ-135 & MQ-6 Gas Sensors: To detect methane (CH_4) and carbon monoxide (CO).
- DHT11 Sensor: To monitor temperature and relative humidity levels.
- MEMS Vibration Sensor: To detect micro-tremors or structural instability within the mine.
- 16x2 LCD Display: For real-time local display of gas, temperature, and vibration data.
- Buzzer & GSM Module (SIM800): To provide audio alerts and send SMS notifications when safety thresholds are breached.

Landslide Detection:

- Soil Moisture Sensor: To assess the level of water saturation in the soil.
- Rain Sensor: To measure rainfall intensity contributing to slope instability.
- Tilt Sensor: To track angular shifts in the terrain that precede mass movement.
- MEMS Vibration Sensor: To detect seismic vibrations or slope tremors.
- GPS Module: For geo-tagging alert locations in multi-node deployments.

3.3 Embedded Logic and Threshold Setting

The ESP32 microcontroller was programmed using the Arduino IDE to acquire, analyze, and act on data from all connected sensors. Threshold values for each parameter (e.g., gas concentration limits, safe soil moisture range, permissible tilt angle) were predefined based on industry safety standards and historical case studies.

- If a parameter exceeds its safety limit, the system:
    1. Activates a buzzer for local warning.

2. Displays the alert message on the LCD (for the coal mine unit).
3. Sends a real-time SMS alert to the assigned safety personnel.
4. Uploads the sensor readings and alert status to the cloud dashboard.

3.4 IoT Integration and Communication

A lightweight MQTT protocol over Wi-Fi was used to send real-time sensor data to a cloud server. Each ESP32 board was programmed to:

- Publish sensor data in JSON format to relevant MQTT topics (e.g., esp32/coal/data, esp32/landslide/data).
- Subscribe to configuration topics for threshold updates or remote commands.
- Send alerts through an SMS gateway (via GSM module) independent of internet availability.

The cloud platform hosts a real-time dashboard for visualizing sensor data, tracking historical trends, and managing alert acknowledgments. For on-the-go access, a mobile application was built using a WebView wrapper, providing the same functionalities as the web dashboard.

3.5 Power Supply and Remote Deployment

Recognizing that remote mine locations may lack reliable power infrastructure, both systems were designed to support:

- Battery Operation
- Solar Charging Modules

The architecture block diagram of both land slide monitoring and coal mine monitoring system is shown in the figure below:

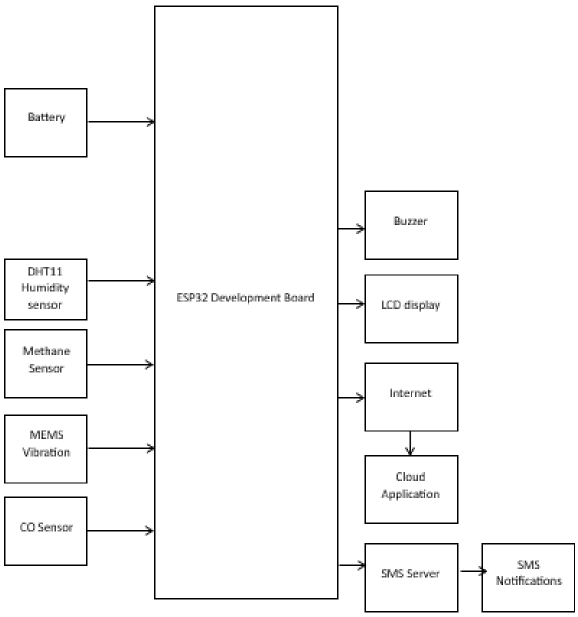

Figure 1: Architecture Diagram, Coal Mine Monitoring System

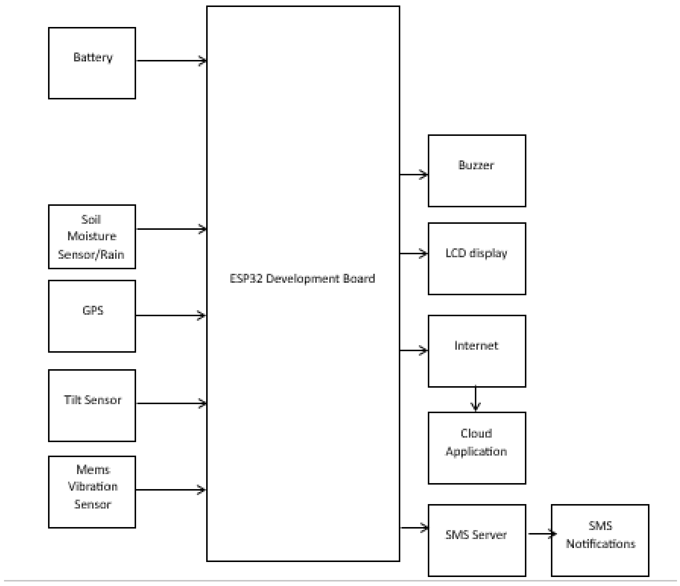

Figure 2: Architecture Diagram, Land Slide Monitoring System

4. IMPLEMENTATION

The proposed monitoring system was implemented by systematically integrating hardware components, embedded programming, and cloud-based communication protocols. The objective was to develop two independent yet coordinated systems: one for detecting hazards in underground coal mines and the other for monitoring landslides in nearby terrain. Both units utilized the ESP32 microcontroller due to its compact design, dual-core processing capabilities, built-in Wi-Fi and Bluetooth features, and energy efficiency making it well-suited for environments where power supply and connectivity can be unreliable.

In the coal mine monitoring unit, hardware assembly started by integrating an ESP32 with a variety of environmental sensors. The MQ-135 and MQ-6 gas sensors were linked to the analog input pins for detecting methane and carbon monoxide two major hazardous gases commonly present in coal mines. These sensors were precisely calibrated to initiate alerts whenever gas concentrations exceeded safe levels. Additionally, a DHT11 sensor was incorporated to track temperature and humidity, both crucial for assessing mining conditions' safety. A MEMS vibration sensor was attached to monitor ground tremors or subtle movements that could indicate potential mine collapses. For immediate on-site data feedback, a 16x2 LCD display showed real-time sensor readings while a buzzer provided audible warnings at the location itself. Moreover, remote personnel received SMS notifications through the SIM800L GSM module configured specifically for sending alerts upon detection of dangerous readings. All these components were assembled onto a compact custom-designed PCB created using EasyEDA software; this design ensured durable construction with minimal wiring suitable for harsh underground environments.

At the same time, a landslide detection system was developed using similar core logic but tailored for monitoring slopes and terrains. An ESP32 board acted as the controller in this setup, interfacing with both a soil moisture sensor and a rain detection module to gauge surface saturation a crucial factor influencing slope stability. To track angular shifts indicating soil movement or displacement on the slope, a tilt sensor was installed on its surface. The MEMS vibration sensor played an essential role by detecting micro-seismic activities or low-frequency ground motions that often signal impending landslides. Sensors were strategically positioned according to anticipated environmental behavior to ensure comprehensive and precise data collection. Like the coal mine unit, this system was constructed on a compact PCB design and powered by rechargeable batteries supplemented with solar charging capabilities for remote autonomous operation. The data flow diagram of the proposed system architecture diagram is shown below in Figure 3.

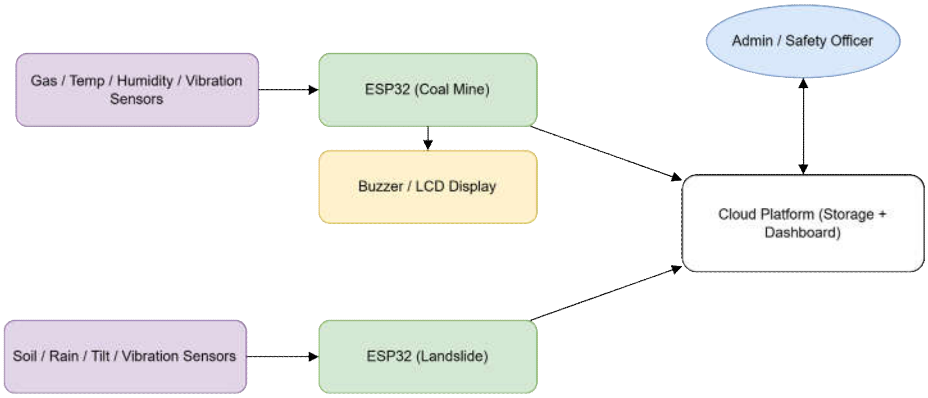

Figure 3. Data flow Diagram

The programming for both devices was accomplished using the Arduino IDE. Custom embedded code was developed to regularly collect sensor readings, assess them against predefined safety thresholds, and trigger alerts when necessary. If a reading surpassed the specified limit, the ESP32 would sound an alarm by activating a buzzer in addition to displaying a warning on an LCD screen (in the coal mine unit) and sending an SMS alert via the GSM module. At the same time, all sensor data regardless of whether any limits were exceeded was transmitted to a cloud platform over Wi-Fi using MQTT protocol. This setup facilitated real-time remote monitoring as well as historical data analysis through an interactive web dashboard and Android application.

To facilitate seamless IoT integration, a cloud dashboard was created utilizing HTML, CSS, JavaScript for the frontend and Flask for the backend. This dashboard displays real-time sensor data with charts and alert indicators. It allows users to modify threshold values, access historical logs, and get notifications through a unified interface. For mobile accessibility, the web application was encapsulated into an Android app using a WebView component while retaining complete functionality for users in field operations. Both platforms employed secure MQTT channels to guarantee reliable and encrypted data transmission. To validate the system's capability for detection and response under adverse conditions, simulated scenarios like elevated gas levels, soil saturation, and artificial tilting were utilized.

5. RESULTS AND DISCUSSION

The suggested dual-monitoring system underwent testing in simulated environments of coal mines and slopes to evaluate its precision, responsiveness, and dependability. This ESP32-based system, equipped with MEMS sensors, effectively recorded essential environmental parameters such as gas concentration, temperature, humidity levels, soil moisture content, tilt angles, and vibrations.

During testing, the gas sensors identified methane and carbon monoxide levels that surpassed the established safety thresholds, which consequently activated alerts as anticipated. The DHT11 consistently delivered stable temperature and humidity measurements. Meanwhile, MEMS sensors demonstrated high sensitivity to even minor tremors and slope tilts. Of particular note was the tilt sensor's ability to precisely detect angular changes as small as 2°, while the vibration sensor effectively responded to low-frequency ground movements, underscoring its value in predicting landslides.
The ESP32's real-time processing allowed for alerts to be generated within 2 seconds of threshold breaches. Even during simulated network outages, the system operated autonomously from the cloud, continuing to provide local alerts through a buzzer and an LCD display. Once reconnected, it achieved more than 98% uptime using Wi-Fi and MQTT protocol for logging data in the cloud. SMS notifications sent via the GSM module were usually received within 4–6 seconds, ensuring timely communication with safety personnel.

With its solar-powered unit, the setup operated continuously for more than 30 hours, showcasing its suitability for use in remote or off-grid locations. The user-friendly web and Android dashboards provided live monitoring capabilities along with historical data review and threshold management features.
The Web Application developed is shown in figure. 4

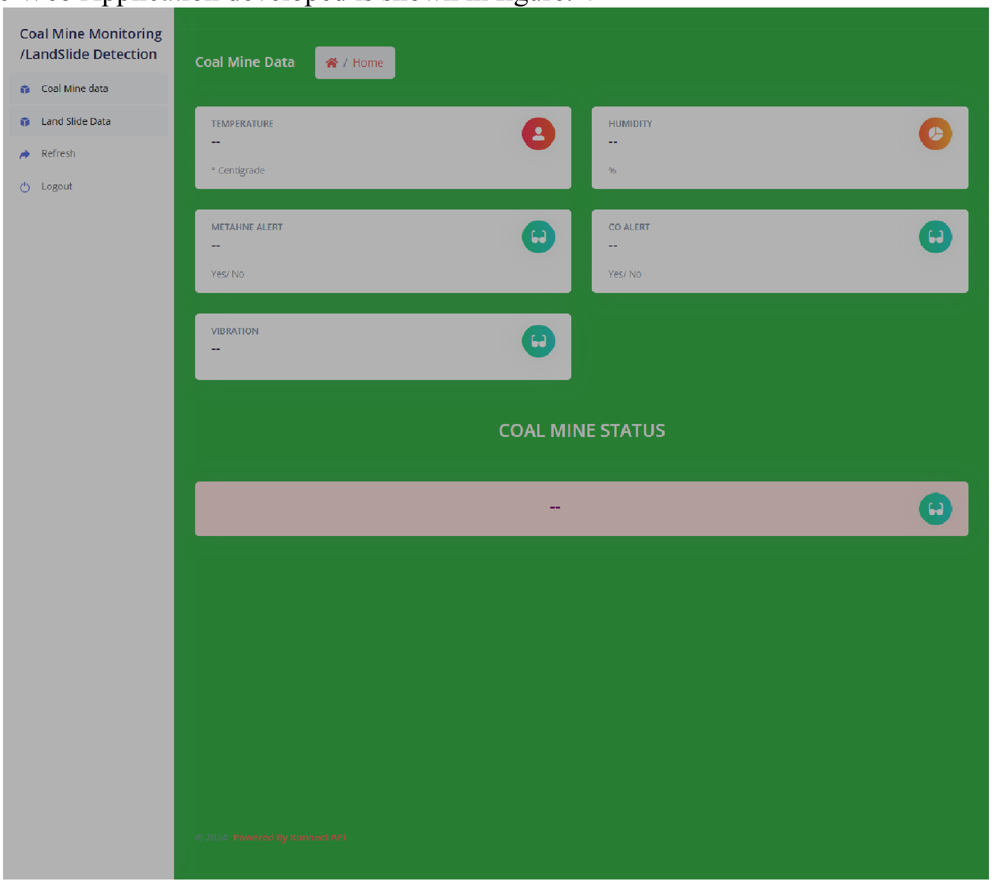

Figure 4. Output Snapshots of the Application

From, the results we can conclude that the system can detect hazards in real-time within coal mines and landslide areas. Although low-cost components such as DHT11 could be upgraded for greater accuracy, the overall design demonstrated reliability, scalability, and suitability for challenging environments. Future enhancements might involve extending communication range through LoRa technology and improving sensor calibration for field applications.

6. CONCLUSION

This paper showcases the feasibility and efficiency of a dual-purpose environmental monitoring system tailored for coal mine safety and landslide risk detection. The system employs an ESP32 microcontroller alongside MEMS-based sensors to monitor vital environmental parameters in real time, such as gas concentrations, humidity, temperature, ground vibrations, soil moisture levels, tilt angles, and rainfall intensity. By incorporating edge-level data processing with wireless communication protocols, it ensures reliable performance even in remote areas lacking infrastructure. A key contribution of this research is the integration of two critical monitoring applications underground coal mining and slope stability into a unified, scalable framework. This system enables real-time alerts through SMS and cloud-based dashboards, promoting prompt decision-making and minimizing response times. Its modular hardware design, combined with low power consumption and solar-powered energy support, guarantees flexibility in deployment as well as sustained operation in the field with minimal maintenance requirements. The implementation highlights the critical role of multi-parameter sensing and threshold-based alerts in improving hazard detection reliability. By facilitating remote configuration and real-time data visualization via web and Android platforms, the system effectively connects field-level sensing with centralized supervision. The seamless integration of these features indicates significant potential for adoption in real-world scenarios, especially in areas where traditional safety infrastructure is lacking or inadequate.

REFERENCES

[1] Wang, J., Yang, C., & Dong, F. (2014). Monitoring and Alarm System for Coal Mine Safety Based on Wireless Sensor Network. *IEEE Journal of Lightwave Technology*, 32(14), 2531–2535. https://ieeexplore.ieee.org/document/6784807

[2] Zhu, Y., & You, G. (2019). Monitoring System for Coal Mine Safety Based on Wireless Sensor Network. *IEEE*. https://ieeexplore.ieee.org/document/8799111

[3] Yang, L., Birhane, G. E., Zhu, J., & Geng, J. (2021). Mining Employees Safety and the Application of Information Technology in Coal Mining: Review. *Frontiers in Public Health*, 9, 709987. https://doi.org/10.3389/fpubh.2021.709987

[4] Jawalkar, M., Malviya, N., Hage, P., Chakule, S., & Pattewar, P. (2022). IoT Based Landslide Detection and Monitoring System. *International Journal for Research in Applied Science & Engineering Technology (IJRASET)*, 10(5). https://doi.org/10.22214/ijraset.2022.43135

[5] Sathishkumar, N., Manoj, A. M., Muniraj, K., Naveenkumar, M., & Praveen, C. (2021). Safety Monitoring System in Coal Mine Using IoT. *Journal of Physics: Conference Series*, 1916, 012196. https://doi.org/10.1088/1742-6596/1916/1/012196

[6] Ramesh, G., Bojjawar, S., Swapna, N., & Uday, K. (2025). An IoT System for Monitoring and Alerting Safety in Coal Mines. *E3S Web of Conferences*, 616, 03001. https://doi.org/10.1051/e3sconf/202561603001

[7] Savitha, G., Deepak, N. A., & Deepak, D. J. (2021). Data Acquisition Using IoT to Monitor Coal Mining Environment. *Proceedings of the 3rd International Conference on Integrated Intelligent Computing*

Communication & Security (ICIIC), Atlantis Press. https://doi.org/10.2991/assehr.k.210331.027

[8] Vishnuvarthan, S., Akram, W. N., & Akiladeswary, G. (2022). IoT Based Coal Mine Monitoring System Using LoRa Cloud. *SSRN*. https://ssrn.com/abstract=4228480

[9] Zhang, Y., Yang, W., Han, D., & Kim, Y. I. (2014). An Integrated Environment Monitoring System for Underground Coal Mines Wireless Sensor Network Subsystem with Multi-Parameter Monitoring. *Sensors*, 14(7), 13149–13170. https://doi.org/10.3390/s140713149

[10] Rehak, D., Dudáček, A., & Poledňák, P. (2013). A Multipurpose Robotic Vehicle for the Rescue of Persons and Interventions in Emergency Situations. *Communications – Scientific Letters of the University of Žilina*.

[11] Dash, S., Tripathy, A., & Choudhury, B. B. (2014). Design and Development of a Robotic Vehicle. *International Journal of Engineering Research and Technology*.

[12] Liao, C. R., Chen, H. F., & Wang, D. N. (2014). Ultracompact Optical Fiber Sensor for Refractive Index and High-Temperature Measurement. *Journal of Lightwave Technology*, 32(14), 2531–2535. https://ieeexplore.ieee.org/document/6827204

[13] Hassard, M., Stoker, G., Vaughn, M., & Bickerstaff, B. (2003). Sensor Evaluation for a Robotic In-Line Inspection Vehicle for Detection of Natural Gas Pipeline Defects and Leaks. *Sandia National Laboratories*.

[14] Dang, A., Chandorkar, V., Pawar, A., & Pawar, D. (2017). Hand Motion Controlled Robotic Vehicle with Obstacle Detection. *International Research Journal of Engineering and Technology (IRJET)*, 4(9), 1146–1148.