

IoT-driven Landslide and Rockfall Hazards Detection and Early Warning System

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Abstract— This project presents a comprehensive IoT-driven Landslide and Rockfall Hazards Detection and Early Warning System specifically designed for monitoring underground mining environments. The system utilizes the ESP32 microcontroller in conjunction with the Blynk IoT platform and a network of environmental and geotechnical sensors to continuously assess hazardous conditions in real time. To monitor ground saturation and water ingress—critical factors in underground slope stability two soil moisture sensors are strategically deployed to detect subsurface water accumulation. An additional soil moisture sensor is configured as a rain gauge substitute for detecting water seepage near tunnel ceilings or shaft entries. To further enhance hazard detection, the system incorporates MEMS accelerometers, which continuously monitor micro-vibrations and abnormal ground movements that may precede landslides or rockfalls. The BMP180 sensor collects environmental parameters such as temperature, atmospheric pressure, and altitude, which help identify sudden environmental shifts and ventilation anomalies within the mine. All sensor readings are transmitted in real-time to the Blynk IoT platform via the ESP32's built-in Wi-Fi capabilities, allowing remote access from control rooms or mobile devices. In case of abnormal readings that exceed safety thresholds, the system triggers immediate on-site alarms using a buzzer and LED indicators, while also sending real-time alerts via email and push notifications through the Blynk app. This cost-effective and modular system offers a scalable solution for early warning and situational awareness in hazard-prone underground mining operations, enabling faster response times and improved worker safety through continuous and remote monitoring of potential landslide and rockfall threats.

Keywords— ESP32, MEMS, rock fall, BMP180, Land, rain, Moisture.

I. INTRODUCTION

Landslides and rockfalls are among the most dangerous geotechnical hazards, particularly in underground mining environments where structural instability can lead to severe consequences, including loss of life, equipment damage, and operational disruptions. These hazards are often triggered by factors such as water infiltration, ground vibrations, geological weaknesses, and environmental changes. In underground mines, where visibility is limited and conditions can change rapidly, early detection and warning systems are essential to ensure worker safety and prevent catastrophic failures.

Traditional methods for monitoring landslide and rockfall risks in mining environments rely on manual inspections and periodic measurements using geotechnical instruments. While these methods provide

valuable information, they are often time-consuming, labor-intensive, and unable to provide continuous real-time monitoring. Moreover, manual inspection may not detect early warning signs such as micro-vibrations or gradual changes in soil moisture, which are critical indicators of potential hazards. As a result, there is a growing need for automated and intelligent systems capable of continuously monitoring environmental and geotechnical conditions. The advancement of the Internet of Things (IoT) has introduced new possibilities for developing smart monitoring systems that can collect, process, and transmit data in real time. IoT-based systems integrate sensors, microcontrollers, and wireless communication technologies to provide continuous monitoring and remote access to data. These systems are particularly suitable for hazardous environments such as underground mines, where real-time information is crucial for decision-making and emergency response.

The proposed IoT-driven Landslide and Rockfall Hazards Detection and Early Warning System is designed to address these challenges by providing a comprehensive and automated monitoring solution. The system is built around the ESP32, which serves as the central processing and communication unit. The ESP32 is chosen for its high processing capability, low power consumption, and built-in Wi-Fi connectivity, enabling seamless integration with cloud-based platforms. The system incorporates a network of sensors to monitor various environmental and geotechnical parameters. Soil moisture sensors are deployed to detect water accumulation and ground saturation, which are key factors contributing to slope instability. Excessive moisture can weaken soil structure and increase the likelihood of landslides or rockfalls. An additional soil moisture sensor is used as a rain gauge substitute to detect water seepage in underground tunnels and shafts.

To detect ground movement, the system integrates MEMS accelerometers that continuously monitor vibrations and shifts in the الأرض. These sensors are capable of detecting micro-vibrations that may precede major structural failures. By analyzing vibration patterns, the system can identify abnormal conditions and provide early warnings.

Environmental parameters are monitored using the BMP180 sensor, which measures temperature, atmospheric pressure, and altitude. These parameters are important for understanding ventilation conditions and detecting sudden environmental changes that may indicate instability. All sensor data is processed by the ESP32 and transmitted to the Blynk cloud platform. The Blynk platform provides a user-friendly interface for real-time data visualization and remote monitoring. Users can access sensor data through mobile applications or web dashboards, enabling continuous monitoring from control rooms or remote locations. In addition to monitoring, the system includes an early warning mechanism that activates when sensor readings exceed predefined safety thresholds. Alerts are generated using on-site indicators such as LEDs and buzzers, as well as remote notifications via email and mobile applications. This ensures that both on-site workers and remote supervisors are immediately informed of potential hazards.

The proposed system offers several advantages, including continuous real-time monitoring, remote accessibility, and automated alert generation. Its modular design allows easy scalability, enabling deployment in different sections of a mine or across multiple sites. Furthermore, the system is cost-effective, making it suitable for implementation in both large-scale and small-scale mining operations. In conclusion, the IoT-driven Landslide and Rockfall Hazards Detection and Early Warning System represents a significant advancement in mine safety technology. By integrating sensor networks, wireless communication, and real-time data analysis, the system provides an efficient and reliable

solution for monitoring hazardous conditions and preventing accidents in underground mining environments.

II. LITERATURE SURVEY

The detection and prevention of landslides and rockfalls have been widely studied in the fields of geotechnical engineering, environmental monitoring, and disaster management. Traditional monitoring methods include geological surveys, manual inspections, and the use of instruments such as inclinometers, extensometers, and piezometers. While these methods provide valuable insights into ground conditions, they are often limited by their inability to provide continuous monitoring and real-time data.

In recent years, researchers have explored the use of sensor-based monitoring systems to improve the detection of geotechnical hazards. Soil moisture sensors have been widely used to monitor water content in soil, which is a critical factor in landslide occurrence. Increased soil moisture reduces soil cohesion and increases the likelihood of slope failure. Studies have shown that monitoring soil moisture levels can provide early indications of potential landslides.

Another important parameter in landslide detection is ground movement. MEMS accelerometers have been extensively used to detect vibrations and movements in the الأرض. These sensors are capable of detecting small changes in acceleration, making them suitable for monitoring micro-vibrations that may precede larger movements. Research has demonstrated that analyzing vibration patterns can help identify early warning signs of landslides and rockfalls.

Environmental factors such as temperature, pressure, and humidity also play a significant role in slope stability. Sensors like the BMP180 have been used in various studies to monitor atmospheric conditions. Sudden changes in pressure or temperature can indicate environmental disturbances that may contribute to geotechnical hazards.

The integration of IoT technology has significantly enhanced the capabilities of monitoring systems. IoT-based systems allow for real-time data collection, processing, and transmission, enabling remote monitoring and analysis. Microcontrollers such as the ESP32 have become popular choices for IoT applications due to their built-in Wi-Fi connectivity and compatibility with various sensors.

Several research studies have implemented IoT-based landslide monitoring systems that transmit sensor data to cloud platforms for analysis. These systems provide real-time alerts and enable remote monitoring, improving response times and reducing the risk of accidents. Among various IoT platforms, the Blynk platform is widely used for its ease of integration and user-friendly interface.

In addition to monitoring, researchers have explored early warning systems that combine sensor data with threshold-based or predictive models. These systems generate alerts when certain parameters exceed predefined limits, enabling timely intervention. Some advanced systems also use machine learning algorithms to analyze data patterns and predict potential hazards.

Despite these advancements, existing systems often face challenges such as high implementation costs, limited scalability, and dependency on complex infrastructure. Some systems require specialized

equipment and expertise, making them less accessible for smaller mining operations. The proposed IoT-driven Landslide and Rockfall Hazards Detection and Early Warning System addresses these challenges by providing a cost-effective and scalable solution. The system integrates multiple sensors to monitor key parameters such as soil moisture, ground vibration, and environmental conditions. The use of IoT technology enables real-time monitoring and remote access, while the modular design allows easy expansion.

Furthermore, the system incorporates both local and remote alert mechanisms, ensuring that hazards are detected and communicated promptly. This combination of sensing, communication, and alerting capabilities makes the system a comprehensive solution for monitoring geotechnical hazards in underground mining environments. Overall, the literature highlights the growing importance of IoT-based monitoring systems in improving safety and efficiency in hazardous environments. The integration of sensor networks, real-time data analysis, and early warning mechanisms represents a significant step forward in disaster prevention and management.

III. METHODOLOGY

The proposed IoT-driven Landslide and Rockfall Hazards Detection and Early Warning System operates by continuously monitoring environmental and geotechnical parameters using a network of sensors integrated with the ESP32. The system is designed to function in real time, ensuring early detection of hazardous conditions in underground mining environments.

Initially, all sensors are initialized and calibrated when the system is powered ON. The ESP32 establishes a Wi-Fi connection and links to the Blynk cloud server for remote monitoring.

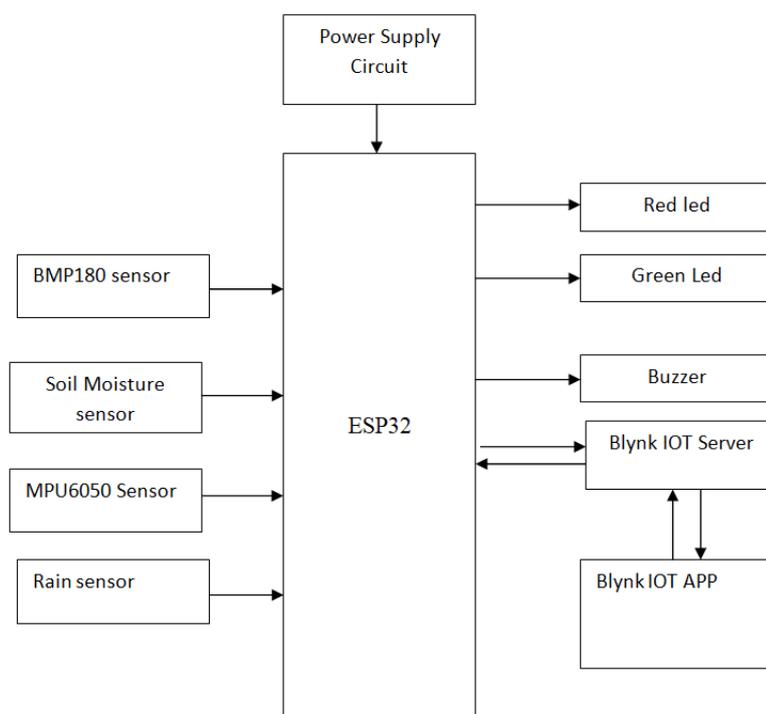


Figure 1: Block Diagram

The system continuously collects data from multiple sensors:

- **Soil Moisture Sensors:** These sensors detect water content in the soil and surrounding surfaces. Two sensors monitor ground saturation, while an additional sensor detects water seepage in tunnel ceilings or shafts.
- **MEMS Accelerometer:** This sensor continuously measures vibrations and detects abnormal ground movement or micro-vibrations that may indicate structural instability.
- **BMP180 Sensor:** It measures environmental parameters such as temperature, atmospheric pressure, and altitude to detect sudden environmental changes.

The ESP32 processes the sensor data and compares it with predefined safety threshold values. If all readings remain within safe limits, the system continues normal monitoring and transmits data to the Blynk dashboard for real-time visualization.

When any parameter exceeds its threshold—for example, excessive moisture indicating water accumulation, abnormal vibration suggesting ground movement, or sudden environmental changes—the system identifies it as a potential hazard. Immediately, the ESP32 triggers local alert mechanisms such as a buzzer and LED indicators to warn nearby workers.

Simultaneously, the system sends real-time alerts through the Blynk platform in the form of push notifications and emails to supervisors or control room operators. This dual-alert mechanism ensures both on-site and remote awareness. The system operates continuously in a loop, ensuring uninterrupted monitoring and rapid response to hazardous conditions. This real-time detection and alert mechanism significantly improves safety in underground environments.

IV. RESULT ANALYSIS

The performance of the IoT-driven Landslide and Rockfall Hazards Detection and Early Warning System was evaluated under various simulated and real-time conditions to assess its accuracy, responsiveness, and reliability. The system demonstrated effective monitoring of environmental and geotechnical parameters, providing continuous real-time data through the Blynk dashboard with minimal latency.

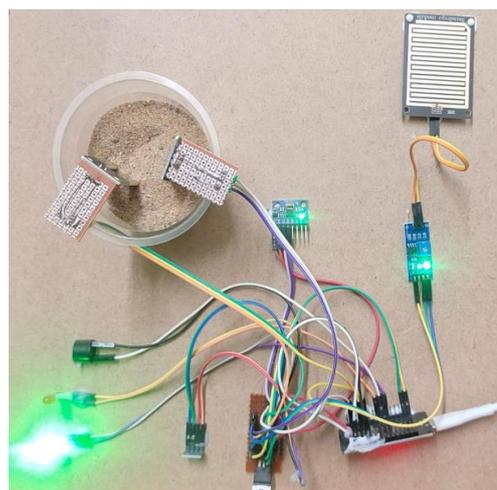




Figure 2: IoT-driven Landslide and Rockfall Hazards Detection and Early Warning System

The soil moisture sensors accurately detected variations in water content, successfully identifying conditions of increased ground saturation and simulated water seepage. The MEMS accelerometer proved highly sensitive in detecting vibrations and micro-movements, enabling early identification of potential instability. The BMP180 provided consistent and stable readings of temperature and atmospheric pressure, contributing to environmental analysis.

The system exhibited fast response times, with alerts being triggered almost instantly when sensor values exceeded predefined thresholds. Local alert mechanisms, including LEDs and a buzzer, effectively notified nearby personnel, while remote notifications via the Blynk platform ensured timely communication to supervisors.

During continuous operation testing, the ESP32 maintained stable connectivity and reliable data transmission without interruptions. The system proved to be scalable and adaptable for deployment in various underground mining environments.

Although minor limitations such as dependency on Wi-Fi connectivity and sensor calibration were observed, the overall system performance was highly satisfactory. The integration of multiple sensors and IoT technology enabled accurate hazard detection, real-time monitoring, and efficient early warning, demonstrating the system's effectiveness in enhancing safety and preventing potential landslides and rockfalls.

V. FUTURE SCOPE

The proposed IoT-driven Landslide and Rockfall Hazards Detection and Early Warning System can be further enhanced by integrating advanced technologies to improve accuracy, prediction capability, and large-scale deployment. One major improvement is the incorporation of machine learning and predictive analytics. By analyzing historical sensor data, the system can predict potential hazards before threshold limits are reached, enabling proactive safety measures rather than reactive alerts.

The system can also be upgraded with additional high-precision geotechnical sensors such as strain gauges, tilt sensors, and ground displacement sensors to provide more detailed analysis of structural stability. Integration of GPS modules can help in tracking the exact location of detected hazards, especially in large mining areas.

Communication can be improved by incorporating alternative technologies such as LoRa, GSM, or satellite communication to ensure reliable data transmission in underground environments where Wi-Fi connectivity may be unstable. Cloud integration with advanced dashboards and data visualization tools can further enhance monitoring and decision-making.

The system can also be extended for smart mining and smart city applications by deploying multiple sensor nodes connected in a network, enabling large-scale monitoring of landslide-prone areas. Additionally, integrating camera modules and computer vision techniques can provide visual confirmation of hazardous conditions.

Overall, future developments can transform the system into an intelligent, predictive, and fully automated hazard management platform.

VI. CONCLUSIONS

The IoT-driven Landslide and Rockfall Hazards Detection and Early Warning System presents an efficient and reliable solution for monitoring hazardous conditions in underground mining environments. The system utilizes the ESP32 as the central controller to collect and process data from multiple sensors, including soil moisture sensors, MEMS accelerometers, and the BMP180. By integrating with the Blynk, the system enables real-time monitoring and remote access to environmental data. The implementation of threshold-based alerts ensures immediate detection of abnormal conditions, triggering both local alarms and remote notifications to enhance safety. The system demonstrated reliable performance, accurate data monitoring, and fast response during testing. Its modular design makes it scalable and suitable for deployment in various underground mining environments. In conclusion, the proposed system provides a cost-effective, scalable, and intelligent solution for early hazard detection and prevention. It significantly improves worker safety and operational efficiency by enabling continuous monitoring and timely intervention, contributing to safer mining operations and effective disaster management.

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