Slopeguard: A Lora-Driven Intelligent Landslide Detection Framework

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Abstract — In hilly and mountainous areas, landslides are among the most destructive natural disasters, particularly during periods of intense precipitation. Human lives, transportation networks, and infrastructure are all severely harmed by sudden slope failures. Conventional monitoring systems are not appropriate for remote locations since they are frequently manual, costly, and do not have real-time alert capabilities. A LoRa-based Internet of Things landslide detection and early warning system is proposed in this paper for ongoing slope monitoring and prompt risk assessment. Numerous sensors are integrated into the system, such as the DHT11 for environmental monitoring, the soil moisture sensor, the vibration sensor, and the MPU6050 for tilt and acceleration. The sensor data is processed by an ESP32 microcontroller and sent to a monitoring station via LoRa communication. LEDs and a buzzer are used to create local alerts, and data is sent to a cloud dashboard for oversight from a distance. For deployment in areas vulnerable to landslides, the suggested system provides long-range communication, low power consumption, dependability, and affordability.
Keywords: early warning system, disaster management, IoT, LoRa communication, and landslide detection.

OVERVIEW

In hilly and mountainous areas, landslides are common natural hazards, especially during the monsoon season. The risk of slope failure is greatly increased by excessive rainfall, soil saturation, deforestation, and seismic disturbances. These catastrophes lead to in traffic jams, building failures, car crashes, and fatalities.

Traditional landslide monitoring methods depend on costly geotechnical equipment, recurring geological surveys, or manual inspection. These systems frequently fall short in providing early warning and are not appropriate for real-time monitoring. Furthermore, the efficacy of GSM-based monitoring systems is limited in remote hill regions, which usually lack reliable internet or cellular connectivity.

Intelligent environmental monitoring is now possible thanks to recent developments in wireless communication and Internet of Things (IoT) technology. Low-power, long-distance wireless transmission is made possible by LoRa (Long Range) communication technology, which makes it perfect for remote monitoring applications.

This project suggests a LoRa-based Internet of Things system that uses several sensors to continuously monitor slope conditions and sends out local and remote early warning alerts.

1. OBJECTIVE

The primary goal of this project is to develop and deploy an Internet of Things (IoT)-based landslide detection and early warning system that is dependable, affordable, and long-range enough to function well in isolated and hilly areas. In order to spot early indications of instability, the system focuses on continuously monitoring slope conditions through multi-sensor data acquisition. In order to identify possible landslide hazards before they become catastrophic events, the system measures important environmental and geotechnical factors like soil moisture, ground vibration, tilt angle, temperature, and humidity.LoRa long-range communication is used to transmit sensor data, guaranteeing consistent connectivity even in places with inadequate network infrastructure. Using LEDs and a buzzer, the system instantly notifies neighbouring communities. Authorities can also remotely monitor and analyze real-time data by uploading it to a cloud dashboard. By providing timely and precise early warnings, the project's low-power design guarantees sustainable deployment in remote areas, boosting public safety and disaster preparedness.

3. LITERATURE REVIEW

A real-time monitoring system that uses LoRa communication to detect slope instability was proposed by the authors of the paper "Improving Road Safety in Landslide Prone Areas: Real-Time LoRa-Based Landslide Detection and Warning System" - Sigiro et al., ICT, 2023. To track ground conditions and send data over long distances, the study used sensors like vibration and soil moisture sensors. When compared to GSM-based models, the system showed better communication reliability in hilly and remote areas. However, the study

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did not fully integrate cloud-based analytics with multi-parameter monitoring and instead concentrated on road safety alerts.

The researchers created an IoT-based landslide prediction system that was improved with edge computing and cloud integration in a different paper titled "Integration of Edge-AI into IoT–Cloud Architecture for Landslide Monitoring and Prediction" – Hernandez & Davis, IEEE IoT Journal, 2023. To increase prediction accuracy, the model gathered environmental data such as ground vibration, soil moisture, and rainfall intensity. Although the system demonstrated improved analytical performance, it was less appropriate for low-cost rural deployment and required more computational resources.

These studies demonstrate how IoT and LoRa technologies are becoming increasingly significant in landslide monitoring. A unified architecture that integrates multi-sensor data collection, long-range communication, instant local alerts, and real-time cloud dashboard monitoring is absent from many current systems, though. By combining all of these features into a single, economical, and energy-efficient framework appropriate for isolated landslide-prone areas, the suggested system fills these gaps.

4.SYSTEM ARCHITECTURE / METHODOLOGY

The modular architecture of the suggested LoRa-Based Landslide Detection and Early Warning System is intended to be dependable, scalable, and low-power. Sensing, processing, communication, alert generation, and remote monitoring are all handled by the system's networked modules. In landslide-prone areas, each module functions in unison to guarantee ongoing slope monitoring and prompt warning generation.

4.1 SENSOR & DATA ACQUISITION MODULE (FIELD UNIT)

This module is used in areas that are vulnerable to landslides. It has sensors like the DHT11 (temperature and humidity), MPU6050 (tilt and acceleration), vibration sensor, and soil moisture sensor. These sensors keep an eye on the ground and surroundings all the time. The ESP32 microcontroller receives the gathered data and analyses it. This guarantees the detection of environmental changes and slope instability in real time.

4.2 DATA PROCESSING & LOCAL ALERT MODULE

All incoming sensor data is processed by the ESP32 microcontroller, which then compares it to preset threshold values. The system classifies the risk level as normal, warning, or critical based on the analysis. The local alert system helps those in the vicinity take preventative measures by instantly delivering on-site warnings through LEDs and a buzzer if abnormal conditions are detected.

4.3COMMUNICATION&MONITORING ODULE

Processed data can be wirelessly transmitted over long distances from the slope unit to the receiver unit thanks to the LoRa module. For remote monitoring, the WiFi-enabled receiver node uploads the data to a cloud platform. Authorities can continuously monitor slope conditions and take prompt action when needed thanks to an online dashboard that shows real-time sensor readings, risk levels, and alert status.

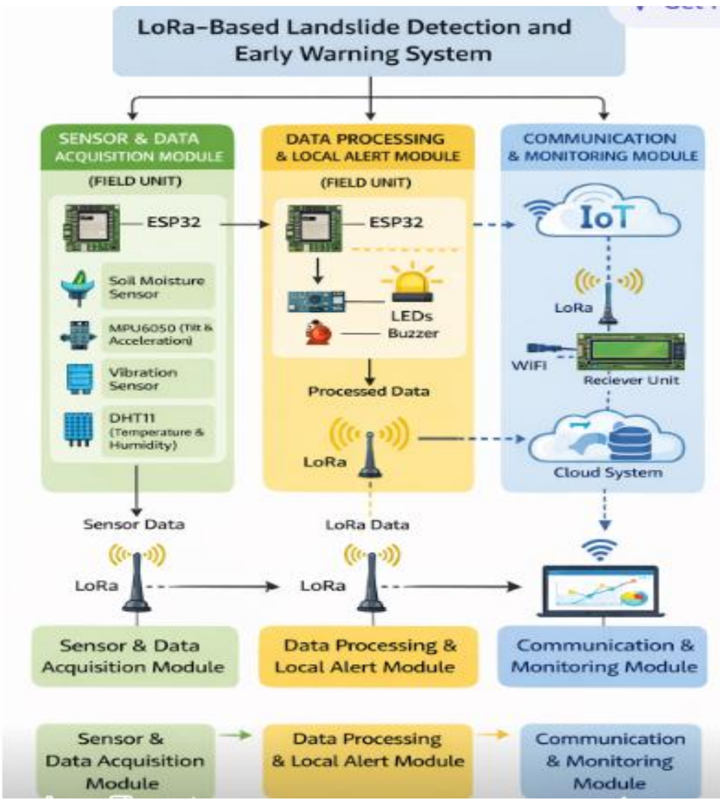

Fig-1: Figure

5. IMPLEMENTATION

In order for monitoring, alert generation, and remote supervision to function seamlessly together, the landslide detection system is implemented with a clear functional

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structure. The Field Monitoring Unit, the Communication Unit, and the Remote Monitoring & Alert Unit are the three main components that make up the system. Every component has a distinct role to play in providing accurate early warning in areas vulnerable to landslides.

5.1 FIELD MONITORING UNIT

Direct installation of this unit occurs in landslide-prone areas. It uses sensors like soil moisture, tilt (MPU6050), vibration, and temperature-humidity (DHT11) to continuously monitor slope conditions. Real-time sensor readings are gathered by the ESP32 microcontroller, which also determines whether the values exceed predetermined safety thresholds. The system instantly detects a possible risk if the readings show unusual soil movement or excessive moisture. The first line of detection is this unit.

5.2 LOCAL ALERT & COMMUNICATION UNIT

When a risk condition is identified, the system immediately notifies those in the vicinity by turning on warning LEDs and a buzzer. The LoRa module is used to transmit the processed data simultaneously. LoRa is appropriate for isolated hilly areas with poor network coverage because it guarantees long-range communication with minimal power consumption. This ensures that vital information gets to the monitoring station promptly.

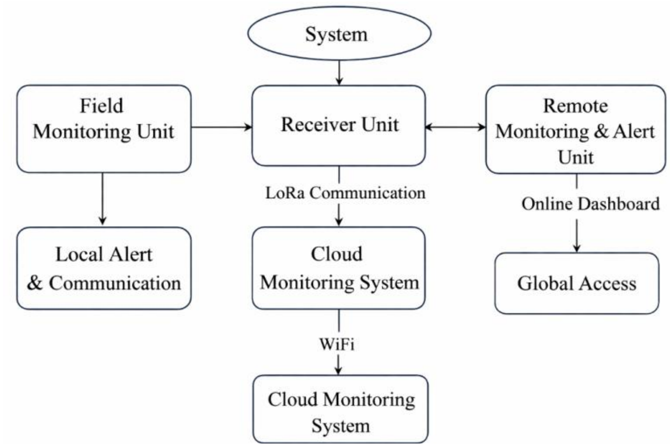
5.3 RECEIVER & REMOTE MONITORING UNIT

Data transmitted from the field unit via LoRa is collected by the receiver unit, which is positioned in a more secure area. For local monitoring, it shows the risk status and sensor values in real time on an LCD screen. Authorities can access the data via an online dashboard after it is uploaded to a cloud platform via WiFi connectivity. Quick preventive action is made possible by the dashboard's risk alerts, graphical analysis, and constant updates.

5.4 SYSTEM RELIABILITY FEATURES

The system is made to work in remote areas. It uses little power and can support battery or solar options. You can change the threshold values depending on the environment, which helps the system fit different terrains. By bringing together sensing, processing, long-range communication, local alerts, and cloud monitoring, the setup provides a practical, low-cost, real-time solution for landslide early warning.

6. BLOCK DIAGRAM



7. RESULTS AND FEATURES

The suggested Landslip Detection and Monitoring System exhibits scalable remote supervision, early warning capability, and dependable real-time monitoring. Continuously gathering environmental and soil parameters like vibration, ground tilt, and soil moisture, the system processes the data locally before sending it via LoRa communication to a distant monitoring station. Stable long-range data transmission, low power consumption, and efficient alert generation in the event of a threshold breach are confirmed by experimental deployment. By guaranteeing both local and remote alerts, the integrated architecture enhances preparedness for disasters and reduces response times.

7.1 REAL-TIME SENSOR MONITORING

Installed in areas susceptible to landslides, the system effectively gathers continuous data from tilt, vibration, and soil moisture sensors. These parameters aid in detecting moisture buildup and unusual ground movement, two major warning signs of impending landslides. The microcontroller efficiently and quickly processes the data.

7.2 LONG-RANGE LoRa COMMUNICATION

Reliable long-distance communication between the receiver unit and the field monitoring unit is made possible by LoRa technology. Even in isolated and hilly areas where traditional communication networks are unreliable, the system manages to achieve stable transmission. This guarantees continuous critical zone monitoring.

7.3 LOCAL ALERT MECHANISM

Every time sensor values surpass predetermined safety thresholds, a local alert system with buzzers and LED indicators is triggered. This gives those in the vicinity instant notice, enabling prompt evacuation and preventative measures.

7.4 CLOUD-BASED REMOTE MONITORING

Through WiFi, the receiver unit sends the gathered data to the cloud server. This makes it possible to store and visualise environmental parameters in real time. It is possible to access historical data for analysis, trend detection, and prediction evaluation.

7.5 ONLINE MONITORING DASHBOARD

Sensor data, alert status, and system performance are all shown graphically on an interactive web dashboard. The system is appropriate for widespread deployment because authorised users can keep an eye on several locations at once.

7.6 SCALABILITY AND ENERGY EFFICIENCY

Additional sensors and monitoring nodes can be integrated thanks to the modular architecture without requiring significant structural changes. Because low-power communication protocols guarantee energy efficiency, the system can be used outdoors continuously.

8. CONCLUSION

For early landslip warning, the developed Landslip Detection and Monitoring System offers a scalable, dependable, and effective solution. The system guarantees real-time detection and quick alert distribution by combining sensor data collection, local processing, LoRa communication, and cloud-based monitoring. In regions where landslides are common, the dual alert system—local and remote—improves public safety. It is a workable solution for disaster risk reduction because of its modular design, which allows for future expansion and integration with sophisticated predictive analytics models.

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