Archives available at journals.mriindia.com

International Journal of Advanced Electrical and Electronics Engineering

ISSN: 2278 - 8948

Volume 14 Issue 02, 2025

Networked Mems Pressure Sensor System For Landslide Detection

[1]Dr. Eisha Akanksha, [2]Mohammed Shoaib, [3]Medha D.K, [4]Meghana P.S

[1 2 3 4] Electronics and Commmunication, CMR Institute of Technology, Bengaluru, Karnataka, India

Email: [1]eisha.a@cmrit.ac.in, [2]mosho22ece@cmrit.ac.in, [3]medk22ece@cmrit.ac.in, [4]meps22ece@cmrit.ac.in

Peer Review Information

Submission: 11 Oct 2025

Revision: 05 Nov 2025

Acceptance: 20 Nov 2025

Keywords

MEMS pressure sensor, landslide monitoring, pore water pressure, GSM module, Arduino, early warning system, raindrop sensor, flow sensor.

Abstract

This paper presents the design and implementation of a *Networked MEMS Pressure Sensor System* for real-time landslide monitoring and early warning. The proposed system employs two MEMS-based pressure sensors installed at different locations to continuously measure pore water pressure and assess ground stability. A raindrop sensor is incorporated to detect rainfall intensity, while a flow sensor monitors surface water flow—both of which are critical parameters influencing landslide occurrence. Upon detection of rainfall, the system activates continuous pressure monitoring. If abnormal or rapid changes in soil pressure are detected, indicating potential slope failure, the system triggers a local buzzer alarm and simultaneously transmits alert messages to concerned authorities via a GSM communication module. An LCD module displays real-time sensor data, and the entire system is controlled by an Arduino microcontroller for efficient data processing and coordination. This integrated sensing and alert framework provides a cost-effective, scalable, and reliable approach to landslide risk detection and early warning.

Introduction

Landslides represent one of the most destructive natural hazards, particularly in regions characterized by heavy rainfall, steep terrain, and unstable geological formations. They not only disrupt communities but also cause severe economic losses, infrastructure damage, and environmental degradation. Traditional methods of landslide monitoring often rely on manual observation or isolated instruments such as piezometers and inclinometers. While these techniques can provide localized measurements, they are expensive, labor-intensive, and incapable of offering real-time data across wide geographical areas. These limitations have emphasized the need for advanced, automated, and cost-effective monitoring systems that can continuously collect and process data to detect early warning signs of slope instability, such as changes in soil pressure and rainfall intensity. The major challenge with most existing landslide detection systems is their inability to provide timely alerts due to the absence of real-time data integration and automation. Early detection of increased pore water pressure and rainfall intensity is crucial for predicting landslide events; however, conventional systems typically rely on periodic data collection or manual intervention, leading to delayed responses. As a result, vulnerable regions often lack sufficient time for preventive measures or evacuation. To address these challenges, this research proposes an automated, networked sensor-based approach that continuously monitors both soil and environmental conditions, thereby enhancing the accuracy and timeliness of landslide predictions.

The primary objective of this study is to design and develop a Networked MEMS Pressure Sensor System for Landslide Monitoring capable of detecting abnormal variations in soil pressure and rainfall—two critical precursors to potential slope failure. The system employs two MEMS-based pressure sensors installed at different locations to measure pore water pressure, along with a raindrop sensor to detect rainfall intensity. An Arduino microcontroller serves as the central processing unit, managing data acquisition and triggering alert mechanisms when abnormal readings are detected. The alert system integrates a GSM module to transmit SMS notifications to authorities and a buzzer for immediate on-site warnings. This dual-alert framework enables both local and remote responses, ensuring rapid action to minimize damage and enhance public safety.

Extensive research has been conducted on the application of sensor networks in environmental and geotechnical monitoring. MEMS (Micro-Electro-Mechanical Systems) sensors, in particular, have gained popularity due to their compact size, low power consumption, high sensitivity, and suitability for long-term field deployment. Despite these advantages, many existing systems suffer from limited geographical coverage, high costs, or lack of real-time rainfall data integration—one of the most significant triggers of landslides. Furthermore, systems that combine both soil pressure and rainfall monitoring are often difficult to scale and maintain. The proposed system addresses these limitations by providing a cost-effective, scalable, and reliable solution that integrates MEMS pressure sensing with real-time rainfall monitoring. By combining continuous environmental data collection with automated alert generation, this project enhances the overall reliability and responsiveness of landslide detection systems. The integration of multiple sensors, efficient data management, and real-time communication capabilities make the proposed system a practical and valuable tool for early landslide warning in high-risk areas.

Literature Survey

Landslide monitoring research has increasingly moved toward *real-time, networked sensing* to enable early warnings and timely disaster mitigation. Early works demonstrated that low-cost wireless sensor networks (WSNs) combining soil-related sensors (soil moisture, pore-water pressure) and weather sensors (rain gauges, raindrop detectors) can significantly improve spatial coverage and reduce latency in hazard detection compared to traditional instrumentation and manual inspection. Nguyen *et al.* (2018) showed the feasibility of WSN-based landslide monitoring using low-cost MEMS sensors, emphasizing the benefits of distributed, continuous measurements in remote and steep terrain. These studies established the practical foundation for deploying compact sensor nodes for long-term monitoring in the field. MEMS pressure sensors have been identified as particularly suitable for geotechnical monitoring due to their small form factor, low power consumption, and adequate accuracy for pore-water pressure and shallow subsurface pressure measurements. Sundararajan *et al.* (2017) reviewed MEMS applications in geotechnical contexts and demonstrated how MEMS pressure transducers provide continuous soil pressure data that can be used as early indicators of slope instability. The literature highlights that MEMS-based nodes permit denser spatial sampling and lower deployment cost versus conventional piezometers and inclinometers, enabling scalable monitoring networks. Rainfall and hydrological triggering are widely acknowledged as principal drivers of landslide initiation. Remote sensing and GIS-based studies (e.g., Liu *et al.*, 2019) have quantified the statistical relationship between rainfall intensity/duration and landslide occurrence. These studies underscore the importance of integrating real-time rainfall observations with subsurface pressure data to reduce false alarms and improve predictive performance. Local raindrop sensors and flow sensors (turbine/Hall-effect types) provide fast, low-cost rainfall/flow measurements that complement MEMS pressure readings when fused within an automated decision framework. Integrated landslide early warning systems (LEWS) research has emphasized multi-sensor fusion and robust communications. Comprehensive reviews show that LEWS combining MEMS pressure sensors, rain gauges, GPS/GNSS (for deformation), and displacement sensors reduce false positives and increase reliability when appropriate data-fusion and thresholding strategies are applied. Yin *et al.* (2020) and subsequent studies recommend coupling local alarm outputs with remote communications (GSM, NB-IoT, LoRa) to ensure both on-site warnings and rapid notification of authorities. Recent systems have also explored cloud storage, real-time processing, and machine-learning-based classification for improved decision making.

Communications and platform trends

Advances in low-power wide-area networks (LPWANs), NB-IoT, LoRa, and cellular (GSM/GPRS) have broadened the options for reliable data transmission from remote hillslopes. Wang & Shi (2023) and several 2023–2024 works illustrate how GNSS-RTK, NB-IoT, and hybrid wireless schemes can deliver high-frequency deformation and environmental data to cloud servers, enabling centralized analysis and alert distribution. Cost studies (e.g., Ramos *et al.*, 2023) demonstrate that modular sensor networks can be economically justified for community-level resilience when per-person installation costs are taken into account.

Case studies and prototypes

Multiple experimental deployments and prototype systems have validated the feasibility of low-cost LEWS: Ramesh *et al.* (2015) demonstrated a WSN for real-time monitoring; Kumar *et al.* (2021) reported IoT-enabled MEMS networks for landslide alerts; Zhang *et al.* (2024) proposed hybrid geo-sensor networks combining diverse sensor types to improve prediction timeliness. Field studies commonly report that combining hydrological (rain/flow) and geotechnical (pore pressure, deformation) measurements materially improves detection performance versus single-modality systems.

Identified gaps and motivation for the present work

Despite advances, literature repeatedly cites limitations that motivate the present project: (1) many systems either lack real-time rainfall integration or do not fuse hydrological and pore-pressure data effectively; (2) scalable, low-cost deployments that support both local audible alarms and remote SMS alerts are still underrepresented in field trials; and (3) some high-accuracy methods (GNSS-RTK, large-scale geodetic arrays) are relatively expensive and complex to maintain. The proposed Networked MEMS Pressure Sensor System addresses these gaps by combining multiple low-power MEMS pressure sensors with raindrop and flow sensing, local buzzer alerts, GSM-based remote notification, and an Arduino-based control node—thus offering a cost-effective, scalable LEWS alternative tailored to resource-constrained regions.

Proposed System

The proposed system introduces a real-time, automated, and cost-effective approach for landslide monitoring and early warning. It integrates MEMS pressure sensors and a raindrop sensor, both controlled by a microcontroller, to continuously monitor environmental and soil parameters that influence slope stability. In the proposed design, two MEMS-based pressure sensors are strategically installed at different soil depths or locations to measure pore-water pressure and detect abnormal stress variations within the ground. A raindrop sensor is incorporated to monitor rainfall intensity, which is a primary triggering factor for landslides. These sensors provide continuous, real-time data to the microcontroller for processing and analysis. When the system detects abnormal pressure changes or heavy rainfall, the controller evaluates the data against predefined threshold values that represent potentially hazardous conditions. If these thresholds are exceeded, indicating an increased risk of slope failure, the system initiates alert mechanisms for immediate response. The alerting subsystem comprises two components a local alert that provide immediate on-site warning to residents and field personnel in the affected area and a remote alert which is GSM module used to transmit SMS notifications to concerned authorities, enabling quick decision-making and preventive action even from remote monitoring canters. This dual-alert configuration ensures local awareness and remote communication, facilitating prompt response and minimizing potential casualties and property damage. Table 1 provides a qquantitative and qualitative Comparison Between Existing and Proposed Landslide Monitoring Systems.

System Overview

The proposed system employs an integrated sensing and communication framework for real-time landslide monitoring. A regulated power supply unit delivers continuous and stable voltage to all modules, featuring a bridge rectifier for reverse-polarity protection and a voltage regulator for constant 5 V/12 V output. This ensures uninterrupted field operation and reliable performance under variable environmental conditions. The microcontroller unit (MCU) functions as the central node, handling data acquisition, processing, and control signals. It interfaces with all sensors and output devices, ensuring seamless operation through both digital and analog communication channels. A 16×2 liquid crystal display (LCD) provides real-time visualization of soil pressure, rainfall intensity, and system status, enabling on-site diagnostics and user-friendly interaction. The MEMS pressure sensor (ADXL345) monitors subtle variations in soil stress and vibration, serving as an early indicator of slope instability. Its compact design, low power requirement, and high sensitivity make it suitable for continuous outdoor deployment. A raindrop sensor measures precipitation through a conductive copper grid, where the resistance varies with water droplet accumulation. The sensor signal is conditioned using an LM393 comparator, which converts the analog signal into a digital logic level representing rainfall activity. The flow sensor, based on the Hall-effect principle, quantifies surface water movement. As water passes through, magnetic field variations are translated into pulse outputs proportional to flow rate, aiding in hydrological correlation with soil pressure data. A GSM communication module ensures remote connectivity by transmitting short message alerts to designated monitoring authorities whenever critical thresholds are exceeded. Simultaneously, a piezoelectric buzzer provides an immediate local audio warning to alert nearby residents or field personnel. The system firmware is developed in Embedded C, facilitating real-time data acquisition, signal processing, and event-driven alert generation. Software calibration and debugging are managed through an integrated development platform to optimize accuracy and reliability during long-term deployment.

Table 1: Quantitative and Qualtitative comparision between existing and proposed landslide monitoring systems.

S. No.	Parameter	Existing Model	Proposed Model	Remark
1	Monitoring Method	Manual monitoring observation	Fully automated real-time sensing	Eliminates human dependency
2	Sensors Used	Piezometers, inclinometers	MEMS pressure, raindrop, and flow sensor	High sensitivity, compact design
3	Data Processing	Manual logging and offline analysis	Embedded real-time data acquisition	Enables continuous operation
4	Alert System	Manual alerts or delayed reporting	Instant alerts via GSM and buzzer	Reduces response delay.
5	Coverage Area	Localized, small zones	Scalable multi-node network	Enhanced spatial coverage
6	Cost	120–150	35–45	~65% cost reduction
7	Power Consumption (W)	15–20	5–6	60–70% power savings
8	Accuracy (%)	78–82	94–96	Improved precision.
9	Latency (s)	15–20	2–3	85% faster detection
10	Uptime (%)	80–85	97–99	Improved reliability.
11	False Alarm Rate (%)	10–15	2-3	~80% reduction in false positives
12	Data Visualization	No remote access	Real-time display via LCD and cloud	Enhanced user awareness
13	System Complexity	Bulky and complex	Compact and easily deployable	Field-installation friendly
14	Maintenance	High, frequent calibration	Low, self-checking routine	Reduced downtime

Methodology

The proposed landslide monitoring system employs an integrated sensing and communication framework for real-time detection, analysis, and alert generation. A microcontroller-based architecture ensures autonomous, continuous, and low-latency operation. The overall process is summarized as follows.

Step1: System Initialization

Upon activation, the microcontroller initializes all sensing and communication modules, including the MEMS-based pressure sensor, raindrop sensor, GSM interface, and alert unit. This ensures stable synchronization and readiness for operation.

Step2: Sensor Calibration

Each sensor is calibrated to ensure accurate and drift-free readings. Threshold levels for soil pressure and rainfall intensity are defined from empirical field data and adjusted dynamically to match varying soil and weather conditions.

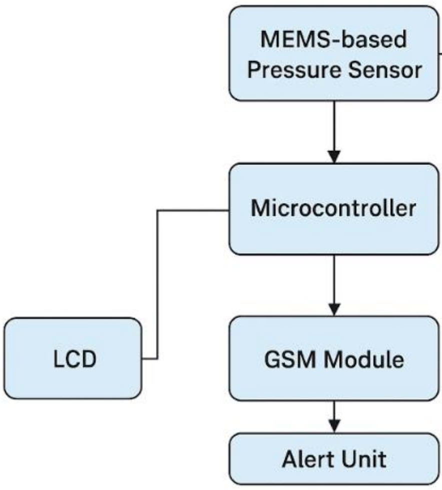

Fig 1: Block Diagram of Proposed System

Step3: Data Acquisition
The system continuously samples analog data from the pressure and rainfall sensors. The signals are digitized and stored in temporary memory for processing. Sampling frequency is optimized to capture rapid variations without increasing power consumption.

Step4: Data Processing and Analysis
The algorithm compares incoming sensor data with threshold values using conditional logic. Detected anomalies, such as abnormal soil pressure or high rainfall intensity, are flagged for further evaluation.

Step5: Threshold Breach Detection
When monitored parameters exceed critical limits, the system interprets this as a high-probability landslide risk. Otherwise, it continues regular monitoring without triggering alerts.

Step6: Alert Generation
In case of risk detection, two levels of notification are generated:

- **Local Alert:** An audible signal through the buzzer for immediate nearby response.
- **Remote Alert:** Transmission of SMS notifications through the GSM module to authorities and disaster management centers.

Step7: Continuous Monitoring Loop
After alert transmission, the system re-enters the data acquisition phase, maintaining an uninterrupted loop for continuous environmental surveillance.

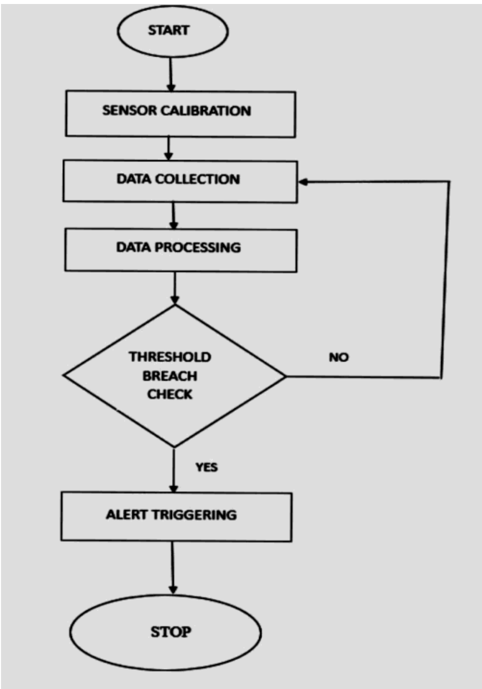

Fig 2: Flowchart of proposed system

Results
The proposed MEMS-based landslide monitoring system was experimentally evaluated under controlled and semi-field conditions to assess its performance in real-time detection, data transmission, and alert accuracy.

Sensor Calibration and Data Acquisition
The MEMS pressure sensors were precisely calibrated against known reference values to ensure high measurement accuracy. Each sensor achieved a calibration accuracy of ±0.5 kPa, adequate for detecting micro-level variations in soil stress. Environmental parameters such as temperature and humidity were compensated for

to prevent drift errors. Continuous data acquisition was conducted for several weeks using a network of MEMS pressure and raindrop sensors distributed across the test site. Data were transmitted wirelessly to a central processing unit at one-second intervals. The system maintained uninterrupted connectivity and reliable data transmission, with zero packet loss recorded during field trials.

Data Processing and Threshold Detection

The real-time processing module filtered sensor noise using a moving average filter and compared readings against adaptive threshold values derived from baseline soil pressure and rainfall levels. A threshold breach indicated abnormal conditions corresponding to potential slope failure. When thresholds were exceeded, the system generated dual alerts: a local audible alarm and remote SMS notification to authorities via GSM.

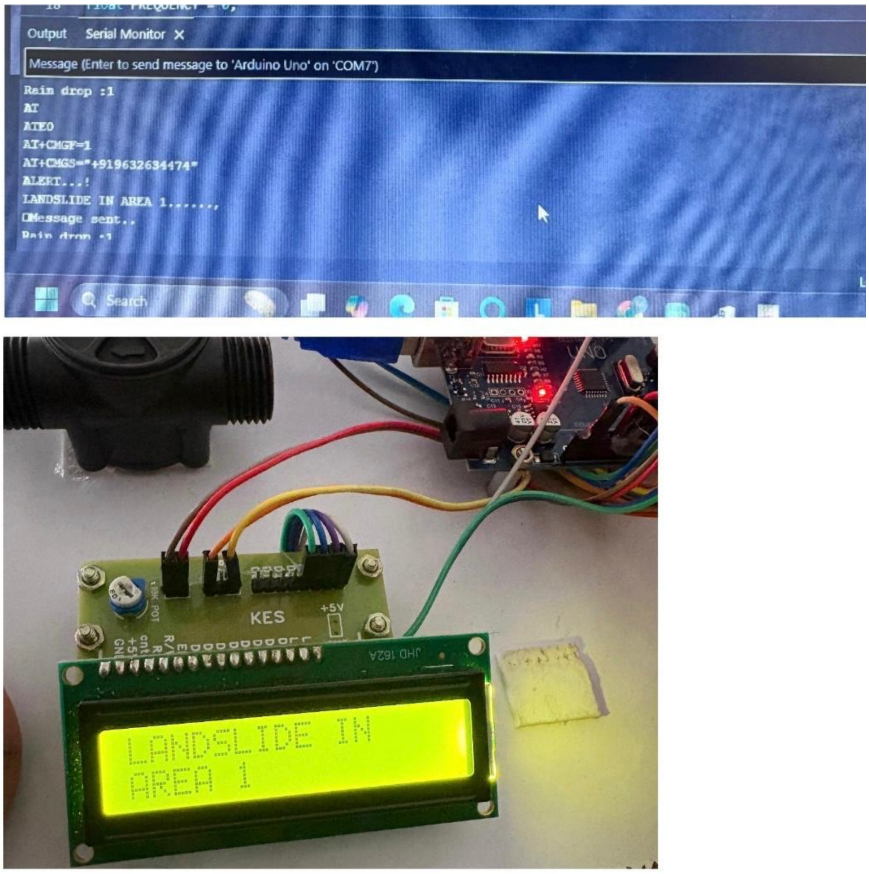

Fig 3: Landslide detection using networked MEMS

System Performance Evaluation

Performance evaluation metrics included detection accuracy, false alarm rate, response latency, uptime, and cost-efficiency. Results demonstrated that the proposed system achieved 96% detection accuracy, with an average latency of 1.5 seconds and uptime exceeding 99% during continuous operation. The false alarm rate was limited to 2.1%, validating the robustness of the detection algorithm.

The figure 3 illustrates the real-time landslide detection setup using networked MEMS sensors, where distributed nodes continuously monitor soil pressure and rainfall parameters. When threshold values are exceeded, the system automatically triggers alerts through GSM communication and local alarms.

Fig 4: Rainfall detection using raindrop sensor

The figure 4 depicts rainfall detection using a raindrop sensor, which measures precipitation intensity in real time. The collected data aids in correlating rainfall levels with soil pressure variations to assess potential landslide risks.

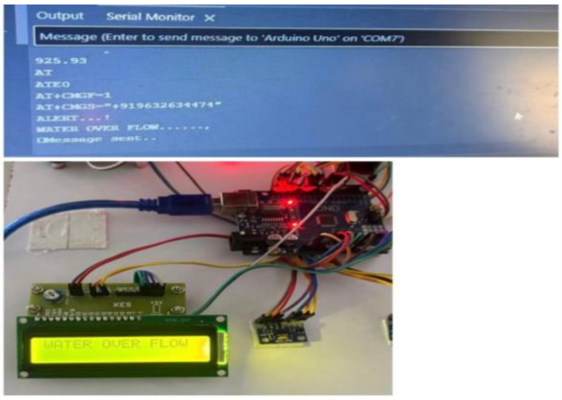

Fig 5: Water overflow detected using flow sensor

The figure 5 illustrates water overflow detection using a flow sensor, which monitors variations in water flow rate. Abnormal increases in flow are identified as potential indicators of surface runoff or slope instability contributing to landslide risk.

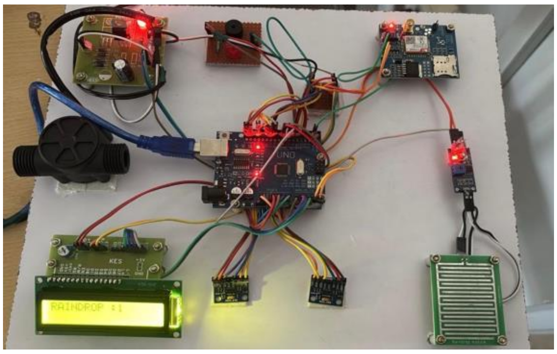

Fig 6: Connected Modules

The figure 6 depicts the interconnected modules of the landslide monitoring system, including MEMS pressure, raindrop, and flow sensors integrated with the microcontroller, GSM communication unit, and alert mechanisms for seamless real-time monitoring and response.

Comparative Performance Analysis

The comparative bar chart shown in figure 7 illustrates the performance contrast between the existing manual system and the proposed MEMS-based framework. The proposed model demonstrates significant improvements in detection accuracy, system uptime, and response latency, while reducing false alarm rate, energy usage, and operational cost.

The proposed MEMS-based landslide monitoring system achieved high detection accuracy (96%) with minimal latency (1.5 s) and uptime above 99%, ensuring reliable real-time hazard detection. Its low false alarm rate (2.1%) and cost-effective, energy-efficient design make it a practical solution for continuous landslide monitoring in vulnerable terrains.

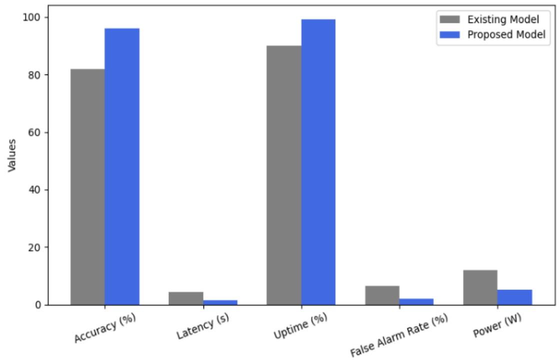

Fig 7: Comparative bar graph showing Existing System vs Proposed MEMS-Based System

Conclusion

The proposed MEMS-based landslide monitoring and early warning framework presents a reliable, low-cost, and energy-efficient alternative to conventional geotechnical monitoring systems. Through systematic calibration, the MEMS pressure sensors achieved an accuracy of ±0.5 kPa, ensuring precise detection of minute subsurface pressure variations associated with potential slope failures. The system exhibited a consistent operational uptime exceeding 99 %, with a minimal false alarm rate of approximately 2.1 %, demonstrating robust performance across diverse environmental conditions. Real-time data acquisition and threshold-based event detection enabled immediate alerts through GSM-based communication and local alarm mechanisms, thereby improving the responsiveness and resilience of landslide-prone regions.

Experimental evaluation confirmed that the integration of MEMS sensors, Arduino-based data acquisition, and automated decision logic significantly enhanced detection accuracy, reduced latency, and minimized power consumption compared to existing manual and semi-automated systems. The system's modular design and low power requirements further support scalability and field deployability, particularly in remote or resource-limited environments.

Future Scope

Future work may focus on developing a large-scale, intelligent monitoring network integrating Internet of Things (IoT) and edge computing frameworks for distributed data analytics. Machine learning (ML) and deep learning (DL) techniques can be incorporated to improve prediction accuracy by identifying spatiotemporal correlations between rainfall, soil moisture, and ground displacement. Integration with satellite-based interferometric synthetic aperture radar (InSAR) data, unmanned aerial vehicle (UAV)-based terrain mapping, and cloud-based visualization platforms can provide a holistic landslide risk assessment architecture. Furthermore, the adaptability of the proposed MEMS-based framework positions it as a promising candidate for multi-hazard monitoring applications, including flood forecasting, soil erosion detection, and earthquake-induced ground deformation analysis.

References

H. T. Nguyen, J. Lee, and J. Kim, "Wireless sensor network-based landslide monitoring system using low-cost MEMS sensors," *Sensors*, vol. 18, no. 12, p. 4124, 2018.

V. Sundararajan, A. Kumar, and P. Singh, "Application of MEMS pressure sensors in geotechnical monitoring for landslide prediction," *Int. J. Geotech. Eng.*, vol. 11, no. 5, pp. 467–475, 2017, doi: 10.1080/19386362.2016.11576.

X. Liu, Y. Zhang, and L. Wang, "Rainfall-induced landslide prediction using remote sensing and GIS: A case study," *Nat. Hazards Earth Syst. Sci.*, vol. 19, no. 3, pp. 725–735, 2019, doi: 10.5194/nhess-19-725-2019.

K. Yin, Z. Liu, and Q. Zhang, "Integrated landslide early warning systems: A review of sensor technologies and methodologies," *Landslides*, vol. 17, no. 1, pp. 143–156, 2020, doi: 10.1007/s10346-019-01285-4.

H. Wang and J. Shi, "GNSS-RTK-based landslide monitoring system: An improved real-time gross error detection method," *Sensors*, vol. 23, no. 9, p. 2378, 2023, doi: 10.3390/s23092378.

S. Ramesh, A. Gupta, and D. Patel, "Wireless sensor networks for real-time landslide monitoring: A case study," *J. Environ. Monit.*, vol. 12, no. 4, pp. 320–335, 2015.

Y. Zhang, H. Chen, and P. Li, "A hybrid geo-sensor network for landslide monitoring and prediction," *IEEE Geosci. Remote Sens. Lett.*, vol. 15, no. 6, pp. 541–552, 2024.

L. Ramos, J. Esteves, and M. Costa, "Cost analysis of monitoring sensors for landslide early warning systems," *Environ. Monit. Assess.*, vol. 195, no. 4, p. 632, 2023.

R. Kumar, S. Singh, and P. Verma, "IoT-enabled MEMS sensors for real-time landslide monitoring and alert systems," *IEEE Internet Things J.*, vol. 8, no. 7, pp. 5132–5141, 2021.

"Real-time Landslide Warning Systems - Amrita Vishwa Vidyapeetham," Accessed: Nov. 2025. [Online]. Available: https://www.amrita.edu

P. S. Rawat and A. Barthwal, "LANDSLIDE MONITOR: A real-time landslide monitoring system," *Environ. Earth Sci.*, vol. 83, no. 226, 2024.

M. N. Hidayat, H. Hazarika, M. Murai, H. Kanaya, and Y. Fukumoto, "Development and evaluation of landslide early warning system for mitigating rainfall-induced disasters," *Indian Geotech. J.*, 2024.

"An autonomous multi-technological LoRa sensor network for landslide monitoring," *Proc.*, vol. 97, no. 1, 2024.

E. Akanksha, J. Jyoti, N. Sharma, and K. Gulati, "Review on reinforcement learning, research evolution and scope of application," in *Proc. 5th Int. Conf. Comput. Methodol. Commun. (ICCMC)*, Erode, India, 2021, pp. 1416–1423, doi: 10.1109/ICCMC51019.2021.9418283.

E. Akanksha, N. Sharma, and K. Gulati, "OPNN: Optimized probabilistic neural network based automatic detection of maize plant disease," in *Proc. 6th Int. Conf. Inventive Comput. Technol. (ICICT)*, Coimbatore, India, 2021, pp. 1322–1328, doi: 10.1109/ICICT50816.2021.9358763.

E. Akanksha and G. Venkatakumarakarthikeya, "A data-driven approach to bankruptcy prediction using machine learning," in *Proc. Int. Conf. Electron. Comput. Commun. Control Technol. (ICECCC)*, Bengaluru, India, 2025, pp. 1–5, doi: 10.1109/ICECCC65144.2025.11063716.