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SHIELD: Systematic Hazard Identification for Early Landslide Detection (Real time Landslide and Flood Detection)

Lulu Farhan[1],Abhinav P K[2],Adidev S R[3], Sreeharishyam P[4], Aswathy K P[5]
1 (Department of Computer Science and Engineering, Government Engineering College Wayanad, India
Email: farhan_22b382cs@gecwyd.ac.in)
2 (Department of Computer Science and Engineering, Government Engineering College Wayanad, India
Email:abhinav_23l109cs@gecwyd.ac.in)
3 (Department of Computer Science and Engineering, Government Engineering College Wayanad, India
Email:adidev_23l116cs@gecwyd.ac.in)
4 (Department of Computer Science and Engineering, Government Engineering College Wayanad, India
Email:sreeharishyam_23l090cs@gecwyd.ac.in)
5 (Department of Computer Science and Engineering, Government Engineering College Wayanad, India
Email: aswathy.kp@gecwyd.ac.in)

Abstract:

This paper presents the development of a low-cost, highly accurate, and proactive landslide prediction and early warning system designed for high-risk regions such as the Western Ghats in Kerala, India. Existing monitoring frameworks primarily rely on reactive approaches that fail to provide sufficient warning time before catastrophic slope failures. To address this, the proposed system integrates Internet of Things (IoT) sensor nodes, edge computing, cloud-based Long Short-Term Memory (LSTM) neural networks, and physics-based Digital Twin simulations into a unified architecture. By combining real-time ground data, such as vibration, tilt, and soil moisture, with Factor of Safety (FoS) calculations, the framework delivers reliable early warnings up to 72 hours before potential events. The integration of multi-channel alerting mechanisms ensures timely dissemination to authorities and local communities. This research demonstrates that synergizing edge-level intelligence with cloud-based deep learning bridges the critical gap between theoretical disaster prediction and practical, life-saving implementation.

Keywords — **Landslide Detection, Early Warning System, Internet of Things, Digital Twin, Long Short-Term Memory, Edge Computing, Factor of Safety.**

I. INTRODUCTION

In hilly and mountainous regions, particularly along the Western Ghats in Kerala, communities face severe threats from rainfall-induced landslides and subsequent floods. Traditional monitoring systems, including manual geological surveys and satellite-based observations, predominantly utilize reactive approaches. These methods often detect events only after initiation, providing insufficient time for evacuation and emergency response. The catastrophic 2024 Wayanad landslides, which resulted in over 400 fatalities, underscored the urgent need for proactive, predictive monitoring technologies.

AI Based Real-Time Landslide And Flood Early Detection is an innovative system developed to address the critical need for proactive disaster management in landslide-prone regions like Kerala. While existing monitoring systems focus on reactive approaches, they often fail to provide sufficient warning time before catastrophic events, leaving communities vulnerable to loss of life and property. This system bridges the critical gap in disaster preparedness by integrating cutting-edge IoT technology, artificial intelligence, and digital twin simulations to deliver reliable early warnings up to 24 hours before potential slope failures. The platform enables real-time monitoring of geological parameters, predictive analysis of landslide risks, and multi-channel alert mechanisms to ensure timely evacuation and mitigation measures. By focusing on proactive disaster prevention and community safety, this project aims to create a more resilient, informed, and protected environment for regions susceptible to landslides and floods.

II. LITERATURE REVIEW

A. Existing Early Warning Frameworks

Recent collaborative research on the 2024 Wayanad landslides highlighted that early warning failures stem from fragmented systems, data accuracy gaps, and poor inter-agency integration [1]. Surveys on real-time flood monitoring using IoT indicate that while IoT architectures show promise, they suffer from limited adaptability to diverse geographical contexts and data scarcity in remote areas [2]. Similarly, Wireless Sensor Network (WSN) based landslide detection systems utilizing Arduino and GSM modules provide continuous monitoring but face significant power supply challenges and high maintenance costs in large-scale deployments [3]

B. Deep Learning and Simulation Approaches

Advanced computational methods have been proposed to enhance prediction accuracy. Stability prediction models utilising Digital Twinning and Convolutional Neural Networks (CNN) offer high accuracy in slope stability assessment but require substantial computational resources and specialised expertise [4]. Furthermore, multi-scale response analyses using Gated Recurrent Unit (GRU) networks and Joint Time-Frequency Analysis (JTFA) provide deep insights into landslide triggering mechanisms; however, their complex architectures limit practical deployment in resource-constrained environments [5].

C. Motivation for Proposed Work

The proposed work addresses the systemic limitations of existing methodologies by developing a hybrid AI-IoT framework. By offloading preliminary inference to edge devices and utilizing lightweight LSTM models in the cloud alongside physics-based Digital Twin simulations, the system achieves a balance between high predictive accuracy and practical deployability in remote, vulnerable regions.

III. SYSTEM ARCHITECTURE AND DESIGN

The system follows a modular architecture designed for scalability, reliability, and seamless data flow across five core components.

A. System Components Overview

The architecture comprises: (1) Sensor Data Acquisition Module, (2) Edge Data Processing and Inference Module, (3) Cloud Data Aggregation Module, (4) Alerting and Visualization Module, and (5) User Authentication Module.

B. Hardware Architecture

The sensor nodes are built using ESP32 microcontrollers equipped with an MPU6050 tilt sensor, an Omron D7S seismic vibration sensor, and capacitive soil moisture sensors. Data transmission from remote slopes to the gateway utilizes LoRa RA-02 modules (operating in the 865-867 MHz band), chosen for their long-range capabilities in hilly terrain. The gateway consists of a Raspberry Pi with a LoRa gateway hat and a SIM800L GSM modem for redundant communication. Nodes are powered by solar panels with 18650 battery backups to ensure autonomous operation.

C. Software Architecture

Edge-level firmware is developed in Arduino IDE (C++), incorporating TensorFlow Lite for on-device noise filtering. The cloud backend utilizes Python with TensorFlow/Keras for LSTM model training, Node.js for RESTful APIs, and InfluxDB for time-series data storage. Visualization is achieved through Unity 3D for the Digital Twin rendering and web-based HTML5/JavaScript dashboards for real-time monitoring.

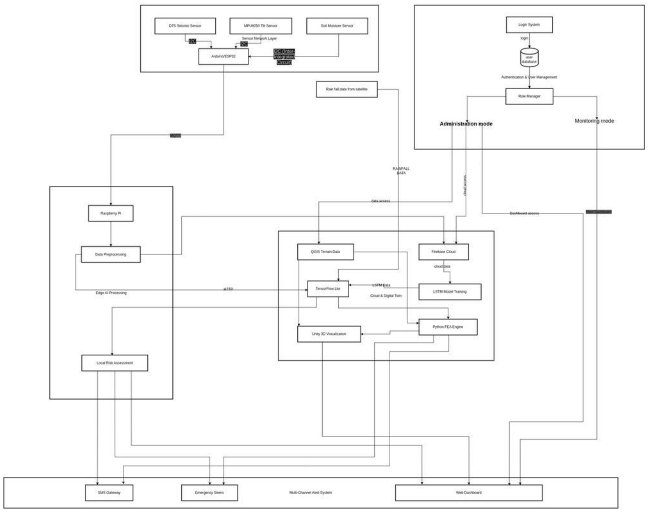

Fig. 1 Overall System Architecture for Landslide and Flood Early Detection System.

IV. METHODOLOGY

The system employs a continuous, multi-stage data processing pipeline to ensure real-time risk assessment.

A. Data Acquisition and Edge Processing

Sensors continuously measure tilt, vibration, and soil moisture. At the edge, raw data undergoes Kalman filtering to eliminate environmental noise. TensorFlow Lite models perform preliminary risk classification locally. If an immediate critical threshold is breached, the edge node autonomously triggers local buzzers and LED indicators, ensuring zero-latency community warnings even if cloud connectivity is lost.

B. Cloud-Based AI Prediction

Aggregated, preprocessed time-series data is transmitted to the cloud via MQTT. An LSTM neural network, trained on historical landslide telemetry and meteorological data, processes this sequential data to predict landslide probability over 72-hour horizons.

C. Software Architecture

To complement the data-driven AI approach, a 3D Digital Twin of the monitored slope is generated using QGIS terrain data. The twin is continuously updated with real-time sensor readings. Physics-based simulations calculate the Factor of Safety (FoS) in real-time. The final risk score is a composite index derived from both the LSTM output and the FoS calculation, significantly reducing false positives.

D. Multi-Channel Alerting

When the composite risk score exceeds predefined thresholds, the system executes an automated escalation protocol. Alerts are disseminated via SMS gateways to registered authorities, push notifications to mobile applications, and updates to the central web dashboard.

V. RESULTS AND DISCUSSION

The proposed framework was evaluated through a comprehensive TELOS (Technical, Economic, Legal, Operational, Scheduling) feasibility study and iterative prototyping.

A. Feasibility and Performance Analysis

Technical validation confirmed that the edge processing latency remains under 5 seconds, while cloud-based LSTM inference completes within 30 seconds. The utilization of LoRa ensured reliable data transmission up to 5-10 km in dense vegetation, a common limitation of Wi-Fi-based systems. Economically, the hardware cost per node is restricted to approximately Rs. 5,500–6,000, making it highly scalable compared to commercial terrestrial interferometry systems.

B. System Integration

Data Flow Diagrams (DFDs) validated the logical flow of information from sensor acquisition through edge filtering, cloud aggregation, and alert dissemination. The iterative Agile development methodology allowed for continuous refinement of the LSTM hyperparameters and Digital Twin physics engines, resulting in a stable Minimum Viable Product (MVP) ready for pilot deployment in vulnerable Western Ghats sectors.

VI. CONCLUSIONS

This paper presented an integrated AI-IoT framework for the real-time detection and early warning of landslides and floods. By shifting from traditional reactive monitoring to a proactive predictive model, the system successfully bridges the gap between advanced deep learning research and practical, cost-effective disaster management. The fusion of LSTM neural networks with physics-based Digital Twin Factor of Safety calculations provides a robust, dual-validation mechanism that significantly enhances prediction reliability. Future work will focus on the pilot deployment of 3-5 sensor nodes in specific Wayanad catchment areas to gather real-world performance metrics and further train the predictive models on hyper-local geological data.

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