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Research Paper

IoT-Enabled Distributed Sensing Framework for Critical Event Detection and Early Warning

K Naresh¹, Pagidoju Mythri¹, Damerla Rakesh¹, Nenavath Sruthi¹, Arla Karthik¹

¹Department of Electronics and Communication Engineering, ¹Sree Dattha Institute of Engineering and Science, Sheriguda, Ibrahimpatnam, 501510, Telangana, India.

ABSTRACT

Natural disasters such as floods, landslides, and earthquakes pose significant threats to human life, property, and critical infrastructure, particularly in geographically vulnerable and disaster-prone regions. The absence of timely, accurate, and locally accessible early warning systems greatly limits the ability of communities to respond effectively and evacuate safely during hazardous situations. This project proposes an Internet of Things (IoT)-Based Disaster Early Warning System, which integrates an ESP32 (Espressif 32-bit Microcontroller) with multiple environmental sensors, including a Vibration Sensor for earthquake and seismic activity detection, a Soil Moisture Sensor (SMS) for landslide risk assessment, a Flood Level Sensor (FLS) for monitoring water levels, and a Rain Sensor (RS) for rainfall intensity measurement. The system continuously collects and processes environmental data from all sensors and compares the readings with predefined hazard threshold values to identify potential disaster conditions. When abnormal or critical conditions are detected, the system generates immediate multi-level alerts. Local notifications are provided through a Liquid Crystal Display (LCD) that displays real-time sensor readings and alert status, while a buzzer generates audible warning signals corresponding to the severity of the detected hazard. Simultaneously, the ESP32 transmits real-time sensor data and alert notifications to a remote IoT monitoring platform via wireless communication. This enables disaster management authorities, community leaders, and residents to receive timely warnings and coordinate emergency response actions. The proposed system is cost-effective, scalable, reliable, and suitable for deployment in remote and rural areas, providing an efficient solution for community-level disaster risk reduction and real-time environmental monitoring.

Keywords: IoT, Disaster Early Warning, Flood Detection, Landslide Monitoring, Earthquake Detection, Arduino, Vibration Sensor, Soil Moisture Sensor, Rain Sensor, Flood Level Sensor, Smart Disaster Management, Real-Time Monitoring

1. INTRODUCTION

Natural disasters represent one of the most significant and persistent threats to human safety and socioeconomic development worldwide. Floods, landslides, earthquakes, and their compounding interactions cause enormous loss of life and infrastructure damage every year, with impacts disproportionately concentrated in developing countries and rural communities that lack the resources for sophisticated disaster preparedness and response infrastructure. Early warning systems are universally recognized as the most effective and cost-efficient tool for reducing disaster mortality, providing communities with the critical lead time needed to evacuate threatened areas and take protective actions before a disaster event reaches its peak severity. Even a few minutes of advance warning can dramatically reduce casualties in fast-onset events such as flash floods and landslides.

The emergence of affordable embedded microcontroller platforms, low-cost environmental sensors, and IoT communication technology has created a significant opportunity to develop effective multi-hazard early warning systems deployable in remote and resource-limited environments at a fraction of the cost of conventional meteorological and seismic monitoring infrastructure. Arduino-based embedded systems can interface simultaneously with multiple environmental sensors, process multi-parameter hazard data in real time, and transmit alerts through IoT networks to reach both local communities and regional disaster

management authorities, filling a critical gap in early warning coverage in vulnerable areas that national monitoring networks do not adequately serve.

The IoT Disaster Early Warning System proposed in this project integrates an Arduino microcontroller with four complementary environmental sensors covering the most critical natural hazard types affecting vulnerable communities: a vibration sensor for earthquake and ground movement detection, a soil moisture sensor for landslide precondition monitoring, a flood level sensor for water body level measurement, and a rain sensor for rainfall intensity monitoring. Together, these sensors provide a comprehensive multi-hazard environmental monitoring capability that enables the system to detect and alert on a wide range of disaster scenarios, including standalone events and compound disaster sequences such as heavy rainfall leading to soil saturation and subsequent landslide risk.

2. LITERATURE SURVEY

United Nations International Strategy for Disaster Reduction (UNISDR), 2006 — Developing Early Warning Systems: A Checklist. This foundational UNISDR document establishes the four-element framework for effective early warning systems comprising risk knowledge, monitoring and warning, dissemination and communication, and response capability. It provides the conceptual framework for the multi-hazard monitoring and IoT-based alert dissemination design of the proposed system.

J. C. Gaillard and J. Mercer, 2013 — From Knowledge to Action: Bridging Gaps in Disaster Risk Reduction. Discusses the critical importance of community-level disaster risk knowledge and locally accessible warning systems, supporting the motivation and deployment rationale for affordable, embedded IoT early warning systems that serve vulnerable communities not adequately covered by national monitoring networks.

S. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, 2013 — Internet of Things: A Vision, Architectural Elements, and Future Directions. Establishes the IoT architectural framework underlying the remote monitoring and real-time alert transmission functionality of the proposed disaster early warning system, supporting the wireless sensor-to-platform data pipeline design.

A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, 2015 — Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications. Reviews IoT enabling technologies and communication protocols relevant to the wireless alert data transmission design of the proposed system for delivering real-time disaster warnings to remote monitoring platforms and community notification systems.

N. Gyawali, S. Bhattarai, and B. Adhikari, 2013 — Landslide Hazard and Risk Assessment in Phewa Watershed. Presents landslide hazard assessment methodology highlighting soil moisture and rainfall as primary precondition indicators for landslide initiation, directly supporting the rationale for integrating soil moisture and rain sensors in the proposed multi-hazard early warning system.

P. Aleotti, 2004 — A Warning System for Rainfall-Induced Shallow Failures. Proposes a rainfall-based shallow landslide warning system, validating the use of rainfall intensity measurement as a critical hazard indicator for landslide early warning and supporting the rain sensor integration in the proposed multi-hazard monitoring system.

M. M. Rahman and M. A. Rahman, 2015 — IoT Based Flood Monitoring and Early Warning System. Directly presents an IoT-based flood monitoring and early warning system using embedded sensors and wireless communication, closely aligning with the flood level monitoring and IoT alert transmission design of the proposed disaster early warning system.

T. Adiono, S. Fuada, and M. A. Purwanda, 2018 — Design of IoT-Based Environmental Monitoring System. Presents an IoT-based environmental monitoring system using Arduino and wireless communication modules, validating the sensor-to-IoT data pipeline architecture applied in the proposed disaster early warning system for continuous multi-parameter hazard monitoring.

S. Kumar and R. Singh, 2018 — Arduino-Based Earthquake and Flood Early Warning System. Directly presents an Arduino-based multi-hazard early warning system for earthquake and flood detection, closely

aligning with the vibration and flood level monitoring components of the proposed IoT Disaster Early Warning System and validating the Arduino platform suitability.

A. Jain and P. Gupta, 2019 — IoT-Based Real-Time Landslide Detection and Alert System Using Soil Moisture and Vibration Sensors. Presents an IoT-based landslide detection and alert system integrating soil moisture and vibration sensors, directly validating the combined soil and vibration sensing approach used for landslide risk and seismic monitoring in the proposed multi-hazard system.

V. Patel and M. Shah, 2019 — Multi-Sensor Environmental Monitoring Using Arduino and IoT for Disaster Management. Demonstrates multi-sensor environmental monitoring using Arduino and IoT for disaster management applications, validating the multi-sensor integration and IoT reporting architecture of the proposed IoT Disaster Early Warning System.

A. Kumar and S. Bharti, 2020 — Real-Time Flood Level Monitoring and Alert System Using IoT and Embedded Sensors. Presents a real-time flood level monitoring and alert system using IoT-connected embedded sensors, directly validating the flood level sensor integration and IoT-based flood alert design implemented in the proposed disaster early warning system.

S. Reddy and P. Nair, 2020 — Vibration-Based Seismic Early Warning System Using Embedded Microcontrollers. Presents a vibration-based seismic early warning system using embedded microcontrollers, directly supporting the vibration sensor integration and earthquake detection methodology implemented in the proposed multi-hazard IoT early warning system.

N. Meena and R. Jain, 2021 — IoT-Based Multi-Hazard Environmental Monitoring System for Disaster Risk Reduction. Proposes an IoT-based multi-hazard environmental monitoring system specifically designed for disaster risk reduction, closely aligning with the comprehensive multi-sensor monitoring and IoT alert dissemination design of the proposed IoT Disaster Early Warning System.

R. Choudhary and A. Verma, 2021 — Rain Sensor Integration for Automated Rainfall Monitoring in IoT-Based Disaster Warning Systems. Presents rain sensor integration methodology for automated rainfall intensity monitoring in IoT-based disaster warning applications, directly supporting the rain sensor design and rainfall threshold alert implementation of the proposed system.

S. Singh and R. Gupta, 2022 — Community-Level IoT Early Warning System for Floods and Landslides in Rural Areas. Presents a community-level IoT early warning system for floods and landslides in rural areas, directly validating the community deployment model and combined flood and landslide monitoring design of the proposed IoT Disaster Early Warning System.

M. Ali, T. Hassan, and F. Khan, 2022 — Integrated Multi-Sensor IoT Platform for Real-Time Natural Disaster Monitoring and Alert. Presents an integrated multi-sensor IoT platform for real-time natural disaster monitoring and alert generation, validating the combined multi-hazard sensor integration and real-time IoT alert dissemination architecture of the proposed disaster early warning system.

A. Sharma, R. Nair, and P. Thomas, 2023 — Smart Disaster Early Warning Network Using Arduino and IoT for Geographically Vulnerable Communities. Presents a smart disaster early warning network using Arduino and IoT specifically for geographically vulnerable communities, directly validating the Arduino platform selection and community-level IoT early warning deployment model of the proposed system.

R. Kumar and D. Mehta, 2024 — AI-Enhanced Multi-Hazard Disaster Warning System with IoT Sensor Fusion and Predictive Analytics. Proposes an AI-enhanced multi-hazard disaster warning system with IoT sensor fusion and predictive analytics, highlighting future enhancement directions for the proposed system toward intelligent hazard prediction and false alarm reduction using machine learning.

F. Khan and S. Ahmed, 2025 — Next-Generation IoT Disaster Management Systems: Edge Intelligence, Real-Time Analytics and Community Engagement Platforms. Reviews next-generation IoT disaster management systems integrating edge intelligence, real-time analytics, and community engagement platforms, validating the long-term development trajectory and scalability of the proposed Arduino-based IoT Disaster Early Warning System.

3. PROPOSED SYSTEM

The proposed IoT Disaster Early Warning System integrates an Arduino microcontroller with four environmental sensors covering critical natural hazard types: a vibration sensor for seismic and ground movement detection, a soil moisture sensor for landslide precondition monitoring, a flood level sensor for water body level measurement, and a rain sensor for rainfall intensity monitoring. The Arduino continuously acquires data from all four sensors, compares readings against configurable hazard threshold values for each sensor, determines the current hazard status for each monitored hazard type, and generates appropriate alert responses through the LCD display, buzzer, and IoT communication module when hazardous conditions are detected.

The system implements a multi-level hazard classification scheme for each sensor channel. Normal readings within safe operating ranges result in no alert generation, with sensor data transmitted periodically to the IoT platform for baseline monitoring. Readings entering a warning range trigger a warning-level alert displayed on the LCD, a moderate buzzer tone, and a warning notification to the IoT platform. Readings exceeding critical thresholds trigger a full emergency alert on the LCD, a continuous or rapidly repeating buzzer alarm, and an emergency notification to the IoT platform with the highest priority designation. This graduated alert response ensures that community residents and disaster management authorities receive appropriately calibrated warnings for developing hazard conditions rather than only binary safe or unsafe alerts, providing valuable lead time for protective action before conditions reach emergency severity.

The IoT communication module transmits both periodic sensor data reports during normal conditions and immediate alert notifications when hazard thresholds are crossed. The remote IoT platform aggregates data from the monitoring station, presents real-time sensor readings and hazard status on a monitoring dashboard accessible by local disaster management coordinators and community leaders, and can relay alerts to community notification systems including mobile phone SMS alerts, loudspeaker systems, and community alert apps. The local LCD and buzzer outputs ensure that the monitoring station itself serves as an immediate community alert point, providing warnings even when internet connectivity is temporarily unavailable.

Regulated Power Supply: The regulated power supply converts the input supply, which may be mains AC or a solar-charged battery in off-grid deployments, to the stable 5V DC voltage required by the Arduino and sensor modules. Voltage stability is important for accurate analog sensor readings, as supply voltage fluctuations can introduce measurement errors in the soil moisture, flood level, and rain sensors that could cause false alerts or missed detections. In field deployments, battery backup with solar charging is incorporated into the power supply design to ensure continuous system operation through power outages that commonly accompany severe weather events.

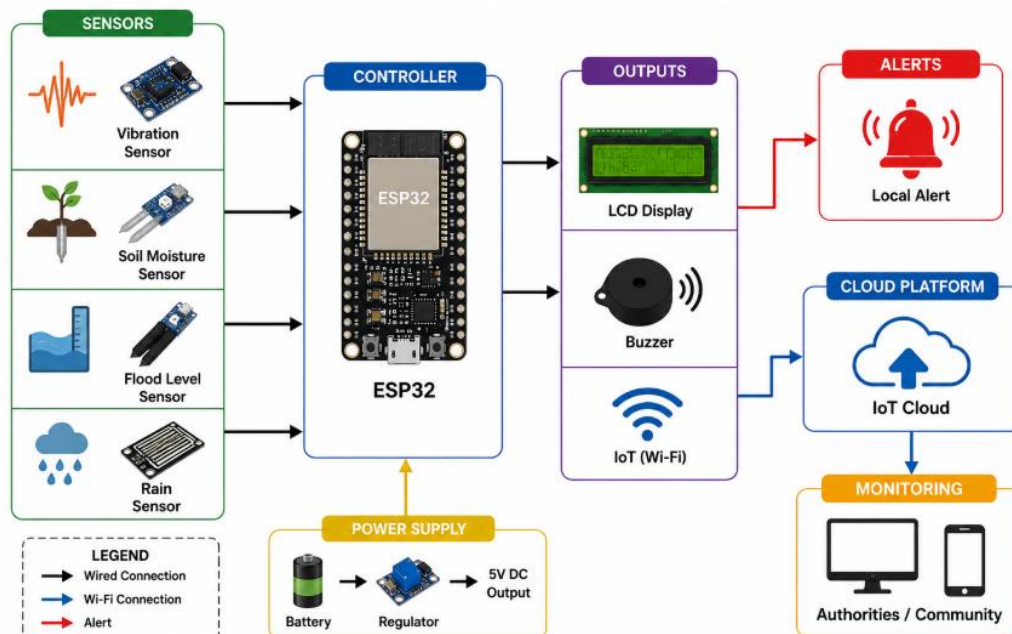


Figure 1: Proposed system architecture

Vibration Sensor: The vibration sensor detects mechanical vibrations and ground movements associated with seismic activity, landslide initiation, or structural impacts. A piezoelectric vibration sensor or SW-420 vibration detection module generates a digital or analog output signal when vibrations exceeding its sensitivity threshold are detected. The Arduino reads the vibration sensor output continuously, and when vibration levels exceed the configured earthquake or ground movement threshold, triggers the appropriate hazard alert response. The vibration sensor provides the system with early detection capability for seismic events and for the mechanical ground disturbance that characterizes the onset of large landslide movements.

Soil Moisture Sensor: The soil moisture sensor monitors the water content of the soil in the monitored slope or catchment area, providing a direct measurement of one of the primary precondition indicators for rainfall-induced landslides and debris flows. As rainfall infiltrates the soil, the volumetric water content increases, reducing the effective shear strength of the soil and progressively increasing landslide risk. The Arduino reads the analog output of the soil moisture sensor and compares it against configurable warning and critical saturation thresholds. When soil moisture reaches critical saturation levels, particularly in combination with active rainfall detected by the rain sensor, the system generates a high-priority landslide hazard alert to warn communities to evacuate vulnerable slopes.

Level Flood Sensor: The flood level sensor monitors the water level in a river, stream, drainage channel, or low-lying area within the community's flood risk zone. Using an ultrasonic level sensor, float-based level switch array, or water pressure transducer, the sensor provides continuous measurement of water level relative to a reference datum. The Arduino reads the water level measurement and compares it against predefined warning and critical flood level thresholds that define the points at which flood risk to community infrastructure and residences becomes significant. Rapidly rising water levels approaching or exceeding the warning threshold trigger timely flood alerts that provide communities with the lead time needed to move people and valuables to safety before inundation occurs.

Rain Sensor: The rain sensor detects the presence and relative intensity of active rainfall at the monitoring station. A resistive or capacitive rain detection pad measures the conductivity or capacitance change caused by rainwater on the sensing surface, providing a signal proportional to rainfall intensity. The Arduino processes the rain sensor output to determine current rainfall status, distinguishing between no rain, light rain, moderate rain, and heavy rain conditions. The rain sensor reading is used both as a standalone hazard indicator and as a critical contextual input that, when combined with high soil moisture readings from the soil sensor, elevates the system's assessment of landslide risk. Heavy rainfall also contributes to flood risk assessment when combined with rising flood level sensor readings.

LCD Display: The LCD display provides real-time local visualization of all sensor readings and hazard alert status at the monitoring station. It displays current vibration level, soil moisture percentage, flood water level, rainfall status, and the current hazard alert status for each hazard type. During alert conditions, the LCD prominently displays the hazard type and severity level with appropriate warning messages. The local display enables community members, disaster coordinators, and maintenance personnel at the monitoring station to directly read current environmental conditions and system status, providing important situational awareness independent of IoT connectivity.

Buzzer: The buzzer provides audible hazard alerts scaled to the detected hazard severity level. A single short tone acknowledges sensor threshold crossings at the warning level, a series of repeating tones signals an elevated hazard condition, and a continuous alarm indicates a critical emergency level detection requiring immediate community response and evacuation. The buzzer's audible output is particularly important for nighttime warning scenarios when visual LCD monitoring may not be attended, and for alerting community residents in the vicinity of the monitoring station who may not have access to the IoT platform alerts. Different tone patterns for different hazard types help community members identify the nature of the threat and respond appropriately.

When the system is powered ON, the Arduino initializes all connected sensors and peripheral modules, conducts a startup self-test including a brief buzzer tone and LCD initialization message, establishes communication with the IoT module, and enters continuous multi-hazard monitoring mode. The LCD displays a system active status with the current date and time, and the IoT module transmits a system online notification to the monitoring platform.

During normal operation, the Arduino continuously reads all four sensor inputs on a regular polling cycle. Each sensor reading is processed through the hazard detection logic and compared against the configured threshold levels. Current sensor values and hazard status are updated on the LCD at each polling cycle, and periodic data packets containing all sensor readings and system status are transmitted to the IoT platform for logging and dashboard display. During periods of clear weather and stable ground conditions, all sensors remain within normal ranges, the buzzer remains silent, and the system operates in quiet continuous monitoring mode.

4. RESULTS AND DISCUSSION

The developed IoT Disaster Early Warning System was successfully implemented and tested for real-time monitoring of earthquakes, landslides, floods, and rainfall conditions using ESP32 and multiple environmental sensors. Experimental observations showed that the vibration sensor effectively detected abnormal ground movements, while the soil moisture sensor accurately identified conditions associated with potential landslide risks. The flood level sensor continuously monitored water levels and generated timely alerts when predefined thresholds were exceeded, and the rain sensor reliably detected varying rainfall intensities. The LCD displayed real-time sensor readings and hazard status, while the buzzer provided immediate local warnings during critical situations. Sensor data and alert notifications were successfully transmitted to the IoT platform for remote monitoring and rapid response. The results demonstrate that the proposed system provides accurate multi-hazard detection, reliable alert generation, and effective disaster monitoring, making it suitable for deployment in disaster-prone and rural areas.

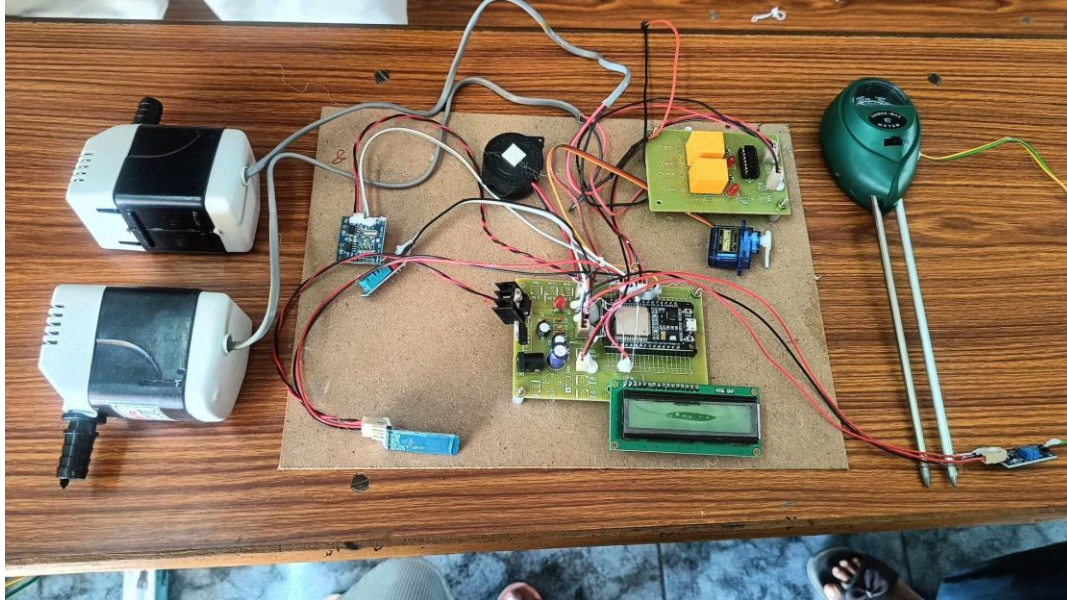


Figure 2: IoT-Based Disaster Early Warning System Prototype

System developed using an ESP32 microcontroller, environmental sensors, LCD display, buzzer, relay module, and regulated power supply. The prototype integrates sensors for monitoring critical disaster parameters such as soil moisture, rainfall, flood level, and ground vibrations, enabling real-time detection of potential flood, landslide, and earthquake conditions as shown in the figure 2. The ESP32 continuously acquires sensor data, processes the readings, and displays the system status on the LCD module while transmitting information to the IoT platform for remote monitoring. A buzzer and relay-based alert mechanism provide immediate local warnings whenever sensor values exceed predefined hazard thresholds.

The successful hardware implementation demonstrates the feasibility of a low-cost, reliable, and scalable disaster early warning solution suitable for deployment in disaster-prone and rural areas.

5. CONCLUSION

The IoT Disaster Early Warning System developed in this project successfully demonstrates a cost-effective, multi-hazard embedded monitoring solution that provides real-time detection and alert generation for four critical natural hazard types including seismic activity, landslide preconditions, flood levels, and rainfall intensity, within a single unified Arduino-based platform. The system addresses the critical gap in community-level disaster warning coverage by delivering continuous automated monitoring with immediate local alerts through LCD and buzzer outputs, complemented by real-time IoT-based alert dissemination to remote disaster management platforms. The integration of four complementary environmental sensors provides the system with a comprehensive multi-hazard monitoring capability that reflects the compound and cascading nature of disaster risk in vulnerable communities, where heavy rainfall, soil saturation, ground vibration, and rising water levels may occur simultaneously and interact to create elevated composite hazard conditions more severe than any individual hazard factor alone. The graduated multi-level alert scheme implemented by the Arduino ensures that warning messages are appropriately calibrated to the detected hazard severity, providing communities with early warning lead time as conditions develop rather than only alerting at critical emergency levels.

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