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AI-Powered Multi-Hazard Early Warning, Human Detection and Environmental Intelligence System

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Abstract: *AI-Powered IoT Digital Twin for Multi-Hazard Prediction, Early Warning, Human Detection and Rescue Support.This project proposes an AI-Powered IoT Digital Twin for Multi-Hazard Prediction, Early Warning, Human Detection and Rescue Support, integrating IoT sensors, LoRa-based wireless communication, AI/ML, sensor fusion, cloud computing and Digital Twin technology. Distributed sensors monitor rainfall, water level, temperature, smoke/gas, soil moisture and ground movement. Sensor data is transmitted through LoRa to a gateway, where AI-based sensor fusion estimates hazard probability and predicts the progression of floods, fires and landslides. Cloud computing enables centralized data storage, historical analysis, remote monitoring and access to the Digital Twin from anywhere. A dynamic Digital Twin visualizes hazard intensity and spatial risk zones while generating risk scores and early warnings. mmWave/radar sensors support human-presence detection and approximate localization during emergencies. The system also incorporates what-if simulation, explainable AI, sensor-fault detection and rescue prioritization. Local processing can support essential monitoring and alerts during internet outages, improving system reliability and emergency response.*

Keywords: Artificial Intelligence (AI), Machine Learning (ML), Internet of Things (IoT), Digital Twin, LoRa Communication, Cloud Computing, Multi-Hazard Prediction, Sensor Fusion, Early Warning System, mmWave Radar, Human Detection, Risk Assessment, What-If Simulation, Disaster Management

I. INTRODUCTION

Natural disasters such as floods, fires, and landslides pose serious threats to human life, infrastructure, and the environment. Conventional monitoring systems often rely on individual sensors and threshold-based alerts, limiting their ability to predict developing hazards and support timely emergency response.

The proposed AI-Powered IoT Digital Twin for Multi-Hazard Prediction, Early Warning, Human Detection and Rescue Support integrates IoT sensors, LoRa communication, AI/ML, sensor fusion, cloud computing, and Digital Twin technology. Environmental data is analyzed to estimate hazard risks and generate early warnings, while cloud computing enables remote monitoring and historical data storage.

A dynamic Digital Twin visualizes hazard intensity and risk zones, while mmWave radar assists in detecting human presence and estimating approximate locations during emergencies. The system also supports what-if simulations and rescue prioritization to improve disaster preparedness, situational awareness, and emergency planning.

II. LITERATURE REVIEW

Existing research has explored IoT-based disaster monitoring systems using environmental sensors to monitor rainfall, water levels, temperature, smoke, soil moisture, and ground movement. LoRa communication enables long-range, low-power data transmission, while AI/ML and sensor fusion techniques support hazard prediction and risk assessment. Cloud computing further enables remote monitoring, centralized data storage, and historical analysis.

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Recent studies have investigated Digital Twin technology for real-time visualization, simulation, and risk management. However, integrating multi-hazard prediction, dynamic risk visualization, mmWave radar-based human detection, and rescue support within a single framework remains a significant engineering challenge. This project aims to integrate these technologies into a unified system for early warning, situational awareness, and emergency response support.

III. OBJECTIVES

- Develop an AI-powered IoT-based multi-hazard monitoring system.
- Monitor environmental parameters in real time using distributed sensors.
- Implement LoRa communication for long-range, low-power data transmission.
- Apply AI/ML and sensor fusion for hazard prediction and risk assessment.
- Create a Digital Twin for real-time visualization of hazard zones.
- Integrate cloud computing for remote monitoring and historical data storage.
- Detect human presence using mmWave radar during emergencies.
- Implement what-if simulations and generate timely early warnings.
- Support rescue prioritization and disaster response planning.

IV. SYSTEM ARCHITECTURE AND DESIGN

The system consists of interconnected functional modules that transform real-world environmental data into intelligent disaster-response information.

Environmental Sensing

IoT sensors measure rainfall, water level, temperature, smoke/gas, soil moisture, and ground movement. mmWave radar supports human-presence detection.

Data Communication

SP32-based sensor nodes collect readings and transmit data to a gateway using LoRa wireless communication.

AI & Cloud Processing

AI/ML algorithms perform sensor fusion, hazard prediction, risk assessment, and sensor-anomaly detection. Cloud computing enables centralized storage, historical analysis, and remote access.

Digital Twin Visualization

A dynamic virtual representation displays real-time sensor values, hazard intensity, risk zones, and approximate locations of detected individuals..

Emergency Intelligence

The system generates early warnings, supports what-if simulations, and prioritizes high-risk areas to assist emergency response and rescue planning.

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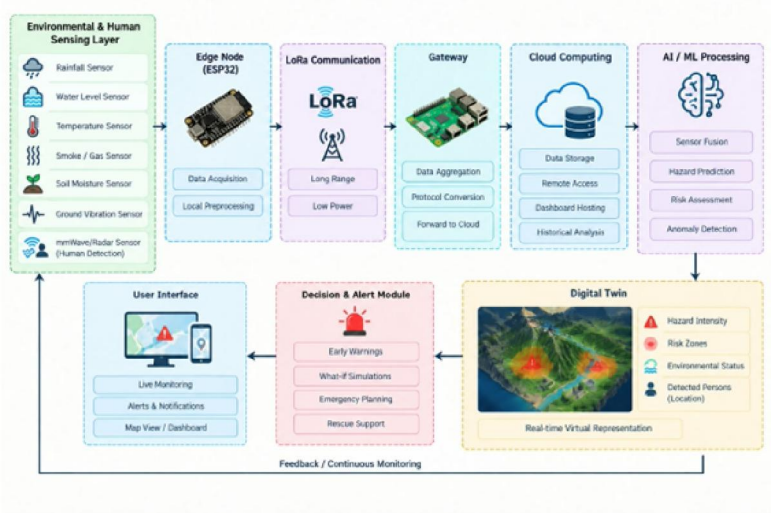


Fig. 1 shows the overall block diagram of the system.

V.METHODOLOGY

• The system collects real-time environmental data using IoT sensors and detects human presence using mmWave radar.
• ESP32 nodes process the sensor readings and transmit the data to a gateway through LoRa communication.
• AI/ML algorithms analyze the collected data using sensor fusion to predict potential hazards and assess risk levels.
• Cloud computing stores historical data and enables remote monitoring and dashboard access.
• The Digital Twin visualizes real-time environmental conditions, hazard intensity, and risk zones.
• The system generates early warnings, supports what-if simulations, and assists rescue prioritization during emergencies.
• System performance is evaluated using prediction accuracy, false-alarm rate, warning lead time, communication reliability, and human-detection performance.

VI. RESULTS AND DISCUSSION

The proposed system is expected to integrate multiple environmental sensors, LoRa-based communication, AI/ML-based hazard prediction, cloud computing, and Digital Twin technology into a unified multi-hazard monitoring platform.

The system is expected to monitor environmental parameters and identify potential flood, fire, and landslide risks by analyzing sensor data. The Digital Twin will provide real-time visualization of environmental conditions, hazard intensity, and dynamic risk zones. mmWave radar will support human-presence detection, while cloud computing will enable remote monitoring and historical data analysis.

Based on the estimated risk levels, the system is expected to generate early warnings and assist in prioritizing high-risk areas for emergency response. What-if simulations may help assess possible hazard scenarios and support evacuation planning.

After prototype development, performance will be evaluated using prediction accuracy, false-alarm rate, warning lead time, LoRa packet-delivery ratio, and human-detection accuracy. The collected experimental results will help assess system reliability, identify limitations, and guide future improvements.

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VII. CONCLUSION AND FUTURE SCOPE

The proposed AI-Powered IoT Digital Twin for Multi-Hazard Prediction, Early Warning, Human Detection and Rescue Support integrates IoT sensors, LoRa communication, AI/ML, sensor fusion, cloud computing, and Digital Twin technology to monitor and assess potential flood, fire, and landslide risks. The system aims to provide early warnings, visualize dynamic hazard zones, detect human presence using mmWave radar, and support rescue prioritization through real-time data analysis and what-if simulations. This integrated approach has the potential to improve disaster preparedness, situational awareness, and emergency response. In the future, the system can be enhanced using advanced AI models and larger datasets for improved prediction accuracy, solar-powered sensor units for energy efficiency, and offline edge processing for reliable operation during internet outages. Further development may include mobile applications for instant alerts, expanded monitoring coverage, improved human localization, and integration with emergency services to enable faster and more coordinated disaster response.

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