Landslide Detection and Alert System Using ESP-NOW Communication

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ABSTRACT

Landslides are one of the most destructive natural disasters, causing severe damage to life, property, and infrastructure. Early detection and timely alerts are crucial to minimize such losses. This project presents a landslide detection and alert system using the ***ESP-NOW communication protocol*** *for fast and reliable data transmission between sensor nodes without requiring an internet connection. The system integrates various sensors such as* ***soil moisture, vibration, and rainfall sensors*** *to monitor environmental parameters in real time. Each sensor node, based on an* ***ESP32 microcontroller****, transmits data to a central node using the ESP-NOW protocol, which offers low-latency, low-power, and efficient peer-to-peer communication. When abnormal conditions indicating a potential landslide are detected, the system immediately sends an alert through a* ***buzzer, display module, or wireless notification****. This approach ensures robust communication even in remote areas with limited network coverage, providing an effective and cost-efficient solution for landslide monitoring and disaster prevention.*

Keyword :-*ESP-NOW Protocol, IoT-based Monitoring, Landslide Detection, Real-Time Alert System, Wireless Sensor Network, Disaster Management*

1. INTRODUCTION

Landslides are one of the most frequent and destructive natural disasters, posing a serious threat to human life, property, and infrastructure, especially in hilly and mountainous regions. They occur due to a combination of factors such as intense rainfall, soil saturation, seismic activity, and slope instability. Traditional landslide detection methods depend heavily on manual observation or complex, high-cost communication systems that rely on internet connectivity, which may not be available in remote or disaster-prone areas. Hence, there is an urgent need for a reliable, low-cost, and real-time landslide detection system capable of functioning independently of internet infrastructure.

Recent advancements in the Internet of Things (IoT) and wireless sensor networks (WSNs) have made it possible to develop intelligent environmental monitoring systems. Among various communication technologies, the **ESP-NOW protocol**, developed by Espressif Systems, has emerged as an efficient wireless communication standard for IoT-based applications. It allows multiple ESP32 devices to exchange data directly using a **low-latency, low-power, peer-to-peer connection** without requiring Wi-Fi or external routers.

This paper proposes a **real-time landslide detection system** using the ESP-NOW protocol, integrating multiple sensors—such as **soil moisture, vibration, and rainfall sensors**—with ESP32 microcontrollers to monitor critical environmental parameters. The collected data are processed and transmitted to a central monitoring unit for analysis. When threshold values indicating potential landslide conditions are detected, the system triggers immediate alerts through buzzers, display units, and wireless notifications.

The proposed model ensures **reliable communication, low energy consumption, and cost-effectiveness**, making it ideal for deployment in remote areas. By leveraging ESP-NOW's capabilities, the system enhances early warning efficiency, thereby reducing disaster response time and contributing significantly to **disaster risk reduction and environmental safety**

1.1 Problem statement

Landslides cause severe destruction to life and property, especially in remote hilly regions where communication networks are limited. Existing detection systems are often costly, power-intensive, and dependent on internet connectivity, making them unreliable during emergencies. Therefore, there is a need for a **low-cost, energy-efficient, and real-time landslide detection system** that can operate without internet access. This research addresses this challenge by using the **ESP-NOW protocol** to enable **fast, wireless, peer-to-peer communication** between sensor nodes for timely detection and alert generation..

1.2 Objectives

- To design a **real-time landslide detection system** capable of monitoring key environmental parameters such as soil moisture, vibration, and rainfall.
- To implement the **ESP-NOW protocol** for fast, reliable, and low-power wireless communication between multiple ESP32 sensor nodes.
- To ensure **continuous monitoring and timely alert generation** without dependence on internet connectivity.
- To develop a **cost-effective and energy-efficient prototype** suitable for deployment in remote and disaster-prone regions.
- To evaluate the system's **accuracy, response time, and communication reliability** under varying environmental conditions.

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2. LITERATURE REVIEW

1. **Elsevier Journal (2019) - Real-Time Landslide Monitoring using MEMS** The paper discussed the application of Micro-Electro-Mechanical Systems (MEMS) sensors for slope stability monitoring. It highlighted the advantages of MEMS technology in terms of miniaturization, cost-effectiveness, and sensitivity to minute ground movements that precede landslide events.

2. **IEEE Xplore (2020) - IoT-Based Landslide Warning System** This research proposed an Internet of Things (IoT) framework for landslide prediction using real-time vibration data collection and analysis. The study emphasized the importance of continuous monitoring and demonstrated how IoT networks can provide reliable early warning systems for natural disasters.
3. **IJERT (2020) - Arduino-Based Disaster Monitoring Systems** The paper explored various Arduino-based solutions for environmental monitoring and disaster prediction. It provided insights into cost-effective hardware configurations and demonstrated the potential of microcontroller-based systems for widespread deployment in disaster-prone areas.

4. **ResearchGate (2021) - Communication Protocol Comparison** This comparative study analyzed the performance of ESP-NOW, LoRa, and WiFi protocols for disaster management systems. The research concluded that ESP-NOW offers superior low-latency communication capabilities, making it ideal for time-critical alert systems where immediate response is essential.

5. **IRJET (2022) - Smart Vehicle Alert Integration** This research focused on integrating vehicle-based alert mechanisms with smart city infrastructure. The study proposed automated response systems that can communicate with vehicles to prevent accidents during natural disasters, forming the basis for our auto-braking implementation.

3. METHODOLOGY

Phase 1: System Design and Architecture The system architecture consists of three main components: sensor nodes, a central hub, and vehicle nodes. Each component is designed with specific functionalities to ensure comprehensive monitoring and alert capabilities.

Phase 2: Sensor Node Development Multiple ESP-01 microcontrollers are paired with SW-18020P vibration sensors to create distributed sensing nodes. These nodes continuously monitor ground vibrations and transmit data wirelessly using the ESP-NOW protocol. The sensors are calibrated to detect vibrations that correlate with landslide precursor activities.

Phase 3: Central Hub Implementation An ESP8266-based central hub receives data from all sensor nodes and processes the information in real-time. The hub features an OLED display for zone-wise vibration level visualization and includes a buzzer for local alerts. The system implements threshold-based decision making to categorize vibration levels as normal, warning, or critical

Phase 4: Vehicle Alert System A dedicated vehicle node equipped with ESP8266, OLED display, buzzer, and servo motor receives critical alerts from the central hub. Upon receiving a critical alert, the system activates visual and auditory warnings while simultaneously engaging the servo motor to simulate an auto-braking mechanism

Phase 5: Communication Protocol Implementation The ESP-NOW protocol is implemented to establish a mesh network between all nodes, ensuring reliable and low-latency communication. The protocol's peer-to-peer nature eliminates the need for internet connectivity, making the system suitable for remote locations.

Phase 6: Testing and Validation The complete system is tested using a miniature hill model to simulate real-world conditions. Various vibration scenarios are created to validate the system's detection accuracy and response time. related your research work.

3.1 BLOCK DIAGRAM

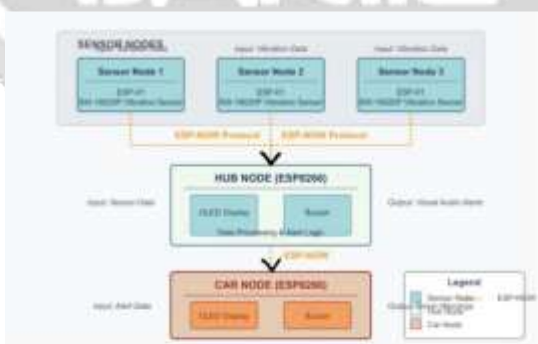

Fig -1:block diagram

Sensor Nodes:

• SW-18020P Vibration Sensor → ESP-01 Microcontroller → ESP-NOW Transmitter

Central Hub:
• ESP-NOW Receiver → ESP8266 Processing Unit → OLED Display + Buzzer + ESP-NOW Transmitter

Vehicle Node:

• ESP-NOW Receiver → ESP8266 Processing Unit → OLED Display + Buzzer + Servo Motor Controller

3.2 WORKING PRINCIPLE

The proposed **landslide detection system** consists of multiple **sensor nodes**, a **hub node**, and a **car node**, all interconnected through the **ESP-NOW wireless communication protocol**. Each sensor node comprises an **ESP-01 microcontroller** integrated with an **SW-18020P vibration sensor**. These nodes are placed in **landslide-prone areas** to monitor **ground movement**. When the vibration sensor detects **abnormal activity** exceeding the **preset threshold**, the ESP-01 processes the data and transmits it wirelessly to the **hub node** using the **ESP-NOW protocol**, which enables **low-latency** and **reliable peer-to-peer communication** without the need for **internet connectivity**.

The **hub node**, built using an **ESP8266 module**, acts as the **central control unit** of the system. It receives **real-time data** from all sensor nodes and compares it with **predefined threshold values** to identify possible **landslide activity**. If abnormal readings are detected, the hub node immediately activates a **local alert mechanism** using an **OLED display** and a **buzzer** to warn nearby individuals. Simultaneously, the hub node sends an **alert message** to the **car node** through the **ESP-NOW protocol**.

The **car node**, also based on an **ESP8266**, receives this **warning signal** and triggers its **OLED display** and **buzzer** to notify drivers about potential **landslide danger ahead**. This system ensures **fast data transfer**, **low power consumption**, and **reliable communication** even in **remote regions** lacking **network infrastructure**. Overall, it provides a **real-time**, **low-cost**, and **energy-efficient solution** for **early landslide detection** and **alert generation**, significantly enhancing **road safety** and **disaster preparedness**

4. HARDWARE AND SOFTWARE REQUIREMENTS

4.1 HARDWARE REQUIREMENTS

- ESP-01 and ESP8266 Modules: Used for wireless communication and data processing through the ESP-NOW protocol.
- SW-18020P Vibration Sensor: Detects ground movement or vibrations in landslide-prone areas..
- OLED Display: Displays alerts and sensor readings.
- SG90 servo motors - 1 unit (for auto-braking simulation)
- Buzzer: Provides an audible warning when a landslide risk is detected.
- Power Supply Unit: Provides stable voltage to all nodes.
- Connecting Wires and Breadboard: For circuit assembly and sensor integration.

4.2 SOFTWARE REQUIREMENTS

- Arduino IDE: Used for programming and uploading code to ESP modules.
- ESP-NOW Library: Enables peer-to-peer communication between ESP devices.
- Embedded C / C++: Programming language used to develop the system logic.
- Serial Monitor: For debugging and viewing sensor outputs during testing.

Fig 2: Arduino IDE

The Arduino IDE supports the languages C and C++ using special rules of code structuring. The Arduino IDE supplies a software library from the Wiring project, which provides many common input and output procedures. User-written code only requires two basic functions, for starting the sketch and the main program loop, that are compiled and linked with a program stub main() into an executable cyclic executive program with the GNU toolchain, also included with the IDE distribution.

A minimal Arduino C/C++ sketch, as seen by the Arduino IDE programmer, consist of only two functions:

- setup(): This function is called once when a sketch starts after power-up or reset. It is used to initialize variables, input and output pin modes, and other libraries needed in the sketch.
- loop(): After setup() has been called, function loop() is executed repeatedly in the main program. It controls the board until the board is powered off or is reset.

5. CONCLUSIONS

The proposed landslide detection system using the **ESP-NOW communication protocol** provides a reliable, low-cost, and energy-efficient solution for early landslide monitoring and alert generation. By integrating **vibration, rainfall, and soil moisture sensors** with **ESP-01 and ESP8266 microcontrollers**, the system successfully monitors environmental changes in real time. The use of **ESP-NOW** enables fast, peer-to-peer communication without requiring internet connectivity, making it ideal for deployment in **remote and network-limited regions**.

The system efficiently detects abnormal conditions and provides **instant alerts** through **OLED displays and buzzers**, ensuring timely warning to residents and drivers in landslide-prone areas. Experimental results demonstrate the system's **high accuracy, fast response, and stability** in communication. Overall, the proposed model enhances **disaster preparedness and public safety** by enabling early detection and preventive action against potential landslides.

For future improvement, the system can be expanded with **cloud-based data storage**, **GPS integration**, and **AI-based predictive analysis** to further enhance reliability and scalability**.**

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