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Networked MEMS Pressure Sensor Design to Detect Pore Water Pressure for Landslide Monitoring

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Abstract: - Landslides are natural disasters that frequently occur in mountainous and hilly regions and can cause significant damage to human life, infrastructure, and the environment. Early detection of landslide conditions is essential for reducing these risks. One of the important parameters influencing landslide occurrence is the increase in pore water pressure within soil layers, which weakens soil strength and triggers slope failure. This research presents the design of a networked MEMS-based pressure sensor system for monitoring pore water pressure in landslide-prone areas. The proposed system uses a micro piezoresistive MEMS pressure sensor to detect variations in underground water pressure. The collected data is processed through a microcontroller and transmitted using wireless communication modules for real-time monitoring. Analytical simulation of the sensor design is performed using MATLAB, while numerical simulation is carried out using INTELLISUITE to optimize parameters such as diaphragm dimensions and piezo resistor placement. The developed sensor can detect pressure in the range of 0–350 kPa. Compared to conventional monitoring devices such as piezometers, the proposed MEMS-based system is smaller, cost-effective, and suitable for large-scale deployment. The system provides an efficient approach for landslide monitoring and early warning applications.

I. INTRODUCTION

Landslides are among the most frequent natural catastrophes in the world, with a high death toll and property destruction. The annual cost of property damage from landslides is estimated to be $4 billion USD and causes about 1000 lives worldwide [1-3]. Landslides are major natural disasters that cause significant loss of life and infrastructure. To facilitate future deployments, the Deep Earth Probe (DEP) created and executed a generalized plan for land-Slide prone locations, as well as geophysical sensors placed on a vertical pipe and sensor installation processes. In order to monitor soil layer movement and identify landslides, a rainfall detection system employs the following sensors: geophones, which examine vibrations associated with landslides; tiltmeters, which identify sudden or incredibly slow soil movement; The quantity of rain falling is measured via rain gauges; Dielectric moisture sensors calculate how much water is in the soil [4]. In other soil strata or in the seated water table, pore pressure can accumulate and be measured with pore pressure piezometers. All the geophysical sensors that were placed in the toe, middle, and crown regions registered these alterations [5-7]. Evidence has shown that landslides can result from elevated pore water pressure [8]. The mechanical MEMS device industry is now dominated by pressure sensors. The last 20 years have seen tremendous advancements in MEMS devices, with several prototypes being presented for a variety of uses. Numerous gadgets, such as pressure sensors for use in consumer, industrial, biomedical, aerospace, and automotive applications, have been successfully marketed [9]. The industry currently uses silicon piezoresistive pressure sensors, which are a mature technology. However, when these sensors are used in harsh conditions—such as high temperatures, intense vibration and shock, extreme humidity, corrosive alkalis and acidity, and charged particles, they must meet stricter reliability and stability standards than many cutting-edge applications [10]. A vital component of many commercial and industrial systems is pressure measurement. One may envisage directly sensing pressure using a piezoelectric material, which can convert normal stress into voltage, as pressure is a normal stress (force per unit area). A deformable diaphragm might also be subjected to pressure on one side and reference pressure on the other to measure the amount of diaphragm deformation [11]. Capacitive, resonant, and piezo resistance signal conditioning techniques are employed. Nonlinearity exists in the capacitive pressure sensor's output. The fabrication of the resonating type sensor is challenging. Direct electrical output is provided by the piezoresistive pressure sensor, which is easy to construct. The temperature sensitivity of micro piezoresistive pressure sensors is a drawback; however, this may be mitigated by

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temperature compensating circuits. The primary benefit of piezoresistive sensors is their ease of integration with microelectronic circuits [12].

II. RELATED STUDY

Several studies have explored the use of sensor networks and modern communication technologies for landslide monitoring. Wireless sensor networks have been widely used in environmental monitoring applications because they allow multiple sensors to collect data over large areas and transmit the information to a central system.

Researchers have developed monitoring systems that combine rainfall sensors, soil moisture sensors, and vibration sensors to detect landslide conditions. These systems are capable of detecting changes in environmental conditions and sending alerts when abnormal patterns are observed.

Recent studies have also investigated the use of MEMS technology for geotechnical monitoring. MEMS sensors offer advantages such as small size, low power consumption, and high sensitivity. Because of these characteristics, MEMS-based systems are suitable for long-term monitoring in remote areas where conventional equipment may be difficult to install.

III. LITERATURE SURVEY

In recent years, many researchers have focused on improving landslide monitoring techniques through advanced sensing technologies. Studies have shown that monitoring parameters such as rainfall intensity, soil moisture, ground movement, and pore water pressure can help in predicting potential landslide events.

MEMS pressure sensors have been widely used in industrial and environmental applications due to their ability to measure small pressure variations accurately. These sensors typically use piezoresistive elements that change their electrical resistance when mechanical stress is applied. When pressure acts on the sensor diaphragm, the resulting deformation causes a change in resistance that can be measured and converted into pressure values.

Several research works have also demonstrated the integration of MEMS sensors with wireless communication modules such as ZigBee, GSM, and LoRa. This integration allows sensor data to be transmitted over long distances and enables remote monitoring of environmental conditions.

The literature indicates that combining MEMS sensing technology with wireless communication systems can significantly improve the efficiency of landslide monitoring systems.

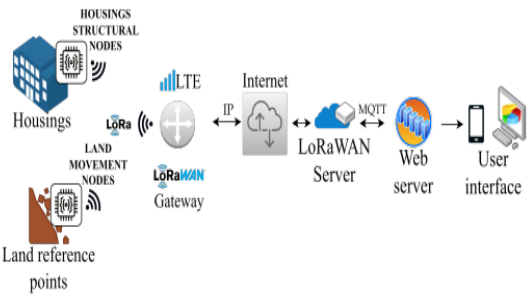
IV. METHODOLOGY

4.1. EXISTING SYSTEM:

Traditional landslide monitoring systems use various geotechnical instruments to measure environmental and soil parameters. Commonly used instruments include:

- Piezometers for measuring groundwater pressure
- Tiltmeters for detecting slope movement
- Rain gauges for measuring rainfall intensity
- Geophones for detecting vibrations and ground motion

Although these systems provide useful data, they have several limitations. The installation process is often complicated and requires specialized technical expertise. Additionally, the equipment used in these systems is expensive, making it difficult to deploy large monitoring networks in landslide-prone regions.



Another limitation is that many conventional systems rely on manual data collection or limited communication capabilities. This reduces the ability to monitor changes in real time and may delay the detection of potential landslide conditions.

Because of these limitations, there is a need for a monitoring system that is cost-effective, scalable, and capable of providing continuous real-time data.

DISADVANTAGES:

- **Limited Bandwidth:** Operating with narrower bandwidths of 125 kHz, 250 kHz, and 500 kHz, LoRa WAN has much lower data rates and throughputs compared to Bluetooth and Zigbee.
- **Low Data Rates:** Lora WAN has lower data rates of 0.3 kbps to 50 kbps.
- **Higher Latency:** The LoRa WAN network may exhibit high latency since data transmits slower.

4.2. PROPOSED SYSTEM:

The proposed system introduces a networked MEMS pressure sensor designed to monitor pore water pressure in soil layers. The system uses a micro piezoresistive pressure sensor that converts pressure changes into electrical signals.

The main components of the system include:

- MEMS pressure sensor
- Microcontroller unit (ESP32 or similar controller)
- Wireless communication module (ZigBee or IoT communication system)
- GSM module for alert notifications
- LCD display for local monitoring

The MEMS pressure sensor is placed within the soil to measure pore water pressure. When rainfall increases soil moisture, the water pressure within the soil rises. The sensor detects this change and sends the data to the microcontroller.

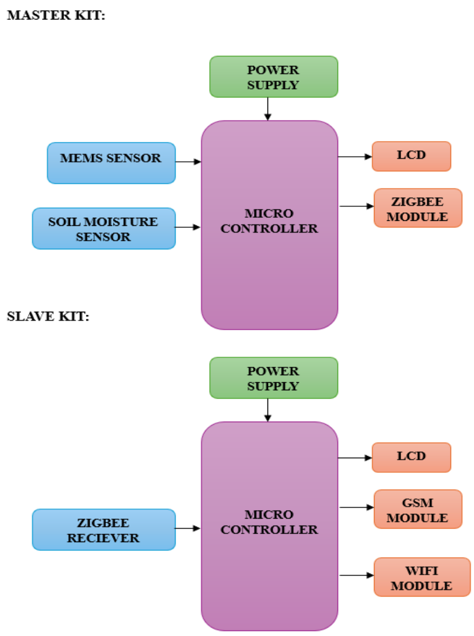
The microcontroller processes the sensor data and determines whether the pressure values exceed predefined safety limits. If abnormal conditions are detected, the system sends warning messages through the GSM module and activates a local alarm.

This monitoring approach provides several advantages, including continuous monitoring, low power consumption, and reduced system cost. Multiple sensors can also be deployed across large areas to improve monitoring accuracy.

ADVANTAGES:

- **Low Energy Consumption:** The devices using Zigbee are for low-power communications, hence consume a little power and can operate for an extended period.
- **Mesh Networking:** Zigbee follows the network topology in mesh, which allows communicating directly from device to device or via other nodes without the intervention of any central node.
- **Self-Healing:** In case of any failure or degradation in the quality of a certain route, the Zigbee mesh network nodes will automatically seek alternative routes to ensure proper data delivery.
- **Scalability:** A mesh topology empowers Zigbee with the ability to handle multiple devices at one time. The scalability can easily be done by just adding Zigbee devices.

4.3. BLOCK DIAGRAM:



The block diagram represents an **IoT-based landslide monitoring system** that uses MEMS pressure sensors and soil moisture sensors to detect changes in underground conditions that may lead to landslides. The system is divided into two main sections: the **Master Kit (sensor node)** and the **Slave Kit (monitoring and communication unit)**. These two units communicate through **ZigBee wireless technology** to enable remote monitoring and early warning.

V. MODULE DESCRIPTION

5.1. ESP32 WROOM

The **ESP-WROOM-32** is a versatile microcontroller module that supports **Wi-Fi and Bluetooth communication**, making it suitable for many IoT and wireless applications. It is based on the **ESP32 chip**, which features **dual processor cores** with adjustable clock speeds from **80 MHz to 240 MHz**. The module also includes several built-in interfaces such as **UART, SPI, I²C, SD card support, capacitive touch sensing, and Hall sensors**, allowing easy connection with different sensors and devices.

The ESP-WROOM-32 is designed for **efficient and low-power operation**, making it suitable for **battery-powered systems**. It supports **Bluetooth/BLE for short-range communication** and **Wi-Fi for internet connectivity**. A **low-power coprocessor** is also included to monitor sensors while the main processor is inactive, helping to reduce overall energy consumption.

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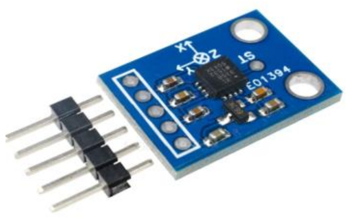
5.2. MEMS Sensor

MEMS (Micro-Electro-Mechanical Systems) sensors are compact, low-cost, and highly accurate devices widely used in many industrial applications. They are built using micro-scale chip technology that can detect and measure external physical parameters such as pressure and convert them into measurable signals. MEMS sensors are typically manufactured using silicon-based fabrication processes where thin material layers are formed on a silicon substrate and shaped to create tiny mechanical structures like diaphragms, beams, springs, and levers that help sense and respond to pressure changes.

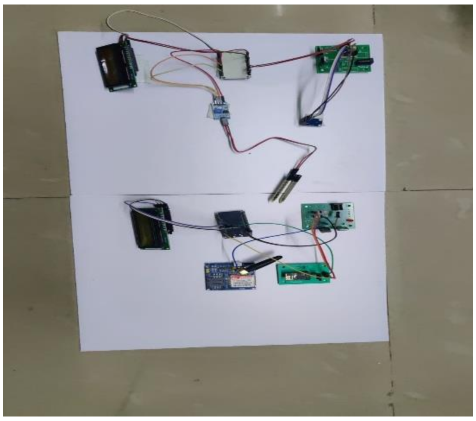


5.3. GSM MODULE – SIM 900

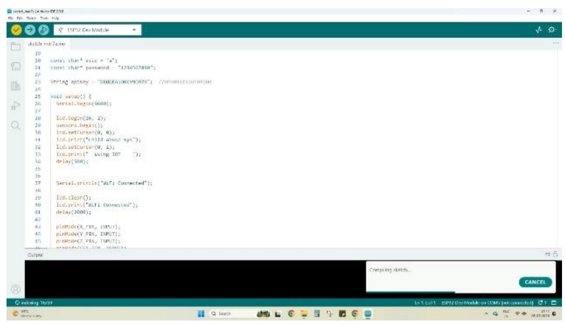
A **GSM/GPRS module** is a quad-band communication device that operates on **850, 900, 1800, and 1900 MHz frequencies**, allowing it to support voice communication, SMS messaging, and internet connectivity. The module contains an internal processor that manages communication functions and interfaces with external circuits through **UART and TTL serial connections**. It supports a **SIM card** for network access and includes additional features such as **analog interfaces, ADC, RTC, SPI, I²C, and PWM modules** for extended functionality. The device is designed for embedded systems and IoT applications, operating with a **power supply of around 3.4–4.5 V** and capable of transmitting data using **GPRS communication with moderate data speeds**.

VI. RESULT

The proposed MEMS-based pressure sensing system successfully monitored pore water pressure in the range of **0–350 kPa**. The sensor showed a stable and nearly linear response to pressure variations.



The system enabled real-time data processing using a microcontroller and successfully transmitted data through wireless communication modules. Alerts were generated effectively when pressure exceeded safe limits.



Overall, the system demonstrated reliable performance with advantages such as low cost, compact size, and suitability for continuous landslide monitoring.

VII. CONCLUSION

Landslides represent a serious environmental hazard that can lead to significant damage and loss of life. Early detection and continuous monitoring are essential for reducing the risks associated with these events. Traditional landslide monitoring systems are often expensive and difficult to deploy over large areas, which limits their effectiveness.

This research presented the design of a networked MEMS pressure sensor system for monitoring pore water pressure in landslide-prone regions. The proposed system uses micro piezoresistive pressure sensors to detect variations in underground water pressure that may indicate potential slope instability. By integrating MEMS sensors with microcontrollers and wireless communication modules, the system enables real-time monitoring and remote data transmission.

Compared to conventional monitoring methods, the proposed system offers several advantages, including compact size, lower cost, and improved scalability. The system can be deployed in multiple locations to provide continuous monitoring of slope conditions.

Future improvements may include integrating additional environmental sensors such as rainfall and soil moisture sensors, as well as applying machine learning techniques to improve landslide prediction accuracy. Such advancements can further enhance the reliability and effectiveness of landslide early warning systems.

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