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EFFECT OF SOIL MOISTURE ON VIBRATION DETECTION USING AN ESP32-BASED IoT SYSTEM

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ABSTRACT: Earthquakes are natural disasters that frequently occur due to inadequate soil structure and varying soil moisture conditions, which significantly influence ground vibration characteristics. This study aims to investigate the effect of soil moisture conditions, specifically dry and wet soil on vibration response. The system employs an SW-420 vibration sensor integrated with an ESP32 microcontroller for data acquisition and real-time monitoring. The experiment was conducted on a small-scale soil medium, with vibration data recorded at one-second intervals for a duration of 60 seconds. The measured vibration signals were transmitted and monitored in real time, then analyzed to determine which soil condition exhibits greater vibration damping characteristics. The results indicate that soil moisture has a significant effect on the vibration sensor response. The highest average ADC value was obtained in dry soil at 823.21, while wet soil produced a lower average ADC value of 533.16. The decrease in ADC values demonstrates increased vibration damping as soil water content increases. These findings confirm that higher soil moisture enhances energy absorption and reduces vibration transmission. Therefore, the IoT-based vibration detection system using the ESP32 and SW-420 sensor is capable of distinguishing soil vibration characteristics under different moisture conditions and shows strong potential for further development as an early warning system for landslide mitigation.

Keywords: ESP32, Internet of Things, Landslide Early Warning System, Soil Moisture, SW-420 Sensor, Vibration Detection.

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INTRODUCTION

Earthquakes are natural disasters that generate ground vibrations capable of causing severe damage to infrastructure and triggering secondary hazards such as landslides. Although earthquakes are mainly driven by tectonic activity, the local soil condition, particularly soil moisture content, plays a crucial role in modifying vibration propagation near the ground surface. Variations in soil moisture alter mechanical properties such as density, stiffness, and damping, which directly influence vibration amplitude and attenuation (Deng, 2025).

From the perspective of wave propagation in porous media, soil behaves as a multiphase system consisting of solid particles, air, and pore water. An increase in soil moisture enhances energy dissipation due to viscous and frictional interactions between soil grains and pore fluids, resulting in greater vibration damping compared to dry soil conditions (Ben-Noah et al., 2023). These effects are especially significant for near-surface vibrations, which are relevant for early detection and monitoring systems.

Recent developments in the Internet of Things (IoT) have enabled low-cost, real-time environmental monitoring systems using compact sensor nodes. Among various IoT platforms, the ESP32 microcontroller has gained wide adoption due to its integrated Wi-Fi and Bluetooth connectivity, low power consumption, and flexible sensor interfacing capabilities (Espressif, 2025). These features make the ESP32 suitable for real-time vibration monitoring applications in disaster-prone areas.

For vibration sensing, the SW-420 vibration sensor is commonly used in low-cost monitoring systems because of its simple design, adjustable sensitivity, and compatibility with microcontrollers. The sensor operates based on mechanical vibration detection using a spring mechanism and comparator circuit, making it suitable for detecting ground motion events (Pakpahan et al., 2020). However, most existing studies focus on system implementation rather than systematically evaluating how environmental factors particularly soil moisture affect sensor response.

Several IoT-based landslide and vibration monitoring systems have been proposed, combining vibration sensors with wireless data transmission to provide early warning capabilities (Awad et al., 2024; Dwiyanto et al., 2025). Nevertheless, quantitative experimental studies that compare dry and wet soil conditions using short-interval, real-time vibration data remain limited. This gap highlights the need for controlled experiments to better understand vibration attenuation behavior under different soil moisture states.

Therefore, this study investigates the effect of soil moisture (dry and wet conditions) on vibration detection using an ESP32-based IoT system integrated with an SW-420 vibration sensor. Vibration data are collected at one-second intervals over a 60-second observation period using a small-scale soil medium. The results are expected to contribute to the optimization and calibration of low-cost IoT-based vibration monitoring systems, particularly for applications related to landslide and ground instability early warning systems (Laksono et al., 2024).

METHODS

This study employed an experimental research design with a quantitative approach. The experiment was conducted under controlled conditions to evaluate the effect of soil moisture on vibration detection performance. Two soil moisture conditions were considered: dry soil and wet soil. The vibration response measured by the sensor served as the primary parameter for comparison. The vibration detection system was developed using an ESP32 microcontroller as the main processing and communication unit. An SW-420 vibration sensor was connected to the ESP32 to detect ground vibrations. The ESP32 processed the sensor output and transmitted the data wirelessly for real-time monitoring. The system architecture enabled continuous data acquisition and immediate visualization of vibration signals.

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The experiment was performed on a small-scale soil medium prepared in a controlled environment. The soil was conditioned into two states: dry soil and wet soil. For the wet soil condition, water was added until the soil reached a visibly saturated state. The vibration sensor was embedded at a fixed position within the soil to ensure consistent measurement conditions. A controlled vibration source was applied at a constant distance from the sensor. The same vibration intensity and placement were maintained for both soil conditions to ensure experimental consistency.

Vibration data were collected at one-second intervals over a total duration of 60 seconds for each soil condition. The SW-420 sensor output was converted into digital values using the analog-to-digital converter (ADC) of the ESP32. All measurements were recorded in real time and stored for subsequent analysis. The recorded vibration data were analyzed using descriptive statistical methods. The average ADC values obtained from dry and wet soil conditions were compared to evaluate the vibration damping effect of soil moisture. A lower ADC value was interpreted as higher vibration attenuation due to increased soil moisture content.

RESULTS AND DISCUSSION

The vibration signals measured by the ESP32-SW-420 system were recorded at one-second intervals over a 60-second observation period for both dry and wet soil conditions. Figure 1 illustrates the temporal variation of ADC values obtained from the vibration sensor.

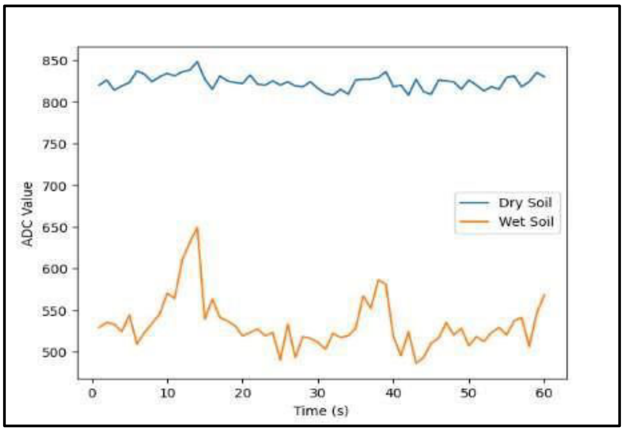

Figure 1. ADC Response of Vibration Sensor Under Dry and Wet Soil Conditions Over 60 Seconds.

The results show that dry soil consistently produced higher ADC values compared to wet soil throughout the measurement period. The vibration signal in dry soil appears more stable with relatively small fluctuations, whereas the wet soil signal exhibits larger variations and lower overall amplitude.

Table 1. Statistical Summary of ADC Values.

Soil Condition	Mean ADC	Minimum	Maximum	Standard Deviation
Dry Soil	823.42	808	848	8.33
Wet Soil	533.17	486	649	31.08

The average ADC value for dry soil is approximately 823.42, while wet soil yields a significantly lower mean value of 533.17. In addition, wet soil exhibits a much larger standard deviation, indicating greater signal instability due to enhanced vibration damping. The separation between the two curves remains consistent throughout the observation period, confirming that soil moisture strongly affects vibration transmission.

The experimental results clearly demonstrate that soil moisture significantly influences vibration detection performance. Dry soil exhibits higher and more stable ADC values, indicating efficient vibration propagation. In contrast, wet soil produces substantially lower ADC values, reflecting increased vibration attenuation. This behavior can be explained using wave propagation theory in porous media. When soil pores are filled with water, viscous damping and frictional losses increase, causing a portion of the mechanical vibration energy to dissipate as heat rather than being transmitted to the sensor (Deng, 2025). As a result, the vibration amplitude detected in wet soil is significantly reduced.

Laboratory studies have shown that the propagation velocities of shear and dilatational waves decrease significantly with increasing soil saturation, reflecting the influence of water distribution on vibration transmission characteristics in porous media such as wet soils (Lin et al., 2024). In addition, other studies have found that both the amplitude and velocity of Rayleigh waves decrease as soil moisture increases, indicating the presence of non-linear damping effects associated with soil water conditions (Lee et al., 2023). In the context of IoT-based landslide monitoring, the performance of moisture and vibration sensors demonstrates that integrating these two parameters is essential for accurately detecting ground changes under varying soil moisture conditions (Susanto et al., 2019). Overall, the ESP32-based IoT system integrated with the SW-420 vibration sensor demonstrates adequate sensitivity to distinguish between dry and wet soil conditions within a short monitoring window. This confirms its potential application as a low-cost vibration monitoring node for early warning systems in landslide-prone areas, provided that moisture-dependent calibration is applied.

CONCLUSION

This study investigated the effect of soil moisture on vibration detection using an ESP32-based IoT system integrated with an SW-420 vibration sensor. Experimental results obtained from real-time monitoring at one-second intervals over a 60-second period demonstrate that soil moisture significantly influences vibration signal characteristics. Dry soil consistently produced higher and more stable ADC values, indicating efficient vibration transmission through the soil medium. In contrast, wet soil exhibited substantially lower ADC values and higher signal variability, confirming that increased water content enhances vibration damping due to viscous and frictional energy dissipation within the soil matrix.

The findings confirm that soil moisture is a critical parameter affecting vibration-based monitoring systems. Without moisture-dependent calibration, vibration sensors may underestimate ground motion in wet soil conditions, potentially reducing detection reliability during periods of high landslide risk. Therefore, adaptive thresholding or multi-sensor integration is recommended for practical field deployment. Overall, the ESP32-SW-420 system demonstrated sufficient sensitivity to distinguish vibration characteristics between dry and wet soil conditions within a short observation window. This low-cost IoT-based approach shows strong potential for application in early warning systems for ground instability and landslide mitigation, particularly in regions with highly variable soil moisture conditions.

SUGGESTIONS

Based on the findings of this study, several recommendations can be proposed for future research and practical implementation. First, future studies should investigate the dynamic relationship between soil moisture variation and vibration signal characteristics under real field conditions, particularly during rainfall events, to improve the reliability of early warning systems for landslides. Incorporating long-term monitoring data may help capture seasonal and environmental influences that were not fully addressed in this study.

Second, the development of adaptive or moisture-dependent vibration detection thresholds is strongly recommended. Fixed thresholds calibrated under dry soil conditions may not be suitable for wet or saturated soils due to non-linear damping effects, potentially leading to missed detections of early ground movement. Therefore, integrating soil moisture sensors with vibration sensors in IoT-based monitoring systems is essential to enhance detection accuracy and system robustness.

Finally, future work should explore advanced signal processing techniques and machine learning approaches to better distinguish meaningful vibration patterns from noise under varying soil moisture conditions. Such improvements could significantly enhance the effectiveness of smart monitoring systems in mitigating landslide risks and supporting disaster prevention efforts.

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REFERENCES

Awad, S. J., Kurhade, S. D., Gawand, R. S., & Golimbade, M. K. (2024). Landslide Detection System Using IOT. *International Journal of Scientific Research & Engineering Trends, 10*(2), 167-171.

Ben-Noah, I., Friedman, S. P., & Berkowitz, B. (2023). Dynamics of Air Flow in Partially Water-Saturated Porous Media. *Reviews of Geophysics, 61*(2), 1-34. https://doi.org/10.1029/2022RG000798

Deng, T. (2025). Poroelastic Effects on Seismic Monitoring in Partially Saturated Loosely Deposited Sands. *Frontiers in Earth Science, 13*(1), 1-12. https://doi.org/10.3389/feart.2025.1561168

Dwiyanto, D., Hidayat, I., Alamsyah, R., Lestari, N. S., Ramadi, G. D., & Sukirno, S. (2025). Development of a Solar Powered IoT Based Landslide Detection System. *Brilliance : Research of Artificial Intelligence, 5*(2), 854-859.

https://doi.org/10.47709/brilliance.v5i2.6887

Espressif. (2025). *ESP32 Series Datasheet v5.2*. Shanghai: Espressif Systems.

Laksono, I., Kynta, D., Fadli, M., Wijaya, V., & Hermanto, D. (2024). Pemantauan Kelembaban Tanah Berbasis IoT Menggunakan Sensor *Soil Moisture*. *Algoritme : Jurnal Mahasiswa Teknik Informatika, 5*(1), 24-34. https://doi.org/10.35957/algoritme.v5i1.8961

Lee, S., Woo, D. K., & Choi, H. (2023). Contactless Estimation of Soil Moisture Using Leaky Rayleigh Waves and a Fully Convolutional Network. *Vadose Zone Journal, 22*(6), 1-13. https://doi.org/10.1002/vzj2.20285

Lin, J., Zhang, N., & Zhang, Y. (2024). Study of the Prediction of Vibrations in Soft Soil Foundations Based on Field Tests. *Sensors, 24*(8), 1-15. https://doi.org/10.3390/s24082564

Pakpahan, I. E. A., Sihombing, P., & Nasution, M. K. M. (2020). Analysis of the SW-420 Vibration Sensor Performance on Vibration Tools by using a Fuzzy Logic Method. In *International Conference on Culture Heritage, Education, Sustainable Tourism, and Innovation Technologies* (pp. 543-550). Novi Sad, Serbia: University of Novi Sad.

Susanto, E., Budiman, F., Mukhtar, D. P. H., & Latief, M. H. (2019). Slope, Humidity and Vibration Sensors Performance for Landslide Monitoring System. In *2019 IEEE Asia Pacific Conference on Wireless and Mobile (APWiMob)* (pp. 139-142). Bali, Indonesia: IEEE Xplore.