QuakeSense: Design and Implementation of an IoT-Based Earthquake Alert System Powered by Raspberry Shake 4D with Solar Technology Integration

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Abstract: *This study focuses on the development and implementation of an IoT-based earthquake bell and SMS notification alert system powered by the Raspberry Shake 4D (RS4D) seismograph at Caraga State University's Hinang Hall. The system integrates real-time seismic monitoring capabilities with automated alert mechanisms that activate at a predefined threshold of intensity IV based on the PHIVOLCS Earthquake Intensity Scale (PEIS). A comprehensive approach was employed, including the construction of a seismograph vault to minimize environmental noise interference, configuration for both local and international network data sharing, and the implementation of an audible bell alarm for immediate on-site warning and SMS notifications for remote awareness. Results demonstrate significant improvement in signal quality after vault construction, with reduced environmental noise influence and enhanced earthquake detection capabilities. The developed system successfully enables real-time seismic data collection and transmission while providing timely alerts during seismic events, contributing to campus safety and disaster preparedness.*

Keywords: Earthquake Early Warning (EEW) Systems; Raspberry Shake 4D (RS4D); PHIVOLCS Earthquake Intensity Scale (PEIS); Bell Alarm; SMS Notification Alert

1. INTRODUCTION

Earthquakes are among the Earth's biggest and deadliest natural disaster due to its unpredictable nature and potential for widespread destruction [1]. Lately, interest in issuing Earthquake Early Warning (EEW) system is increasing globally, and research has found significant benefits of having EEW system to warn the public [2]. However, according to Anthony et al. [3], despite having acceptable performance to capture these local events, the current nodal sensors used by the seismological community are likely not suitable for long-term monitoring applications because of their relatively short battery life span, and its inability to transmit data in real time and making it available globally. In accordance with this, the Raspberry Shake 4D have been proposed as a candidate for densifying earthquake monitoring networks [4] and implementing an earthquake alert system [5].

Earthquake warning systems plays a crucial role that provides significant benefits by offering timely alerts to individuals and organizations in areas at risk of ground shaking from an earthquake [6]. In periods of emergency, such when an earthquake occurs, the absence of an early warning system arises several challenges such as lack of preparedness, inadequate response coordination, increased panic and confusion, resource allocation challenges, and psychological impact [7]. Notably, the December 3, 2023 earthquake with a magnitude of 7.4 that trembled the municipality of Hinatuan, Surigao del Sur, had a significant impact on numerous cities and municipalities [8]. One notable example of the damage caused by the earthquake event was the Engineering Building, Hinang Hall at Caraga State University (CSU). Thus, developing an earthquake alert and monitoring system is an essential tool for risk management and disaster preparedness that help save lives and minimize the potential impact of the disaster [7,9].

Accordingly, this study highlights the use of Raspberry Shake 4D in detecting seismic activities. The Raspberry Shake 4D (RS4D) is a seismograph powered by Raspberry Pi designed specifically for earthquake monitoring. Among all other Raspberry Shake seismograph models, RS4D is the most suitable for monitoring strong ground motion in earthquake-prone areas [10]. It detects a wider range of seismic activities, has advanced capabilities in detecting ground vibrations, and providing reliable data on seismic events making it the most compatible for earthquake warning systems [11]. The main advantages of RS4D compared to other traditional seismographs such as the United States Geological Survey's aftershock deployment is its cost-effectiveness, ease of installation, real-time data transmission, and densification of networks [12].

Moreover, it is also of at most importance to emphasize that the study focuses on the design and implementation of the alert system leveraging the advanced seismic monitoring capabilities of the Raspberry Shake 4D within the Hinang Building of Caraga State University. Specifically, this study intends to enable real-time data sharing for local and international network, integrate a bell alarm, and implement a digital earthquake alarm notifier through SMS that automatically disseminate earthquake alerts at a minimum shaking threshold of intensity IV based on the PHIVOLCS Earthquake Intensity Scale (PEIS).

The significance of developing and implementing an earthquake alert and monitoring system in CSU, Hinang Hall aligns directly with the United Nation's Sustainable Development Goals (SDGs), more particularly, the SDG 11: Sustainable Cities and Communities, SDG 3: Good Health and Well-being, and SDG 9: Industry, Innovation, and Infrastructure [9,13]. In summary, the study significantly aids not only in enhancing campus safety with real-time earthquake alerts, but also supports wider sustainable development objectives that includes reducing risks to people and infrastructure, strengthening disaster preparedness, and supporting mental health and psychological well-being.

2. REVIEW OF RELATED LITERATURE

Table 1. Summary of related literature

Study / Feature	A	B	C	D	E	F	G	H	I	J	K
[6]	✓	✓	✗	✗	✓	✓	✗	✗	✓	✓	✗
[7]	✓	✓	✗	✗	✓	✓	✗	✗	✓	✗	✗
[8]	✓	✓	✗	✗	✓	✓	✗	✗	✗	✓	✗
[9]	✓	✓	✗	✗	✗	✗	✗	✗	✗	✓	✓
[10]	✓	✓	✗	✗	✓	✓	✓	✗	✗	✗	✓
[11]	✓	✓	✗	✗	✓	✓	✓	✗	✗	✓	✓
Proposed Study	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓

Legend: A – Monitoring System, B – Real-time Data Collection, C – Audible Alert, D – Digital Alert, E – Real-time Data Sharing, F – Local Server Data Sharing, G – Automated International Server Data Sharing, H – Underground Deployment, I – IoT-based, J – Cost Effective, K – Network Densification

This study proposes a novel framework incorporating distinct enhancements over existing systems, aimed at delivering a more robust, efficient, and economically feasible solution for modern monitoring and alert applications. Highlighting unique and enhanced features such as audible alert, digital alert, solar integration, IoT-based, real-time data sharing, international and local server data sharing, and underground deployment.

3. METHODOLOGIES

This section provides an outline of the methodologies employed in the design and implementation of an earthquake alert system utilizing the Raspberry Shake 4D.

3.1 Theoretical framework

This section presents the theoretical framework of the study.

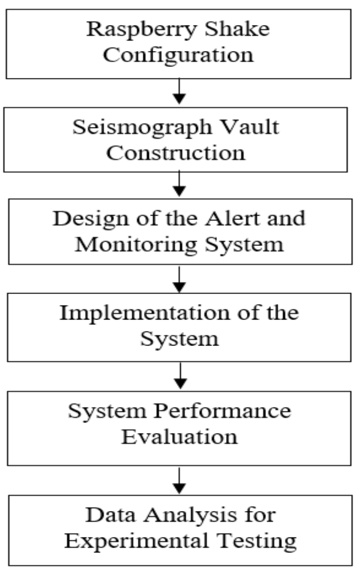


Figure 1. Theoretical framework

The study follows a structured framework beginning with the configuration of the Raspberry Shake 4D and the construction of a seismograph vault for accurate data collection. It proceeds to the design and implementation of the earthquake alert system, followed by performance evaluation. The framework concludes with data analysis and experimental testing to ensure the system's reliability and effectiveness in real-time monitoring and alerting.

3.2 System block diagram

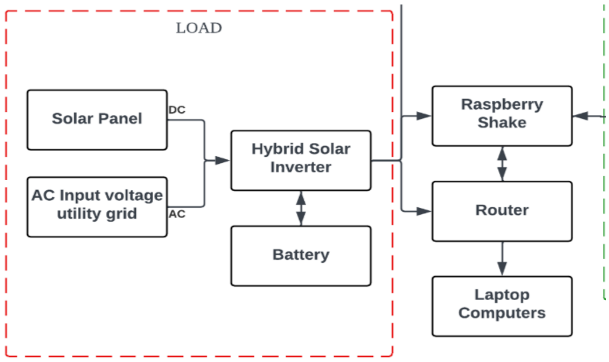


Figure 2A. Block diagram of the system

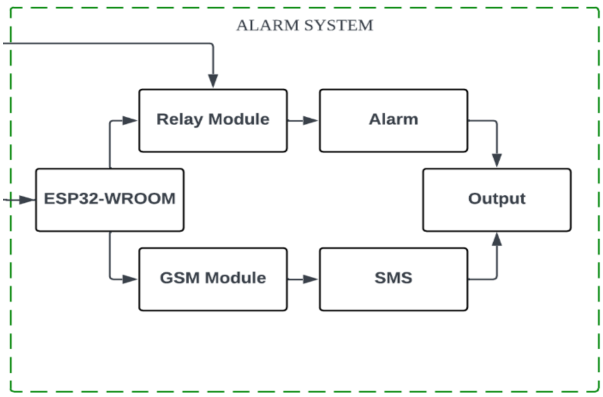
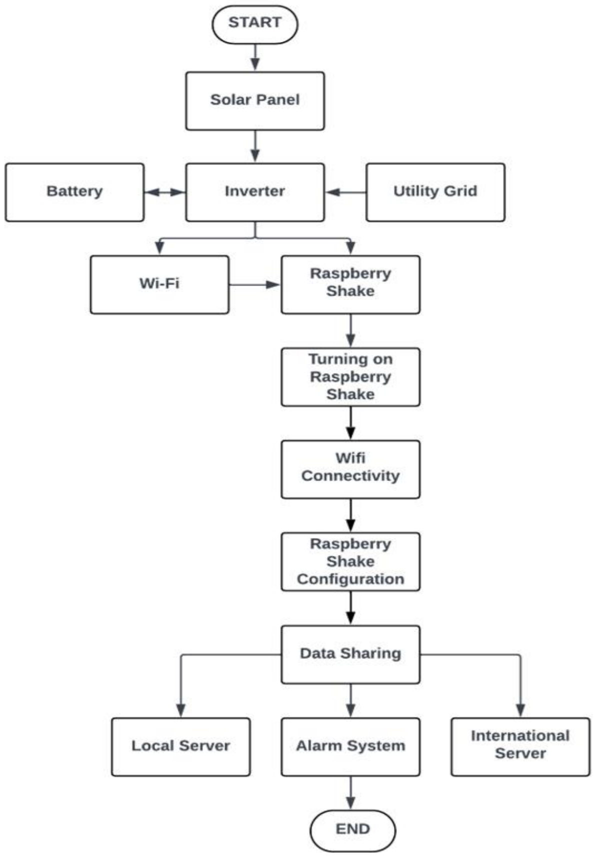


Figure 2B. Block diagram of the system

The whole system is designed to be equipped with a hybrid energy setup power supply composed of a solar panel, a battery, and an AC utility grid, all connected to a hybrid solar inverter to ensure uninterrupted power supply. On the other hand, the RS4D seismograph, allocated by the University of the Philippines Resilience Institute (UPRI) is the one responsible for detecting real-time ground motion, which data is then transmitted for sharing through securing Wi-Fi connectivity. Subsequently, in designing the bell and SMS notification alert system, the ESP32-WROOM microcontroller was included in the set up. It is responsible for receiving the data input from the Raspberry Shake and processing it for output. Upon detecting a significant seismic activity, the ESP32 triggers a relay module connected to the bell alarm to disseminate audible warning, and simultaneously activates the GSM module to send SMS alerts.

3.3 System flowchart

This section presents the interconnected schematic representation of the stages and methods for designing an IoT-Based Earthquake Bell and SMS Notification Alert System Powered by a Raspberry Shake 4D.



. Figure 3. Flowchart of the system

The first stage highlights the integration of a power supplied either by a solar panel, battery, or the utility grid, managed via an inverter. This powers the Raspberry Shake 4D and its Wi-Fi connectivity. Once the Raspberry Shake is turned on, it connects to the Wi-Fi and undergoes device configuration. After successful configuration, the system of the RS4D initiates data sharing. The collected seismic data is then simultaneously sent to three primary outputs:

1. Local Server – stores and processes data locally for internal monitoring.
2. International Server – connects to the global seismic platform of the RS4D for real-time data access.
3. Alarm System – triggers an Earthquake Bell and SMS alert notification, ensuring immediate warning and response.

This automated sequence ensures continuous monitoring and rapid alert dissemination during seismic events.

3.4 Alarm system flowchart

In designing the alarm system, the process begins with the occurrences of an Earthquake as the input of the system. The RS4D seismograph captures the seismic signals and transmits the data to the ESP32-WROOM for output processing and analysis. If the set parameters are not met, the LCD Serial monitor will display "LOW", and an SMS earthquake notification will be disseminated but the bell alarm will remain off. On the other hand, if the parameters are met, the system will simultaneously display "HIGH" on the serial monitor, activates bell alarm, and send an SMS notification to the recipients.

3.4 Alarm system flowchart

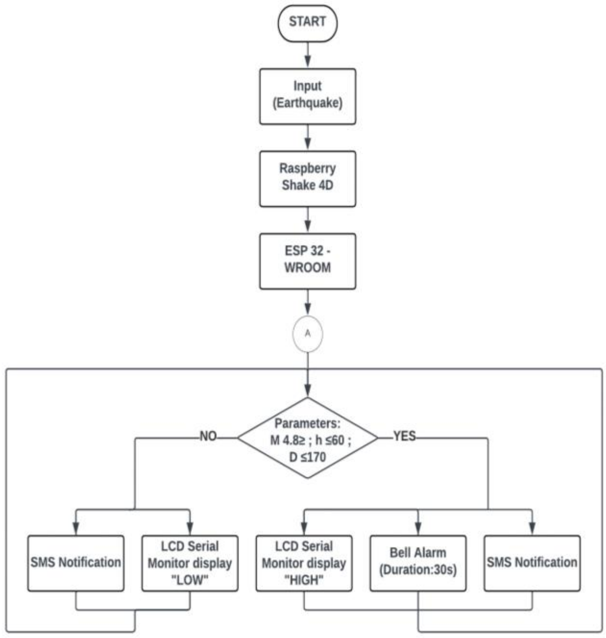


Figure 4. Flowchart of the alarm system

3.5 RS4D data sharing configuration

The configuration to enable real-time data sharing locally and internationally begins first with RS4D configuration via Secure Shell (SSH) to connect the designated computer to the device. Once connected, control on the Raspberry Shake and checking on the device's status were enabled. This will also allow the device to share data internationally via the official website of the Raspberry Shake system which is the Station View and the official mobile app, Shake Net. Second is the installation of EarthquakeHub Client on the device. This process is essential for enabling seismic data sharing from Raspberry Shake to the University of the Philippines Resilience Institute (UPRI). After running the installation script and restarting the device, the UPRI's network interface, which is the target network for real-time data sharing locally becomes accessible at rs.local:3000. After this, a configuration for authentication was done, which plays a crucial role in allowing the device to send seismic data while preventing unauthorized access. This process allows the local network of UPRI to access the real-time data detected by the RS4D. Wherein in any case of earthquake event in Butuan City, UPRI will simultaneously receive the real-time data during the event.

3.6 Magnitude threshold calculation

In order to effectively trigger an earthquake alert system, it is essential to accurately determine key seismic parameters immediately following a seismic event. The RS4D seismograph provides an earthquake event's data including its magnitude, depth, location, and the distance of the earthquake's epicenter away from the device. However, it does not provide the intensity of that earthquake. In line with this, since the study would like to trigger an earthquake warning based on the severity of the seismic activity felt specifically in Butuan City, Agusan del Norte, historical earthquake data from the official records of Philippine Institute of Volcanology and Seismology ranging from 2016-2024 were used. Wherein significant earthquakes hit the City of Butuan, Agusan del Norte with an intensity IV shaking, described as Moderately Strong by the PHIVOLCS Earthquake Intensity Scale. The historical data were used to estimate the magnitude threshold required for an intensity IV shaking to occur in Butuan City, with respect to the earthquake's magnitude, depth, and hypo-central distance.

Table 2. Earthquake historical data (2016-2024)

Date	Location	h	D	M	I
01-17-24	Hinatuan, Surigao Del Sur	23km	100km	5.7	IV
02-01-23	Compostela, Davao De Oro	17km	115km	6.0	IV
03-07-23	New Bataan, Davao De Oro	2km	127km	5.9	IV
11-16-20	San Agustin, SDS	54km	67km	6.0	IV
03-08-19	Burgos, Surigao Del Norte	16km	87km	6.2	IV
05-10-18	Libjo, Dinagat Islands	16km	88km	5.7	IV
06-24-18	Tubay, Agusan Del Norte	5km	24km	4.8	IV
02-10-17	Surigao City,Surigao Del Norte	10km	98km	6.7	IV
09-04-16	Talacogon, Agusan Del Sur	8km	62km	6.0	IV
09-24-16	Mati, Davao Oriental	38km	164km	6.5	IV

Where:
R = Depth, **D** = Distance, **M** = Magnitude, **I** = Intensity

The relationship of an earthquake's magnitude, distance, depth, and intensity were discussed in Torregosa R. et al. [14] and Besana G.M. et al. [15]. Stating that the used of the perimeters stated above, as well as its hypo-central distance are essential in the process of estimating and simulating strong motions. Similarly, in estimating the threshold magnitude required for the specified intensity IV, adhering to the PHIVOLCS Earthquake Intensity Scale, the study of [15] and Wald D.J. et al. [16] used an attenuation law equation shown in eq. 1, in addition to the approximation of attenuation formula shown in eq. 2 with respect to the relationship between the Modified Mercalli Intensity (MMI) Scale and an earthquake's magnitude, distance, and depth.

$$I = a + bM - log10R - dR \qquad \text{eq. 1}$$

$$MMI = aM + b\, log10\, R + c \qquad \text{eq. 2}$$

Where:
I = Intensity
a = Estimated attenuation value for magnitude determination
b = an independent random variable that takes on a specific value for each earthquake.
M = Magnitude
h = Depth
dR = Distance
MMI = Modified Mercalli Intensity
c **= dR**

The intensity calibration relating intensity to magnitude and hypo-central distance for the estimation of the magnitude threshold required to trigger an intensity IV shaking in Ampayon, Butuan City, references equations 1 and 2 for a sample calculation using the earthquake historical data from Table 1. Mathematically expressed as

$$I = aM - log10\,(D_{hypo}) + b \qquad \text{eq. 3}$$

Equation 3 shown above is used to specify the mathematical expression for the magnitude threshold needed to trigger an intensity IV shaking. Defined as

$$M = \frac{I + log10\,(D_{hypo}) - b}{a}$$

$$M = \frac{4 + log10\,(D_{hypo}) - b}{0.240} \qquad \text{eq. 4}$$

Where:
I = 4 (for intensity IV)
a = 0.240 (Estimated attenuation value for magnitude determination)
D_{hypo} = hypo-central distance of the earthquake

$$\boldsymbol{D_{hypo}} = \sqrt{(Distance)^2 + (Depth)^2} \qquad \text{eq. 5}$$

b = an independent random variable that takes on a specific value for each earthquake

$$\boldsymbol{b} = 4 - 0.240\,M + log10\,(D_{hypo}) \qquad \text{eq. 6}$$

For event 1 calculation:

$$I = aM - log10\,(D_{hypo}) + b$$

$$M = \frac{I + log10\,(D_{hypo}) - b}{a}$$

I = 4, *a* = 0.240, M = 5.7

$$M = \frac{4 + log10\,(D_{hypo}) - b}{0.240}$$

$$\boldsymbol{D_{hypo}} = \sqrt{(Distance)^2 + (Depth)^2}$$

$$\boldsymbol{D_{hypo}} = \sqrt{(100)^2 + (23)^2}$$

$$\boldsymbol{D_{hypo}} = 102.61\text{ km}$$

$$\boldsymbol{b} = 4 - 0.240\,M + log10\,(D_{hypo})$$

$$log10\,(D_{hypo}) = log10\,(102.61) = 2.01$$

$$\boldsymbol{b} = 4 - 0.240\,(5.7) + 2.01$$

$$\boldsymbol{b} = 4.642$$

$$M = \frac{4 + 2.01 - 4.642}{0.240}$$

$$\boldsymbol{M = 5.7}$$

For event 2 calculation:

$$M = \frac{I + log10\,(D_{hypo}) - b}{a}$$

I = 4, a = 0.240, M = 6.0

$$M = \frac{4 + log10\left(D_{hypo}\right) - b}{0.240}$$

$$\boldsymbol{D_{hypo}} = \sqrt{(Distance)^2 + (Depth)^2}$$

$$\boldsymbol{D_{hypo}} = \sqrt{(115\ km)^2 + (17\ km)^2}$$

$$\boldsymbol{D_{hypo}} = 116.25\ km$$

$$\boldsymbol{b} = 4 - 0.240\ M + log10\ (D_{hypo})$$

$$log10\left(D_{hypo}\right) = log10\ (116.25) = 2.07$$

$$\boldsymbol{b} = 4 - 0.240\ (6.0) + 2.07$$

$$\boldsymbol{b = 4.63}$$

$$M = \frac{4 + 2.07 - 4.63}{0.240}$$

$$\boldsymbol{M = 6}$$

Table 3. Sample data calculation for intensity IV

Event	Magnitude (M)	Hypo-central Distance (D_{hypo})	Log10 D_{hypo}	Parameter b
1	5.7	102.6km	2.01	4.642
3	6.0	116.2km	2.06	4.62
4	5.9	127.0km	2.10	4.684
5	6.0	86.5km	1.93	4.490
6	6.2	88.5km	1.94	4.452
7	5.7	88.4km	1.95	4.582
8	4.8	24.5km	1.38	4.228
9	6.7	98.51km	1.99	4.382
10	6.0	62.5km	1.79	4.35
11	6.5	168.3km	2.22	4.661

Based on the calculated sample data for earthquakes causing an intensity IV shaking in Butuan City, the results correspond directly to its reported magnitude, demonstrating that the proposed equation for magnitude threshold calculation is reasonable.

Table 4. Magnitude calculation based on the equation

Events	Reported Magnitude	Calculated Magnitude
1	5.7	5.7
2	6.0	6.0
3	5.9	5.9
4	6.0	6.0
5	6.2	6.2
6	5.7	5.7
7	4.8	4.8
8	6.7	6.7
9	6.0	6.0
10	6.5	6.5

Hence, based on the earthquake historical data, the magnitude threshold for an intensity IV shaking is set to

Table 5. Parameter for alarm trigger

Magnitude	Depth	Hypo-central Distance
$4.8 \geq$	$\leq 60\ km$	$\leq 170\ km$

The magnitude, depth, and hypo-central distance that was set as the parameter to trigger an alarm warning also considered the public's opinion on a survey of Becker J.S. et al., (2020) where the respondents desired to be warned at magnitude threshold of 5 or higher. The depth parameter also considered the range for a shallow-focus earthquake which is between 0-70 km deep.

3.7 Seismograph vault construction

The construction of the seismograph vault is one the most important aspect of the station installation. The purpose of the station is to reduce the environmental noise interference in order to acquire a good quality of seismic data available at the location.

Figure 4. Site selection & vault hole excavation
Figure 5. Inner & outer barrel enclosure

Figure 6. Surface enclosure & vault door frame

4. RESULTS AND DISCUSSION

This section presents the results and data collected, supported by a comprehensive discussion and visualization that foster a deeper grasp of the findings. It includes waveforms, and graphs that illustrate the system performance. The data gathered are explained thoroughly, aligning results to the study objectives, underscoring seismic data, alarm system behaviour, and the unexpected variations significant to the system.

4.1 Enabling local and international data sharing

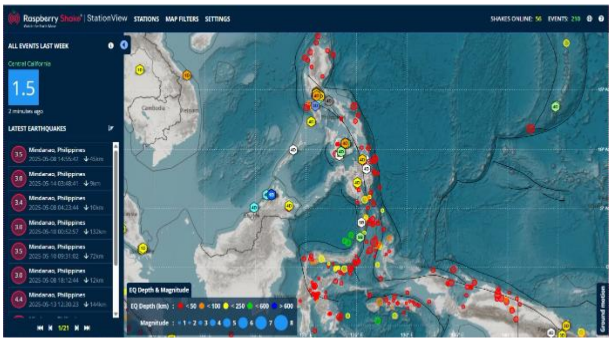


Figure 7. International data sharing

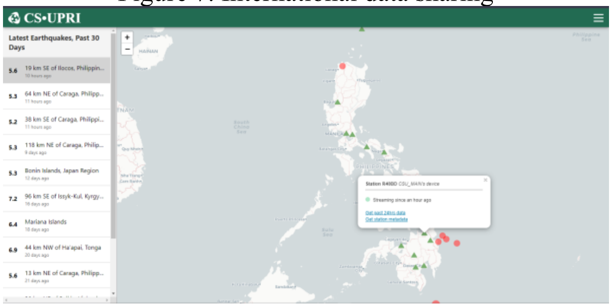


Figure 8. Local server data sharing

Figure 7 presents the international server interface, established after the configuration process. The results show that the device was properly configured, as the key parameters such as the data producer, data consumer, data forwarding, and server connection are all active, which are crucial for running the international server, indicating that the RS sensor is ready for local and international data sharing and seismic data collection. Meanwhile, Figure 8 illustrated the established connection between UPRI and Caraga State University. In which the collection of real time seismic data of the Raspberry Shake (R40BD) sensor at Caraga State University device is simultaneously shared and received by the UPRI network.

4.2 Noise detection comparison before and after vault construction

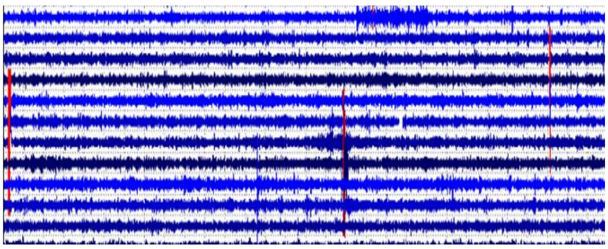


Figure 9. Background noise before vault construction

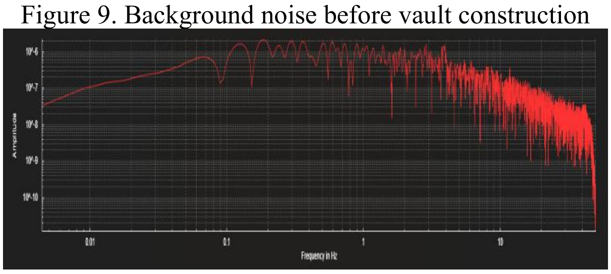


Figure 10. Amplitude when a car passed by after vault construction

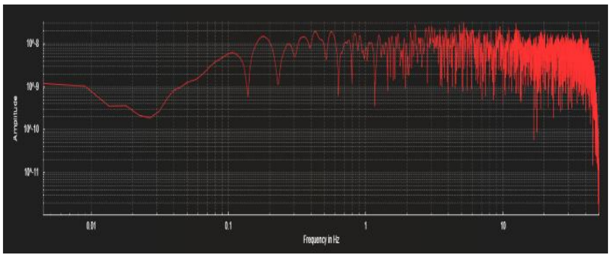


Figure 11. Amplitude when a motorcycle passed by after vault construction

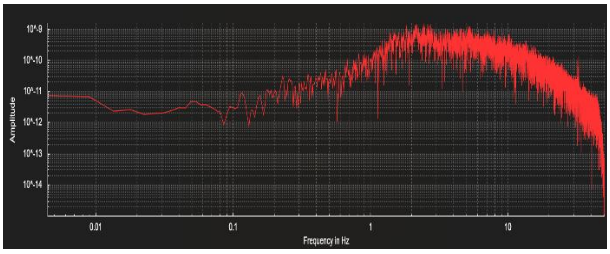


Figure 12. Amplitude recorded at school hours after vault construction

This is a comparison of environmental noises levels before and after deployment of the Raspberry Shake into the vault. The results show the effectiveness of the vault in reducing the noise levels detected by the Raspberry Shake. Figure 9, depicts the noise levels recorded prior to the sensor's deployment into the vault. The amplitude versus frequency plot shows significantly higher frequency values (2Hz to 5Hz) range, indicating elevated noise level before proper installation. After the sensor was deployed in the designated vault, a noticeable reduction in noise was observed. Additionally, figures 10, 11, 12 illustrates the three amplitude versus frequency plots recorded from different vibration sources specifically, a passing car, a motorcycle, and school activity after the Raspberry Shake sensor was deployed. The results indicate that the vibrations caused by environmental noise were lessen and not interpreted as earthquake activity by the Raspberry Shake sensor.

4.3 Data collection comparison before and after vault construction

This section presents one of the unique features of installing the seismograph which is its underground deployment that provides more reliable and less noisy data collection.

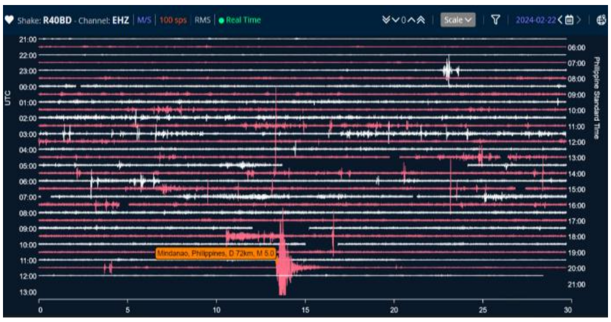


Figure 13. Data collection before vault construction

Figure 14. Data collection after vault construction

The difference in vibration or seismic activity detection before and after proper installation of Raspberry shake vault. As shown in Figure 13, higher levels of environmental noise, spikes, harmonics, and data gaps are evident before the Raspberry Shake was installed in the vault. During this period, the device was placed in a classroom, where nearby student activity such as footsteps and noise affected the readings. In contrast, the data collected after proper installation demonstrates the vault's effectiveness in significantly minimizing noise.

4.4 Alert system implementation

Figure 15. Alert system implementation

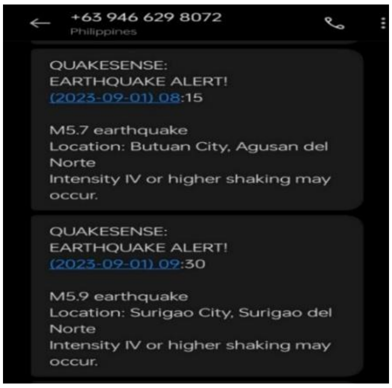


Figure 16. SMS notification alert

The implementation of the IoT-based earthquake alert system enables the detection of seismic activity and the issuance of public alerts based on predefined thresholds and parameters. The integration of a bell alarm, SMS notifier, and LCD display enhances and maximizes the system's capability to provide timely alerts, with the potential to contribute significantly to disaster preparedness and management. Integrating the GSM module with the alarm bell configuration enables effective and quick distribution of information through sending SMS notifications to limited designated recipients enabling timely and effective response actions.

4.5 Bell and SMS notification alert system

The integration of a bell and SMS notification system in the earthquake alert setup is centered on the ESP32 (WROOM) microcontroller, which serves as the main controller for processing seismic alerts and coordinating response mechanisms. Upon detecting seismic activity that reached the set parameter, the ESP32 activates a 5V relay module, which serves as an interface between the low-voltage controller and the high-voltage AC 220V alarm bell. This triggers a loud audible alarm, ensuring immediate awareness within the local area. Simultaneously, the ESP32 communicates with the SIM800L V2 GSM module via serial interface to send SMS alerts to designated recipients, extending the system's warning capabilities beyond physical boundaries. This dual-alert mechanism ensures both localized and remote warnings, enhancing the system's effectiveness in critical situations. The components were tested for reliability and synchronization, confirming the system's capacity to deliver timely alerts essential for earthquake preparedness and safety.

4.6 Lead time estimation based on historical data simulation

In the implementation of a simulated earthquake early warning system using the Raspberry Shake 4D and ESP32 microcontroller, where historical earthquake data is hardcoded as input, the lead time between data input and the triggering of alerts is primarily governed by system processing and communication delays. Once the ESP32 reads and processes the simulated data, based on the experimental testing, the **audible bell alarm is activated almost instantly within 100 milliseconds** via a 5V relay. Meanwhile, the **SMS alert**, transmitted through the SIM800L V2 GSM module, is typically **delivered within 3 to 6 seconds**, depending on the network quality. This demonstrates that, even in simulated environments, the designed alert system can effectively replicate the alert logic flow and provide actionable outputs within an acceptable timeframe.

In terms of the alarm system's overall efficiency, since the bell alarm activates nearly instantly, and the SMS typically reaches users within 5 seconds, both warnings will likely occur well before the arrival of the S-wave if alerts are based on P-wave arrival (or even pre-determined simulation data). Thus, the system can provide timely alerts, potentially offering at least 7–12 seconds of lead time in ideal conditions, sufficient for basic protective actions like "drop, cover, and hold."

While historical input limits dynamic detection, it serves as a practical prototype. For real-time data from RS4D, further integration with real seismic triggers would enhance precision, but this design demonstrates that the system can operate within a useful time window for earthquake early warning.

4.7 Bell alarm and SMS notification alert ranges

The earthquake early warning system uses a bell alarm and SMS notification to alert individuals. The **bell alarm can be clearly heard within a 40–60meter radius**, covering an area even outside the premises of Hinang Building, making it effective for nearby individuals who are not included in the SMS list. It provides immediate, audible alerts, but its reach is limited by distance, noise, and obstructions. The **SMS notification**, on the other hand, **can alert designated recipients regardless of location, as long as GSM service is available**. However, it is typically limited to a small number of preconfigured contacts (10–42 per instance), and may experience a short delay of about 4–6 seconds. Together, these two systems provide complementary coverage—the bell serves local, instant warnings while the SMS reaches selected users remotely.

4.8 Accuracy evaluation

$$Accuracy = \frac{TP + TN}{TP + FP + TN + FN}$$

$$Accuracy = \frac{20 + 18}{20 + 2 + 18 + 0}$$

$$Accuracy = 0.95 * 100 = 95\%$$

5. CONCLUSION AND RECOMMENDATION

In essence, the study achieved its primary objective which is to design and implement an IoT-based earthquake alert system integrating a bell alarm for audible alerts and SMS notifications for digital warnings.

Moreover, the study also accomplished its specific objectives, which is to:

- Enable real-time data sharing in local and international server.
- Reduce environmental noise interference.
- Integrate a bell alarm for audible earthquake alert.
- Enable an SMS notification alert for digital earthquake warning.

The following recommendations are proposed for future improvements and implementation:

1. Extended Deployment and Scaling
2. Government Agencies Collaboration

Overall, the deployment of the Raspberry Shake 4D in this study highlights its practical application in localized seismic monitoring. With strategic enhancements, this system can significantly contribute to earthquake preparedness, risk reduction, and public safety in seismic-prone regions.

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