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Implementation of Wireless Sensor Network (WSN) for Earthquake Detection

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Abstract – **The current earthquake monitoring system uses a seismometer that can capture seismic vibrations very well but is expensive, heavy, and difficult to launch. Therefore, earthquake monitoring stations can only be launched in a few places in small numbers. This study aims to implement a Wireless Sensor Network (WSN) system for earthquake monitoring. The WSN system has advantages in cost, size, and ease of launch, so it is very appropriate to be used for this purpose. An earthquake detection sensor system has been designed in this study using a vibration sensor and a piezoelectric sensor. When an earthquake occurs, the resulting shock will trigger the vibration sensor and activate the sensor *node*. The shock data is then captured by the piezo sensor and processed by the microcontroller using Fast Fourier Transform (FFT) to determine the frequency value of the shock. The data is then sent to a gateway via a sensor network and uploaded to the Cayenne monitoring website. Operators can then view the data on the website. Three sensor nodes are implemented in this study. The test is done by placing those sensor nodes together in random positions. A shock is then given to the three sensor nodes, and the resulting data is then observed. The results show that the three sensors can detect, retrieve, process, and send shock data to the Cayenne monitoring website.**

Keywords: Earthquake Detection, Disaster Monitoring, Wireless Sensor Network.

I. INTRODUCTION

Earth is often hit by various types of natural phenomena and natural disasters. Both events occur due to changes or disturbances to various components that exist in nature. Natural disasters are natural events that can cause many losses, for example, earthquakes, tsunamis, hurricanes, floods, and volcanic eruptions.

Natural disaster management must be carried out as quickly as possible so as not to cause a more significant impact. The disaster management process can be improved if natural disaster events are known or detected in advance. The disaster detection process can be done by studying the early signs of the disaster.

Earthquakes are generally referred to as vibrations that occur on the ground suddenly and can cause the collapse of buildings, thereby claiming thousands of lives [1]. Earthquakes can occur for two reasons: volcanic activity (volcanic earthquakes) and collisions or shifts in the earth's plates (tectonic earthquakes). We can anticipate volcanic earthquakes by paying attention to the condition of the mountain, but tectonic earthquakes cannot be anticipated because there are no known signs. However, both types of earthquakes will produce two types of seismic waves. Therefore, we can predict earthquake events through these waves.

The first wave is called the P-wave (Primary wave), and the second wave is referred to as the S-wave (Shear wave) [2]. P-wave and S-wave have fast propagation values of 6-7 km/s and 3-5 km/s, respectively [3], so the P-wave propagates faster than the S-wave [2,4]. P-wave has a higher frequency than S-wave, where P-wave ranges from 1-10Hz, while S-wave has a frequency below 1Hz [2], [4]–[6]. However, S-wave can do more damage than P-wave [3]. Early warning systems are generally designed enough to detect P-waves early.

The earthquake early warning system is a fascinating study [3]. An early warning can save many lives seconds and minutes before a disaster strikes [1]. The current earthquake monitoring system uses a seismometer that can capture seismic vibrations very well but is expensive, heavy, and difficult to install [2,4]. Therefore, earthquake monitoring stations can only be launched in a few places [2,4]. The early warning system also does not require high accuracy, so the quantity value takes precedence over the quality value.

Some references use the Wireless Sensor Network (WSN) to form an earthquake early detection and warning system [1,3]. WSN is a power-efficient sensor network that measures, processes, and informs the surrounding environment. For example, reference [7]–[9] has conducted a literature study on using WSN as earthquake detection and warning system and concluded that WSN is a good solution for disaster management activities. The characteristics of WSNs, which are energy efficient, inexpensive, and can be launched quickly, are one of the reasons for using WSNs in disaster management [5].

This research will try to apply WSN for detection and early warning of earthquakes using a simple prototype and components that are common and inexpensive.

II. METHODOLOGY

WSN has been widely used in various fields, one of which is the development of methods for detecting earthquakes. In the reference, there are three main

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components in WSN: nodes, gateways, and software. The node serves to detect or collect data in the field. The gateway serves as a medium for sending and receiving data from the node to the software, and then the data sent will be processed in the software.

Liu et al. explained in their work the challenges they faced in detecting earthquakes. Specifically, the study looked at the volcanic earthquake detection system. The challenges they faced are that real-time seismic data transmission is complex because it requires a large bandwidth. Also, high computing power is required to calculate P-waves accurately, making it difficult for low-power systems to do so [4].

Rahman et al. described other methods that could be used to detect earthquakes with WSN apart from utilizing the waves generated during an earthquake, namely by paying attention to animal movement patterns with WSN, monitoring underground water pressure, and monitoring radon gas [9]. They also explained, in a simple way, the method of developing WSN with ICT (Information Communication Technology).

Several research references also support this research. For example, Benkhelifa et al. described various projects that use WSN for disaster management. Some of the projects described in the paper are “SENDROM (Sensor Network for Disaster Relief Operation)”, “INSYEME (Integrated System for Emergency)”, “Telemedicine with WSNs”, “WINSOC (Wireless Sensor Network with Self Organization Capabilities for Critical and Emergency Applications)”, “USN4D (Ubiquitous Wireless Sensor Network for Development)”, “AWARE”, and “MiTag” [10].

Tan et al. discussed in detail how WSN is used to detect and manage volcanic earthquake disasters. They examined the quality of data from WSN related to earthquakes, which were then used to detect volcanic seismic waves. They also use new algorithms for processing the data. The algorithm is implemented using TinyOS to evaluate 24 TelosB motes over 5.5 months [2].

Liu et al. conducted a study to estimate the time of earthquakes due to volcanoes by detecting P-wave (Primary wave). The network architecture is hierarchical, with many inexpensive sensors capable of picking up seismic signals. In addition, a coordinating sensor is used to perform data processing. It is explained in their work that each sensor will select one of the signal segments and process it first. This process is known as compressive sampling [4].

Then, Lara et al. conducted a research to determine the optimal topology and number of sensors to monitor volcanoes in real-time. In their study, the ADXL202E accelerometer sensor was used, and it was concluded that the appropriate topology was a random topology using 12 nodes [5].

Alphonsa and Ravi conducted a research to produce an early warning system related to earthquakes using IoT and WSN. The components are inexpensive: accelerometer, vibration sensors, PIC (Peripheral Interface Controllers) microcontrollers, and the ZIGBEE communication system. Furthermore, the system can display the results using the LCD screen.

Based on the related works that have been discussed previously, this study tries to take advantage of cheaper components. The system used in this study consists of earthquake detection and monitoring system.

Figure 1 shows an overview of the designed system. Figure 1 point (1) describes a collection of sensor nodes placed separately at several locations. Point (2) describes the Sink, which is in charge of receiving data from each sensor node and forwarding it to the monitoring website via the internet. Finally, point (3) describes a monitoring website that can be accessed via the internet. The monitoring website will display a graph of earthquake events detected by each sensor node.

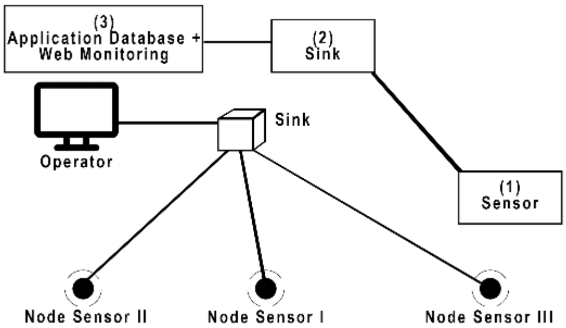

Figure 1. Overview of WSN Implementation for Earthquake Detection

Figure **2** displays the components used in each sensor node along with their wiring diagram. A Sensor node consists of Battery as a sensor power source; 5V IC Regulator LM7805; ATmega 328P as a microcontroller; NRF24L01 as a wireless communication module; SW-420 vibration sensor and Piezo sensor as an earthquake signal capture sensor.

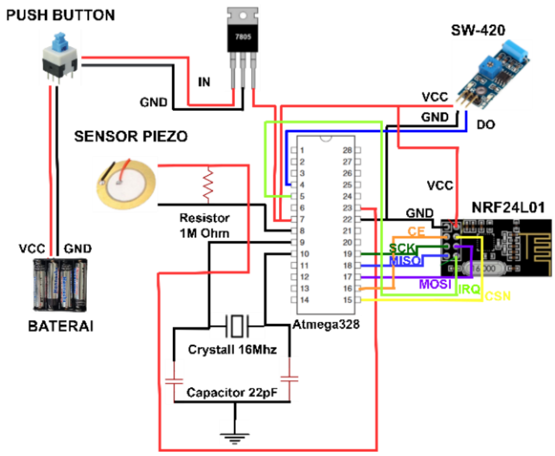

Figure 2. Sensor node wiring diagram

The Push button is used to activate the sensor node manually. Regulator IC is used to stabilize the system voltage. Other peripherals are connected to microcontroller pins. The SW-420 output pin is connected to pin 4 (external interrupt pin). This is so that the microcontroller can actively retrieve and send data when the sensor detects a strong vibration. Next, the Piezo sensor is connected to pin 23 of the microcontroller (*Analog-to-Digital Converter* pin). Then the NRF24L01 radio module uses the Serial Peripheral Interface (SPI) protocol to communicate with the microcontroller, so it is connected to the SPI pin of the microcontroller. Figure 3 shows the sensor node that has been assembled.

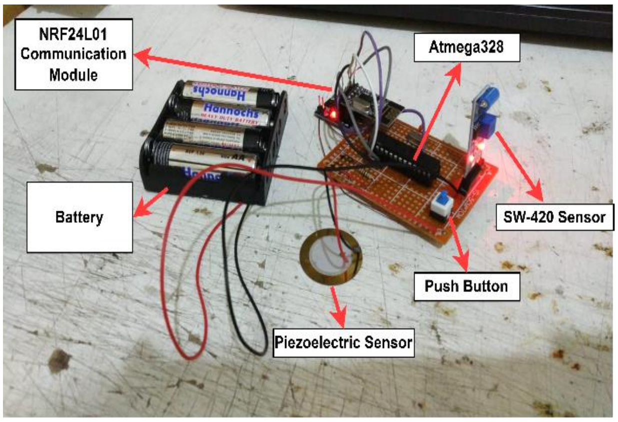

Figure 3. Result of wiring node sensor

Figure 4 shows the sink system used in this study. The sink system consists of two components: a NodeMCU ESP32 microcontroller and an NRF24L01 radio module. We use the ESP32 microcontroller because it is equipped with a WiFi module. Figure 4 below shows the wiring of the sink.

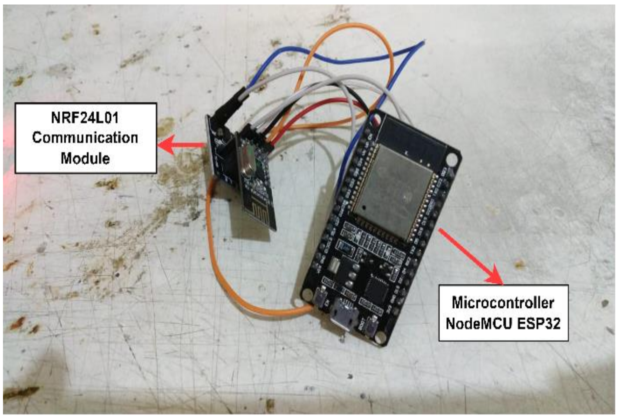

Figure 4. Result of wiring sink

The following is a simple explanation of the main components used in the existing system.

The SW-420 Vibration Sensor is a vibration sensor that provides a logic high ('1') when it detects vibration and a logic low ('0') when it does not [11]. Author of reference [12] has applied this sensor in his earthquake monitoring system, and the system has been able to detect shocks from a long distance. Figure 5 shows the SW-420 vibration sensor.

Figure 5. SW-420 Vibration Sensor

Piezoelectric sensors can be used to measure pressure changes. This sensor has two parts, namely the positive terminal and the negative terminal. The positive terminal is the inner circle that functions to produce a positive voltage. The negative terminal is the sensor's outer circle, which provides a negative voltage. The sensor will generate positive and negative voltages based on the distance between the terminals. The vibration signal will press and pull the two plates so that a positive and negative voltage will appear at the two terminals. This sensor has an impedance of 500Ω, a voltage of 30Vp-p, and a pressure sensitivity of 5V/µƐ [13]. R. Hoque et al. has used this sensor to detect the earthquake's initial vibration but did not use it as the primary sensor to measure the magnitude of the earthquake vibration [14]. Figure 6 shows an image of a piezoelectric sensor.

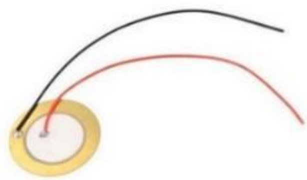

Figure 6. Piezoelectric Sensor

NRF24L01 is a long-range wireless communication module that uses the 2.4GHz frequency. This module has a bandwidth of 2Mbps, which is more than enough to transmit data from the sensor node to the sink. Furthermore, the power used by this module is also relatively low, namely 12.3mA, when actively transmitting data, so it is very suitable for use in WSN systems [15]. Figure 7 shows an image of NRF24L01 communication module.

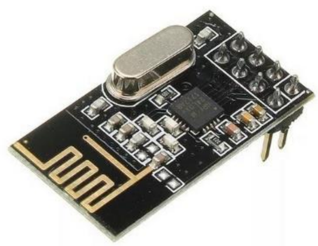

Figure 7. NRF24L01 communication module

FFT (*Fast Fourier Transform*) is used to process signals captured using Piezo sensor. FFT can show the intensity and frequency of the signal that makes up the signal [16]. The signal frequency with the largest amplitude will be sent to the website for monitoring.

The system testing process is carried out in two scenarios. First, the sensor nodes will be placed in several different places, and then a shock will be given around the sensor nodes. The second scenario is done by shaking the location of the sensor node. Both scenarios were carried out to see the response of the sensor nodes related to the vibrations generated.

III. Results dan Discussion

The test is carried out in a room by placing sensor nodes in different locations. The distance between the sensor and the sink is 1 meter. This distance ensures that data transmission from the sensor node to the sink can run properly.

Sensor node 1 is placed on a soft and not sofa chair, sensor node 2 is placed on a small table, and sensor node 3 is placed on a medium-sized table and is thicker than the table for sensor node 2.

The data generated by the sensor will be sent directly to the website. This study uses the Cayenne website to monitor. Figure 8 shows the website dashboard view.

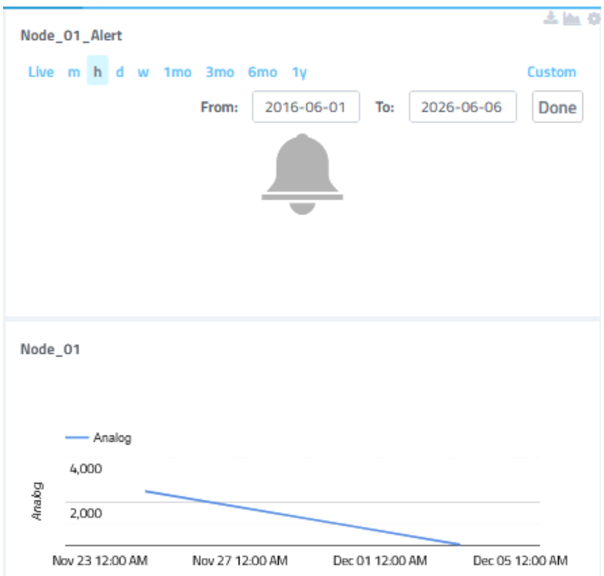

Figure 8. Widgets used on monitoring websites

Each sensor node displays data on the website through two widgets: the line chart widget and the lamp widget. The line chart widget displays a graph of the vibration amplitude of the earthquake detected by the sensor. The lamp widget signals the operator that the sensor has detected an earthquake.

The detection results for sensor node 1 for the first test scenario are shown in Table 1. The values in the table are presented in graphical form in Figure 9 and Figure 10. First, the line chart in Figure 9 describes the value of the frequency (Hz) of vibration observed by the sensor every time. Then, the warning graph depicts the warning given by the sensor when it detects vibration. The warning values can be '0' or '1', where the value '0' indicates that the sensor does not detect a vibration, and the value '1' indicates that the sensor detects a vibration. This description applies to the tables and graphs shown in the following paragraphs. The table shows that the sensor node is active when it is hit and can determine the frequency of the vibration it observes.

Table 1. Sensor node 1 detection result – first scenario

Time	FFT Value	Alert Value
04:25:17	0	0
04:24:15	4550.848	1
04:23:13	0	0
04:22:42	0	0
04:21:55	0	0
04:20:53	0	0
04:20:23	0	0
04:19:52	0	0
04:19:19	0	0
04:18:17	21.672	1
04:15:26	0	0

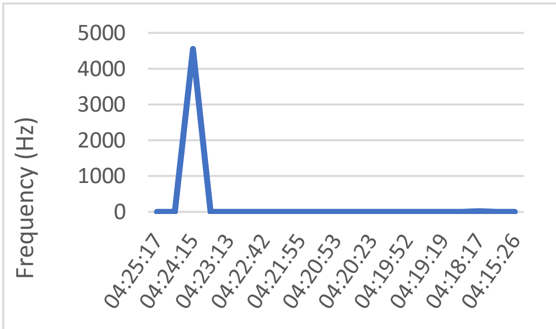

Figure 9. Line chart of node 1 in the first scenario

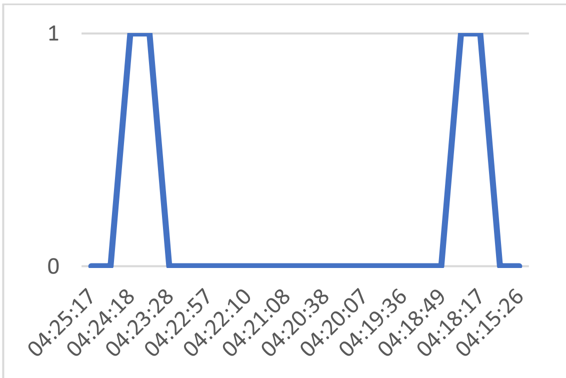

Figure 10. Warning graph of node 1 in the first scenario

Based on the graph, it can be observed that the sensor detects >4500Hz vibration. The alert graph also shows that the sensor detected two vibrations at minute 4:15–4:18 and 4:23–4:24.

Table **2** shows the detection results of sensor node 2 in the first scenario. The values in the table are displayed in graphical form in Figure 11 and Figure 12. Like sensor node 1, sensor node 2 is active when given a shock and can determine the frequency of vibrations it observes.

Table 2. Sensor node 2 detection result – first scenario

Time	FFT Value	Alert Value
04:25:17	0	0
04:24:15	4550.848	1
04:23:28	0	0
04:22:58	0	0
04:22:11	0	0
04:21:08	0	0
04:20:38	0	0
04:20:08	0	0
04:19:36	0	0
04:19:05	0	0
04:18:17	21.672	1
04:17:45	246.629	1
04:15:41	0	0

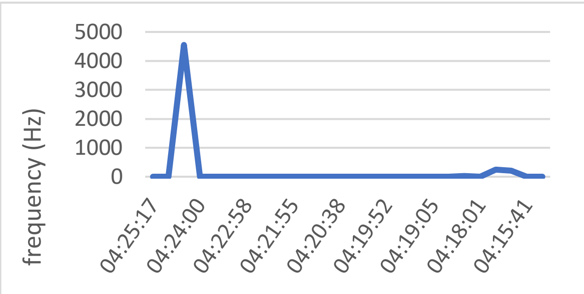

Figure 11. Line chart of node 2 in the first scenario

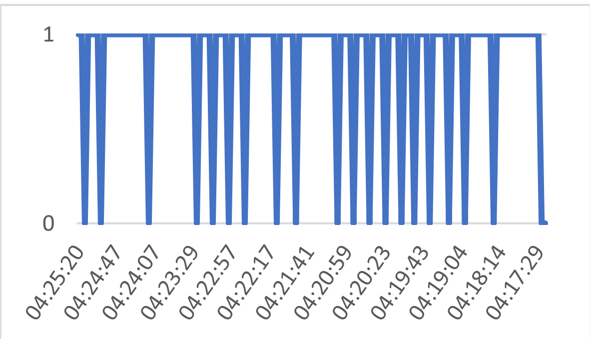

Figure 12. Warning graph of node 2 in the first scenario

Figure 11 shows a 4500 Hz vibration at minute 4:24 and a 207-246Hz vibration at minute 4:15–4:17. Unfortunately, the warning graph for sensor node 2 in Figure 12 indicates that the sensor observed many vibrations. This may be caused by noise on the SW-420 vibration sensor; thus, the microcontroller is active when there is no vibration. This problem will be observed and fixed in future research.

Table 3 shows the detection data from sensor node 3 in the first scenario. The data is displayed in the form of a graph in Figure 13 and Figure 14.

Table 3. Sensor node 3 detection results – first scenario

Time	FFT Value	Alert Value
04:25:17	0	0
04:24:15	4550.848	1
04:23:44	0	0
04:22:58	0	0
04:22:11	0	0
04:21:23	0.116	1
04:20:38	0	0
04:19:52	0	0
04:19:05	0	0
04:18:17	21.672	1
04:17:29	207.837	1
04:16:42	0	0
04:15:57	47.157	1
04:15:26	0	0

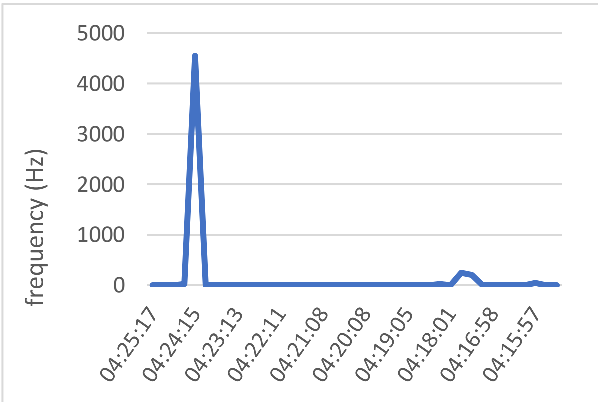

Figure 13. Line chart of node 3 in the first scenario

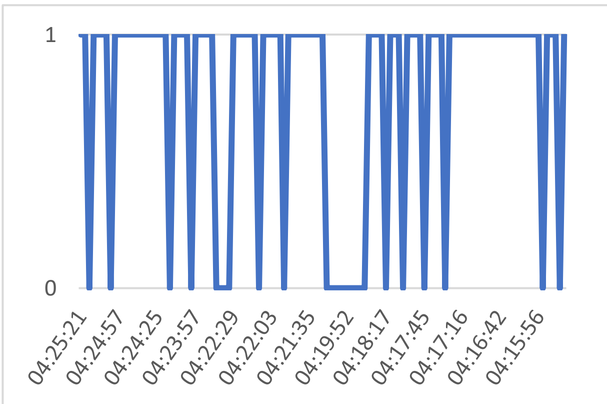

Figure 14. Warning graph of node 3 in first scenario

Figure 13 shows a 4500 Hz vibration at minute 4:24 and a 207Hz vibration at minute 4:17–4:18. The same as the warning graph of sensor node 2 in Figure 12, sensor node 3's warning graph in Figure 14 also indicates that the sensor detects a large amount of vibration. The following paragraphs will discuss the system testing results for the second experimental scenario.

Table 4 shows the detection results from sensor node 1 for the second scenario. Figure 15 and Figure 16 present the data in graphical form.

Table 4. Sensor node 1 detection result – second scenario

Time	FFT Value	Alert Value
04:26:19	235.546	1
04:25:32	0	0
04:25:02	0	0
04:24:15	4550.848	1
04:23:28	0	0
04:22:58	0	0
04:22:11	0	0
04:21:08	0	0
04:20:38	0	0
04:20:08	0	0
04:19:36	0	0
04:18:49	0	0

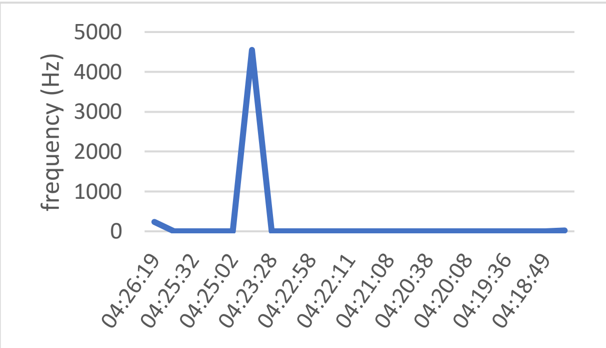

Figure 15. Line chart of node 1 in the second scenario

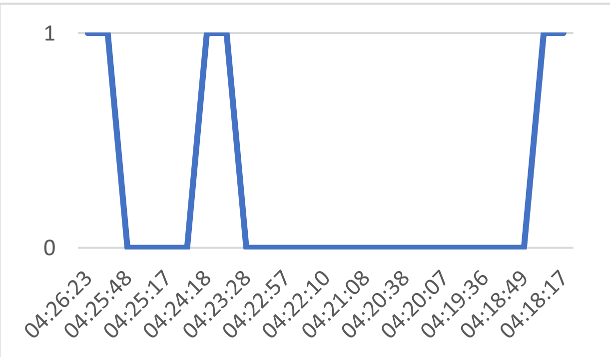

Figure 16. Warning graph of node 1 in the second scenario

Figure 15 shows that sensor node 1 detects a vibration with a frequency of 4500Hz at minute 4:24 and 235Hz at minute 4:26. Figure 16 indicates that the sensor successfully sends an alert to the monitoring website when vibration is detected.

Table **5** shows the data generated by sensor node 2 for the second scenario. The data is presented in the form of a graph in Figure 17 and Figure 18.

Table 5. Sensor node 2 detection results – second scenario

Time	FFT Value	Alert Value
04:26:49	31.076	0
04:26:19	235.546	1
04:25:32	0	0
04:25:02	0	0
04:24:15	4550.848	0
04:24:00	0	1
04:23:13	0	0
04:22:42	0	0
04:21:55	0	0
04:20:53	0	0
04:20:23	0	0
04:19:52	0	0
04:19:19	0	0
04:18:49	0	0
04:18:01	0	0
04:17:29	207.837	1

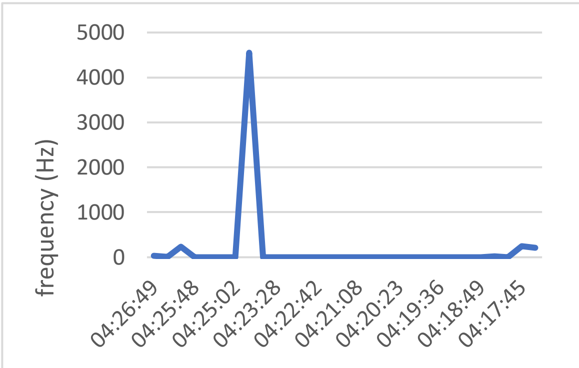

Figure 17. Line chart of node 2 in the second scenario

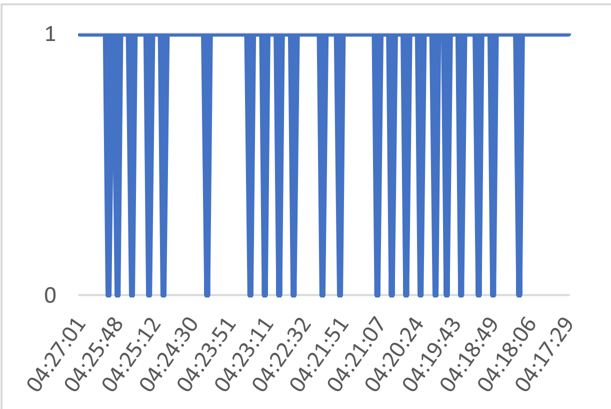

Figure 18. Warning graph of node 2 in the second scenario

In Figure 17, it is shown that sensor node 2 detects the highest vibration wave of 4500Hz at minute 4:24–4:25, then 246Hz vibration wave was detected at minute 4:17–4:18, and 235Hz at minute 4:26. However, the sensor node 2 warning graph in Figure 18 still shows that the sensor gives a warning even though there is no vibration.

Shows the detection data from sensor node 3 for the second scenario. The data is displayed in Figure 19 and Figure 20.

Table 6. Sensor node 3 detection results – second scenario

Time	FFT Value	Alert Value
04:27:04	0	0
04:26:19	235.546	1
04:25:32	0	0
04:24:15	4550.848	1
04:24:00	0	1
04:23:13	0	0
04:22:26	0	0
04:21:38	0	0
04:20:53	0	0
04:20:08	0	0
04:19:19	0	0
04:18:33	0	0
04:17:45	246.629	1

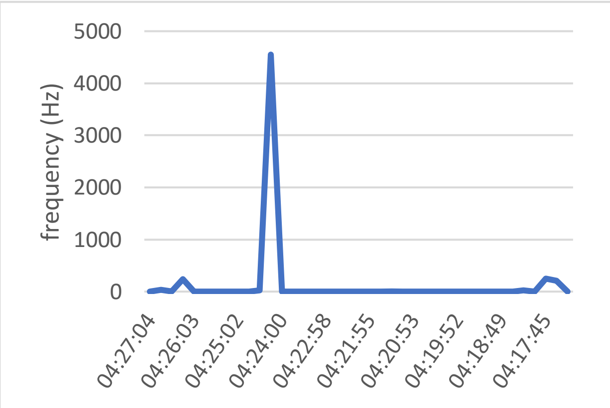

Figure 19. Line chart graph of node 3 in the second scenario

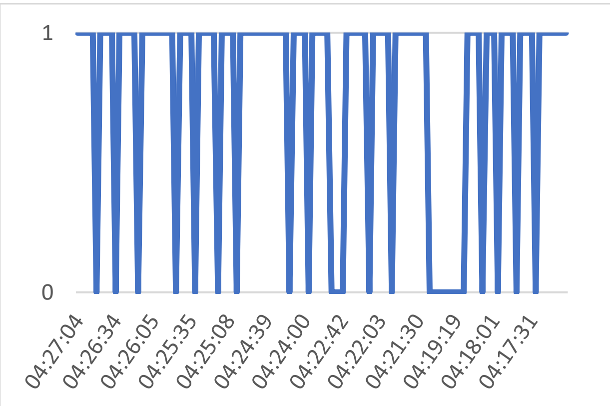

Figure 20. Warning graph of node 3 in the second scenario

In Figure 19, it is shown that there are vibration waves of 4500Hz at minute 4:24, 207-246Hz waves at minute 4:17, and 235Hz waves at minute 4:26. The warning graph Figure 20 still shows noise problems on sensor node 3.

Through the results obtained for the three sensor nodes in both scenarios, a discussion regarding the results is as follows.

First- It was observed that there were differences in the detection results obtained on the wave frequency graph and the warning graph on sensor nodes 2 and 3. The wave graph at sensor node 1 is in line with the warning graph. However, the wave graphs at sensor nodes 2 and 3 do not align with the warning graph. This may be caused by noise contained in sensor nodes 2 and 3. This problem will be further explored in the future research.

Second- It was observed that the vibration frequency observed by the three sensor nodes was in the range of 207– 4500 Hz. This value is much greater than the frequency of earthquake vibrations, which is typically below 10Hz. This indicates that the sensors used are inappropriate for an earthquake early warning system. Nevertheless, the author plans to use the accelerometer sensor in future studies as used in related works.

Third- It is observed that there is a pause in the detection data of the three sensor nodes. The shocks are given continuously in both experimental scenarios, so the sensor is expected to display these vibrations continuously. This problem may be caused by the lag time required to process and send the data to the website. The lag time is influenced by the microcontroller's speed in processing data, the speed of the radio module network, and the internet.

IV. Conclusion

In this study, an earthquake early warning system has been designed with two types of sensors, the SW-420 vibration sensor to detect the presence of vibration and a piezo sensor to measure the strength of the vibration. The proposed system has succeeded in detecting, retrieving, processing, and sending shock data to the monitoring website, but the resulting data is inaccurate. This is due to the limitations of the piezo sensor in capturing vibration signals. The piezo sensor can only capture signals in the 200 – 4500 Hz range. The response of the three sensor nodes to the two experimental scenarios shows that the sensor is still affected by noise, so the sensor can be active when there is no vibration. The author also observes a gap in the data received by the monitoring website. Further research on this system needs to be conducted, especially regarding the suitable sensors to detect and retrieve earthquake signal data. The delay in sending data from the sensor to the website must be reduced as much as possible. The system must also be designed to be more resistant to noise. Further development of this system must be done so it can be launched in real scenarios.

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