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Comparative Analysis Of Accelerometer Sensor And Piezoelectric Sensor Capabilities In The Early Warning System Earthquake Disaster

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ABSTRACT

An earthquake is a vibration or shock caused by a sudden release of energy from within the earth, which produces seismic waves. The Indonesian region is currently vulnerable to volcanic and tectonic earthquakes due to the Pacific Ring of Fire, where the Indo-Australian tectonic plate collides with the Pacific tectonic plate. So this study aims to conduct a comparative analysis between earthquake disaster early warning systems that use sensors Accelerometers and Piezoelectric sensors. The two types of sensors used are an Accelerometer IMU 9 DOF to measure the acceleration of ground motion and a Piezoelectric sensor to measure vibration. Using the ESP32 which processes sensor data and sends data to Google Sheets using the Wi-FI module in real-time. Sampling data from the readings of each sensor will be used to determine the most accurate use of sensors for detecting earthquakes. In the results of the comparison of the two sensors, the average percentage of errors where the sensor Accelerometer with an error of 0.104% and a piezoelectric sensor with an error of 100% so that it can be concluded that the Accelerometer sensor is more accurate than the piezoelectric.

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1. INTRODUCTION

An earthquake is a vibration or shock caused by a sudden release of energy from within the earth, which produces seismic waves. According to Howell (in Mulyo, 2004), an earthquake is defined as a vibration or a series of vibrations on the earth's surface that are temporary and spread in all directions. This phenomenon originates from the Earth's crust, which is located relatively close to the underground surface [1]. The current Indonesian region is vulnerable to volcanic and tectonic earthquakes due to the Pacific Ring of Fire, where the Indo-Australian tectonic plate collides with the Pacific tectonic plate [2]. Collisions and frictions between these plates cause high seismic activity in Indonesian territory which can result in earthquakes.

sensors are a core component in the earthquake early warning system, which detects ground movements that are early signs of an earthquake. The two types of sensors used are accelerometer sensors to measure the acceleration of ground movements and piezoelectric sensors to measure vibrations due to earthquakes. [3]

As technology develops, the monitoring of vibrations that occur in a building becomes more facilitated, allowing field data measurements to be carried out more effectively. This monitoring process involves the stages of observation, recording, and evaluation of various parameters attached to the building structure, aiming to assess the health and performance of the structure on an ongoing basis. [4]

This research aims to conduct a comparative analysis of earthquake disaster early warning systems using accelerometer sensors and piezoelectric sensors. By understanding more deeply the characteristics and performance of these two types of sensors, it is hoped that ways can be found to improve the effectiveness of early warning systems so that they can provide faster, more accurate, and reliable warnings to people who are threatened by earthquakes. This research is expected to make a significant contribution to efforts to reduce earthquake risk and protect human life. [5] [6] [7]

2. METHOD

3.1. Research Object and Subject

The object of this study is to make innovations and select the use of accelerometer sensors and piezoelectric sensors in earthquake disaster detection, while the subject in this study is a comparative analysis between accelerometer sensors and piezoelectric sensors.

3.2. Research Tools and Materials

The authors in this study use tools as research support, as well as utilize the necessary materials to support the research process. In this study, the tools and materials used include software and hardware, which are listed in tables 1 and 2.

3.2.1 Hardware

Table 1. Hardware Requirements List

No.	Name	Uses
1	Laptop	Used to create programs on the Arduino IDE. The laptop specifications used are the Asus Vivobook M1403Q laptop with an AMD Ryzen 7 5800H processor, 16 GB RAM memory, 512 GB storage, Radeon graphics type, and uses the Windows 11 Home Single Language operating system
2	IMU *9DOF* Accelerometer Sensor	Used to detect the acceleration of a vibration.
3	Piezoelectric Sensor	Used to detect vibration.
4	ESP 32	It is used to program and connect electronic devices to the internet.
5	Cable Jumper	Used to connect circuits between tools.
6	PCB Matrix Strip Board	Used as a board for assembling components.

1. IMU 9DOF Accelerometer

The 9 DoF (Degrees of Freedom) IMU (Inertial Measurement Unit) sensor is a type of sensor that is able to measure the movement and orientation of an object in 3D space. This sensor has 9 degrees of freedom (DoF) which comes from a combination of three sensors, namely Accelerometer (3 DoF): Measures linear acceleration on the X, Y, and Z axes, Gyroscope (3 DoF): Measures angular velocity (rotation) on the X, Y, and Z axes, and Magnetometer (3 DoF): Measures the magnetic field to determine the direction (compass) on the X, Y, and Z axes. [8]

2. Piezoelectric Module Sensor

A piezoelectric sensor is a device that utilizes the piezoelectric principle to convert pressure, vibration, or mechanical force into electrical signals. These sensors use piezoelectric materials such as quartz crystals or piezoelectric ceramics (e.g. PZT), which generate an electrical charge when subjected to mechanical deformation. The basic principle of piezoelectric sensors is based on the direct piezoelectric effect, where piezoelectric materials generate an electrical charge when subjected to external pressure or force. When mechanical stress is applied to a piezoelectric material, the distribution of the internal charge in the crystal changes, resulting in an electrical voltage on the surface of the material. [9]

3. ESP-32

The ESP32 is a microcontroller introduced by Espressif Systems in 2016. The microcontroller can be programmed using the Arduino IDE, an open source software, by installing the necessary hardware packages. One of the advantages of the ESP32 is the WiFi and Bluetooth features, which make it easier to develop IoT systems that require wireless networks. To connect the ESP32 to a WiFi network via the Arduino IDE, a dedicated library that supports WiFi connections is required. After that, the SSID and password of the WiFi network to be used need to be declared. [10]

4. Cable Jumper

Jumper cables are cables used to connect components in prototyping. These cables are usually connected to a microcontroller, such as a NodeMCU, via a breadboard. Depending on the need, jumper cables are available in three versions, namely male to female, male to male, and female to female. This cable has a length of about 10-20 cm and is a type of fiber cable with a round-shaped housing. In designing electronic circuit designs, these cables are required to connect various components (Ilham, Hardisal & Candra, 2020). [11]

5. PCB Matrix Board

PCB Matrix Strip Board, or better known as point PCB, is a printed circuit board consisting of an arrangement of holes and copper layers on a Cooper Clad PCB. This board is made of ebonite or fiberglass material, with one or both sides coated with a layer of copper. The main function of this PCB is to simplify the assembly of electronic circuits that only require jumper wires. [12]

3.2.2 Software

Table 2. Software Requirements List

No.	Name	Uses
1	Arduino IDE	Used to create programs that will be uploaded to the Arduino Uno.
2	Draw IO	Used for a wide variety of diagrams, such as research diagrams, block diagrams, and flowcharts.
3	Google Spreadsheed	Used to store data generated from sensors.
4	Vibrometer	Used to take data as a reference.

1. Arduino IDE

Arduino is an IDE (Integrated Development Environment) software that functions as a tool for developing microcontroller applications. Using Arduino, we can write source code, compile, upload compilations, and test applications through serial terminals. Microcontrollers themselves are chips or ICs (integrated circuits) that can be programmed to perform various specific tasks. The main purpose of embedding a program in a microcontroller is so that the electronic circuit can read and process the input, then produce the appropriate output. ESP8266, which is Java-based, allows users to run microcontroller applications on a variety of computer platforms. The programs used for these microcontroller applications are generally written in C/C+. [13]

2. Draw IO

Draw.io is a platform specifically designed for creating diagrams online. To use it, you just need a browser that supports HTML5 and an internet connection. Draw.io has also connected with Google Drive to store files, in addition to allowing export in JPG, PNG, SVG, and XML formats. [14]

3. Google Sheets

Google Sheets is an online-based spreadsheet app that allows you to create, format, and collaborate with others. The main advantage of Google Sheets is the ability to access data anytime and anywhere. Even though it is stored online, the data remains secure and always updated in real-time. In addition, Google Sheets also provides various features such as VLookUp, SUM, IF, filters, and graphs, which makes it easier for users to operate them. [15]

4. Vibrometer

Vibrometer is an Android application that utilizes data from the accelerometer sensor on a smartphone to detect earthquake vibrations. This application serves as a data comparison of the earthquake detection system that is being developed. The main purpose of this application is to provide a reference of the original earthquake values, which will later be compared with data from sensors. [16]

3.3. Block Diagram

Diagram blocks are basic representations of hardware that will be used to support the operation of a system. The following is an figure of the block diagram in this study.

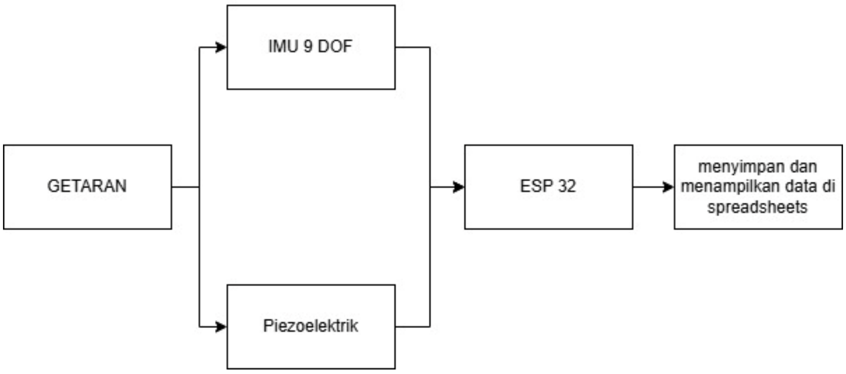

Figure 1. Block Diagram

In the system block diagram Figure 1, there is an input of an IMU 9 DOF sensor and a piezoelectric sensor connected to the ESP32 microcontroller and the magnitude data results will be sent to a spreadsheet and then displayed.

3.4. Schematics Design

The assembly scheme on this system uses the ESP32 device as the microcontroller, the IMU 9 DOF sensor and the piezoelectric ensor as input. Here are two sets of schematics of each sensor.

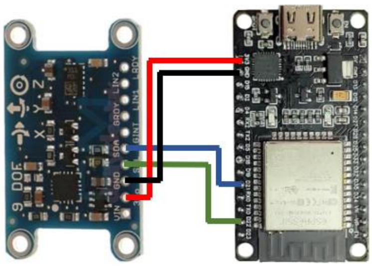

Figure 2. IMU 9DOF Schematics

For schematics, the design in figure 2 uses two components, namely IMU 9DOF as a sensor that detects earthquakes and ESP-32 as data processing

Table 3. Wiring IMU 9DOF

IMU 9DOF	ESP-32
VCC	VCC
GND	GND
SCL	Pin 21
SDA	Pin 22

In table 3 where vcc will be connected to vcc, GND will be connected to GND, SCL Pin will be connected to pin 21, SDA Pin will be connected to Pin 22

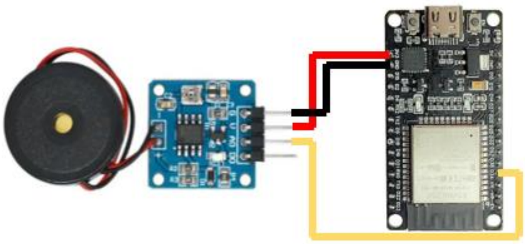

Figure 3. Piezoelectric Schematics

For the schematic design, the design in figure 3 uses two components, namely Piezoelectric as a sensor that detects earthquakes and ESP-32 as data processing

Table 4 Piezoelectric IMU Wiring

Piezoelectric	ESP-32
VCC	VCC
GND	GND
A0	Pin 34

In table 4 where vcc will be connected to vcc, GND will be connected to GND, Pin A0 will be connected to pin 34.

3.5. System Flowchart

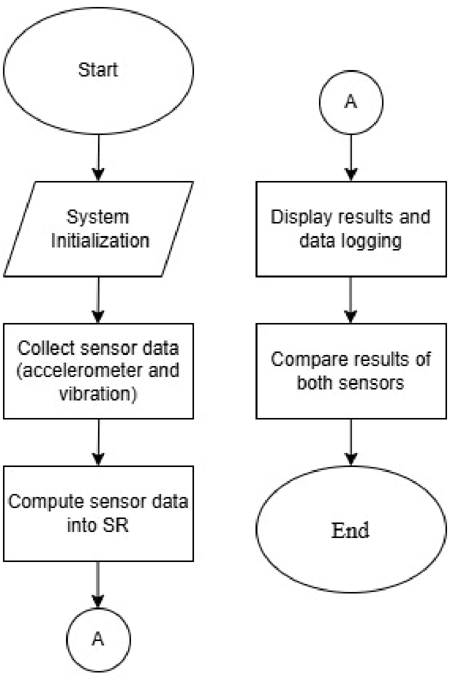

Figure 4. System Flowchart

The flowchart in figure 4 above illustrates the systematic process for data processing from accelerometer sensors and vibration sensors. The process begins with the initiation of the system, where the hardware and software are prepared to be ready for use. After that, the system retrieves data from both sensors, namely the accelerometer and vibration sensors, to obtain raw information. The data obtained is then further processed by performing certain calculations to convert it into a form that is suitable for the reference system (SR). The results of the calculation are then displayed to users and stored in the data logging process for analysis or documentation purposes. Furthermore, data from both sensors is compared to ensure accuracy and consistency of results, as well as detect possible errors. Once all the steps are complete, the process is terminated at the "Done" stage. This flowchart shows a structured workflow for the systematic collection, processing, and analysis of sensor data.

3. RESULTS AND DISCUSSION

4.1. Testing Techniques

The testing technique is one of the most important things because it will make an artificial earthquake that occurs directly, the following testing techniques are used:

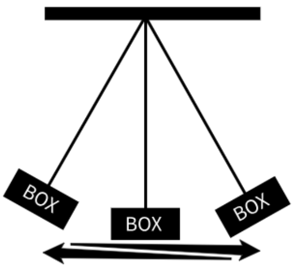

Figure 5. Presentation Techniques

This testing technique is carried out by swinging right and left. This is done because it tests the response of the structure to the movement of the soil that occurs during an earthquake.

4.2. Hardware Design Results

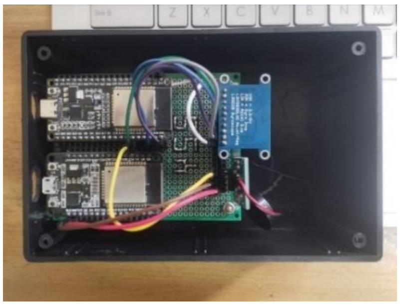

Figure 6. Hardware Design Results

The results of this hardware design use two Esp32s, an IMU 9 DOF sensor and a Piezoelectric sensor, where the IMU sensor uses +3.3v, GND, SDA, SCL while in Piezoelectric the pins used are +5v, GND, A0.

4.3. Software Design Results

Table 5. Software Design Results

DATE	TIME	PIEZOELEKTRIK
30/01/2025	23.06.46	9.4
30/01/2025	23.06.50	9.67
30/01/2025	23.06.52	10.67
30/01/2025	23.06.56	9.45
30/01/2025	23.07.05	10.2
30/01/2025	23.07.08	9.96
30/01/2025	23.07.12	5.73

DATE	TIME	PIEZOELEKTRIK
30/01/2025	23.06.42	10.06
30/01/2025	23.06.45	16.56
30/01/2025	23.06.48	15.09
30/01/2025	23.06.51	7.76
30/01/2025	23.06.54	7.39
30/01/2025	23.06.57	4.82
30/01/2025	23.07.00	1.04

In the results of this software design, the data is received in real-time on google spreadshet, which is shown in Table 5. Screenshot the data that is displayed is not all because there is a lot of data generated.

4.3. Data Capture

There are two data collection processes, namely data from sensor results and data from direct measurements using the vibrometer application. The accelerometer sensor data results can be converted by the following formula:

$$\mathrm{M} = \sqrt{x^2 + y^2 + z^2} \tag{1}$$

Meanwhile, in the Piezoelectric sensor, the data results can be converted by the following formula:

$$\mathrm{M} = 2.2 + 1.8\ \log a0 \tag{2}$$

So in the formula above M is the magnitude and a0 is the acceleration in the following data that has been converted according to the formula above: cm/det^2

Table 6. Sensor Data

Accelerometer	Piezoelectric	Vibrometer
2.0	0	2.2
2.9	0	2.6
2.8	0	3.5
2.7	0	3.3
3.7	0	4.1
2.5	0	2.8
5.0	0	5.2
4.5	0	4.6
3.5	0	4.0
6.3	0	5.1
5.0	0	5.0
3.6	0	3.9
3.4	0	3.6

In the data collection shown in table 5, data was generated as many as 10 samples/second from the Accelerometer and Piezoelectric sensors.

4.4. Data Analysis

This data analysis process aims to compare the results obtained by the 9DOF and Piezoelectric IMU sensors with reference values using a vibrometer application on a smartphone. To determine the percentage of error values, a fractional relative error formula is used, namely:

$$\in \mathrm{t} = \frac{Error\ Sebenarnya}{Nilai\ terbaca} x\ 100\% \tag{3}$$

Results of data analysis:

Table 7. Accelerometer Data Analysis

Piezoelectric	Vibrometer	Score difference	Percentage Value Error (%)
2.0	2.2	0.2	0.09
2.9	2.6	0.3	0.12
2.8	3.5	0.7	0.2
2.7	3.3	0.6	0.18
3.7	4.1	0.4	0.1
2.5	2.8	0.3	0.11
5.0	5.2	0.2	0.04

4.5	4.6	0.1	0.02
3.5	4.0	0.5	0.12
6.3	5.1	1.2	0.23
5.0	5.0	0	0
3.6	3.9	0.3	0.08
3.4	3.6	0.2	0.05
Average			0.104

The value of the data analysis results from the Accelerometer was 0.104%

Table 8. Piezoeellic Data Analysis

Piezoelectric	Vibrometer	Score difference	Percentage Value Error (%)
0	2.2	2.2	100
0	2.6	2.6	100
0	3.5	3.5	100
0	3.3	3.3	100
0	4.1	4.1	100
0	2.8	2.8	100
0	5.2	5.2	100
0	4.6	4.6	100
0	4.0	4.0	100
0	5.1	5.1	100
0	5.0	5.0	100
0	3.9	3.9	100
0	3.6	3.6	100
Average			100

The value of the data analysis results from Piezoelectric was 100%. From the average error of the two sensors, the smallest error is the accelerometer, so it can be concluded that the use of accelerometer sensors is more accurate in measuring the magnitude of earthquakes compared to piezoelectric.

4.5. Chart Comparison

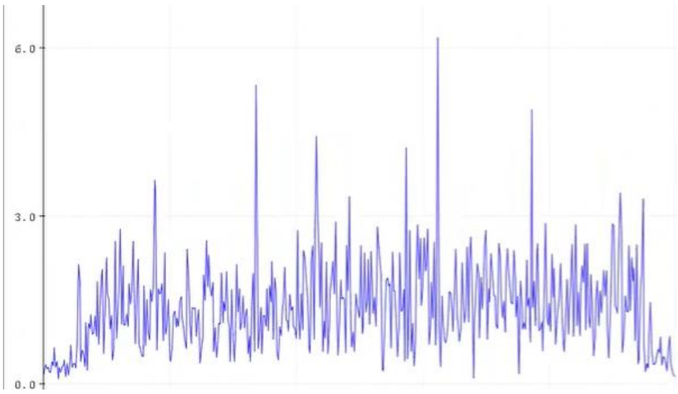

Figure 8 IMU 9 DOF Graph Results

Figure 8 is a graphic image generated from the IMU 9DOF accelerometer sensor where the sampling rate data is generated at 10 samples/second.

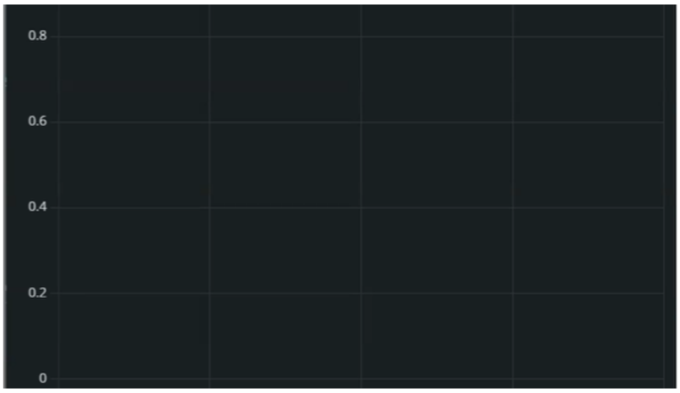

Figure 9 Piezoelectric Graph Results

In figure 9 the results of the piezoelektrial graph there is no Movement because the piezoelectric sensor has a very strong sensitivity

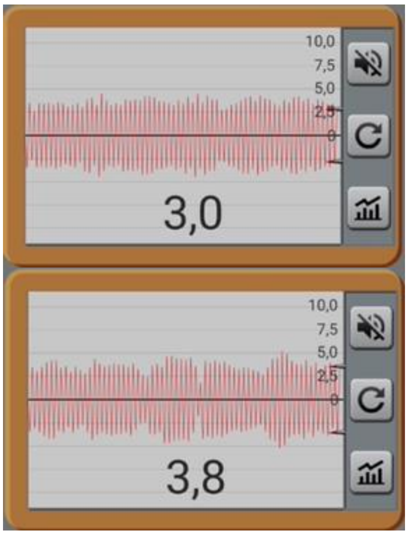

Figure 10 Vibrometer Graph Results

From the graph results, it was produced that the IMU 9 DOF graph produced a graph that was almost similar to the vibrometer graph result, while the piezoelectric sensor did not produce a graph because of the sensitivity of the sensor which must be strong.

4. CONCLUSION

Sampling data was collected using the highest data collection method, which was then converted into a vibration magnitude that represented the magnitude of the earthquake. From the software created on google spreadsheets data can be received in real-time. For analysis to the accuracy and validity of the data, the data from each sensor is compared with the vibrometer application. Piezoelectric sensors do not produce graphics due to the sensitivity of the sensor which must be strong. The results of the comparison of each sensor to the vibrometer application obtained results that were close to where the average error for accelerometer was 0.104%, while the average piezoelectric error was 100%. From the average error results, it shows that the accelerometer sensor is more accurate in measuring the magnitude of the earthquake compared to the piezoelectric.

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