Proceedings of the Technical Sessions, 41 (2025) 68-78
Institute of Physics, Sri Lanka

Development of a Low Cost Geophone for Finding Epicenter of an Earthquake

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1. ABSTRACT

In this study, a low-cost geophone system that uses triangulation and other analytical techniques to precisely locate the epicenter of seismic occurrences is developed. In order to determine the distance to the epicenter, the study uses Python programming to examine the interval between the arrival of primary (P) and secondary (S) seismic waves. Effective motion data capturing is made possible by the combination of an Arduino microcontroller with an MPU6050 sensor, enabling reliable deployment in a variety of settings, particularly those with inadequate infrastructure. The results show that inexpensive geophones may deliver accurate data on par with conventional seismographs, greatly expanding our knowledge of seismic activity and boosting early warning systems in seismically active areas. This emphasizes accessibility and efficiency in data collection and interpretation, which is in line with recent developments in inexpensive seismic instrumentation. In order to illustrate the low-cost system's usefulness in real-world applications, the study also compares the values it produces to those from traditional instruments. Recent studies that investigate sophisticated techniques for analyzing tainted data have provided evidence for the capacity to detect earthquakes using inexpensive sensors. All things considered, this study adds to the expanding corpus of work supporting the incorporation of reasonably priced technologies.

Key words: - Arduino microcontroller, Epicenter detection, Low-cost geophone, MPU6050 sensor, Python programming, Seismic monitoring, Tainted data analysis

2. INTRODUCTION

An earthquake is a natural disaster that occurs when tectonic plates beneath the Earth's surface suddenly release stored energy, leading to seismic waves that cause the ground to shake. The movement and interaction of these plates, along with stress build up along faults in the Earth's crust, are the primary causes of earthquakes. When the accumulated stress exceeds the frictional resistance along a fault, it can result in the rapid rupture of the fault, releasing energy as seismic waves. [3]By changing the stress and pressure inside the Earth's crust, human activities like mining, fracking, and nuclear testing can also cause seismic activity. Furthermore, the stress fields along fault lines can be influenced by elements such as the movement of tectonic plates against one another and variations in sedimentary loading or unloading, which can lead to earthquakes[4][3]. These intricate relationships affect how fractures break and spread along faults, which eventually results in seismic events that can have a big effect on the environment and communities.

Determining the precise location of an earthquake's epicenter is essential for evaluating possible risks, putting early warning systems in place, and supporting disaster relief activities. Despite its great effectiveness, traditional seismic monitoring technology might be unaffordable and unavailable in environments with limited resources. Traditional seismic monitoring technology can be expensive and difficult to implement in resource-limited environments due to the high costs of equipment, installation, and maintenance. These systems require reliable infrastructure like power and internet connectivity, which may not be available in remote areas. Additionally, specialized technical expertise is needed for setup and upkeep, further complicating deployment in places with limited resources. These factors make traditional seismic monitoring systems unaffordable and inaccessible in such regions. [5][6] To overcome these challenges, a low-cost geophone-based system has been developed for accurately locating earthquake epicenters. By employing a range of methods for epicenter determination and visualizing the results through graphing, this approach offers an affordable and effective solution for seismic monitoring, particularly in areas with limited resources. The importance of low-cost geophone in finding the epicenter of seismic events lies in their ability to provide high-quality data at an affordable price, making them an attractive option for researchers and scientists working in the field of seismology. The use of low-cost geophones can demonstrate that these instruments can provide useful information on the geometry and mechanics of seismic faults, even in areas with limited resources [1] [2].One of the significant advantages of low cost geophone makes them suitable for deployment in a variety of environments. This is particularly important in regions where the infrastructure for conducting seismic research may be limited. There are some challenges of conducting seismic research due to the difficult access to the area and the limited infrastructure, including power and communication systems [1].

2.1 Methods of finding the Epicenter

There are several techniques for locating an earthquake's epicenter, each with pros and cons of its own. Triangulation Method, Least Square Method, Inversion Method, Grid Search Method, Travel time Analysis and Azimuth method are widely used in seismology for earthquake monitoring, locating epicenters, and understanding the Earth's internal structure. While other advanced methods may require high technology and cost, these traditional methods remain essential and effective tools in earthquake research and monitoring [12][13]. Seismic station data and observed arrival times (S-P time differences) can be utilized to apply these principles in code for estimating the earthquake epicenter location.Each seismic station's geographic coordinates and observed arrival times are fundamental inputs for such location estimation methods in seismology.

2.2 IRIS Website [11]

The Incorporated Research Institutions for Seismology (IRIS) webpage refers to the online platform provided by the Incorporated Research Institutions for Seismology (IRIS) consortium, offering various functionalities and services related to seismological research and data analysis. The IRIS Web Portal allows employees to access Employee Self-Service and other administrative functions within the IRIS system and other university software solutions. Users can log in using their NetID and password to access features like Employee Self-Service for reviewing and updating personal information, PI reports, and work items from IRIS and Employee Self-Service for review and approval. Additionally, the IRIS Web Portal provides access to reports from the IRIS Data Warehouse, functions for shopping and ordering office supplies, links to miscellaneous functions like the Taleo Recruiting System and Concur Travel System, and more. The IRIS webpage serves as a central hub for employees to manage various administrative tasks and access essential resources within the university system [11].The IRIS dataset is a popular tool for testing Python code, ensuring its functionality and accuracy before applying it to more complex datasets.

3. METHODOLOGY

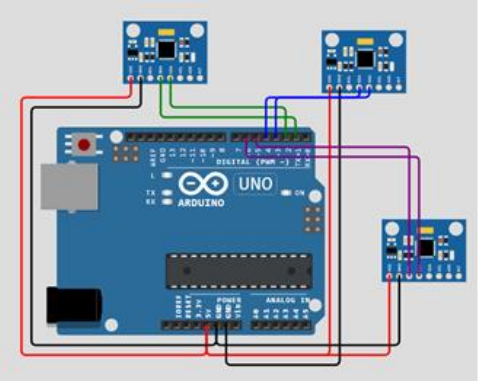


Figure 1. Schematic Diagram using Arduino and MPU6050

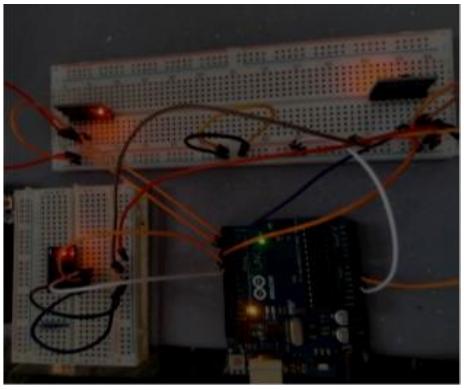
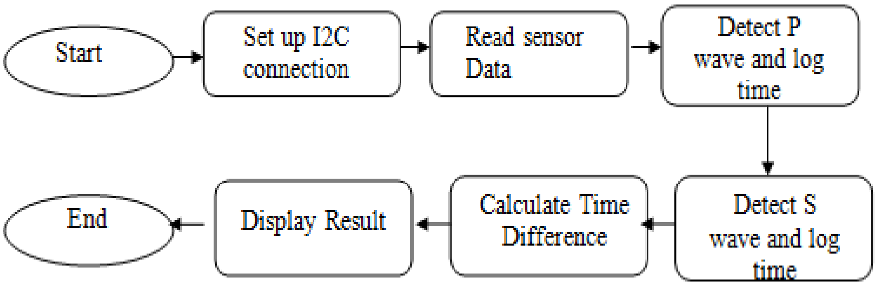


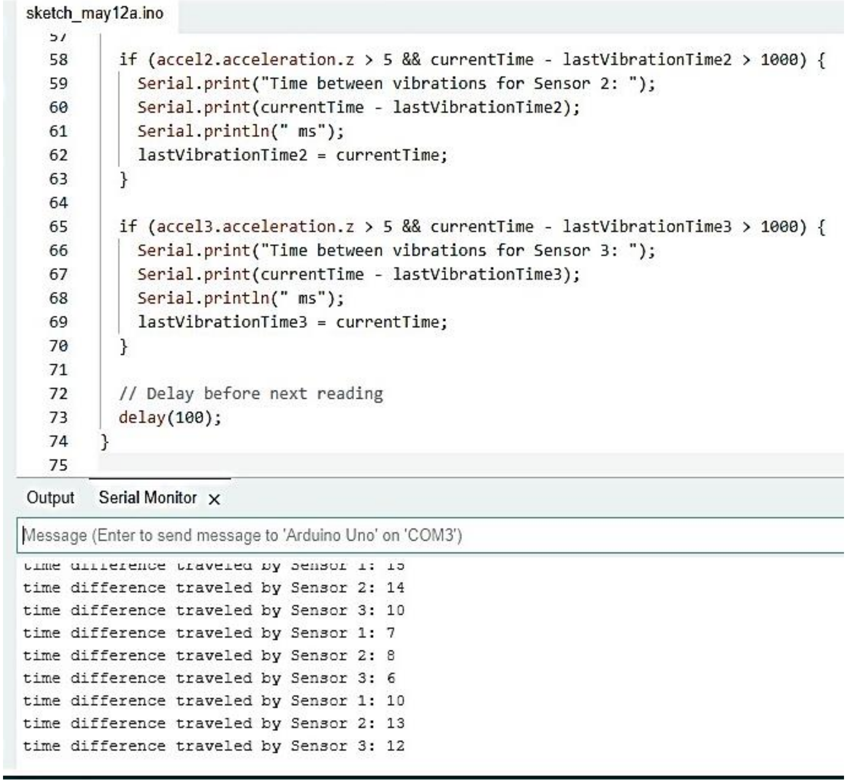
Figure 2. Arduino and MPU6050 based epicenter Detection Circuit Setup

An MPU6050 and Arduino Uno boards were used in the design and implementation of the low-cost geophone system for locating earthquake epicenters. The MPU6050 sensor was chosen for its affordability, compactness, and dual functionality, combining both an accelerometer and a gyroscope. The sensor provides raw output data in the form of acceleration along the X, Y, and Z axes from the accelerometer, as well as angular velocity data from the gyroscope. To calculate the time duration between the arrival of the P-wave and S-wave, the acceleration data is recorded as seismic waves pass through the sensor. The P-wave (Primary wave) arrives first, followed by the S-wave (Secondary wave). By measuring the time difference between the arrivals of these two waves, the time duration between them can be calculated using Arduino Software. Comparing this time difference across multiple sensors placed at three locations allows for the estimation of the distance to the epicenter using different methods. The epicenter was then calculated using Python programming.[7][8][5]Before applying the Python code to seismic data, its functioning was verified using the IRIS dataset to guarantee correctness. The system was built to estimate the distance to the epicenter and pinpoint its location using a variety of analytical techniques, such as triangulation and other cutting-edge approaches. This method showed that a scalable and affordable seismic monitoring solution was feasible. The system prioritized affordability and ease of use while guaranteeing dependable performance in identifying and evaluating seismic activity through a variety of techniques.[4][10]

Flow chart of the code:



The process begins with setting up I2C communication to initialize the MPU6050 sensor, which enables the Arduino to read accelerometer data. This data is crucial for detecting seismic waves. The Arduino continuously reads the accelerometer's output, which provides real-time acceleration values along the X, Y, and Z axes. To detect the P-wave (Primary wave), the code monitors the accelerometer for any significant change in acceleration, with a threshold indicating the arrival of the P-wave, which is typically faster and has smaller amplitude. When the P-wave is detected, the Arduino logs the current time. Afterward, the system continues to monitor for the S-wave (Secondary wave), which arrives slower and with larger amplitude. Once the S-wave is detected, its arrival time is also logged. The time difference between the P-wave and S-wave is then calculated by subtracting the P-wave detection time from the S-wave detection time. This calculated time difference is vital for estimating the distance to the earthquake's epicenter. Finally, the time difference between the two waves is either displayed on the serial monitor or saved for further analysis or processing.



```
  if (accel2.acceleration.z > 5 && currentTime - lastVibrationTime2 > 1000) {
    Serial.print("Time between vibrations for Sensor 2: ");
    Serial.print(currentTime - lastVibrationTime2);
    Serial.println(" ms");
    lastVibrationTime2 = currentTime;
  }

  if (accel3.acceleration.z > 5 && currentTime - lastVibrationTime3 > 1000) {
    Serial.print("Time between vibrations for Sensor 3: ");
    Serial.print(currentTime - lastVibrationTime3);
    Serial.println(" ms");
    lastVibrationTime3 = currentTime;
  }

  // Delay before next reading
  delay(100);
}
```

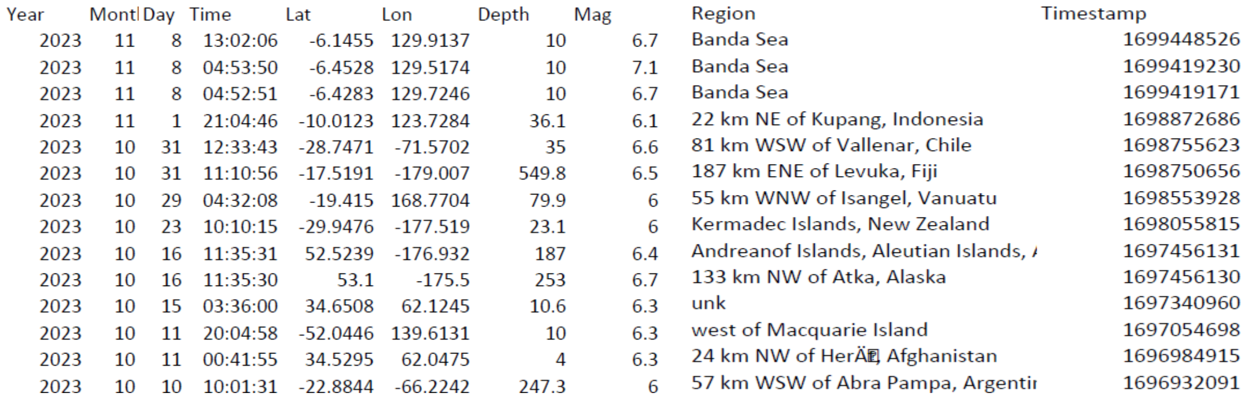
```
time difference traveled by Sensor 2: 14
time difference traveled by Sensor 3: 10
time difference traveled by Sensor 1: 7
time difference traveled by Sensor 2: 8
time difference traveled by Sensor 3: 6
time difference traveled by Sensor 1: 10
time difference traveled by Sensor 2: 13
time difference traveled by Sensor 3: 12
```

Figure 3. The time duration between the P-wave and S-wave for each sensor by serial Monitor of Arduino.

After obtaining the time duration readings from each sensor, these values were input into a Python code to calculate the earthquake's epicenter using different methods. The primary method for locating the epicenter was the triangulation method, for which the code was constructed. To verify that the code was functioning correctly, Actual earthquake data from the IRIS webpage was retrieved and input it into the code. This allowed calculating the latitude and longitude of the earthquake's actual location on the world map. After obtaining the latitude and longitude, the latitude reading along with the corresponding longitude was used to gather station data, including the distance between the stations and the earthquake's epicenter. Finally, this distance data was input into the code to check whether the calculations were accurate.

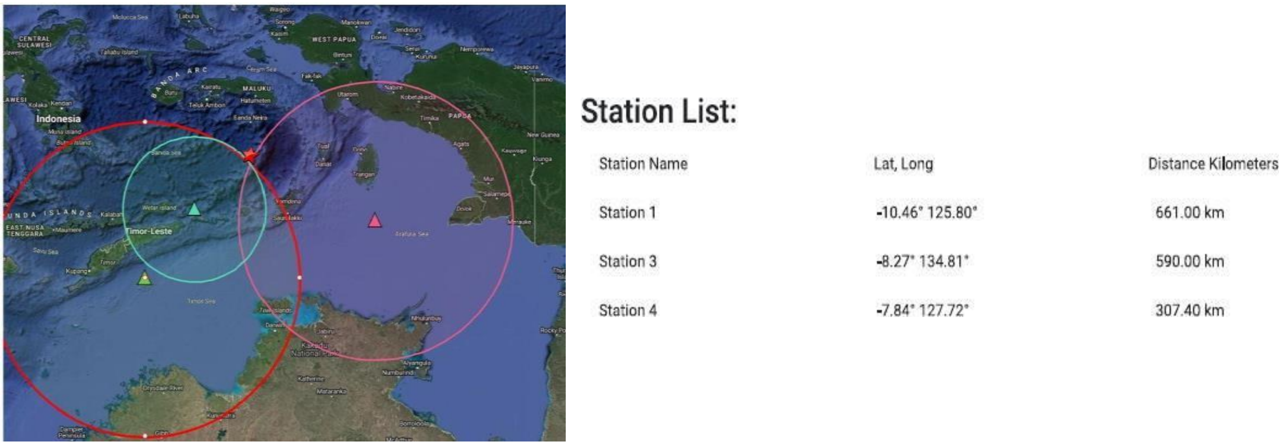
4. RESULT AND DISCUSSION

The first reading was chosen to find station data. First coordinates :- (-6.1455, 129.9137) Using the methods provided on the IRIS webpage, the station data associated with these coordinates was calculated. The station distance data was input into the code and used it to find the epicenter



Year	Mont	Day	Time	Lat	Lon	Depth	Mag	Region	Timestamp
2023	11	8	13:02:06	-6.1455	129.9137	10	6.7	Banda Sea	1699448526
2023	11	8	04:53:50	-6.4528	129.5174	10	7.1	Banda Sea	1699419230
2023	11	8	04:52:51	-6.4283	129.7246	10	6.7	Banda Sea	1699419171
2023	11	1	21:04:46	-10.0123	123.7284	36.1	6.1	22 km NE of Kupang, Indonesia	1698872686
2023	10	31	12:33:43	-28.7471	-71.5702	35	6.6	81 km WSW of Vallenar, Chile	1698755623
2023	10	31	11:10:56	-17.5191	-179.007	549.8	6.5	187 km ENE of Levuka, Fiji	1698750656
2023	10	29	04:32:08	-19.415	168.7704	79.9	6	55 km WNW of Isangel, Vanuatu	1698553928
2023	10	23	10:10:15	-29.9476	-177.519	23.1	6	Kermadec Islands, New Zealand	1698055815
2023	10	16	11:35:31	52.5239	-176.932	187	6.4	Andreanof Islands, Aleutian Islands,	1697456131
2023	10	16	11:35:30	53.1	-175.5	253	6.7	133 km NW of Atka, Alaska	1697456130
2023	10	15	03:36:00	34.6508	62.1245	10.6	6.3	unk	1697340960
2023	10	11	20:04:58	-52.0446	139.6131	10	6.3	west of Macquarie Island	1697054698
2023	10	11	00:41:55	34.5295	62.0475	4	6.3	24 km NW of HerÄ, Afghanistan	1696984915
2023	10	10	10:01:31	-22.8844	-66.2242	247.3	6	57 km WSW of Abra Pampa, Argenti	1696932091

Figure 4. The latitude and longitude of the earthquake epicenter represent the exact location of the earthquake on the IRIS webpage



Station List:

Station Name	Lat, Long	Distance Kilometers
Station 1	-10.46° 125.80°	661.00 km
Station 3	-8.27° 134.81°	590.00 km
Station 4	-7.84° 127.72°	307.40 km

Figure 5. Visual representation of the earthquake epicenter location based on station data and triangulation-

The coordinates, obtained from the IRIS webpage are (-6.1455, 129.9137), and code reads (-6.15, 129.94) after inputting the station data to the main code. Both are almost the same.

The time difference readings were taken from the Arduino for each station (Figure III):

- Station 1: 10 seconds
- Station 2: 13 seconds
- Station 3: 12 seconds

The time difference readings were input into the Python code to determine the epicenter using Triangulation Method.

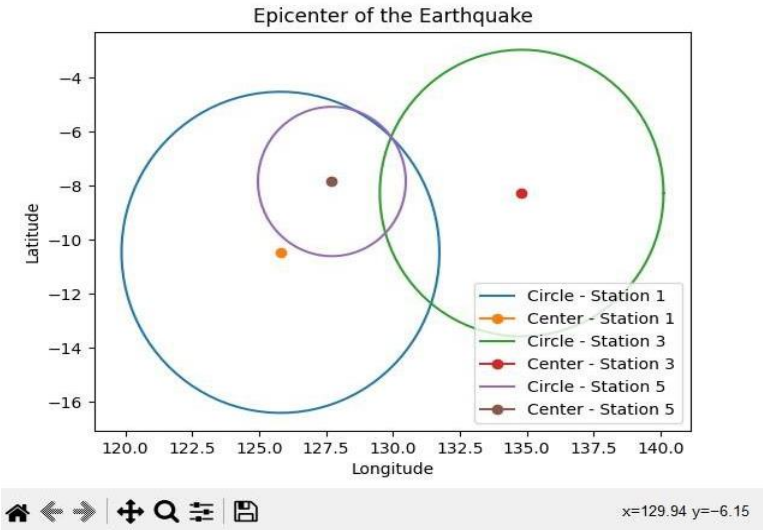


Figure 6. Implementation of the main code with IRIS data for epicenter calculation-

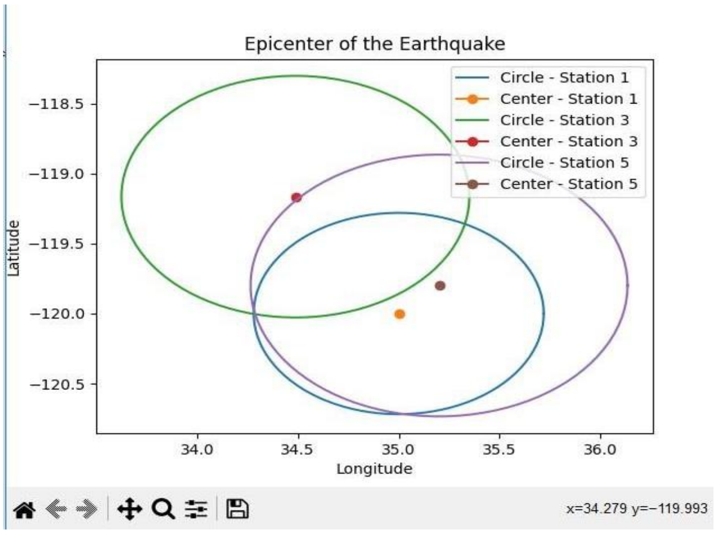


Figure 7. Output of python code based on Arduino time difference readings for Epicenter

Other methods were focused on to determine the epicenter, with the following results for each method. Python code was constructed for each of these methods

Table I:-Epicenter coordinates determined using different methods

Method	Latitude, Longitude
Triangulation	34.279, -119.993
Azimuth method	33.3855, -114.7277
Grid search method	35.188, -119.20
Inversion method	-326.3236, -119.8284
Least square method	15.098, -198.884
Triangulation method using simple Euclidean distance	29.91, - 133.33

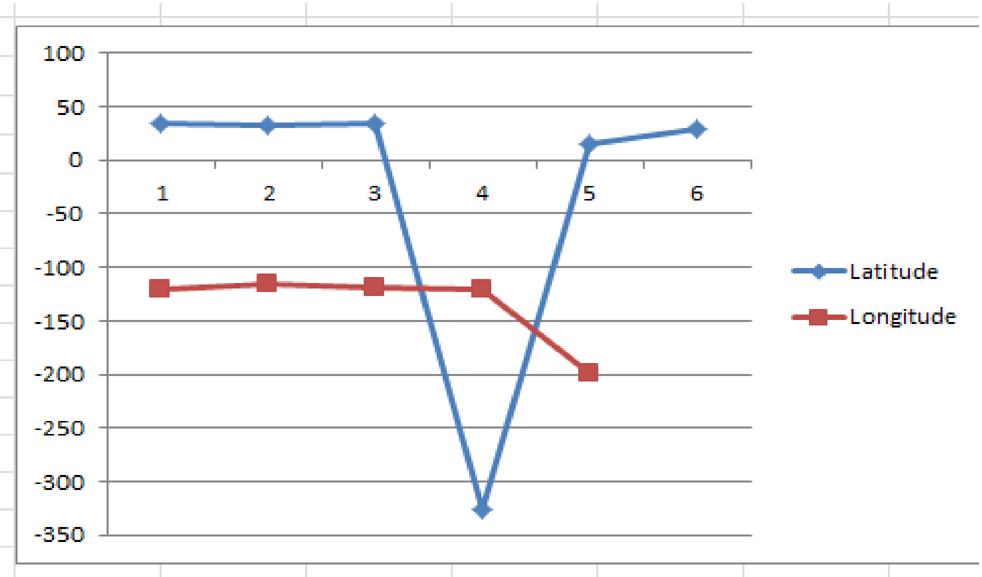


Figure 8. Variation in Latitude and Longitude across Different Epicenter Determination Methods

For each method, I plotted graphs of the latitude and longitude readings to observe the variation. The data demonstrates the use of multiple techniques to estimate the latitude and longitude of an earthquake epicenter, with triangulation (34.279, -119.993) identified as the most accurate method. Other methods show significant variations in their results, underscoring the importance of assessing the reliability and applicability of each technique in seismic analysis. The **azimuth method** (33.3855, -114.7277) provides coordinates reasonably close to those of triangulation. However, its reliance on the accurate determination of wave propagation direction and sensor orientation introduces potential sources of error. Small inaccuracies in azimuth angle measurements can lead to deviations in the estimated epicenter. The **grid search method** (35.188, - 119.20) also offers results relatively near the triangulation coordinates. This method's accuracy depends on the resolution of the grid and the quality of the input data. Slight deviations may result from approximations in the grid-based analysis, especially when computational resources limit grid density.

The **inversion method** (-326.3236, -119.8284) produced results far from the expected epicenter, indicating potential issues in the input dataset or parameter estimation. Inversion techniques rely heavily on solving complex mathematical models, which can magnify errors if initial conditions, wave arrival times, or assumptions about the Earth's structure are inaccurate. The **least square method** (15.098, -198.884) shows significant deviation, likely due to its sensitivity to noisy or incomplete datasets. This method minimizes the overall error, but outliers or inaccuracies in the data can skew the results, leading to coordinates far from the true epicenter. The **triangulation method using simple Euclidean distance** (29.91, -133.33) deviates from the accurate triangulation method due to its simplified approach. By ignoring the Earth's curvature and the complexities of wave propagation through heterogeneous geological structures, this method sacrifices accuracy for computational simplicity. The observed variations arise from several factors, including differences in algorithmic assumptions, the sensitivity of each method to input data quality, and their ability to account for complexities like wave refraction, reflection, and attenuation in the Earth's crust. While triangulation proves to be the most accurate due to its robust utilization of P- and S-wave arrival times across multiple sensors, other methods are influenced by their respective limitations, such as sensitivity to noise, parameter initialization errors, or oversimplified models.

This comparison highlights the critical need to use precise input data and carefully select methodologies based on the application requirements. While triangulation is effective for accurate epicenter localization, combining it with other methods could enhance reliability in cases where input data quality is variable.

5. CONCLUSION

This study presents the development of a low-cost geophone system for accurately locating earthquake epicenters using triangulation and other analytical techniques. The system combines an Arduino microcontroller with an MPU6050 sensor to capture motion data effectively, making it suitable for deployment in various settings, particularly those with limited infrastructure. By analyzing the time difference between the arrival of primary (P) and secondary (S) seismic waves, the system calculates the distance to the epicenter using Python programming. The research compared multiple methods for epicenter determination, including triangulation, azimuth, grid search, inversion, and least square methods. Results showed that the triangulation method (34.279, -119.993) provided the most accurate coordinates, while other methods exhibited varying degrees of deviation. This low-cost geophone system demonstrates the potential for affordable seismic monitoring solutions, particularly in resource-limited environments, and highlights the importance of precise input data and careful method selection for accurate epicenter localization.

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