Journal of Computation Physics and Earth Science
ISSN: 2776-2521 (online)
Volume 4, Number 2, October 2024, Page 54 - 61
https://journal.physan.org/index.php/jocpes/index

A Literature Review of Low-Cost Accelerometer Sensors for Earthquake Detection: Performance Analysis and Accuracy Assessment

Muhammad Rafi Athallah Disastra[1], Adhe Abdurrafi[2]

[1]Undergraduate Program in Applied of Instrumentation Meteorology, Climatology Geophysics (STMKG)
[2]Undergraduate Program in Applied of Industrial Engineering (Bhayangkara University)

Article Info

Article history:

Received August 1, 2024
Revised September 3, 2024
Accepted October 10, 2024

Keywords:

Low-cost accelerometers,
Seismic monitoring,
Accuracy

A B S T R A C T

This literature review synthesizes findings from 20 studies that explore earthquake detection systems using low-cost accelerometer-based sensors integrated with microcontrollers, such as Arduino, and other IoT technologies. The comparative analysis focuses on sensor selection, sensitivity, noise levels, and system efficacy across various implementations. The ADXL355, LIS3DHH, MPU6050, and ADXL345 accelerometers emerged as commonly tested sensors, each demonstrating unique strengths in seismic activity monitoring. Studies highlight the ADXL355 and LIS3DHH for their low noise and high sensitivity, making them preferred for detecting subtle ground movements, while the MPU6050's six-axis functionality offers versatility in multi-dimensional motion analysis. Additionally, research underscores the importance of accurate calibration and noise mitigation techniques to enhance data reliability. The review concludes that low-cost accelerometers, particularly when combined with IoT frameworks, provide feasible solutions for scalable earthquake early warning systems. However, challenges persist in balancing sensitivity and stability in noisy environments, indicating a need for further refinement in sensor technology and signal processing algorithms to improve detection accuracy and reduce false alarms in real-world applications.

Corresponden Author:

Muhammad Rafi Athallah Disastra,
Undergraduate Program in Applied of Instrumentation Meteorology, Climatology Geophysics (STMKG)
Tangerang City, Banten, Indonesia
Email: rafi.athallah1@gmail.com

1. INTRODUCTION

In recent years, the development of low-cost Micro-Electro-Mechanical Systems (MEMS) accelerometer sensors has revolutionized earthquake detection and vibration monitoring capabilities. These technological advancements have made it increasingly feasible to deploy widespread sensor networks for early warning systems and structural monitoring at a fraction of the cost of traditional seismological equipment [13][14][17]. This review synthesizes findings from 20 recent studies examining various low-cost accelerometer sensors, their performance characteristics, and their applications in seismic monitoring.

The growing frequency and impact of seismic events worldwide has highlighted the critical need for reliable, cost-effective earthquake detection systems [1]. While conventional seismological instruments provide high accuracy, their substantial cost and complexity often limit widespread deployment, particularly in developing regions or areas requiring dense sensor networks. Low-cost accelerometer sensors have emerged as a promising alternative, offering an attractive balance between performance and accessibility [7].

Several Low-cost accelerometer sensors have been prominently featured in recent research, including the ADXL series (ADXL355, ADXL345, ADXL335), MPU series (MPU9250, MPU6050), and LIS series (LIS3DHH, LIS331DLH). These sensors vary in their specifications, capabilities, and performance characteristics, making it essential to understand their relative strengths and limitations for specific applications.

This review examines key performance metrics such as noise levels, sensitivity, accuracy, and reliability across different sensor types. Particular attention is paid to comparing their effectiveness in detecting seismic events, measuring vibrations, and providing reliable data for early warning systems [2]. Additionally, we explore how these sensors perform when integrated with various microcontrollers and IoT platforms for real-world applications.

The findings from this review aim to provide researchers, engineers, and system developers with comprehensive insights into the current state of low-cost accelerometer technology for earthquake detection and vibration monitoring. This information is crucial for making informed decisions about sensor selection and system design in future implementations of earthquake monitoring networks and early warning systems.

2. RESEARCH METHOD

This research employs a comprehensive review of existing literature on low-cost accelerometers, focusing on their applications and advancements in earthquake detection. The study centers on low-cost accelerometers and their performance metrics. It explores how low-cost accelerometers can effectively measure vibrations and motion, assessing their accuracy and reliability. The literature review identifies several studies that highlight the effectiveness of low-cost accelerometers in real-time monitoring systems. These studies will be discussed in detail in the results and discussion section, emphasizing their implications for enhancing earthquake detection.

3. RESULT AND DISCUSSION

In this review, we analyzed 20 research papers focusing on various low-cost accelerometer sensors and their applications in earthquake detection and vibration monitoring. These papers provide detailed insights into the performance, accuracy, and practical implementation of different sensor types. The following table summarizes the key findings from each study, including the sensors used, their applications, and specific performance metrics. This compilation offers a comprehensive overview of current research in low-cost earthquake detection systems and highlights the varying capabilities of different accelerometer sensors. Table 1 presents a detailed summary of these research papers and their key findings regarding accelerometer sensor performance.

TABLE I. Literature Review

No	Author	Title	Reviews
1	J. Lee, J. S. Kim, S. Choi, and Y. W. Kwon	A Smart Device Using Low-cost Sensors to Detect Earthquakes	The research paper evaluated four different acceleration sensors for their performance and accuracy. The sensors mentioned are ADXL355, LIS3DHH, MPU9250, and MMA8452. The ADXL355 and LIS3DHH sensors outperformed the other sensors (MPU9250 and MMA8452) in terms of noise level and sensitivity, making them more suitable for detecting earthquakes. The study emphasized that lower noise levels and higher sensitivity are critical for accurately capturing the acceleration changes caused by seismic events [1].
2	J. Lee, I. Khan, S. Choi, and Y. W. Kwon	A Smart IoT Device for Detecting and Responding to Earthquakes	The research paper evaluates four low-cost accelerometer sensors for earthquake detection: ADXL355, LIS3DHH, MPU9250, and MMA8452. The paper discusses the performance of these sensors in detecting earthquakes using a proposed algorithm. The ADXL355 and LIS3DHH sensors generally performed better in terms of noise levels, while the ADXL355 showed high probabilities of detecting earthquakes accurately, despite some false detections due to noise in the other sensors. Overall, the ADXL355 and LIS3DHH sensors outperformed the others in terms of noise and sensitivity, making them

			more suitable for earthquake detection applications [2].
3	I. I. Sianturi, D. Hamdani, and E. Risdianto	Design an Earthquake Early Warning System Based on Arduino Uno Microcontroller with Accelerometer-MPU6050 sensor and NodeMCU-ESP8266	The accelerometer used in this research paper is the MPU6050 sensor. The MPU6050 is a motion sensor with a 16-bit with a 3-axis gyroscope and accelerometer, and also a Digital Motion Processor (DMP), which functions to measure the position of an object. The microcontroller and interface with 16-bit output data make the sensor's accuracy very high [3].
4	Z. M. Cho and W. Z. Hein	Design and Construction of Earthquake Detection and Location Reporting System on Google Map	The accelerometer used in this research paper is the MPU-6050, which is an integrated 6-axis motion tracking device containing a 3-axis accelerometer and gyroscope. The data taken from the accelerometer is described as accurate, as the MPU-6050 sensor provides precise information on acceleration forces and tilt angles. The sensor captures x, y, and z-axis data with 16-bit analog-to-digital conversion for each channel, ensuring high accuracy in the measurements [4].
5	P. K. Sinha, S. Saraiyan, M. Ghosh, and V. Nath	Design of Earthquake Indicator System Using ATmega328p and ADXL335 for Disaster Management	This research paper explores the use of the ADXL335 accelerometer, a low-power, three-axis MEMS device with a range of ±3g, in detecting vibrations for earthquake monitoring. The ADXL335 accurately captures vibrations, which are then processed by an ATmega328p microcontroller, converting analog signals to digital and calculating peak ground acceleration. When vibrations exceed a set threshold, the system triggers an alarm, indicating that the ADXL335 data is reliable for significant seismic activity detection. This integration of the ADXL335 and ATmega328p enables effective monitoring and timely earthquake warnings, demonstrating high accuracy in data collection [5].
6	Gunoro, Suprapto, J. Iriani, B. V. Sundawa, Abdullah, and Cholish	Design of Earthquake Warning Alarm Using Accelerometer Sensor Based on Internet of Things	The research paper utilizes the ADXL335 accelerometer sensor to detect earthquakes. This sensor provides three output coordinate points (X, Y, Z) with analog values that are processed by an Arduino Nano microcontroller to estimate the earthquake's intensity on the Richter scale. The study establishes a correlation between tilt angles and Richter scale values, with analog values ranging from 100 to 400 corresponding to different intensity levels (e.g., 2-3 Richter scale for a 15-degree tilt and 7-10 Richter scale for a 90-degree tilt). However, the paper does not specify the exact accuracy or percentage of error associated with these measurements, indicating that while the system can provide a rough estimate of earthquake intensity, the precision of the data is not quantitatively assessed [6].
7	Z. Sun, S. J. Dyke, F. Pena, and A. Wilbee	Development of Arduino-Based Wireless Control System	The research paper examines the ADXL345 accelerometer from Analog Devices, a tri-axial MEMS sensor with a ±16 g measurement range and 13-bit resolution. Users can select a sampling rate from 6.25 Hz to 3200 Hz, and the device operates

			with low power. Accuracy testing reveals that at a 100 Hz sampling rate, the ADXL345 has a measurement error of approximately 0.214, which is low compared to a reference wired accelerometer. This low error rate indicates the ADXL345 provides highly accurate data for the research [7].
8	A. Apriyansa, J. Bintoro, and E. Sandi	Development of Early Real-Time Disaster Mitigation Warning System Landslide with Gyroscope ADXL345 Sensor	This research paper presents an early warning system utilizing the ADXL345 accelerometer sensor, which measures tilt and acceleration to detect landslide-prone conditions. Through a calibration process, the system ensures reliable sensor readings, with specific tilt values like 0 degrees yielding 5 bits and 90 degrees reaching 277 bits. Testing confirms the system's effectiveness in determining slope status and sending alerts when angles exceed set thresholds, such as 75 degrees. The results from both lab and field tests demonstrate the system's feasibility and reliability, indicating that the ADXL345 provides accurate data for landslide detection [8].
9	F. H. Chen, H. L. Shieh, and J. F. Tu	Development of Earthquake Detection and Warning System Based on Sensors	The research paper utilizes the ADXL345 three-axis accelerometer for earthquake detection and building tilt detection. The ADXL345 is noted for its low power consumption and high resolution, which is 4 mg/LSB. This high resolution allows the accelerometer to measure changes in tilt of less than 1.0°. The accelerometer's digital output data is transmitted in a 16-bit binary code format, making it suitable for precise measurements in various applications, including static acceleration and tilt sensing [9].
10	R. Hoque, S. Hassan, M. A. Sadaf, A. Galib, and T. F. Karim	Earthquake Monitoring and Warning System	The research paper uses the ADXL-345 digital accelerometer to detect ground acceleration during earthquakes, focusing on identifying P-waves, the primary seismic shock waves. Although specific accuracy metrics are not provided, the system is designed to capture low-frequency vibrations (1–3 Hz) typical of P-waves. The ADXL-345's ability to detect these signals accurately is critical to the system, which relies on data matching from multiple sensor nodes to confirm seismic activity and provide timely alerts, emphasizing the importance of data accuracy for effective earthquake detection [10].
11	V. Babu and V. Rajan	Flood and Earthquake Detection and Rescue Using IoT Technology	The research paper explores the MPU6050 module, a MEMS device combining a 3-axis accelerometer and 3-axis gyroscope, used to measure motion-related parameters such as acceleration, velocity, orientation, and displacement. The MPU6050's Digital Motion Processor (DMP) supports complex calculations, enhancing its functionality. While the paper outlines the module's capabilities, it does not specify data accuracy, noting that accuracy generally depends on calibration, environmental factors, and application context. For precise accuracy information,

			manufacturer specifications or controlled empirical testing are typically required [11].
12	Yulkifli, A. Nofriandi, R. Triyono, W. Audia, and N. A. Sati'At	Initial Design of IoT-Based Earthquake Intensitymeter Using MMI Scale with Smartphone Display	The research paper talks about the use of the MPU6050 accelerometer sensor for measuring earthquake intensity. This sensor can measure Peak Ground Acceleration (PGA) values on three axes (x, y, and z) simultaneously. The accuracy of the data obtained from the MPU6050 accelerometer is indicated by an average linearity test result, which shows a 0.994 R-squared value. This high value indicates that the sensor is functioning well and provides reliable data for the initial design of the earthquake intensity meter [12].
13	N. Bahari, N. I. M. Nor Azmi, M. W. Nasrudin, R. Che Yob, N. H. Ramli, and H. Lago	IoT Based Earthquake Detection System	The research paper uses the MPU6050 accelerometer sensor for earthquake detection, highlighting its compactness, cost-effectiveness, and adjustable sensitivity range starting at ±2g. The sensor detects ground vibrations essential for identifying seismic activity, with the system designed to distinguish between earthquake-induced vibrations and other sources. It features ten intensity levels, from minor to dangerous, based on set thresholds that help classify vibration severity accurately. Although specific accuracy metrics are not provided, the paper emphasizes the MPU6050's operational effectiveness and suitability for detecting significant seismic events [13].
14	A. Taale, C. E. Ventura, and J. Marti	On the feasibility of IoT-based smart meters for earthquake early warning	The research paper uses the EpiSensor FBA ES-T as the reference sensor and the LIS3DSH MEMS accelerometer in the smart meters (SMs). The MEMS sensor is deemed unreliable for motion measurements with peak accelerations below 148 mg or RMS values lower than 46 mg, while it shows satisfactory coherence for frequencies greater than 1 Hz when compared to the reference sensor. Overall, the accuracy of the MEMS data improves significantly when the acceleration RMS goes above 20 mg, reducing the error to below 20%. [14]
15	J. V. O. Rodrigues, M. P. G. Pedroso, F. F. Barbosa Silva, and R. G. Leão Junior	Performance evaluation of accelerometers ADXL345 and MPU6050 exposed to random vibrational input	This research paper evaluates the performance of two MEMS accelerometers, the ADXL345 and MPU6050, in monitoring low-intensity random vibrations, particularly in rotating machinery. Data analysis shows that the MPU6050 provides more consistent and uniform responses, with rectification error behavior aligning well with established literature, indicating its reliability for vibration monitoring. In contrast, the ADXL345 exhibited anomalies and higher offset shifts—about five times that of the MPU6050—suggesting it is less reliable for precise measurements. Overall, the MPU6050 is recommended as a stable sensor for mechanical vibration monitoring, while the ADXL345's accuracy in similar applications is questioned [15].

16	G. Murariu *et al.*	Personal seismograph system - a functional prototype	This research paper examines the MPU6050, a module with both gyroscope and accelerometer, capable of detecting motion and intensity across three axes with 16-bit analog-to-digital converters. The MPU6050's sensitivity is sufficient to capture vibrations relevant to seismic events, indicating reliable data for monitoring and assessing seismic activity, though specific accuracy metrics are not provided. The system is designed for real-time earthquake detection and classification, suggesting an accuracy level suited for practical disaster management applications [16].
17	A. D'Alessandro and G. D'Anna	Suitability of Low-Cost Three Axis MEMS Accelerometers in Strong-Motion Seismology: Tests on the LIS331DLH (iPhone) Accelerometer	This research paper compares the LIS331DLH MEMS accelerometer, found in iPhones, with the EpiSensor FBA ES-T accelerometer, used as a reference sensor, for recording seismic activity. Tests show that the LIS331DLH offers excellent frequency and phase response comparable to standard strong-motion seismology accelerometers, though it slightly underestimates actual acceleration. Despite limited sensitivity due to self-noise, it achieves a high signal-to-noise ratio for moderate to strong earthquakes (magnitude >5) near epicenters, with an average correlation over 0.998 to the reference sensor. The study concludes that while the LIS331DLH is promising for strong-motion seismology, further calibration and testing are recommended for scientific use [17].
18	E. Husni and F. Laumal	The Development of an Earthquake Early Warning System Using an ADXL335 Accelerometer	The accelerometers used in this research paper are ADXL335 accelerometers. The data taken from the ADXL335 accelerometer is generally accurate, but it is observed that the vibration values are not stable in a non-vibrating condition. The values sometimes change to 0.010 or -0.010. The noise density is 150 µm for both the X-axis and Y-axis, while it is 300 µm for the Z-axis. The peak noise density values are 0.084 for the X-axis and Y-axis, and 0.064 for the Z-axis. This indicates that the noise levels are within acceptable limits, ensuring the data's reliability for detecting vibrations [18].
19	Y. Pramudya and M. Islamiah	Vibration characteristics study on observatory using accelerometer ADXL345 sensor and Arduino	The accelerometer used in this research paper is the ADXL345 sensor. The data taken from the ADXL345 accelerometer is calibrated using a Vernier Force Dual-Range Sensor. The calibration process entails fitting the data to a damped oscillation harmonic equation and applying a linear regression equation to convert the accelerometer's output into acceleration units (m/s^2). The resulting conversion equation is $y = 0.0354\ m/s^2\ x + 0.1602\ m/s^2$, where x represents the amplitude measurement from the ADXL345 accelerometer sensor and y corresponds to the amplitude measurement from the Vernier Force Dual-Range Sensor. This calibration ensures that the data from the ADXL345 accelerometer is accurate

			and reliable for measuring vibrations at the observatory [19].
20	M. Hasibuzzaman, A. Shufian, R. K. Shefa, R. Raihan, J. Ghosh, and A. Sarker	Vibration Measurement & Analysis Using Arduino Based Accelerometer	The research paper utilizes the ADXL-345 tri-axial accelerometer, which is known for its high-resolution capabilities in measuring acceleration across three dimensions. This accelerometer is particularly valued for its precision, providing data with an accuracy of ±4.5%, which is essential for applications that require reliable measurements of mechanical acceleration and vibration. The ability to capture detailed and accurate data is crucial in various fields, such as safety monitoring and machinery condition assessment, as it enables the effective detection of faults and abnormal vibrations. By employing the ADXL-345, the research ensures that the findings are based on robust and trustworthy data, ultimately contributing to the reliability of the study's conclusions and recommendations [20].

4. CONCLUSION

This comprehensive review of 20 research papers has offered important insights into the current status and capabilities of low-cost accelerometers sensors in earthquake detection and vibration monitoring applications. The findings demonstrate that MEMS accelerometer technology has made significant strides in providing viable alternatives to traditional, more expensive seismic monitoring equipment.

Among the sensors evaluated, the ADXL355 and LIS3DHH consistently demonstrated superior performance in terms of noise levels and sensitivity. The MPU6050 emerged as a reliable middle-ground solution, offering good performance characteristics with high linearity (R-squared value of 0.994) and versatility in various scenarios [12]. While some sensors, such as the ADXL335 and MMA8452, showed moderate performance levels, they still proved adequate for basic monitoring applications where cost is a primary consideration [2].

A significant finding from this review is the trade-off between cost and performance in low-cost accelerometer sensors. While these sensors may not match the precision of professional seismological equipment, their cost-effectiveness and reasonable accuracy make them valuable for creating sensor networks and implementing widespread early warning systems, especially in regions with limited resources [3].

The review also highlights several areas requiring further research and development. These include improving false detection rates, enhancing low-frequency response capabilities, and developing more robust calibration methods [2]. Additionally, the incorporation of these sensors with IoT platforms and real-time monitoring systems presents both opportunities and challenges that warrant continued investigation.

The evolution of low-cost accelerometer technology suggests promising developments in earthquake detection. The increasing accuracy and reliability of these sensors, combined with their decreasing costs, indicate a future where comprehensive earthquake monitoring networks could become more accessible to communities worldwide. This democratization of seismic monitoring technology could significantly contribute to improving earthquake preparedness and response strategies globally.

REFERENCE

[1] J. Lee, J. S. Kim, S. Choi, and Y. W. Kwon, “A Smart Device Using Low-Cost Sensors to Detect Earthquakes,” 2019 IEEE Int. Conf. Big Data Smart Comput. BigComp 2019 - Proc., pp. 1–4, 2019, doi: 10.1109/BIGCOMP.2019.8679190.

[2] J. Lee, I. Khan, S. Choi, and Y. W. Kwon, “A smart iot device for detecting and responding to earthquakes,” Electron., vol. 8, no. 12, Dec. 2019, doi: 10.3390/electronics8121546.

[3] I. I. Sianturi, D. Hamdani, and E. Risdianto, “Design an Earthquake Early Warning System Based on Arduino Uno Microcontroller with Accelerometer-MPU6050 sensor and NodeMCU-ESP8266,” Asian J. Sci. Educ., vol. 6, no. 1, pp. 46–56, 2024, doi: 10.24815/ajse.v6i1.36114.

[4] Z. M. Cho and W. Z. Hein, “Design and Construction of Earthquake Detection and Location Reporting System on Google Map,” Int. J. Sci. Res. Eng. Dev., vol. 2, no. 3, pp. 691–698, 2019, [Online]. Available: www.ijsred.com

[5] P. K. Sinha, S. Saraiyan, M. Ghosh, and V. Nath, "Design of earthquake indicator system using ATmega328p and ADXL335 for disaster management," in Lecture Notes in Electrical Engineering, Springer Verlag, 2019, pp. 565–572. doi: 10.1007/978-981-13-0776-8_53.

[6] Gunoro, Suprapto, J. Iriani, B. V. Sundawa, Abdullah, and Cholish, "Design of Earthquake Warning Alarm Using Accelerometer Sensor Based on Internet of Things," Int. J. Res. Vocat. Stud., vol. 3, no. 1, pp. 32–35, Apr. 2023, doi: 10.53893/ijrvocas.v3i1.194.

[7] Z. Sun, S. J. Dyke, F. Pena, and A. Wilbee, "Development of Arduino based wireless control system," in Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2015, SPIE, Mar. 2015, p. 94351D. doi: 10.1117/12.2083707.

[8] A. Apriyansa, J. Bintoro, and E. Sandi, "Development of early real-time disaster mitigation warning system landslide with gyroscope ADXL345 sensor," in Journal of Physics: Conference Series, IOP Publishing Ltd, Oct. 2021. doi: 10.1088/1742-6596/2019/1/012080.

[9] F. H. Chen, H. L. Shieh, and J. F. Tu, "Development of Earthquake Detection and Warning System Based on Sensors," Sensors Mater., vol. 35, no. 4, pp. 1211–1220, 2023, doi: 10.18494/SAM4116.

[10] R. Hoque, S. Hassan, M. A. Sadaf, A. Galib, and T. F. Karim, Earthquake Monitoring and Warning System Rahinul. ICAEE Conference Secretariat, School of Engineering & Computer Science, Independent University, Bangladesh, 2015.

[11] V. Babu and V. Rajan, "Flood and Earthquake Detection and Rescue Using IoT Technology," Proc. 4th Int. Conf. Commun. Electron. Syst. ICCES 2019, no. Icces, pp. 1256–1260, 2019, doi: 10.1109/ICCES45898.2019.9002406.

[12] Yulkifli, A. Nofriandi, R. Triyono, W. Audia, and N. A. Sati'At, "Initial Design of IoT-Based Earthquake Intensitymeter Using MMI Scale with Smartphone Display," in Journal of Physics: Conference Series, Institute of Physics, 2024. doi: 10.1088/1742-6596/2734/1/012025.

[13] N. Bahari, N. I. M. Nor Azmi, M. W. Nasrudin, R. Che Yob, N. H. Ramli, and H. Lago, "IoT Based Earthquake Detection System," J. Adv. Res. Appl. Sci. Eng. Technol., vol. 51, no. 1, pp. 160–170, 2024, doi: 10.37934/araset.51.1.160170.

[14] A. Taale, C. E. Ventura, and J. Marti, "On the feasibility of IoT-based smart meters for earthquake early warning," Earthq. Spectra, vol. 37, no. 3, pp. 2066–2083, 2021, doi: 10.1177/8755293020981964.

[15] J. V. O. Rodrigues, M. P. G. Pedroso, F. F. Barbosa Silva, and R. G. Leão Junior, "Performance evaluation of accelerometers ADXL345 and MPU6050 exposed to random vibrational input," Res. Soc. Dev., vol. 10, no. 15, p. e286101523082, Nov. 2021, doi: 10.33448/rsd-v10i15.23082.

[16] G. Murariu et al., "Personal seismograph system - A functional prototype," 2019 6th Int. Symp. Electr. Electron. Eng. ISEEE 2019, 2019, doi: 10.1109/ISEEE48094.2019.9136139.

[17] A. D'Alessandro and G. D'Anna, "Suitability of low-cost three-axis MEMS accelerometers in strong-motion seismology: Tests on the LIS331DLH (iPhone) accelerometer," Bull. Seismol. Soc. Am., vol. 103, no. 5, pp. 2906–2913, 2013, doi: 10.1785/0120120287.

[18] E. Husni and F. Laumal, The Development of an Earthquake Early Warning System Using an ADXL335 Accelerometer. IEEE, 2018.

[19] Y. Pramudya and M. Islamiah, "Vibration characteristics study on observatory using accelerometer ADXL345 sensor and Arduino," in AIP Conference Proceedings, American Institute of Physics Inc., Nov. 2019. doi: 10.1063/1.5132658.

[20] M. Hasibuzzaman, A. Shufian, R. K. Shefa, R. Raihan, J. Ghosh, and A. Sarker, Vibration Measurement & Analysis Using Arduino Based Accelerometer. IEEE, 2020.