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Analysis of Correction for the Indonesian People's Accelerograph (ARI) based on MEMS ADXL 355

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Abstract

Indonesia, geographically situated on the Pacific Ring of Fire, has one of the highest potentials for earthquake and tsunami disasters worldwide, second only to Japan. These seismic events pose significant threats, including loss of life and infrastructure damage. One of the key strategies to mitigate earthquake risks is the implementation of Earthquake Early Warning System (EEWS) technology, which heavily relies on the spatial distribution of accelerographs. The Indonesian People's Accelerograph (ARI) has been designed as an affordable and independently built solution to record ground vibration acceleration, utilizing the MEMS-based ADXL 355 sensor and an ESP32 microcontroller for efficient EEWS implementation. This study focuses on the development and correction of the ARI system to enhance instrument response accuracy by analyzing ground acceleration vibration data through an inversion-based method applied to ARI recordings. The results demonstrated that the ARI accelerograph exhibits pole values of 1.31260317e-07 and -2.43562359e-02, zero values of -1.23898531e-06 and 2.77232055, and a gain of 72.97. These findings confirm that the ARI accelerograph provides reliable seismic data, highlighting its potential as an essential tool in reducing earthquake risk and mitigating seismic disaster impacts through improved earthquake early warning capabilities.

Keywords: accelerograph; MEMS; earthquake; gain; poles; zeros

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INTRODUCTION

Earthquakes are natural disasters that cannot be precisely predicted in terms of time and location. They can trigger devastating secondary effects such as tsunamis, landslides, liquefaction, and infrastructure damage, often resulting in significant casualties. Due to its geographical position along the Pacific Ring of Fire, Indonesia experiences high seismic activity, making earthquake preparedness and mitigation crucial (Cremen & Galasso, 2020). One of the most effective strategies for reducing earthquake risks is the implementation of Earthquake Early Warning Systems (EEWS). The effectiveness of EEWS heavily depends on the density and distribution of accelerograph networks, which detect seismic activity and provide real-time data for warning dissemination (Gunoro et al., 2023; Peng et al., 2019). Therefore, expanding the coverage of accelerographs across Indonesia is essential to enhance the accuracy and speed of earthquake alerts.

An accelerograph is a vital component of EEWS, designed to detect and record ground acceleration during seismic events. This instrument provides critical data on earthquake intensity and ground motion dynamics, which is crucial for issuing timely warnings (Y. Wu &

Mittal, 2021). By continuously recording seismic signals and transmitting them to centralized servers, accelerographs enable real-time analysis and rapid alert distribution to affected regions. The spatial distribution of accelerographs significantly influences the reliability of EEWS, reinforcing their role as fundamental elements in minimizing earthquake risks and improving public safety (Patanè et al., 2022).

The Meteorology, Climatology, and Geophysics Agency of Indonesia (BMKG) is responsible for monitoring seismic activity and managing the national accelerograph network. Currently, Indonesia operates 801 accelerograph stations, consisting of 267 non-collocated and 534 collocated stations, covering a land area of approximately 1,922,570 km² (BMKG, 2024). In contrast, Japan, despite having a significantly smaller landmass, has deployed over 2,000 accelerographs, ensuring more extensive earthquake monitoring and faster response times (Phung et al., 2020). Expanding Indonesia's accelerograph network presents financial and logistical challenges, necessitating the development of cost-effective and scalable accelerograph systems to facilitate mass deployment.

Recent advancements in accelerograph technology have focused on improving affordability and efficiency while maintaining high sensitivity and reliability. MEMS (Micro-Electro-Mechanical Systems)-based accelerographs, such as those using the ADXL 355 sensor, have emerged as promising solutions for large-scale seismic monitoring (Papanikolaou et al., 2021; Zhang et al., 2022). The ESP32 microcontroller, integrated with the ADXL 355 sensor, offers robust computational capabilities and wireless connectivity, enabling real-time data acquisition and transmission to centralized processing servers (Fu et al., 2019). MEMS-based accelerographs provide significant advantages over traditional seismometers, including lower cost, compact design, and ease of deployment, making them ideal for dense seismic networks (Cascone et al., 2021; Chandrakumar et al., 2022).

Despite their lower cost, MEMS accelerometers have demonstrated performance levels suitable for earthquake early warning applications. Advances in sensor technology have significantly improved the bias stability and noise characteristics of MEMS devices, narrowing the performance gap between MEMS-based accelerometers and conventional force-balanced seismometers (Alteriis et al., 2021; A. Wu et al., 2021). Properly calibrated MEMS accelerometers can produce high-fidelity seismic data, particularly in urban environments where a dense network of sensors is crucial for accurate earthquake detection and hazard assessment (Bravo-Haro et al., 2021; Patanè et al., 2022).

This study focuses on the development of the Indonesian People's Accelerograph (ARI) system, designed to enhance earthquake monitoring capabilities through a cost-effective and scalable solution. The ARI system integrates the ADXL 355 sensor and ESP32 microcontroller to capture ground acceleration data, with an emphasis on optimizing its response characteristics. A key aspect of this development is the accurate determination of the system's response function through pole-zero analysis, a critical factor in ensuring reliable seismic data acquisition (Ma et al., 2023). The pole and zero values of an accelerograph define its dynamic response to seismic signals, affecting its ability to capture ground motion across various frequency ranges. Precise calibration of these parameters is essential to minimize instrument-induced distortions and ensure that recorded data accurately represents true ground motion (Scafidi et al., 2024).

To enhance the reliability of ARI, this study employs an inversion-based approach for pole-zero correction, utilizing spectral frequency analysis methods such as Fast Fourier Transform (FFT). FFT has been widely adopted in seismology for its computational efficiency and ability to decompose seismic signals into their frequency components, allowing for accurate instrument response modeling (Bilal et al., 2022). Alternative spectral methods, such as wavelet transforms and Short-Time Fourier Transform (STFT), have also been explored in recent studies, but FFT remains a preferred choice due to its balance between accuracy and computational efficiency (Lim et al., 2022; Rodriguez & Myklebust, 2022).

Furthermore, the integration of MEMS-based accelerographs into seismic networks is gaining global recognition as an effective method for enhancing earthquake preparedness. Countries such as China and Japan have successfully implemented large-scale MEMS accelerograph networks, supported by government funding and strategic partnerships (Xie et al., 2021). In developing regions, financial constraints and infrastructure limitations pose significant challenges to seismic network expansion. However, leveraging low-cost MEMS accelerometers enables broader deployments without imposing excessive financial burdens, making them a viable solution for countries with limited resources (Manglik, 2023). Additionally, mobile-based seismic detection systems utilizing smartphone accelerometers have emerged as complementary solutions for increasing earthquake monitoring coverage in regions with sparse seismic instrumentation (Bossu et al., 2021; Kong et al., 2020).

By implementing MEMS-based accelerographs such as ARI, Indonesia can significantly improve its EEWS, enhancing real-time seismic monitoring and disaster response capabilities. The outcomes of this study aim to contribute to the advancement of cost-effective seismic monitoring systems, supporting national efforts to mitigate earthquake risks and improve public safety in earthquake-prone regions.

METHOD

The ARI accelerograph integrates a Micro-Electro-Mechanical System (MEMS) sensor and an IoT-based ESP32 microcontroller as the primary data acquisition components. The MEMS ADXL 355 sensor combines mechanical and electronic elements, enabling motion detection by converting movement into capacitance changes, which are then transformed into electrical signals. These electrical signals are processed through an internal Analog-to-Digital Converter (ADC) to generate digital signals representing acceleration values along the x, y, and z axes (Fu et al., 2019; Prato et al., 2021). The acceleration data from the MEMS ADXL 355 sensor is subsequently transmitted to the ESP32 microcontroller via an Inter-Integrated Circuit (I2C) digital communication interface. The ESP32 microcontroller processes and transmits the data via WiFi or a GSM network using an additional GSM module, allowing for remote data storage and further analysis on a centralized server.

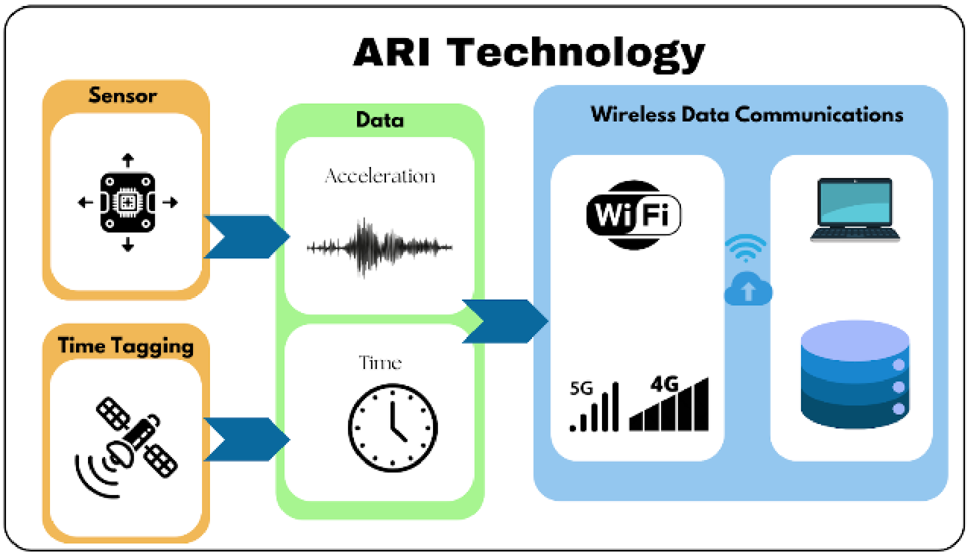

Figure 1. ARI System Diagram

The raw ground acceleration data obtained by ARI is inherently influenced by the instrument's response, necessitating a correction method to ensure accurate seismic data representation. To achieve this, the study employs an inversion-based approach for correcting the instrument response, utilizing spectral frequency analysis.

Transfer Function Model

The determination of the instrument response function in this study follows an inversion-based method that analyzes the frequency spectrum of seismic recordings. This method aims to resolve the transfer function equation of the accelerograph system. The ARI accelerograph records data in the MiniSEED (MSEED) format, which is subsequently processed using the Fast Fourier Transform (FFT) to derive the frequency spectrum. The transfer function is then obtained in the s-domain (Laplace Transform) for further analysis (Viswanatha et al., 2020).

Fast Fourier Transform (FFT) Process

The FFT is a widely used mathematical algorithm that converts signals from the time domain to the frequency domain. It enables spectral analysis of recorded vibrations, facilitating an understanding of dominant frequencies and the seismic wave characteristics (Ehirim & Akpan, 2017; Munyithya et al., 2020). The FFT process includes data reading, preprocessing, application of the FFT, conversion to the frequency domain, and frequency interpretation.

While FFT is computationally efficient and widely adopted in seismology, it has certain limitations when analyzing non-stationary signals. Alternative methods, such as Continuous Wavelet Transform (CWT) and Short-Time Fourier Transform (STFT), offer better time-frequency resolution for transient seismic events (Babić et al., 2018; M. Tang et al., 2023). Nevertheless, FFT remains the preferred method in this study due to its balance between accuracy and computational efficiency.

Spectrum Model Fitting

Model fitting or optimization is performed using the least-squares method through the curve_fit function from Scipy. This approach enables the simulation of the system response under specific input conditions and mathematical models, which are then compared with the original spectral data (Huang et al., 2021; L. Tang et al., 2020). Least-squares fitting minimizes the sum of squared errors, improving the precision of instrument response corrections. However, it is sensitive to outliers and assumes a linear relationship between observed and predicted data, which may introduce inaccuracies in nonlinear systems (Islam et al., 2017; Merrill et al., 2024).

Pole-Zero Determination Techniques

Determining pole-zero parameters in seismic instruments is crucial for accurate calibration and performance optimization. Several techniques have been explored in recent research:

1. **Complex Time Delay Analysis**: Extracts pole-zero parameters by analyzing seismic wave transmission and reflection characteristics, providing insights into instrument dynamics (Chen, 2022).
2. **Least 1-Norm Pole-Zero Modeling**: An iterative estimation technique that enhances seismic signal modeling accuracy, particularly in noisy environments (Shi et al., 2017).
3. **Frequency Response Function Methods**: Bode and Nyquist plots assist in visually identifying poles and zeros, aiding in stability and transfer function analysis (Viswanatha et al., 2020).
4. **Ambient Noise Correlation Techniques**: Utilizes cross-correlation of ambient seismic noise to validate pole-zero characteristics, improving long-term instrument monitoring (Muir & Zhan, 2021).
5. **Computational Algorithms**: Techniques such as Padé approximants simplify complex pole-zero relationships, reducing computational overhead and enhancing interpretability (Han & Kim, 2018).

Calibration and Performance Optimization

To ensure accurate data acquisition, MEMS-based accelerographs require rigorous calibration. Best practices include:

1. **Dynamic Characterization**: Evaluating linearity and amplitude response across frequencies following standards like ISO 16063-21 (Prato et al., 2021; Schiavi et al., 2023).
2. **Sampling Rate Management**: Controlling sampling variability to minimize calibration uncertainty (D'Emilia et al., 2021).
3. **Auto-Calibration Mechanisms**: Real-time adjustments through embedded self-calibration techniques (Łuczak et al., 2024).
4. **Environmental Considerations**: Addressing temperature fluctuations that impact sensor sensitivity (Landi et al., 2023).
5. **Statistical Analysis of Calibration Data**: Leveraging statistical models to assess calibration sensitivity and reliability (Krokidis et al., 2022).

Enhancements for Real-Time Seismic Data Processing

Modern advancements in real-time seismic processing have introduced innovative methodologies to optimize low-cost accelerograph systems:

1. **Machine Learning for Noise Reduction**: Convolutional Neural Networks (CNNs) and Generative Adversarial Networks (GANs) effectively denoise seismic signals, improving signal-to-noise ratios (Li et al., 2021; H. Zhao et al., 2023).
2. **Hybrid Analytical Methods**: Combining Singular Value Decomposition (SVD) with deep learning to refine seismic data processing (Ji & Wang, 2022).
3. **Adaptive Filtering Techniques**: Time-frequency domain polarization filtering enhances seismic signal clarity (X. Yang et al., 2019).

By integrating these methodologies, the ARI system aims to provide reliable, high-quality seismic data while maintaining cost-efficiency. This study advances the development of robust, MEMS-based accelerograph networks to improve earthquake monitoring and enhance early warning capabilities, particularly in resource-constrained regions.

RESULTS AND DISCUSSION

The performance of the ARI accelerograph system was analyzed to evaluate its effectiveness in detecting seismic activity. The raw acceleration data recorded by the system was corrected using a transfer function model to mitigate instrument response distortions. The corrected data was then utilized to compute ground acceleration values along three axes, providing a comprehensive understanding of seismic activity (Gunoro et al., 2023; Patanè et al., 2022).

Figures 2 and 3 illustrate the comparison between the raw frequency spectrum and the optimized frequency spectrum obtained using the least-squares fitting method. The optimized spectrum closely matches the raw data, indicating that the pole-zero correction process effectively reduces distortions. The obtained pole values were 1.31260317e-07 and -2.43562359e-02, while the zero values were -1.23898531e-06 and 2.77232055, with a gain of 72.97. These parameters are essential for ensuring that the system response aligns with actual seismic events, producing accurate and reliable data (Delden et al., 2023; Maslovskyi, 2022). The correction process ensures that the recorded signals more accurately reflect real ground motion by removing the systematic biases introduced by the instrument itself.

The pole and zero values derived from this research offer insights into the dynamic behavior of the system. The poles define the resonance characteristics of the system, while the zeros determine the frequencies where the system exhibits minimal response. The gain parameter regulates the overall system response magnitude, improving the accelerograph's accuracy in detecting and recording ground motion (Hooijberg et al., 2017; Lutti et al., 2022). These corrections enhance the ability of ARI to capture real-time ground motion data, making it an essential tool for seismic hazard assessment and EEWS applications.

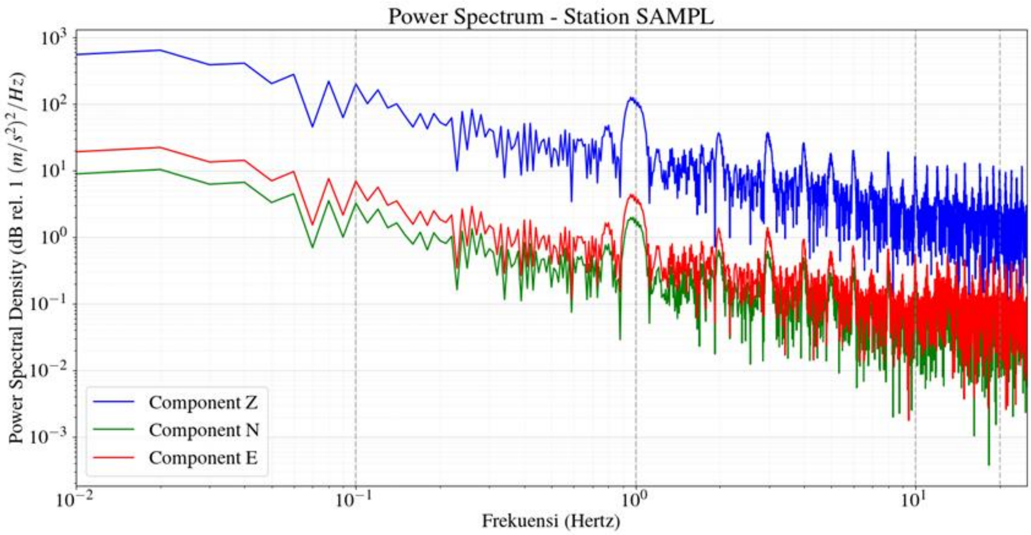

Figure 2. Power Spectrum Graph

The correction process validates that the ARI accelerograph system delivers high-quality and reliable data, making it a valuable component of an Earthquake Early Warning System (EEWS). Utilizing low-cost components such as the ESP32 microcontroller and the MEMS ADXL355 sensor, the ARI system presents a cost-effective solution for dense seismic monitoring networks. This is particularly advantageous in countries like Indonesia, where expanding the number of seismic monitoring stations is critical to improving early warning capabilities (Bravo-Haro et al., 2021; Esposito et al., 2024).

Moreover, integrating FFT with pole-zero analysis provides a powerful methodology for seismic signal analysis. FFT transforms data from the time domain to the frequency domain, facilitating detailed examination of signal frequency components. This approach ensures that accelerograph data is corrected with high accuracy and that the system response is well-calibrated. The least-squares fitting technique further refines correction accuracy by optimizing model parameters, reducing residual errors, and enhancing spectral precision (Pollo et al., 2018; J. Zhao et al., 2021). The results highlight that MEMS-based accelerographs, when properly calibrated, can achieve performance levels comparable to traditional high-end seismic instruments.

Figures 2 and 3 demonstrate the effectiveness of the correction methods applied in this study. The power spectrum graph (Figure 2) illustrates the frequency distribution of seismic signals before and after correction, while the fitted model (Figure 3) confirms that the least-squares optimization accurately aligns the processed signal with theoretical expectations. These figures substantiate that the implemented correction techniques significantly enhance the reliability of the seismic data collected.

The ARI accelerograph system's capability to detect and correct ground motion with high accuracy is crucial for an efficient EEWS. Early warning systems rely on timely and precise detection of seismic activity to issue alerts and mitigate potential damage. Enhancing accelerograph accuracy significantly improves the effectiveness of EEWS, leading to better preparedness and risk reduction in earthquake-prone regions (Y. Wu & Mittal, 2021; B. M. Yang et al., 2021). Additionally, improved ground motion data accuracy supports better earthquake modeling and hazard assessments, contributing to improved seismic resilience strategies.

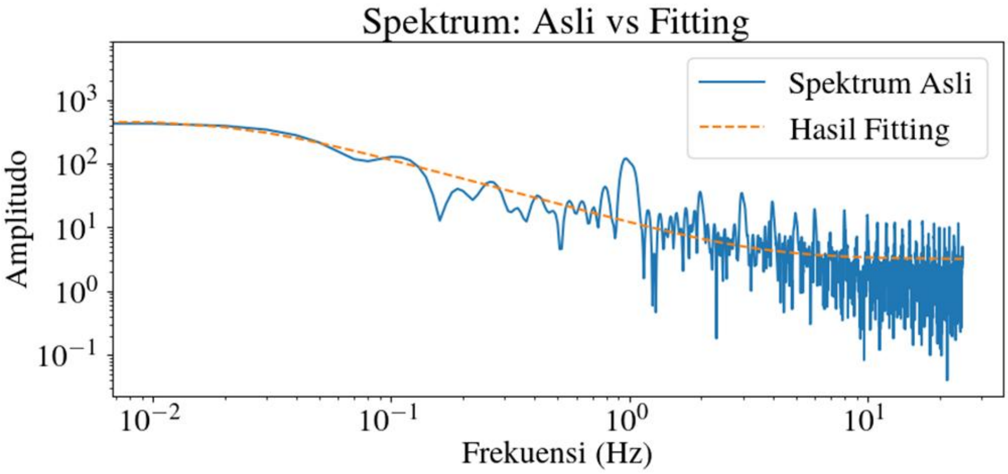

Figure 3. Original Spectrum and Fitting Results

This study demonstrates that the ARI accelerograph system is a viable and efficient tool for earthquake monitoring and early warning applications. The integration of MEMS technology, microcontroller-based data acquisition, and advanced signal processing techniques such as FFT and pole-zero correction makes the ARI system a promising solution for widespread deployment in Indonesia and other seismically active regions (Hu et al., 2021; Nof et al., 2019).

A comparative analysis between the ARI accelerograph system and existing networks in Japan, which operates over 2,000 accelerograph sites, highlights both advantages and limitations. While Japan benefits from a larger and more extensive seismic network, the ARI accelerograph offers a cost-effective alternative that balances affordability with adequate performance. This balance makes it a feasible solution for seismic monitoring in budget-constrained regions where high-cost deployments are impractical (Hu et al., 2021; Varanis et al., 2018).

The low cost of the ARI system makes it an attractive choice for countries with limited financial resources but a high need for seismic monitoring. The ability of the ARI system to provide accurate ground acceleration data at an affordable cost ensures that it can be mass-produced and deployed on a large scale, increasing EEWS coverage and response capabilities (Hilborne & Roffey, 2020; Westwood et al., 2019). Furthermore, integrating MEMS-based accelerographs with cloud-based processing and machine learning techniques could further improve the system's predictive capabilities and real-time data analysis efficiency (Pollo et al., 2018; J. Zhao et al., 2021).

Despite its advantages, MEMS accelerographs, including the ARI system, have some inherent limitations. MEMS sensors are generally more susceptible to temperature fluctuations, electromagnetic interference, and environmental noise, which can affect measurement accuracy (Schiavi et al., 2023; Tahir et al., 2021). However, advancements in sensor technology, including auto-calibration mechanisms and improved signal processing algorithms, continue to narrow the performance gap between MEMS-based and high-end accelerographs (Chandrakumar et al., 2022; Patanè et al., 2022). Future research should focus on improving sensor robustness against environmental factors and enhancing data fusion techniques for integrating MEMS accelerographs with other seismic monitoring instruments.

The ARI accelerograph system represents a crucial step toward expanding seismic monitoring networks in developing regions. By leveraging low-cost technology and advanced data processing techniques, this study contributes to improving seismic hazard assessment and earthquake early warning systems. Future developments should aim to integrate the ARI system with regional and global seismic networks to enhance data accuracy, improve predictive capabilities, and support rapid disaster response (Bravo-Haro et al., 2021; B. M. Yang et al., 2021). Furthermore, the adoption of artificial intelligence and deep learning approaches for real-time signal analysis could enhance the efficiency of low-cost accelerograph systems, making them more adaptable to varying seismic conditions(Jia & Ye, 2023; Y. Wu & Mittal, 2021).

Figures 2 and 3 confirm that the ARI system effectively captures and processes seismic signals, ensuring high-fidelity data collection for earthquake monitoring. This research underscores the importance of continued innovation in MEMS accelerograph technology to bridge the gap between affordability and performance, ultimately contributing to more resilient seismic monitoring and early warning infrastructures worldwide.

CONCLUSION

The Indonesian People's Accelerograph (ARI) has been successfully developed, integrating the MEMS ADXL 355 sensor and ESP32 microcontroller to detect and correct ground acceleration data. The system's performance was evaluated through pole-zero correction and frequency spectrum analysis, yielding accurate data suitable for Earthquake Early Warning Systems (EEWS). The combination of low-cost components and advanced signal processing techniques establishes the ARI accelerograph as a promising solution for enhancing seismic monitoring in Indonesia and other earthquake-prone regions.

The ARI accelerograph system has demonstrated its ability to provide reliable, high-quality data at an affordable cost. Its scalability for mass production and deployment in dense seismic networks enhances early earthquake warning capabilities, thereby improving public safety and disaster preparedness. These findings suggest that the ARI system could serve as a vital tool in mitigating earthquake risks and minimizing seismic disaster impacts.

RECOMMENDATIONS

Future research should focus on expanding the ARI accelerograph network across Indonesia to improve national earthquake monitoring coverage. Extensive field testing in various geological conditions is necessary to further validate the system's performance and adaptability. Additionally, refining calibration methods and enhancing real-time data processing capabilities will increase the accuracy and efficiency of the ARI system, ensuring its reliability in diverse environments.

Integrating machine learning algorithms and cloud-based data processing could enhance ARI's predictive capabilities and real-time analysis. Moreover, collaboration with international seismic monitoring agencies would facilitate knowledge exchange and improve the integration of ARI with global earthquake monitoring networks. By addressing these areas, the ARI system can contribute significantly to the advancement of seismic hazard assessment and early warning strategies on both national and international scales.

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REFERENCES

Alteriis, G. d., Accardo, D., Conte, C., & Moriello, R. S. L. (2021). Performance Enhancement of Consumer-Grade MEMS Sensors Through Geometrical Redundancy. *Sensors*, *21*(14), 4851. https://doi.org/10.3390/s21144851

Babić, R., Babić, L., & Jakšić, B. (2018). New Aspect of Transition Between Line and Continuous Spectrum and Its Relation to Seismic Influence on Structures. *Scientia Iranica*, *0*(0), 0–0. https://doi.org/10.24200/sci.2018.20326

Bilal, M., Ji, Y., Wang, Y., Akhter, M. P., & Yaqub, M. (2022). Early Earthquake Detection Using Batch Normalization Graph Convolutional Neural Network (BNGCNN). *Applied Sciences*, *12*(15), 7548. https://doi.org/10.3390/app12157548

BMKG. (2024). *Senpi-Pusat Seimotek-Geopotensial dan Tanda Waktu*. https://simora.bmkg.go.id/simora/web/alat_seismotek

Bossu, R., Finazzi, F., Steed, R., Fallou, L., & Bondár, I. (2021). "Shaking in 5 Seconds!"—Performance and User Appreciation Assessment of the Earthquake Network Smartphone-Based Public Earthquake Early Warning System. *Seismological Research Letters*, *93*(1), 137–148. https://doi.org/10.1785/0220210180

Bravo-Haro, M., Ding, X., & Elghazouli, A. Y. (2021). MEMS-based Low-Cost and Open-Source Accelerograph for Earthquake Strong-Motion. *Engineering Structures*, *230*, 111675. https://doi.org/10.1016/j.engstruct.2020.111675

Cascone, V., Boaga, J., & Cassiani, G. (2021). Small Local Earthquake Detection Using Low-Cost MEMS Accelerometers: Examples in Northern and Central Italy. *The Seismic Record*, *1*(1), 20–26. https://doi.org/10.1785/0320210007

Chandrakumar, C., Prasanna, R., Stephens, M., & Tan, M. L. (2022). Earthquake Early Warning Systems Based on Low-Cost Ground Motion Sensors: A Systematic Literature Review. *Frontiers in Sensors*, *3*. https://doi.org/10.3389/fsens.2022.1020202

Chen, L. (2022). *Use of Transmission and Reflection Complex Time Delays to Reveal Scattering Matrix Poles and Zeros: Example of the Ring Graph*. https://doi.org/10.48550/arxiv.2202.13539

Cremen, G., & Galasso, C. (2020). Earthquake early warning: Recent advances and perspectives. *Earth-Science Reviews*, *205*, 103184. https://doi.org/10.1016/j.earscirev.2020.103184

Delden, A. v., Scholtus, S., Waal, T. d., & Csorba, I. (2023). *Methods for Estimating the Quality of Multisource Statistics*. 781–804. https://doi.org/10.1002/9781119672333.ch34

D'Emilia, G., Gaspari, A., Natale, E., Prato, A., Mazzoleni, F., & Schiavi, A. (2021). *Managing the Sampling Rate Variability of Digital MEMS Accelerometers in Dynamic Calibration*. https://doi.org/10.1109/metroind4.0iot51437.2021.9488520

Ehirim, C. N., & Akpan, A. S. (2017). Continuous Wavelet Transform Based Spectral Decomposition of 3d Seismic Data for Reservoir Characterization in Oyi Field, Se Niger Delta. *American Journal of Applied Sciences*, *14*(8), 766–771. https://doi.org/10.3844/ajassp.2017.766.771

Esposito, M., Marzorati, S., Belli, A., Ladina, C., Palma, L., Calamita, C., Pantaleo, D., & Pierleoni, P. (2024). Low-Cost MEMS Accelerometers for Earthquake Early Warning Systems: A Dataset Collected During Seismic Events in Central Italy. *Data in Brief*, *53*, 110174. https://doi.org/10.1016/j.dib.2024.110174

Fu, J., Li, Z., Meng, H., Wang, J., & Shan, X. (2019). Performance Evaluation of Low-Cost Seismic Sensors for Dense Earthquake Early Warning: 2018–2019 Field Testing in Southwest China. *Sensors*, *19*(9), 1999. https://doi.org/10.3390/s19091999

Gunoro, G., Suprapto, S., Iriani, J., Sundawa, B. V., Abdullah, A., & Cholish. (2023). Design of Earthquake Warning Alarm Using Accelerometer Sensor Based on Internet of Things. *International Journal of Research in Vocational Studies (Ijrvocas)*, *3*(1), 32–35. https://doi.org/10.53893/ijrvocas.v3i1.194

Han, W., & Kim, N. (2018). Pole-Zero Fitting for Transfer Function of Hearing-Aid Receiver: Evidence-Based Review. *Journal of Audiology & Otology*. https://doi.org/10.7874/jao.2018.00073

Hilborne, V., & Roffey, A. (2020). *From Characterisation to Validation: A Journey Through Master's Level Analytical Chemistry*. 12. https://doi.org/10.3390/proceedings2020055012

Hooijberg, E. H., Steenkamp, G., Preez, J. P. d., & Goddard, A. (2017). Analytic and Quality Control Validation and Assessment of Field Performance of a Point-of-care Chemistry Analyzer for Use in the White Rhinoceros. *Veterinary Clinical Pathology*, *46*(1), 100–110. https://doi.org/10.1111/vcp.12456

Hu, X., Wang, X., Chen, B., Li, C., Tang, Y.-X., Shen, X., Zhong, Y., Chen, Z., & Teng, Y. (2021). Improved Resolution and Cost Performance of Low-Cost MEMS Seismic Sensor Through Parallel Acquisition. *Sensors*, *21*(23), 7970. https://doi.org/10.3390/s21237970

Huang, H., Klingelhoëfer, F., Qiu, X., Li, Y., & Wang, P. (2021). Seismic Imaging of an Intracrustal Deformation in the Northwestern Margin of the South China Sea: The Role of a Ductile Layer in the Crust. *Tectonics*, *40*(2). https://doi.org/10.1029/2020tc006260

Islam, M. M., Tsujikawa, T., Mori, T., Kiyono, Y., & Okazawa, H. (2017). Pixel-by-Pixel Precise Delay Correction for Measurement of Cerebral Hemodynamic Parameters in H2 15O PET Study. *Annals of Nuclear Medicine*, *31*(4), 283–294. https://doi.org/10.1007/s12149-017-1156-5

Ji, G., & Wang, C. (2022). A Denoising Method for Seismic Data Based on SVD and Deep Learning. *Applied Sciences*, *12*(24), 12840. https://doi.org/10.3390/app122412840

Jia, J., & Ye, W. (2023). Deep Learning for Earthquake Disaster Assessment: Objects, Data, Models, Stages, Challenges, and Opportunities. *Remote Sensing*, *15*(16), 4098. https://doi.org/10.3390/rs15164098

Kong, Q., Martin-Short, R., & Allen, R. M. (2020). Toward Global Earthquake Early Warning With the MyShake Smartphone Seismic Network, Part 1: Simulation Platform and Detection Algorithm. *Seismological Research Letters*, *91*(4), 2206–2217. https://doi.org/10.1785/0220190177

Krokidis, S. G., Vlachos, I., Avlonitis, M., Kostoglou, A., & Karakostas, V. (2022). Data-Driven Performance Evaluation of a Low-Cost Seismograph. *Measurement and Control*, *55*(5–6), 340–358. https://doi.org/10.1177/00202940211064448

Landi, E., Prato, A., Fort, A., Mugnaini, M., Vignoli, V., Facello, A., Mazzoleni, F., Murgia, M., & Schiavi, A. (2023). Highly Reliable Multicomponent MEMS Sensor for Predictive Maintenance Management of Rolling Bearings. *Micromachines*, *14*(2), 376. https://doi.org/10.3390/mi14020376

Li, J., Hei, D., Cui, G., He, M., Wang, J., Liu, Z., Shang, J., Wang, X., & Wang, W. (2021). GAN-LSTM Joint Network Applied to Seismic Array Noise Signal Recognition. *Applied Sciences*, *11*(21), 9987. https://doi.org/10.3390/app11219987

Lim, J., Jung, S., JeGal, C., Jung, G., Yoo, J. H., Gahm, J. K., & Song, G. (2022). LEQNet: Light Earthquake Deep Neural Network for Earthquake Detection and Phase Picking. *Frontiers in Earth Science*, *10*. https://doi.org/10.3389/feart.2022.848237

Łuczak, S., Ekwińska, M., & Tomaszewski, D. (2024). A Method of Precise Auto-Calibration in a Micro-Electro-Mechanical System Accelerometer. *Sensors*, *24*(12), 4018. https://doi.org/10.3390/s24124018

Lutti, A., Corbin, N., Ashburner, J., Ziegler, G., Draganski, B., Phillips, C., Kherif, F., Callaghan, M. F., & Domenicantonio, G. D. (2022). Restoring Statistical Validity in Group Analyses of Motion-corrupted MRI Data. *Human Brain Mapping*, *43*(6), 1973–1983. https://doi.org/10.1002/hbm.25767

Ma, K., Wu, J., Ma, Y., Xu, B., Qi, S., & Jiang, X. (2023). An Effective Method for Improving Low-Frequency Response of Geophone. *Sensors*, *23*(6), 3082. https://doi.org/10.3390/s23063082

Manglik, A. (2023). *INSA National Report on Seismological Research in India: 2019 – 2022*. https://doi.org/10.22541/au.167907615.52090686/v1

Maslovskyi, V. (2022). Gender-Age Features and Possibilities of Predicting the Quality of Life in Patients With Myocardial Infarction Without Elevation of ST-segment. *Bulletin of*

Medical and Biological Research, *4*(1), 118–121. https://doi.org/10.11603/bmbr.2706-6290.2022.1.12744

Merrill, J. H., Han, Y., & Roth, C. (2024). A Bayesian Inference Approach to Accurately Fitting the Glass Transition Temperature in Thin Polymer Films. *Macromolecules*, *57*(23), 11055–11074. https://doi.org/10.1021/acs.macromol.4c01867

Muir, J. B., & Zhan, Z. (2021). Wavefield-Based Evaluation of DAS Instrument Response and Array Design. *Geophysical Journal International*, *229*(1), 21–34. https://doi.org/10.1093/gji/ggab439

Munyithya, J. M., Ehirim, C. N., Dagogo, T., & K'orowe, M. O. (2020). Seismic Amplitudes and Spectral Attribute Analysis in Reservoir Characterisation, 'MUN' Onshore Niger Delta Field. *Journal of Petroleum Exploration and Production Technology*, *10*(6), 2257–2267. https://doi.org/10.1007/s13202-020-00917-1

Nof, R. N., Chung, A., Rademacher, H., Dengler, L., & Allen, R. M. (2019). MEMS Accelerometer Mini-Array (MAMA): A Low-Cost Implementation for Earthquake Early Warning Enhancement. *Earthquake Spectra*, *35*(1), 21–38. https://doi.org/10.1193/021218eqs036m

Papanikolaou, V. K., Karakostas, C., & Theodoulidis, N. (2021). A Low-Cost Instrumentation System for Seismic Hazard Assessment in Urban Areas. *Sensors*, *21*(11), 3618. https://doi.org/10.3390/s21113618

Patanè, D., Tusa, G., Yang, W., Astuti, A., Colino, A., Costanza, A., D'Anna, G., Prima, S. D., Fertitta, G., Mangiagli, S., Martino, C., & Torrisi, O. (2022). The Urban Seismic Observatory of Catania (Italy): A Real-Time Seismic Monitoring at Urban Scale. *Remote Sensing*, *14*(11), 2583. https://doi.org/10.3390/rs14112583

Peng, C., Jiang, P., Chen, Q., Ma, Q., & Yang, J. (2019). Performance Evaluation of a Dense MEMS-Based Seismic Sensor Array Deployed in the Sichuan-Yunnan Border Region for Earthquake Early Warning. *Micromachines*, *10*(11), 735. https://doi.org/10.3390/mi10110735

Phung, V.-B., Loh, C. H., Chao, S. H., Chiou, B., & Huang, B. (2020). Ground Motion Prediction Equation for Crustal Earthquakes in Taiwan. *Earthquake Spectra*, *36*(4), 2129–2164. https://doi.org/10.1177/8755293020919415

Pollo, C. F., Meneguin, S., & Miot, H. A. (2018). Evaluation Instruments for Quality of Life Related to Melasma: An Integrative Review. *Clinics*, *73*, e65. https://doi.org/10.6061/clinics/2018/e65

Prato, A., Mazzoleni, F., D'Emilia, G., Gaspari, A., Natale, E., & Schiavi, A. (2021). Metrological Traceability of a Digital 3-Axis MEMS Accelerometers Sensor Network. *Measurement*, *184*, 109925. https://doi.org/10.1016/j.measurement.2021.109925

Rodriguez, I. V., & Myklebust, E. B. (2022). *Deep Compressed Seismic Learning for Fast Location and Moment Tensor Inferences With Natural and Induced Seismicity*. https://doi.org/10.31223/x5v34q

Scafidi, D., Viganò, A., Boaga, J., Cascone, V., Barani, S., Spallarossa, D., Ferretti, G., Carli, M., & Marchi, G. D. (2024). A Dense Micro-Electromechanical System (MEMS)-based Seismic Network in Populated Areas: Rapid Estimation of Exposure Maps in Trentino (NE Italy). *Natural Hazards and Earth System Science*, *24*(4), 1249–1260. https://doi.org/10.5194/nhess-24-1249-2024

Schiavi, A., Prato, A., Mazzoleni, F., Facello, A., & Kwitonda, A. (2023). *Metrological Characterization of Digital Mems Accelerometers in Dynamic Conditions: An Investigation of Linearity in Amplitude and Temperature Effects*. 1–4. https://doi.org/10.21014/tc22-2022.033

Shi, L., Jensen, J. R., & Christensen, M. G. (2017). *Least 1-Norm Pole-Zero Modeling With Sparse Deconvolution for Speech Analysis*. 731–735. https://doi.org/10.1109/icassp.2017.7952252

Tahir, M. A. R., Saleem, M. M., Bukhari, S. A. R., Hamza, A., & Shakoor, R. I. (2021). An Efficient Design of Dual-Axis MEMS Accelerometer Considering Microfabrication Process Limitations and Operating Environment Variations. *Microelectronics International*, *38*(4), 144–156. https://doi.org/10.1108/mi-02-2021-0023

Tang, L., Jin, L., Chen, J., Wang, S., Wang, R., & Hu, X. (2020). Seismic Impact of Large Earthquakes on Estimating Global Mean Ocean Mass Change From GRACE. *Remote Sensing*, *12*(6), 935. https://doi.org/10.3390/rs12060935

Tang, M., Huang, B., Xie, R., & Chen, Z. (2023). A Seismic Inversion Method Based on Multi-Scale Super-Asymmetric Cycle-JNet Network. *Applied Sciences*, *14*(1), 242. https://doi.org/10.3390/app14010242

Varanis, M., Silva, A., Mereles, A., & Pederiva, R. (2018). MEMS Accelerometers for Mechanical Vibrations Analysis: A Comprehensive Review With Applications. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, *40*(11). https://doi.org/10.1007/s40430-018-1445-5

Viswanatha, V., Reddy, R., & Rajeswari. (2020). Characterization of Analog and Digital Control Loops for Bidirectional Buck–boost Converter Using PID/PIDN Algorithms. *Journal of Electrical Systems and Information Technology*, *7*(1). https://doi.org/10.1186/s43067-020-00015-6

Westwood, R., Westwood, A. R., Hooshmandi, M., Pearson, K., LaFrance, K., & Murray, C. (2019). A Field-validated Species Distribution Model to Support Management of the Critically Endangered Poweshiek Skipperling (Oarisma Poweshiek) Butterfly in Canada. *Conservation Science and Practice*, *2*(3). https://doi.org/10.1111/csp2.163

Wu, A., Shin, J., Ahn, J.-K., & Kwon, Y. (2021). Augmenting Seismic Data Using Generative Adversarial Network for Low-Cost MEMS Sensors. *Ieee Access*, *9*, 167140–167153. https://doi.org/10.1109/access.2021.3132901

Wu, Y., & Mittal, H. (2021). A Review on the Development of Earthquake Warning System Using Low-Cost Sensors in Taiwan. *Sensors*, *21*(22), 7649. https://doi.org/10.3390/s21227649

Xie, J., An, Z., Fu, L., Li, K., Li, X., Wen, Z., Cui, J., Lin, G., & Wang, P. (2021). *Strong Ground Motions From the 21 May 2021 M6.4 Yangbi Earthquake in Western China Obtained From a Dense Network of Accelerographs and Intensity Meters*. https://doi.org/10.21203/rs.3.rs-977960/v1

Yang, B. M., Mittal, H., & Wu, Y. (2021). Real-Time Production of PGA, PGV, Intensity, and Sa Shakemaps Using Dense MEMS-Based Sensors in Taiwan. *Sensors*, *21*(3), 943. https://doi.org/10.3390/s21030943

Yang, X., Gao, Y., Zhang, W., Wang, Y., & Lan, M. (2019). Polarization Filtering Method for Suppressing Surface Wave in Time-Frequency Domain. *International Journal of Geosciences*, *10*(04), 481–490. https://doi.org/10.4236/ijg.2019.104028

Zhang, W., Li, H., Li, L., Huang, W., & Wu, Q. (2022). *Fiber Optic Sensors for Seismic Wave Detection*. 150. https://doi.org/10.1117/12.2654743

Zhao, H., Zhou, Y., Bai, T., & Chen, Y. (2023). A U-Net Based Multi-Scale Deformable Convolution Network for Seismic Random Noise Suppression. *Remote Sensing*, *15*(18), 4569. https://doi.org/10.3390/rs15184569

Zhao, J., Li, Z., Gao, Q., Zhao, H., Chen, S., Huang, L., Wang, W., & Wang, T. (2021). A Review of Statistical Methods for Dietary Pattern Analysis. *Nutrition Journal*, *20*(1). https://doi.org/10.1186/s12937-021-00692-7