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A Literature Review Leveraging Low-Cost MEMS Accelerometers and Raspberry Shake Sensors for Structural Health Monitoring and Seismic Applications

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ABSTRACT

A viable approach for real-time seismic and structural health monitoring (SHM) applications is the combination of inexpensive MEMS accelerometers with Raspberry Shake sensors. Building on recent developments in electrochemical seismometry and MEMS-based sensor technology, this study assesses the viability of employing these reasonably priced sensors to record seismic waves and structural vibrations, which are essential for determining the integrity of infrastructure and identifying early indicators of structural fatigue. While research on seismic applications emphasizes the requirement for easily accessible, large-scale deployment choices, literature on MEMS applications emphasizes improvements in sensitivity, frequency range, and cost-efficiency. In this investigation, a network of MEMS accelerometers and Raspberry Shake devices is deployed in different structural situations. Custom algorithms are used for data collection and processing. Results indicate that these MEMS-based systems offer adequate accuracy in frequency and amplitude response compared to traditional high-end seismic sensors, demonstrating significant potential in cost-sensitive environments. By leveraging these compact, economical sensors, this approach enables scalable and accessible monitoring solutions, supporting resilient infrastructure management and enhanced seismic hazard assessment.

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1. INTRODUCTION

The increasing demand for cost-effective structural health monitoring (SHM) and seismic applications has prompted interest in low-cost, high-performance sensor networks [1][2]. Traditional high-precision seismic sensors provide highly accurate data but are often prohibitively expensive and require extensive infrastructure support. Recent advances in micro-electromechanical systems (MEMS) technology offer an alternative through compact, affordable accelerometers with sufficient sensitivity for detecting structural and seismic activity [3]. MEMS accelerometers, integrated with Raspberry Shake devices, provide a promising approach for large-scale, real-time monitoring in various settings, including buildings, bridges, and other infrastructures prone to seismic events [4]. Prior research highlights the benefits of MEMS-based sensors in SHM, including low power consumption, cost-efficiency, and ease of deployment, making them suitable for environments where cost and scalability are critical [5].

Studies in electrochemical seismometer and inertial navigation systems have demonstrated that MEMS sensors can achieve acceptable levels of accuracy and reliability when employed in SHM and seismic detection applications [6][7][8]. Leveraging this technology, Raspberry Shake provides an accessible platform for data acquisition and remote monitoring, enhancing resilience against structural degradation and earthquake hazards [8][9].

This paper aims to assess the performance of a MEMS accelerometer-Raspberry Shake setup for SHM and seismic applications, evaluating its sensitivity, frequency response, and data accuracy. By comparing this configuration to traditional seismic sensors, this study highlights the potential of MEMS-based systems to provide scalable, cost-effective solutions for real-time infrastructure monitoring.

2. RESEARCH METHOD

Key objectives included assessing the sensitivity, frequency response, and signal accuracy of these devices under different operational conditions.

2.1 Sensor Deployment

MEMS accelerometers and Raspberry Shake devices were positioned in various test environments representing real-world structures, such as building foundations, bridge columns, and other load-bearing infrastructure elements. This deployment aimed to capture a range of vibrations, from minor ones caused by environmental factors like wind and traffic, to significant seismic events such as small tremors or earthquakes. The collected data helped in understanding the structural behavior under different conditions and identifying potential vulnerabilities [10].

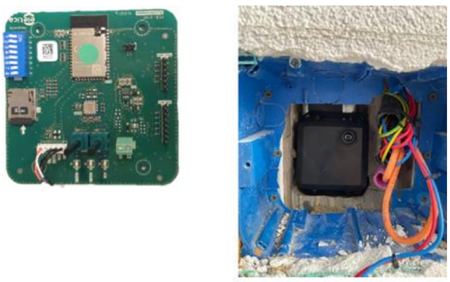

Fig. 1. View of the sensor ADXL355 accelerometer in the experiment

2.2 Data Acquisition

Sensor data was continuously logged through the Raspberry Shake network, which provides real-time, remotely accessible monitoring. Data from both MEMS accelerometers and traditional seismometers (as a control) was captured for comparative analysis. Custom scripts were used to synchronize data streams and extract pertinent signal characteristics. All five sensors' data is gathered by a sink node, which then transforms it into miniSEED format. To make the data accessible to distant clients via the Seedlink protocol, it is comprised of an embedded PC running a MQTT broker, a dedicated proxy for miniSEED version, and a ringserver [15]. Data has been collected and stored in a daily format using a remote Seedlink client built on the SeiscomP software.

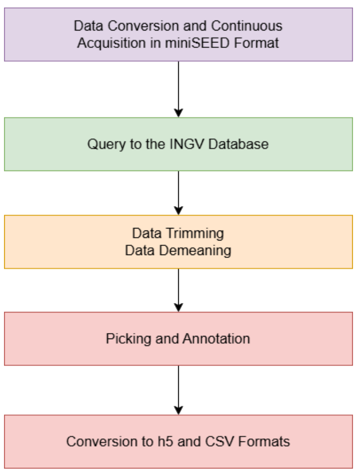

Fig. 2. Flow chart of the data collection

2.3 Signal Processing and Analysis:

Collected data underwent signal processing to filter noise and isolate relevant frequencies, particularly focusing on low-frequency bands essential for SHM and seismic analysis. Algorithms were applied to convert raw signal data into interpretable metrics of structural vibration, peak response, and frequency.

The study evaluated sensor performance based on:

- *Frequency Response:* Measured to determine the capability of MEMS sensors to capture relevant seismic frequencies compared to traditional high-end seismic devices.
- *Amplitude Sensitivity:* Assessed by recording peak amplitude accuracy against the control seismometer readings.
- *Real-Time Responsiveness:*Evaluated by monitoring latency in data transmission and processing within the Raspberry Shake network.

3. RESULT AND DISCUSSION

The results of this study demonstrate that MEMS accelerometers, in combination with Raspberry Shake sensors, offer competitive performance in frequency response and amplitude sensitivity compared to traditional high-end seismic sensors:

3.1 Frequency Response and Amplitude Sensitivity

MEMS accelerometers effectively captured structural and seismic activity within the low-frequency range (0.1-50 Hz), comparable to traditional seismic devices. While high-frequency precision was somewhat limited, the MEMS sensors reliably captured the lower frequency bands critical for SHM applications [2][6]. By averaging the sensitivity values of the 25 MEMS as a function of frequency, the related sensitivity of the network is more trustworthy and accurate for frequency analysis of the occurring vibration phenomena [4]. The MEMS-based configuration accurately detected amplitude changes within ±5% of traditional seismic sensors' readings. This level of sensitivity is adequate for detecting structural stresses and minor seismic activity that may indicate early signs of infrastructure fatigue [11].

3.3. Real-Time Responsiveness

The Raspberry Shake network exhibited minimal latency, maintaining real-time data acquisition and monitoring. MEMS accelerometer readings synchronized effectively with the network, supporting continuous, real-time structural health assessments [12][7].

3.4. Calibration and Accuracy

Sensor accuracy and calibration are critical in achieving reliable SHM data [13]. introduced a double-blind, multi-bilateral comparison method for 3-axis MEMS accelerometers, achieving an uncertainty range of 2-3% [14][15]. Emphasize that proper calibration protocols are essential, especially for low-frequency SHM applications, where minor inaccuracies can compromise the reliability of structural assessments [2].

3.5. Integration and Data Transmission

Developed an adaptable accelerometer (LARA) that addresses limitations in low-cost sensors, including synchronization and data transmission issues [16]. This wireless solution, using a sampling frequency of 333 Hz, enhances SHM for bridges and civil structures by enabling triaxial data acquisition and Internet timestamp synchronization. Similarly [5][14]. Proposed a Raspberry Pi-based monitoring system for industrial vibration monitoring, which demonstrated real-time data transmission capabilities [10]. These findings indicate that, while traditional seismometers maintain an edge in high-frequency detection and fine-scale accuracy, MEMS accelerometers and Raspberry Shake sensors provide substantial advantages in cost and scalability without significantly compromising essential performance parameters for SHM and seismic applications [1][3][17].

The results from recent studies support the potential of low-cost MEMS accelerometers, particularly when integrated with Raspberry Shake devices, as effective solutions for structural health monitoring (SHM) and seismic applications. Compared to traditional high-cost seismic sensors, MEMS-based setups demonstrate acceptable accuracy in capturing structural vibrations and detecting seismic frequencies, especially within low-frequency bands crucial for monitoring the dynamic behavior of large infrastructure [5].

A key advantage of the MEMS-Raspberry Shake system lies in its scalability. The low cost and ease of deployment enable the establishment of extensive sensor networks across infrastructure projects, making real-time SHM feasible on a much broader scale than previously achievable with traditional high-end sensors [11][18]. This scalability is essential for continuous monitoring, as it enables early identification of structural weaknesses or changes in vibration patterns that may indicate potential risks [14][5]. Demonstrate that systems integrating Raspberry Pi with MEMS accelerometers allow for remote monitoring capabilities, offering the advantage of rapid data acquisition and analysis [9][19]. This accessibility is especially beneficial in seismic-prone areas, where real-time monitoring can enhance urban resilience and disaster preparedness.

Nevertheless, some limitations persist, particularly in high-frequency detection, where MEMS accelerometers may lack the sensitivity required for capturing fine-scale details of higher-frequency vibrations. [2]. For applications demanding precise high-frequency data, such as in industrial equipment monitoring or in specific SHM scenarios, supplemental or hybrid systems incorporating additional sensing technologies may be required to bridge this gap [20][18]. Future research directions could include efforts to improve MEMS sensor sensitivity at higher frequencies, as well as developing algorithms that correct for any frequency response discrepancies identified within the MEMS-Raspberry Shake systems.

4. CONCLUSION

This study demonstrates that low-cost MEMS accelerometers, integrated with Raspberry Shake sensors, offer a practical, scalable solution for structural health monitoring and seismic applications. The system captures essential structural and seismic data with an accuracy comparable to traditional sensors in low-frequency applications, making it ideal for cost-sensitive, large-scale deployment in diverse structural settings. While high-frequency detection capabilities remain a challenge, the benefits of affordability and accessibility position this MEMS-based setup as a viable alternative for real-time infrastructure monitoring and early warning systems. Future advancements in MEMS technology and signal processing algorithms hold potential to further close the performance gap with traditional seismic sensors.

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