EXPLORING VIBRATION MEASUREMENT PRECISION: A COMPARATIVE ANALYSIS OF A DIY, LOW-COST ACCELERATION MEASUREMENT UNIT VERSUS A PREMIUM STANDARD ACCELEROMETER SYSTEM

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Abstract- This study focuses on the fabrication and utilization of a low-cost acceleration measurement unit in the construction industry. The ADXL 345 Accelerometer is integrated with an Arduino Mega 2560 microcontroller to facilitate monitoring and recording of readings. The accelerometer captures acceleration along three axes and is connected to the microcontroller. While the low-cost acceleration measurement unit offers approximate measurements, it is subject to certain limitations. The research highlights the importance of creating affordable sensors in scenarios where premium sensors are not readily available or cost-effective. To evaluate the accuracy of the developed prototype, a comparison is made against a premium acceleration measurement unit (AMUs) comprising MEMS type accelerometer 4030 by TE Connectivity controlled by the DAQ System7000 by Vishay Intertechnology, Inc. USA. The relative error is calculated with respect to a finite element model. The obtained results demonstrate that the relative error is not significantly high, thereby indicating the potential reliability of the acceleration measurement unit.

Keywords- Accelerometer, Arduino, Dynamic response, Monitoring and recoding

1 Introduction

Accelerometers play a vital role in various technical domains, including aerospace engineering, civil engineering, and electronics. These devices are primarily used to measure accelerations along one or more axes. Accelerometers are used in the building sector to monitor and evaluate the response of the structure to seismic activity, wind forces, and vibrations. Accelerometers are carefully positioned in key areas of a building to collect continuous data on structural behaviour for post-event and real-time analysis [1].

For assessing a building's structural performance, integrity, and safety, precise acceleration measurements are essential for vibrational analysis techniques. This collected data provides insightful information about how structures behave dynamically under various loading scenarios. It helps reduce the risk of damage and failure by assisting in the design of structures that can withstand anticipated loadings and accelerations. Computed results from the analysis of dynamic acceleration data include displacement, velocity, and frequency. These measurements make it easier to evaluate how structures respond, spot potential weaknesses, confirm design presumptions, and make the necessary adjustments to maintain structural integrity.

However, the cost of acceleration measurement sensors is frequently out of reach, particularly in developing nations like Pakistan. There is a pressing need to develop/fabricate low-cost, in-house acceleration measurement units that can be used across various industries in order to address this issue and make such sensors available. These devices can still offer useful information and act as a cost-effective solution, even though their accuracy and precision might not be as good as those of high-end sensors [2].

A study [3] examines the use of an inexpensive Arduino-based vibration measurement system for structural health monitoring. They mentioned the drawbacks of inexpensive components and how they affect measurement accuracy. When choosing such systems, the authors stress the importance of carefully considering the trade-off between cost and accuracy. The experimental validation of vibration-based energy harvesting for structural health monitoring with Arduino-based systems is presented by Kaur and Bhalla in 2015 [4]. In addition to highlighting the significance of precise vibration measurement for effective energy harvesting, they also express concern about the potential shortcomings of inexpensive Arduino units in achieving the necessary level of accuracy. Tomaneng et al. propose an advanced Arduino-based seismic monitoring system in 2022 [5], with the goal of improving vibration measurement accuracy. They incorporate sophisticated signal processing algorithms and noise reduction techniques to overcome the drawbacks of inexpensive Arduino units. A study [6] offers a soft-gauge solution based on the low-cost triple-axis accelerometer MMA7361L and LabVIEW software for lift vibration analysis with national standards precision. The MMA7361L and NI USB6009 3-dimensional vibration signals are fed into a soft-gauge programmed in LabVIEW to filter, and the fast Fourier transform (FFT) is used to determine the power spectral density (PSD) and spectrogram of vibrations of filtered vibration signals. [7] in paper used inkjet-printed sensor in the mesoscale to investigate its behavior in low-frequency domain (20Hz). This frequency fits its applications in the field of seismic monitoring. Based on results and performances authors encourage the use of all-inkjet-printed sensor because of low cost and disposable features.

The aforementioned literature review showcases several studies that have examined and compared low-cost and premium Arduino-based systems for vibration measurement.

This study focuses on the fabrication of a low-cost acceleration measurement unit and compares the results with a finite element model and measurements from a MEMS type accelerometer 4030 by TE Connectivity connected to a DAQ System7000 by Vishay Intertechnology, Inc. USA. The measurements are displayed and recorded using the Arduino Mega 2560 in conjunction with the ADXL 345 3-axis acceleration measurement sensor. The outcomes of this research have significant implications for various departments, given the diverse applications of this sensor.

2 Experimental Procedures

There were numerous in-depth discussions with relevant technology experts prior to the creation of the new prototype. The choice of an appropriate accelerometer was given careful thought throughout the procedure. The sensitivity requirements, frequency range, size, price, and environmental conditions of the intended application are just a few of the variables that affect the selection of an accelerometer [8]. The ADXL 345 accelerometer was decided upon for this study in accordance with these factors. With variable sampling rates up to 100Hz, this accelerometer can detect acceleration in three dimensions. The ADXL345 is a small and energy-efficient component that is frequently used in electronic devices, such as smartphones, tablets, and game controllers, to detect changes in orientation and movement.

2.1 Arduino Mega 2560

The Arduino Mega 2560 is a reliable platform for displaying and storing information in computer memory. It employs the ATmega2560, an 8-bit AVR-based microcontroller with 256 KB of flash memory for storing program code, 8 KB of SRAM for storing data, and 4 KB of EEPROM for nonvolatile storage. The Arduino Mega 2560 is an improved version of the original Arduino boards, with an increased number of features and capabilities than the Arduino Uno. It is especially useful for projects that require many I/O pins, a large amount of program memory, and advanced functionality. The Arduino Mega 2560 is frequently used in projects requiring enhanced processing power and communication capabilities, such as robotics, automation, data recording, and other applications.

Features of Arduino Mega 2560:

- Microcontroller
- Digital I/O Pins
- Analog Inputs
- Communication Interfaces
- Memory Expansion
- Additional I/O

- Power Supply

Fusion 360, a program renowned for its sophisticated 3D modelling capabilities, is used to create the enclosure (see Figure 1b) for the Arduino and accelerometer. It makes it possible to design the casing in a precise and unique way. Once the design is complete, a CNC (Computer Numerical Control) machine is used to precisely cut the required acrylic sheets to the required sizes.

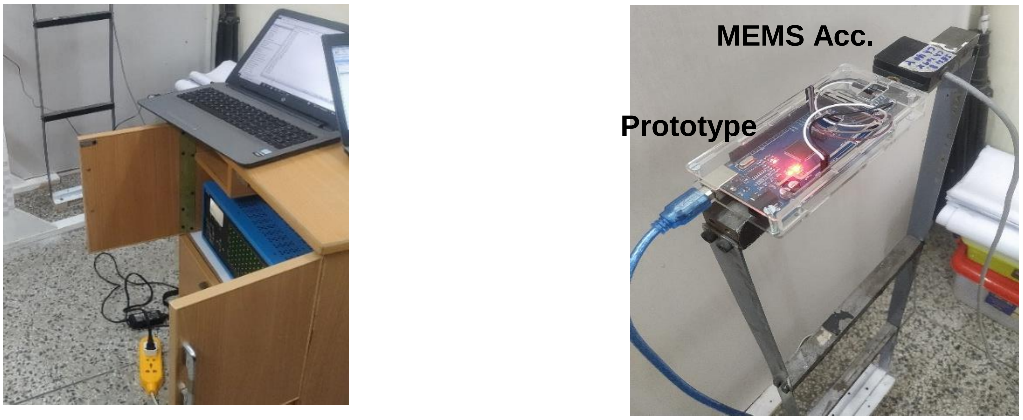
(b)

(a)

Figure 1: Prototype assemblage (a) Arduino Mega 2560 board (b) Acrylic casing

2.2 Steel Frame Test Model

The premium acceleration sensor (MEMS Accelerometer by TE Connectivity) and the prototype are both attached to the top of the model. Finger-tap force is used to cause vibrations in the steel frame while samples are being collected for a predetermined amount of time. 'Coolterm' software is utilized to save the data. The readings collected are displayed using the Arduino IDE software. The chosen accelerometer's accuracy is within $\pm 3g$ range. Using Finite Element Method (FEM), response time history and power amplitude of the steel frame are conducted to obtain a structural response set of data. This data is then compared with the readings from the premium and prototype acceleration measurement units to determine the relative inaccuracy.



(a)

(b)

Figure 2: Testing setup (a) DAQ System7000 (b) Prototype and MEMS (4020) acceleration measurement unit mounted on steel frame model

3 Research Methodology

The results of the experiment (see Section 4) and analyzed through the utilization of graphs representing the power spectrum and time response. The power spectrum is a mathematical representation that illustrates the distribution of a signal's power or energy across different frequencies. It is obtained by subjecting the signal to a mathematical operation called the Fourier transform, which decomposes the signal into its constituent frequencies. By examining the power spectrum, valuable insights can be gained regarding the frequency composition of the signal under investigation.

On the other hand, the time-based response of a system or signal depicts its behavior over time in response to a specific input or stimulus. It represents the output of the system as a function of time when subjected to a particular input. This temporal response provides significant information about the dynamic characteristics of the system, including its transient response, stability, and other inherent qualities.

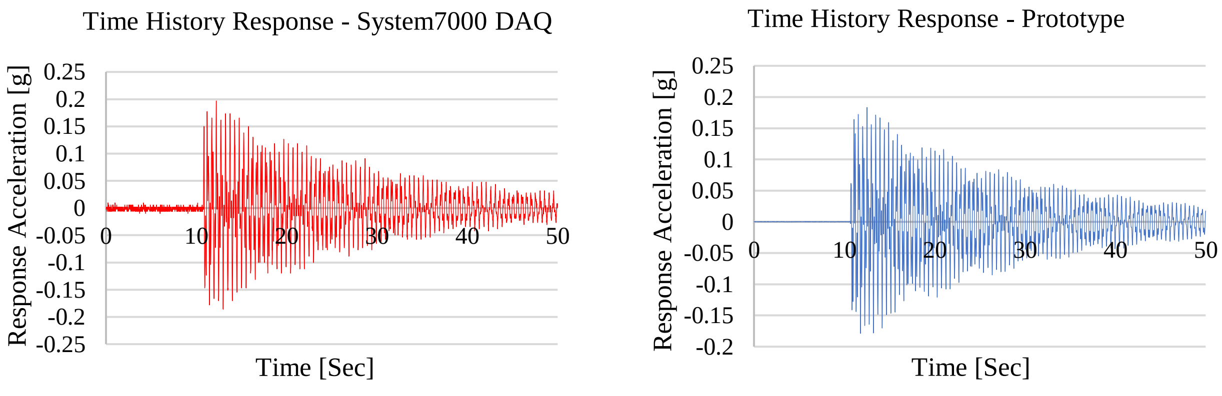
The power spectrum makes it possible to identify and characterize frequency components that make up the signal, highlighting dominant frequencies or potentially interesting spectral features. On the other hand, the temporal response demonstrates how the system or signal develops and changes over time, providing essential information about its transient behaviour, damping properties, and general dynamic response.

4 Results

Figures 3(a) and 3(b) are time history response graphs which give a visual representation of the structure's response to vibrations. It is clear from the graphs that the Premium Acceleration Measurement Unit displayed higher acceleration values than the Prototype. Particularly, at 12.5 seconds into the test, the Prototype recorded its highest acceleration reading of 0.183 g. The System7000, on the other hand, recorded a maximum acceleration reading of 0.199 g. These numbers demonstrate how the two systems' acceleration measurements differ from one another.

The System7000 consistently showed higher acceleration values than the Prototype over the length of the 50-second test. This shows that throughout the testing period, the premium measurement unit consistently recorded higher acceleration levels. The premium system appears to be better able to detect and record weaker magnitudes of acceleration based on the higher values it recorded.

When assessing the efficiency and dependability of the prototype acceleration measurement unit, it needs to take these conclusions into account. It is advised to conduct additional research and testing to determine the Prototype's limitations and possible areas for development, especially with regard to precisely measuring acceleration values.



(a) (b)

Figure 3: Time history model response (a) System7000 DAQ (b) Prototype

Figure 4 illustrates the frequency content and power distribution of the signal received from the vibrating structure. The graph shows the relationship between frequency, which represents the speed at which the signal oscillates, and power spectrum, which represents the distribution of power or energy across various frequencies. Applying the Fourier transform, which breaks the signal down into its component frequencies, yields the power spectrum. The estimated modal frequencies of the test model are presented in the Table 1.

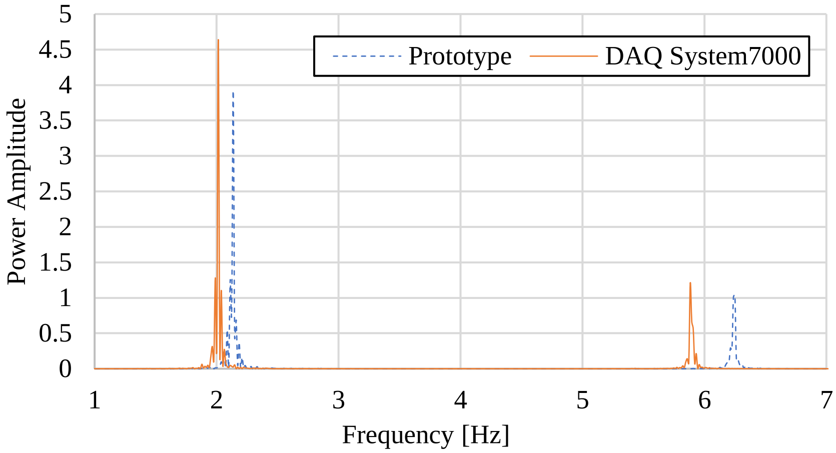


Figure 4: Frequency vs Power Spectrum

Table 1: Dynamic characteristics

Mode (Hz)	FE Results	Prototype	System7000-DAQ
1	1.97	2.14 (+9%)	2.01 (+2%)
2	5.93	6.25 (+5%)	5.88 (-1%)
Note: Parentheses percentage difference is calculated w.r.t to FE Results.			

When compared to the results from the Finite Element Model (FEM), the results analysis provides important information about the relative error and accuracy of the prototype and the System 7000-DAQ.

The prototype displays a relative error of 9% at Mode 1, which deviates from the FEM results by about 9%. The System7000, on the other hand, shows a relative error of 2%, which indicates a closer alignment with the FEM results. According to these results, the System7000 produces measurements that are more accurate than the prototype at Mode 1.

About Mode 2, the prototype shows a relative error of 5%, which denotes a minimal departure from the FEM findings of 5%. The System7000, on the other hand, displays a negative relative error of -1%, which indicates a slight underestimation in comparison to the FEM results. It is notable that a negative relative error implies that the System7000 is marginally more accurate than the prototype at Mode 2 than the FEM results.

5 Conclusions

The outcomes of the experiment show that, up to a point, both inexpensive and expensive acceleration measurement units can measure vibrations effectively. However, there have been some apparent differences in terms of their precision and dependability.

- A cost-effective option, the low-cost prototype unit showed limitations in terms of accuracy and sensitivity. As a result of measurement errors and instrument sensitivity, the readings were less accurate.
- The expensive premium acceleration measurement unit displayed superior performance in terms of accuracy and precision. Its high-quality parts, cutting-edge signal processing procedures, and improved noise reduction techniques made its vibration measurements more reliable and precise.
- The premium unit is suitable for applications where accuracy is crucial because it can pick up even the smallest changes in vibration patterns and finer details.

It is crucial to take the particular needs of the project or application into account when choosing between inexpensive and expensive units. The inexpensive unit might be an option if cost is the main consideration, and the application allows for some margin of error. The premium unit is recommended, despite its higher price, for applications that call for exceptional accuracy and dependability.

The comparison's conclusion emphasizes the compromises between cost and effectiveness in vibration measurement. Understanding the advantages and disadvantages of each choice and choosing the ideal Arduino Mega unit in accordance with their unique requirements will help engineers and researchers make well-informed choices.

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