Design and Development of A Portable Vibrometer Using ESP32 Microcontroller and ADXL345 Sensor

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Abstract
Traditional vibration meters are often expensive, limiting their accessibility. This study proposed the design and development of a portable vibration meter that can be implemented at low cost using MEMS accelerometers (ADXL345) and an ESP32 microcontroller. To monitor vibrations, Class I small machines are used. The main aims were to design, develop, test the accuracy, and determine the significant difference in the Velocity and acceleration between the designed portable vibration meter and the commercial vibration meter. When laboratory-testing induction motors with a horsepower range of 0.25-1.0, each motor was measured using both a designed portable vibration meter and a commercial vibration meter; an experimental arrangement was employed to gather data. Evaluation of the results by means of a paired t-test revealed that there was no significant difference in vibration readings between the designed portable vibration meter and the commercial vibration meter in a 0.25 HP induction motor. However, when induction motors were rated higher than 1.0 HP, the results from the designed portable vibration meter differed significantly from those of the reference vibration meter in acceleration data. The study demonstrated that the designed portable vibration meter was comparable to a commercial vibration meter for a 0.25 HP induction motor. However, calibration is necessary to enhance the performance of the designed vibration meter for high-rated machinery, which can help small businesses monitor their machine health and reduce maintenance costs.

Keywords: acceleration, induction motors, paired t-test, vibration monitoring, velocity

INTRODUCTION

Vibration is the physical condition of an object that materializes as cyclical or periodic motion of its condition during start-up, shut-down, and upright position (Rao, 2019). This oscillatory motion back and forth of the objects of an elastic body or medium is typically produced when any physical system is displaced from its equilibrium state and allowed to respond to the forces that are likely to be at work trying to bring the equilibrium state back again. From motors to pumps and everything in between, machines that move or transfer power are essential for industries across the spectrum. Pal et al. (2022) state that one of the fundamental tasks in condition monitoring over the last few years has been to detect machine vibrations from rotating machinery, such as pumps, fans, or turbines. Such vibration monitoring can help determine when there are bearing problems and other mechanical failures as well. Issues with these machines mainly include increased vibration, which triggers higher costs and production downtime. High-cost equipment used in traditional vibration monitoring has made it expensive and inaccessible to small- to medium-sized businesses. Secondly, current solutions may not be cost-effective or easy for operations personnel to use. Measuring the vibrations of rotating machines with a smart vibration meter is challenging, but this project aims to address that issue with an enhanced vibration measurement device. By offering a solution for monitoring vibrations, this research aims to enhance the reliability of machines and lower maintenance expenses, benefiting industries that heavily depend on these machines.

Induction motors often experience bearing faults, which can significantly impact the condition and performance of the machine. According to Siddiqui et al. (2019), bearing-related problems are major causes of the mechanical failure of rotating parts. Because these problems occur often, induction motors must be monitored and detected early to maintain reliability. If undetected, these problems can lead to costly repairs and prolonged downtime. ISO 10816 and ISO 20816 Series specify the rules for determining the degree of vibration on various types of machines with an emphasis on vibration monitoring (Edwards, 2024).

Varanis et al. (2018). MEMS technology offers several benefits due to its small size, cost-effectiveness, and flexibility in addressing various engineering problems. In this article, the authors highlight three key parameters that define an accelerometer's performance: sensitivity, useful frequency range (bandwidth), and precision. They also discuss the advantages and shortcomings of MEMS accelerometers compared to established industrial-grade vibration sensors. Its applications span from industrial machinery monitoring to consumer electronics, showing the increasing relevance of MEMS accelerometers in mechanical systems monitoring.

Pedotti et al. (2020) developed an inexpensive solution for monitoring vibrations in rotating machines through a network of small MEMS accelerometers. Their results indicate those cheap sensors can keep up with vibrations and observe misalignment and noises from the bearings as they occur. This concept creates an affordable alternative to costly traditional methods, making it a viable option for industries that require reliable diagnostic tools with minimal investment. This is a low-cost, almost disposable way of performing routine machine maintenance and fault detection.

The research answered the demand for low-cost and efficient vibration monitoring in induction motors (Adli et al., 2020). The application of MEMS accelerometers in developing a low-cost vibration meter provides much-needed practical alternatives to expensive commercial sensors, offering comparable performance at significantly lower prices. This will enable wider access to reliable diagnostic tools, allowing for the quick identification of mechanical faults and reduced maintenance costs. Pedotti et al. (2020) have developed a cost-effective method for monitoring the vibrations of rotating machines using small MEMS accelerometers. Their results also show that with this type of sensor, it would be feasible to capture vibrations and detect problems in real time, which would be a more practical and cost-effective alternative compared with classical systems in industries requiring efficient diagnostic tools.

MATERIALS, METHODOLOGY, AND LITERATURE REVIEW

Materials of the Study

The research utilized the ADXL345 MEMS accelerometer due to its ultralow power consumption, cost-effectiveness, and suitability for industrial applications, which can withstand 10,000 g of shock. The ESP32 WROM microcontroller provides faster processing speeds of up to 240 MHz and 600 DMIPS, with a data rate of 150 Mbps, enabling faster calculations, efficient execution of complex algorithms, and high-speed communication between devices.

Other components included a power source, a toggle push button, a display screen, and a buck converter. The 9V battery provides power to all components, allowing for a longer operational time. A buck converter was used to step down the voltage level to 3.3V, which is in line with the voltage requirement of all electronic components. The OLED offers low power consumption, a faster response time, and a high-quality image for display. Three switches of different types, where one latching switch was used for simple operation, which turns off or on the device, and two momentary switches to provide toggle features between axes (1) and between acceleration and Velocity (2).

Methodology

There were only two things that required careful consideration: the quality and capabilities of both the vibration sensor and the microcontroller, to produce a device capable of measuring vibrations.

Figure 2 shows the actual wiring connection of the designed vibration meter. Input voltage of 9V is stepped down to 3.3V. The momentary switch leading to pin G2 was to toggle between axes of interest. You isolate the axis subjected to testing, such as the x-axis, so that other values or data from different axes, such as y and z, do not show in the display. The momentary switch leading to the G4 pin was a simple toggle option, allowing users to choose whether to display acceleration or velocity. Each of these parameters has a different calculation, which is why a toggle function separates them.

Design of a Portable Vibration Meter.

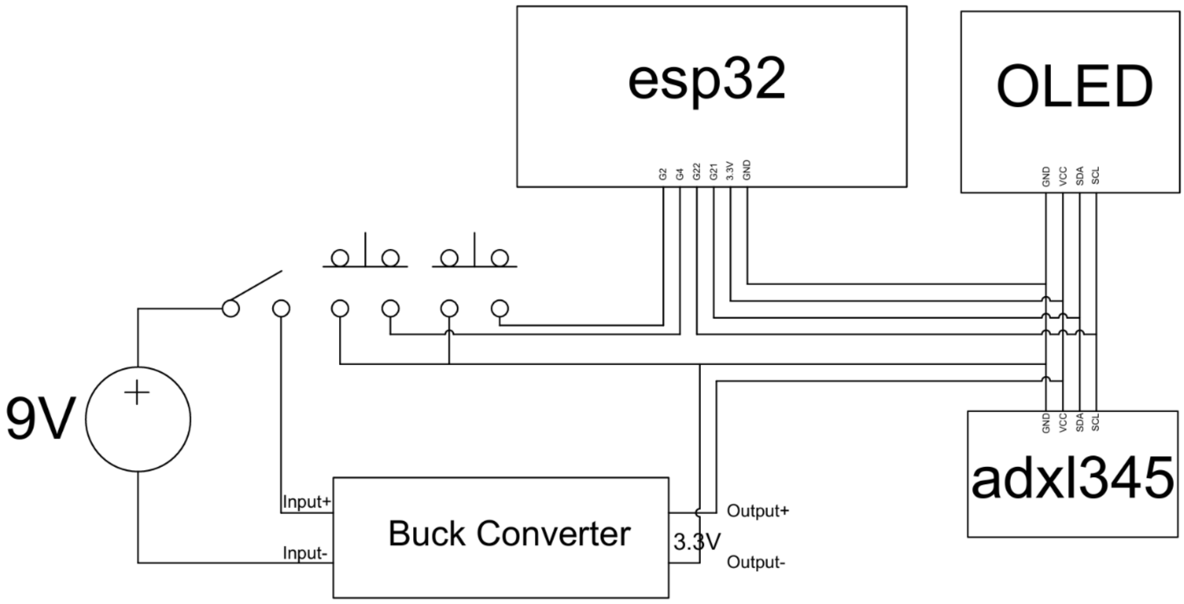

Figure 2. Schematic Diagram of a Portable Vibration Meter.

Figures 3 to 5 showshow the dimensionsdimensions for the case, which,which were carefully constructed to fit all the components inside, including the wires, with proper allowances. Perform actual measurements of the components and refer to the datasheet provided for each element to determine its dimensions, resulting in more accurate sets of measurements for proper fitting of the casing. This layout was designed using AutoCAD software and subsequently exported as an STL file. File format to fit the requirements of the 3D printer. The thickness of the main casing is 3 mm.

Development of a Portable Prototype Vibration Meter.

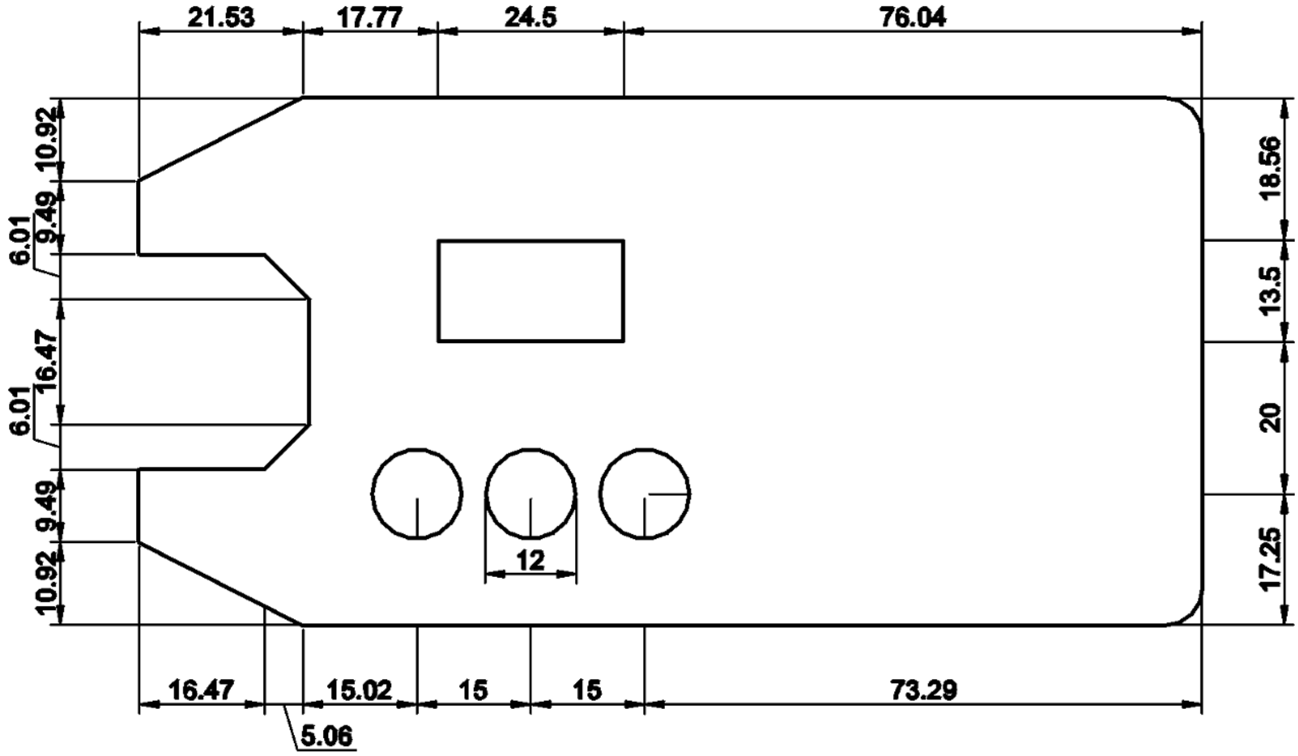

Figure 3. Dimensions for the Cover of the Casing, Top View.

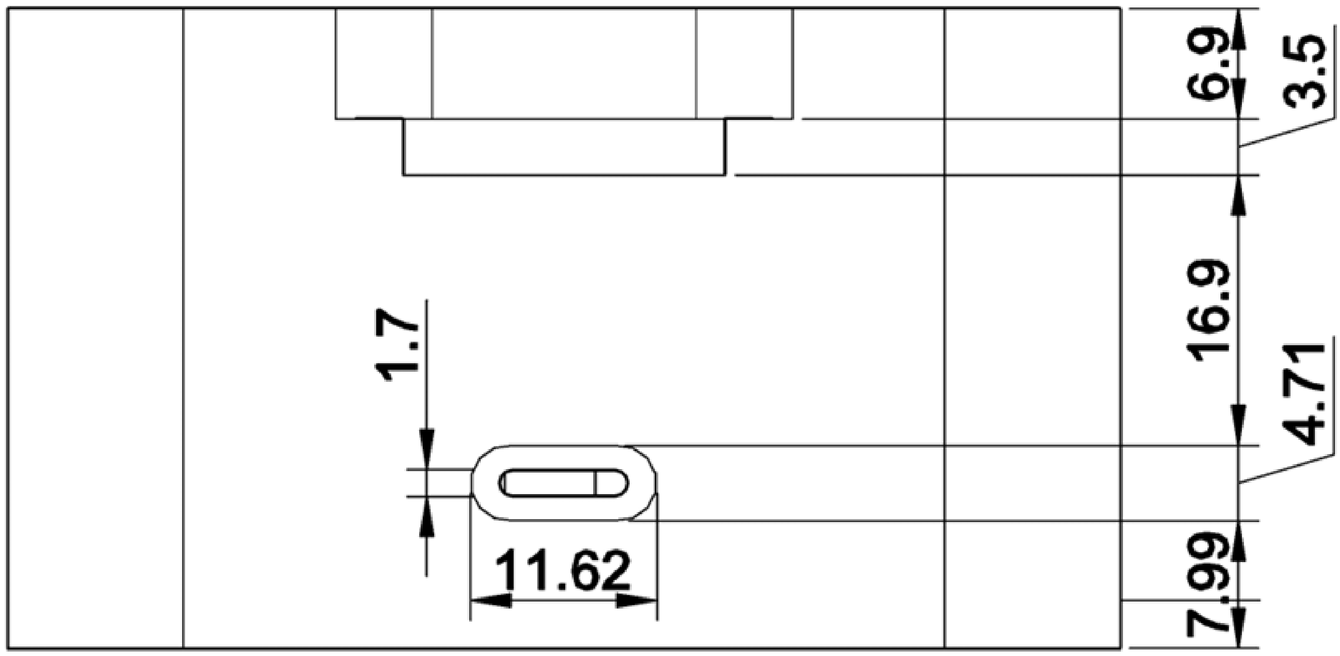

Figure 4. Dimensions for the Body of the Casing, Top View (mm)

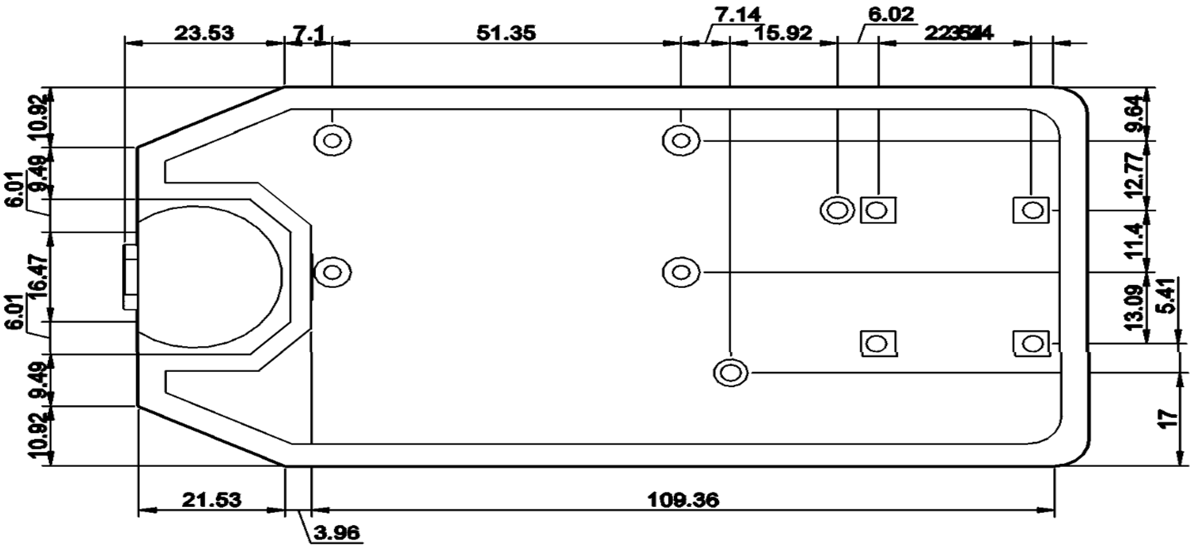

Figure 5. Dimensions for the Body of the Casing, Front View (mm).

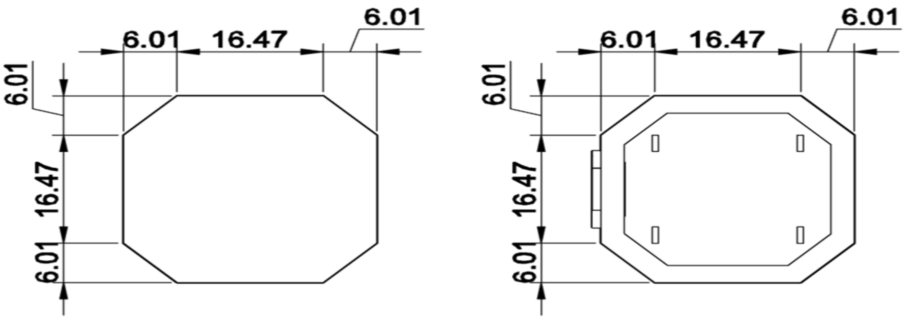

Figure 6. Dimension for the ADXL345 casing, Top view

Figures 6 and 7 were the front and top views for the housing of the ADXL345 and the magnet. The research was designed to enclose the ADXL345 and secure the magnet. This is the central part for measuring acceleration and Velocity.

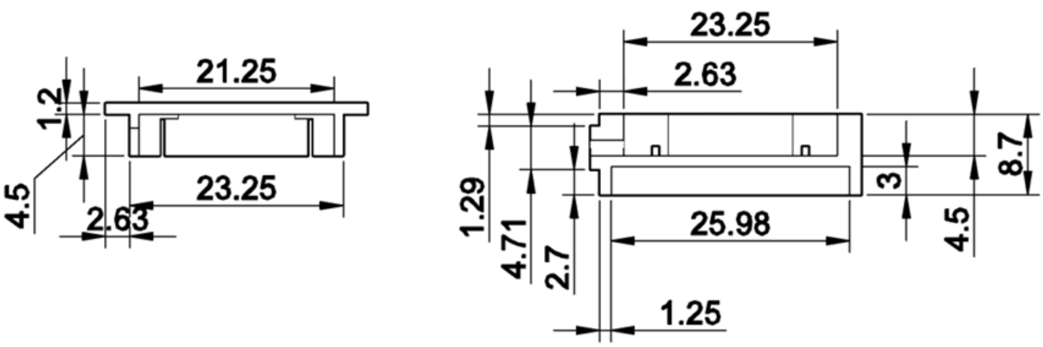

Figure 7. Dimension for the ADXL345 casing, Front view. Calibration of the Sensor

Figure 8 was related to the behaviour of ADXL345 at the initial setup. The data it produced were far from the desired value, which is 9.81 m/s2 acceleration due to gravity. This "raw data" was not suitable for processing by the esp32; thus, it needs to undergo a calibration process. The two-point calibration method utilizes two known values, specifically the point at the origin (0,0) and the point at the X value. The known values for adxl345 were its values when its sensing orientation was along with the orientation of the acceleration due to gravity pointing downward, which will be referred to as A+. When both orientations were in opposite directions, then it will be referred to as A-. When the orientation is perpendicular to gravity, then the data of ADXL345 is zero—figure 9 Sensing Orientation of ADXL345 and Orientation of Gravity.

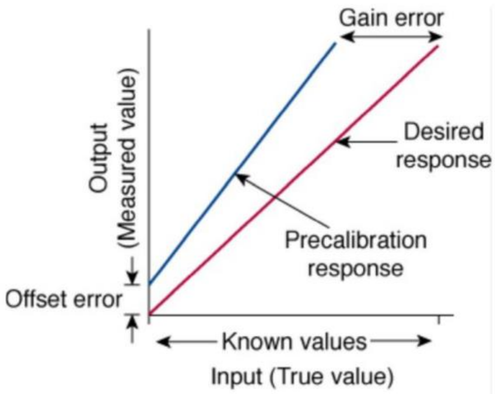

Figure 8. Two-Point Calibration in Graph.

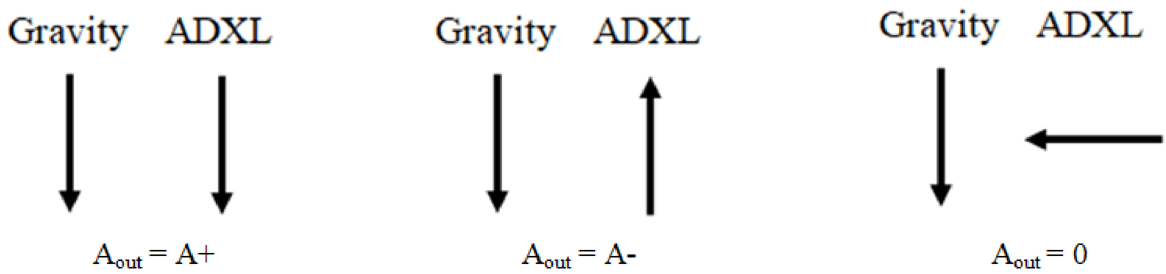

Figure 9. Sensing Orientation of ADXL345 and Orientation of Gravity.

Figure 10 illustrates that two-point calibration is a technique that rescales the output, corrects the sensitivity, and offsets sensor errors (Fisher, n.d.). The values or resulting data of the ADXL345 must follow the ideal accelerometer values, which correspond to a 0 g offset and near-perfect sensitivity, to determine the validity of the calibration results. The following formulas are taken from a website called Analog Devices, having an article entitled "Using an accelerometer for Inclination Sensing," authored by Christopher J. Fisher. The sensor is likely to display a value beyond the intended range due to static stress during manufacturing and limitations in factory calibration, which significantly affects the offset and sensitivity.

$$\square_{OFFSET}\ [g] = 0.5 \text{ x } (A_{+1g} + A_{-1g})$$

$$\text{Gain} = 0.5 \text{ x } \left(\frac{A_{+1g} - A_{-1g}}{1g}\right)$$

$$A_{ACTUAL} = \left(\frac{A_{OUT} - A_{OFF}}{GAIN}\right)$$

Figure 10. Calibration Formula.

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Figures 11 to 16 show the raw data of the sensor in its initial state. Significant error was noticeable in all axes. Regarding programming objectives, the data for negative acceleration appears positive, but in reality, it was negative. This was done to have data with absolute values.

Figure 11. Raw Data of the Sensor X+

Figure 12. Raw Data of the Sensor X-

Figure 13. Raw Data of the Sensor Y+

Figure 14. Raw Data of the Sensor Y-

Figure 15. Raw Data of the Sensor Z+

Figure 16. Raw Data of the Sensor Z-

Table 2 shows the tabulated results of the positive and negative raw data of ADXL345 and the calculated offset and gain values using the formula above.

Table 2. Raw Data of Different Axis and Calculated A_{OFFSET} and Gain Values.

Axis	A+	A-	A_{OFFSET}	Gain
X	10	-10.17	-0.0850	1.0280
Y	10.16	-10.17	-0.0050	1.0361
Z	8.16	-11.86	-1.8500	1.0204

Statistical Treatment

A paired t-test is a statistical tool used to determine if there was no significant difference (zero difference) between two observations (Cuemath, n.d.), in this case, data from ADXL345 to reference data from vibration meter GM63A. Through this method, we can effectively construct a concrete conclusion regarding the function of ADXL345 to deliver sustainable results.

For convenience, the research used MATLAB to perform the paired t-test. All of the data taken from both ADXL345 and commercial vibration meter are input into the program with a level of significance value of 0.05

Literature Review

Varanis et al. (2018). MEMS technology offers several benefits due to its small size, cost-effectiveness, and flexibility in addressing various engineering problems. In this article, the authors highlight three key parameters that define an accelerometer's performance: sensitivity, useful frequency range (bandwidth), and precision. They also discuss the advantages and shortcomings of MEMS accelerometers compared to established industrial-grade vibration sensors. Its applications span from industrial machinery monitoring to consumer electronics, showing the increasing relevance of MEMS accelerometers in mechanical systems monitoring.

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The study by Islam et al. (2020) is a tutorial guide on reading mechanical vibration with Arduino using an accelerometer. It can record the vibration data with the highest precision attainable, and it incorporates a set of features that makes this device very sophisticated compared to others of the same type. It enhances safety by utilizing wireless data transmission and offers a more cost-effective alternative to conventional vibration measurement devices. The paper also suggests that it can be further improved through continued research, making it a consistent method for enhanced vibration monitoring.

Romanssini et al.(2022). Acceleration in the Detection of Faults on a Bearing within Rotating Machinery. The presence of surface defects in bearings, such as spalling or pitting, creates sharp spikes in vibration. Acceleration measurements are one of the primary methods to record these sudden jolts, which are due to the high-frequency signals generated by such imperfections. The rolling elements of the bearing go over this deformed area and create some double impact due to changing forces in directions, so vibration patterns are different when looking for acceleration data quite at an early stage. So, this makes it a strong technique for preventing.

Bastami et al. The study (2021) examines the effect of defect size on rolling element bearings by analyzing the statistical features of vibration signals. It clearly showed a relation between the defect ratio and the acceleration level in the system. The larger defect sizes formed, the greater magnification brought. From this correlation, it is discerned that greater defects have more vibrating energy and, thus, turn out to have higher acceleration in the vibration analysis. The offer of the Literature is also reinforced by a graph in their publication, which shows a direct increase in achieved acceleration depending on defect size. This is particularly important for condition monitoring and fault diagnosis, as acceleration levels can be effective measures of bearing defects.

Kudelina et al. (2020) examined how bearing faults influence the vibration patterns in BLDC motors, using accelerometers to gather vibration data across different fault conditions. Through Fast Fourier Transform (FFT) analysis, they discovered that faults in the inner race, outer race, and rolling elements generated distinct frequency peaks in the vibration spectrum. As the faults became more severe, the peak amplitudes in the vibration spectrum increased. The use of accelerometers provided precise, real-time data, demonstrating that vibration monitoring is an effective method for detecting faults early on. The study highlights the importance of predictive maintenance in preventing motor failures and enhancing overall operational performance.

The study published by Artono et al. (2021) focused on designing smart monitoring devices for induction motors, which are integral to the industrial machinery chain and a crucial part of factories. In many sectors, induction motors are dominant, and it is essential to monitor their condition as part of the principle operation-only strategy for PI. Preventing failures that lead to unplanned downtime (loss of production) or costly repairs all leverages predictive maintenance. In this paper, a smart device is recommended, equipped with sensors and IoT technology, for real-time monitoring of motor performance.

This method has a crucial constituent that upgrades operational efficiency and reduces maintenance costs, thereby enhancing its reliability for motor-driven systems (Artono et al., 2020).

RESULTS AND DISCUSSIONS

The design of a portable vibration meter successfully included the ESP32 microcontroller and ADXL345 sensor in a compact 3D-printed casing. The dimensions of the components were compact in accordance with the design. The design turned out to be functional and easy to handle; the researchers were able to toggle acceleration to Velocity and vice versa, just like the push buttons on all axes, meeting the goals of portability and durability. Figure 17 shows the wiring connections and designated pins on where the components are to be placed.

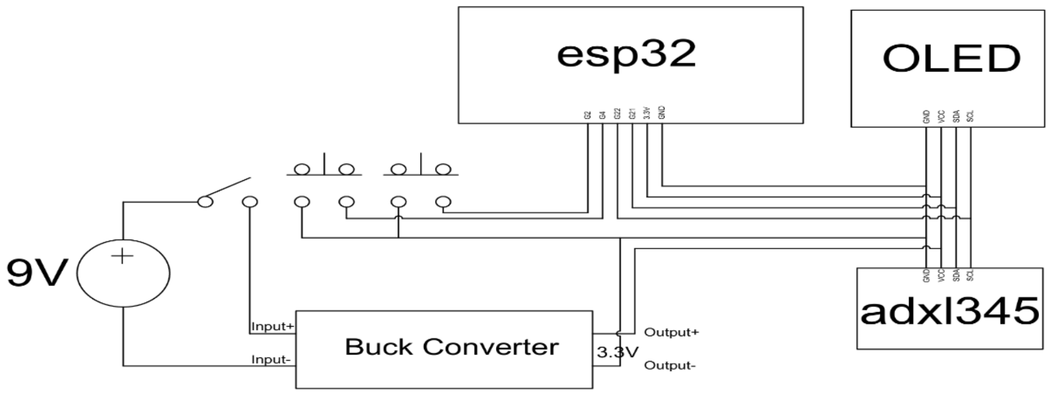

Figure 17. Schematic Diagram

Figure 18 shows the designed portable vibration meter in its final form. Visible from the outside are the power button, the toggle button and the display screen.

Figure 18. Designed of a Portable Vibration Meter.

In the development of the portable vibration meter, shown in Figure 19, all the components were soldered properly, and the programming was assembled correctly. As shown in the appendices section, figure 21, the 3D-printed casing fits everything securely. The design performed well during testing, and the device operated as intended—see Table 9. The cost of the designed vibration meter was only 1,867 pesos, compared to the commercial vibration meter, which cost 5,000 pesos. It has a difference of 3,133 pesos. The research resulted in a low-cost, portable vibration meter.

Figure 19. Development of the Portable Vibration Meter.

Tested the accuracy and reliability, Table 3A. Results of a 0.25 HP induction motor show a less significant difference between the two measured values on a 0.25 HP motor, which ranges from 0.01 to a maximum difference of 0.45. There were some observable differences in the data regarding velocity, unlike acceleration, which suggests that the acceleration-measuring capability of the device was far more effective on lower machines.

Table 3B. The results of a 1HP induction motor analysis show that the acceleration values of the ADXL345 significantly deviate from those of the commercial vibration meter, which ranges from 1.98 to a maximum of 2.49. On the other hand, Velocity has improved its record values. As observed, the difference in value ranged from only 0.04 to a maximum value of 0.4, which may imply that as motor ratings increased, Velocity tended to be more reliable than acceleration data.

Table 3C. Results of a 1.5HP Induction Motor show there were some observable differences between the reference data and ADXL345. Still, it was significantly larger in both acceleration and Velocity for the X-axis, from 1.5 to 2.05. Other recorded data for both the Y and Z axes show excellent values, suggesting that ADXL345 possesses quality measuring attributes. The velocity difference ranged from 0 to 0.8 maximum, while the acceleration ranged from 0.05 to 0.3.

The following data can be interpreted as follows: the capacity and reliability of the designed vibration meter were significantly improved at lower ratings of the induction motor for both velocity and acceleration measurements, as seen in the data with the 0.25 HP motor. However, as the motor increases in size and capacity, the Velocity achieves some excellent results, excluding the X-axis at 1.5 HP.

Table 3A. Results of a 0.25HP Induction Motor.

Velocity mm/s			Acceleration m/s^2		
C	A	D	C	A	D

Y	Y		Y	Y	
1.5	1.42	**0.08**	1.2	1.21	**0.01**
1.7	1.45	**0.25**	1.2	1.21	**0.01**
1.8	1.59	**0.21**	1.2	1.23	**0.03**
1.8	1.59	**0.21**	1.3	1.36	**0.06**
1.9	2.15	**0.25**	1.3	1.38	**0.08**
1.7	1.42	**0.28**	1.2	1.21	**0.01**
1.8	1.45	**0.35**	1.3	1.21	**0.09**
1.7	1.59	**0.11**	1.3	1.23	**0.07**
1.8	1.59	**0.21**	1.2	1.23	**0.03**
1.5	1.59	**0.09**	1.2	1.36	**0.16**
1.7	2.15	**0.45**	1.3	1.38	**0.08**
1.8	1.42	**0.38**	1.3	1.21	**0.09**
1.8	1.45	**0.35**	1.3	1.21	**0.09**
1.9	1.59	**0.31**	1.2	1.23	**0.03**
1.7	1.59	**0.11**	1.2	1.36	**0.16**
1.8	1.59	**0.21**	1.3	1.38	**0.08**
1.5	1.59	**0.09**	1.2	1.21	**0.01**
1.7	1.45	**0.25**	1.2	1.21	**0.01**
1.8	1.59	**0.21**	1.3	1.23	**0.07**
1.8	1.42	**0.38**	1.3	1.36	**0.06**

Legend:

C - Commercial vibration meter (GM63A)

A - ADXL345 sensor (Designed Portable Vibration Meter)

D - Difference between measurements (C - A)

Table 3B. Results of a 1HP Induction Motor.

Velocity mm/s						**Acceleration m/s^2**					
C	**A**	**D**	**C**	**A**	**D**	**C**	**A**	**D**	**C**	**A**	**D**
X	**X**		**Y**	**Y**		**X**	**X**		**Y**	**Y**	
1.5	1.20	**0.3**	1.3	1.21	**0.09**	3.5	1.08	**2.42**	3.0	1.02	**1.98**
1.6	1.20	**0.4**	1.3	1.26	**0.04**	3.5	1.10	**2.4**	3.0	1.07	**1.93**
1.6	1.44	**0.16**	1.3	1.28	**0.02**	3.6	1.15	**2.45**	3.0	1.13	**1.87**
1.6	1.44	**0.16**	1.4	1.37	**0.03**	3.7	1.21	**2.49**	3.5	1.13	**2.37**
1.7	1.73	**0.03**	1.4	1.37	**0.03**	3.7	1.26	**2.44**	3.5	1.35	**2.15**
1.6	1.44	**0.16**	1.3	1.21	**0.09**	3.7	1.21	**2.49**	3.0	1.02	**1.98**
1.7	1.73	**0.03**	1.4	1.32	**0.08**	3.7	1.26	**2.44**	3.3	1.13	**2.17**
1.5	1.20	**0.3**	1.4	1.35	**0.05**	3.5	1.08	**2.42**	3.2	1.35	**1.85**
1.6	1.20	**0.4**	1.3	1.32	**0.02**	3.5	1.10	**2.4**	3.3	1.13	**2.17**
1.5	1.20	**0.3**	1.4	1.35	**0.05**	3.5	1.08	**2.42**	3.2	1.35	**1.85**
1.6	1.20	**0.4**	1.4	1.35	**0.05**	3.5	1.10	**2.4**	3.2	1.35	**1.85**
1.7	1.73	**0.03**	1.3	1.32	**0.02**	3.7	1.26	**2.44**	3.3	1.13	**2.17**

1.6	1.44	**0.16**	1.4	1.35	**0.05**	3.7	1.21	**2.49**	3.2	1.35	**1.85**
1.7	1.73	**0.03**	1.3	1.35	**0.05**	3.7	1.26	**2.44**	3.2	1.35	**1.85**
1.5	1.20	**0.3**	1.4	1.32	**0.08**	3.5	1.08	**2.42**	3.3	1.13	**2.17**
1.5	1.20	**0.3**	1.3	1.21	**0.09**	3.5	1.08	**2.42**	3.0	1.02	**1.98**
1.6	1.20	**0.4**	1.4	1.35	**0.05**	3.5	1.10	**2.4**	3.2	1.35	**1.85**
1.6	1.44	**0.16**	1.3	1.28	**0.02**	3.7	1.21	**2.49**	3.0	1.13	**1.87**
1.7	1.73	**0.03**	1.4	1.37	**0.03**	3.7	1.26	**2.44**	3.5	1.13	**2.37**
1.5	1.20	**0.3**	1.3	1.21	**0.09**	3.5	1.08	**2.42**	3.0	1.02	**1.98**

Legend:

C - Commercial vibration meter (GM63A)

A - ADXL345 Sensor (Designed Portable Vibration Meter)

D - Difference between measurements (C - A)

Table 3C. Results of a 1.5HP Induction Motor.

Velocity mm/s									**Acceleration m/s^2**					
C	**A**	**D**	**C**	**A**	**D**	**C**	**A**	**D**	**C**	**A**	**D**	**C**	**A**	**D**
X	**X**		**Y**	**Y**		**Z**	**Z**		**X**	**X**		**Y**	**Y**	
8.5	6.45	**2.05**	2.2	2.23	**0.03**	4.3	4.30	**0**	7.1	5.81	**1.29**	2.6	2.55	**0.05**
8.5	6.45	**2.05**	2.2	2.25	**0.05**	4.3	4.52	**0.22**	7.1	8.87	**1.77**	2.9	2.57	**0.33**
8.6	6.84	**1.76**	2.3	2.28	**0.02**	4.5	4.53	**0.03**	7.2	5.96	**1.24**	2.9	2.60	**0.3**
8.8	6.84	**1.96**	2.3	2.30	**0**	4.6	4.57	**0.03**	7.3	6.13	**1.17**	2.9	2.60	**0.3**
8.9	7.37	**1.53**	2.7	2.66	**0.04**	4.7	4.78	**0.08**	7.3	6.56	**0,74**	3.0	2.86	**0.14**
8.6	6.84	**1.76**	2.3	2.28	**0.02**	4.3	4.52	**0.22**	7.2	5.96	**1.24**	2.6	2.55	**0.05**
8.8	6.84	**1.96**	2.2	2.23	**0.03**	4.5	4.53	**0.03**	7.3	6.13	**1.17**	2.6	2.55	**0.05**
8.6	6.84	**1.76**	2.3	2.28	**0.02**	4.6	4.57	**0.03**	7.2	5.96	**1.24**	2.6	2.55	**0.05**
8.8	6.84	**1.96**	2.2	2.23	**0.03**	4.6	4.57	**0.03**	7.3	6.13	**1.17**	2.6	2.55	**0.05**
8.9	7.37	**1.53**	2.2	2.25	**0.05**	4.7	4.78	**0.08**	7.3	6.56	**0.74**	2.9	2.57	**0.33**
8.6	6.84	**1.76**	2.3	2.28	**0.02**	4.3	4.30	**0**	7.2	5.96	**1.24**	2.9	2.60	**0.3**
8.9	7.37	**1.53**	2.2	2.25	**0.05**	4.3	4.52	**0.22**	7.3	6.56	**0.74**	3.0	2.86	**0.14**
8.5	6.45	**2.05**	2.3	2.28	**0.02**	4.3	4.52	**0.22**	7.1	5.81	**1.29**	2.6	2.55	**0.05**
8.5	6.45	**2.05**	2.3	2.30	**0**	4.5	4.53	**0.03**	7.1	8.87	**1.77**	2.6	2.55	**0.05**
8.6	6.84	**1.76**	2.3	2.28	**0.02**	4.6	4.57	**0.03**	7.2	5.96	**1.24**	2.6	2.55	**0.05**
8.5	6.45	**2.05**	2.2	2.23	**0.03**	4.3	4.30	**0**	7.1	5.81	**1.29**	2.6	2.55	**0.05**
8.6	6.84	**1.76**	2.2	2.25	**0.05**	4.3	4.52	**0.22**	7.2	5.96	**1.24**	2.9	2.60	**0.3**
8.8	6.84	**1.96**	2.3	2.28	**0.02**	4.5	4.53	**0.03**	7.3	6.13	**1.17**	2.9	2.60	**0.3**
8.9	7.37	**1.53**	2.3	2.30	**0**	4.6	4.57	**0.03**	7.3	6.56	**0.74**	2.9	2.60	**0.3**
8.6	6.84	**1.76**	2.2	2.25	**0.05**	4.7	4.78	**0.08**	7.2	5.96	**1.24**	2.9	2.60	**0.3**

Legend:

C - Commercial vibration meter (GM63A)

A - ADXL345 Sensor (Designed Portable Vibration Meter)

D - Difference between measurements (C - A)

Table 4 shows that for the 0.25 HP induction motor velocity, the p-value was insufficient, and the t-statistic exceeded the critical value, indicating that the result was statistically significant at the 0.05 level. However, the rejection of the null hypothesis does not mean the values were far apart, as the t-statistics were close to the critical value. On the other hand, for acceleration, the p-value is greater than the significance level of 0.05, and the t-statistics were small compared to the critical value, indicating that the result is not statistically significant at the 0.05 level. In Table 8, shown in the appendices, Vibration Severity Per ISO 10816, Class 1 small machines' velocity values ranged from 1.2 to 1.8 mm/s, which was considered satisfactory, indicating the machine is healthy.

The 1 HP induction motor, as shown in Table 4, indicated that all interpretations were significant at the 0.05 level. However, this does not mean the values were far from the reference data. Looking at the t-statistics for Velocity, it was not as large compared to the t-statistics for acceleration. With a significance level of 0.05, the p-value is insufficient to conclude that the null hypothesis for this 1 HP induction motor was accepted. In Table 8, shown in the appendices, Vibration Severity Per ISO 10816 for Class 1 small machines indicates velocity values ranging from 1.2 to 1.8 mm/s, which was considered satisfactory, meaning the machine is healthy.

The 1.5 HP induction motor, as shown in Table 4, indicates that for Velocity in the Y and Z axes, the t-statistic for the Y-axis was less than the critical value, and the p-value was greater than the significance level of 0.05, indicating that the result was not statistically significant at the 0.05 level. Although the Z-axis was important at the 0.05 level, the t-statistics values were close to the critical values, and the p-value was insufficient, leading to the rejection of the null hypothesis. Similarly, for acceleration results, the t-statistic falls outside the necessary range, resulting in significance at the 0.05 level. In Table 8, shown in the appendices, the Vibration Severity Per ISO 10816 for Class 1 small machines indicates that velocity values were considered unsatisfactory, although the machine is still healthy.

Table 4. Paired t-test Results for the 0.25 HP, 1 HP, and 1.5 HP Induction Motors.

0.25HP INDUCTION MOTOR					
Velocity mm/s	**p-Value**	**t-Statistics**	**Critical Value**	**Degrees of Freedom**	**Interpretation**
Y-axis	0.0061	3.0864	+2.0930	19	**Significant@0.05**
Acceleration m/s^2					
Y-axis	0.2357	-1.2246	+2.0930	19	**Not Significant@0.05**
1HP INDUCTION MOTOR					
Velocity mm/s	**p-Value**	**t-Statistics**	**Critical Value**	**Degrees of Freedom**	**Interpretation**
X-axis	0.0000	5.6256	+2.0930	19	**Significant@0.05**
Y-axis	0.0001	4.7852	+2.0930	19	**Significant@0.05**
Acceleration m/s^2					
X-axis	0.0000	347.7448	+2.0930	19	**Significant@0.05**
Y-axis	0.0000	51.3566	+2.0930	19	**Significant@0.05**

1.5HP INDUCTION MOTOR					
Velocity mm/s	**p-Value**	**t-Statistics**	**Critical Value**	**Degrees of Freedom**	**Interpretation**
X-axis	0.0000	42.4455	+2.0930	19	**Significant@0.05**
Y-axis	0.1915	-1.3544	+2.0930	19	**Not Significant@0.05**
Z-axis	0.0077	-2.9807	+2.0930	19	**Significant@0.05**
Acceleration m/s^2					
X-axis	0.0006	4.0793	+2.0930	19	**Significant@0.05**
Y-axis	0.0000	6.2054	+2.0930	19	**Significant@0.05**

CONCLUSION

The research demonstrates the potential of cost-effective vibration meters, such as the one developed in this study, which can serve as practical alternatives for monitoring machinery with lower power ratings. This was particularly relevant for industries or enterprises that are working with limited budgets. The similarity of the velocity measurements recorded suggests that affordable MEMS accelerometers can be further developed to compete with their commercial counterparts. The significance of appropriate mounting and positioning, as highlighted by the results, offered critical insights for machine operators and reinforced best practices aimed at preserving machine health and minimizing mechanical failures.
The research recommended the use of a superior model of MEM's accelerometer sensor to compensate for any insufficiency of the ADXL345 sensor. Although the ADXL345 can yield reliable results, it would be beneficial to the development of the designed vibration meter to explore alternatives for achieving high-quality outcomes. Moreover, the designed vibration meter is suitable for use with 1 HP or less induction motors, provided it is properly mounted, to produce more accurate results. Additionally, solar power can be integrated into the portable vibration meter to improve energy efficiency. Incorporating noise immunity to minimize external interference. Solid wire ensures secure and durable wire connections for reliable performance.

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