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Original Research

Design and Feasibility Study of Low-Cost ADXL1002-STM32 Data Acquisition for Vibration Analysis

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ABSTRACT

Designing of low –cost measurement systems for vibration acquisitions has attracted a wide interest of researchers of condition monitoring applications. This paper presents the design and feasibility assessment of the electronic board of a combined ADXL1002 and STM32F103C8T6 open-source module to perform as a vibration signal acquisition system. The board flowchart is illustrated and a software based on MATLAB is made to facilitate a friendly user platform. The device performance, in terms of correct acceleration reading is performed by comparing the actual and device measured values of acceleration under static and dynamic conditions, is conducted. Results showed that the present device performs accurately with an error percentage around 6%.

Keywords: MEMES accelerometer, ADXL1002, condition monitoring, structural health monitoring

1. Introduction

1.1. Use of word-processing software

Vibration analysis still attracts the interest of a wide range of researchers. Vibration analysis is very helpful and effective structural health monitoring and rotating machinery condition monitoring. However, vibration analysis requires sensors and data acquisition which are usually cost huge money that cannot be afforded by many researchers. For this reason, the demand for low cost but reliable DAQs has become persistent need. The MEMEs accelerometers have a wide range of types according to their specifications such as the frequency response and maximum acceleration. However, for vibration applications ADXL335, ADXL345, ADXL355 and ADXL1002 are the suitable types.

Many researchers have published on the use of various MEMES accelerometers combined with open-source electronic boards. An ADXL335 accelerometer combined with open-source boards were used for various applications of vibration data such as vibration of rolling element bearing using a microchip dsPIC30F4011[1], cam jump rig in combination with Arduino Mega2560 board [2], mechanical vibrations of beams using Arduino uno [3], grinding process using Arduino Nano [4].

Other researchers have also investigated the use of ADXL345 for vibration measurement applications. The anomaly inspection in drones was performed using ADXL345 combined with Arduino DUE [5]. The study has compared the reliability of the sensor with other sensors. The feasibility of vibration monitoring using based on wireless sensor network (WSN) was evaluated in [6]. Other applications of using ADXL345 includes the autonomous sensing of the vibration of power transmission lines [7], vibration of element bearing [8, 9], and fall detection system [10].

On the other hand, the performance of ADXL355 as a vibration sensor was also evaluated by the researchers[11]. Among the applications that used the ADXL355 are: structural health monitoring [12-17], hay rotary tedder vibration monitoring, industrial IoT applications [18], pavement vibration monitoring [19], and road roughness estimation [20].

However, according to the best knowledge of authors, few research has been published on the use of ADXL1002 accelerometer combined with STM32.
In the current research, the design and performance evaluation of low cost DAQ is presented. The specifications of accelerometer and DAQ board is illustrated. In addition, the evaluation of vibration acquisition performance is also conducted and depicted.

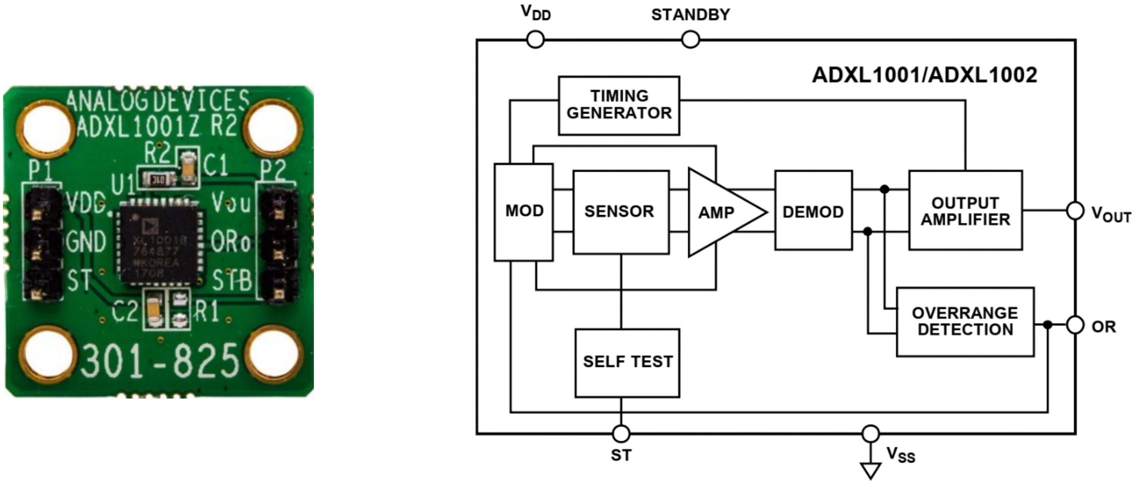
2. Description of sensor and microcontroller

In this study, the ADXL1002 is used. The specifications are illustrated in Table 1 as in below.

Table 1 Important Specifications of ADXL11002

Property	Value
No. of axis	1
Range (g)	±50
Maximum bandwidth in kHz	11
Temperature range in C^{o}	-40 to +125
Type / interface	analog
Mechanical sensitivity (µg/)	±25
Electrical sensitivity (mV/g)	±40

These specifications are made the accelerometer suitable for applications of condition monitoring, predictive maintenance and health usage monitoring system (HUMS). Figure 1 shows the ADXL1002 board and internal function diagram.



(a) **(b)**

Figure 1. ADXL1002 Board and Circuit Diagram (a) ADXL1002 Board and (b) Internal Function Diagram

2.1. STMF32F103C8T6 Microcontroller

STM32F103C8T6 is one of the prominent low-cost high-performance microcontrollers that is based on Arm Cortex-M3 MCU. It is designed to work with a clock of 72 MHz and a flash memory of 64 kB. STM32F103C8T6 has two built-in analog-to-digital converters (ADC) with a resolution of 12-bit, conversion time of 1 µs, and up to 8 channels. This facilitates the ability to read the analog signal from the ADXL1002, including the full bandwidth of 11 kHz, with a single channel and sampling rate of up to 25 ksps [8, 9]. Figure 2 depicts the STM32F103C8T6 board with full pinout.

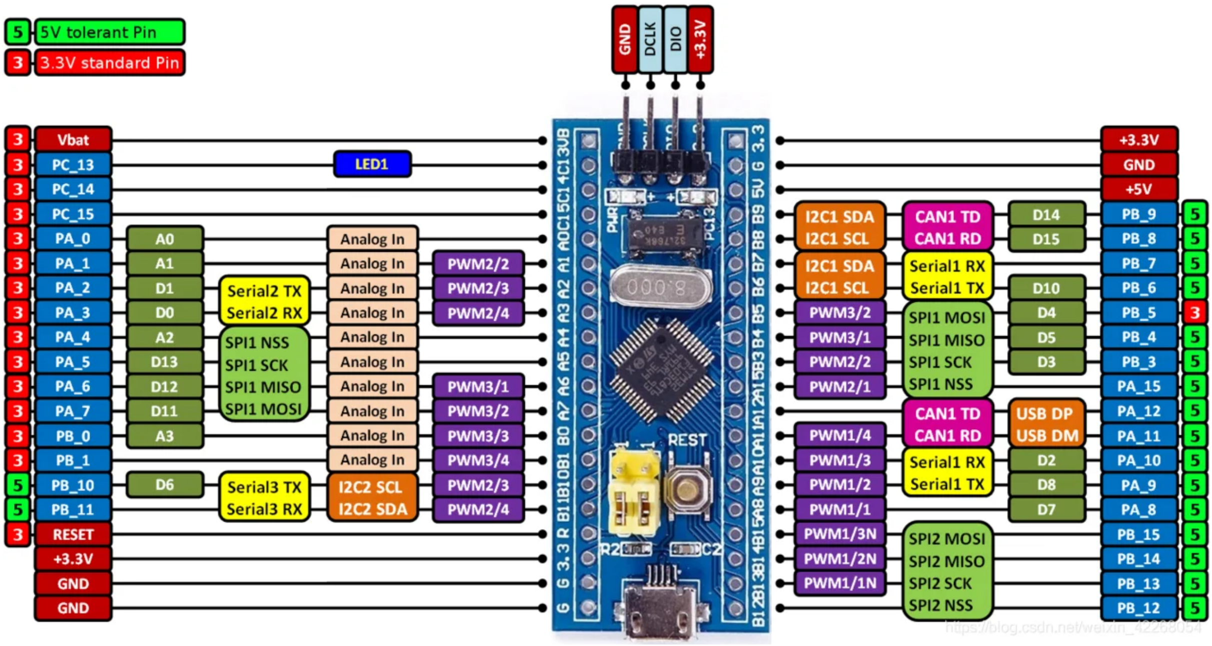


Figure 2. STM32F103C8T6 Pinout.

3. Description of The Electronic Circuit

Figure 3 illustrates the general description of the circuit where the ADXL1002 is directly connected to the STM32 board. In addition, the STM32 board is connected to the computer via a USB cable which provides the power supply (+5 V) for both boards and communication link to collect data with a rate of 12 Mbps. Pin PC13 on the STM32 is used to enforce the ADXL1002 to enter the standby operating mode when the software is not collecting data and there is no need for the ADXL1002 readings. This is useful if a change in the position of the ADXL1002 is required.

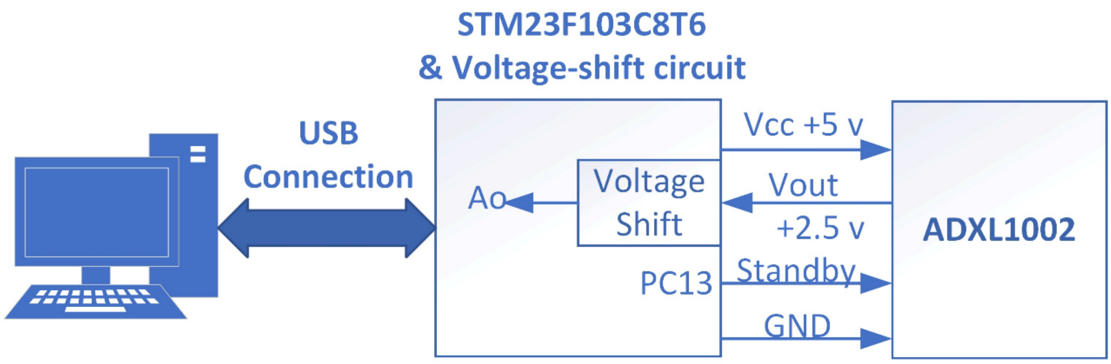


Figure 3. Circuit Diagram.

With zero acceleration (0 g), the ADXL1002 provides a DC voltage of 2.5 V. Since the electrical sensitivity of the ADXL1002 is 40 mV/g, the output voltage will be in the range of 0.5 – 4.5 V for the full range of -50 – +50 g. On the other hand, the STM32F103C8T6 board has an internal voltage regulator that provides a voltage of 3.3 V for the STM32 MCU. Consequently, the full ADC voltage range is 0 – 3.3 volts. Therefore, a voltage shift and conditioning circuit is required between the output of the ADXL1002 and the ADC (A0 pin) on the

STM32 board. This circuit provides 1.65 V for the steady state case of the ADXL1002 with 2.5 V and a full range of 0.33 – 2.97 V for the ± 50 g.

The data-logger software, as shown in Figure 4, was built using MATLAB Application Designer 2022B to offer different functionalities, analyses, and measurements for the ADXL1002 data. The software provides real time and offline data plot with FFT analysis with tabulated values. Also, it includes an optional low-pass filter to improve the reliability of collected data and reduction of noise. In addition, it provides the ability to select different sampling rates within the range of 100 – 25000 sps. Moreover, it offers saving data in different formats including MATLAB format, MS Excel, and text files.

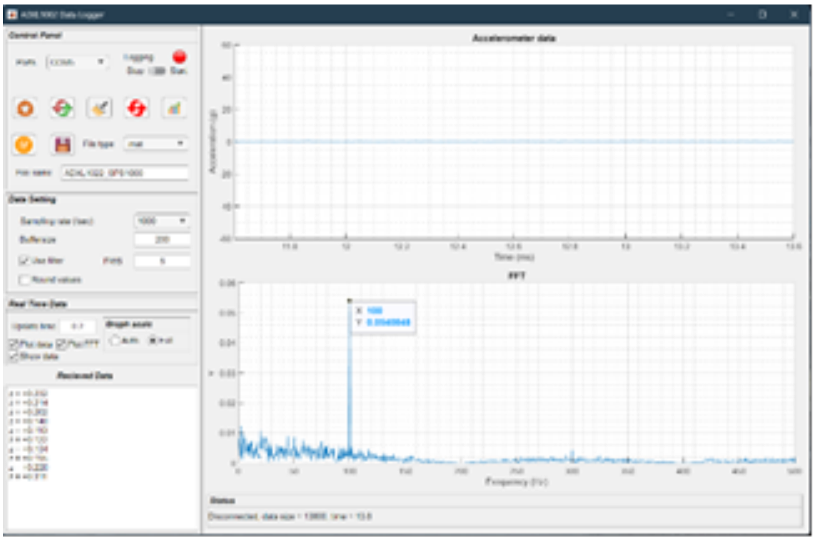


Figure 4. Circuit Diagram.

4. Sensor Evaluation

Sensors must be evaluated to ensure their preciseness and to make them reliable for use. In this study, the accelerometer is placed horizontally and firmly on a flat surface that is perpendicular to x axis. After that, the output voltage is recorded using oscilloscope. Then, the relevant acceleration is calculated using the following equation. Then, the accelerometer is rotated by 90 o.

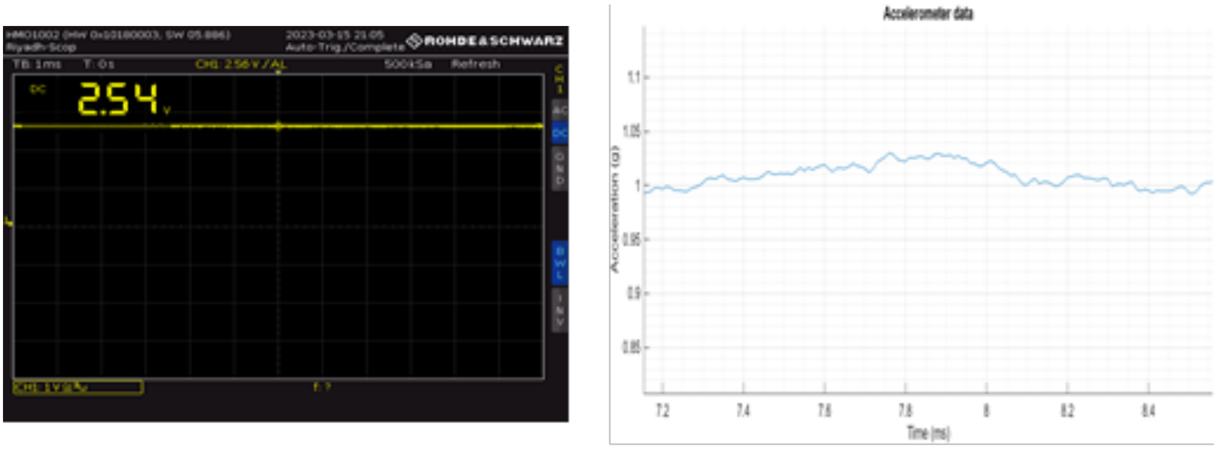
$$A = V_o \times S \tag{1}$$

Where A is the acceleration in (g), Vo is the output volt measured by the oscilloscope (v), and S is the sensor sensitivity (mg/V).

5. Results and Discussion

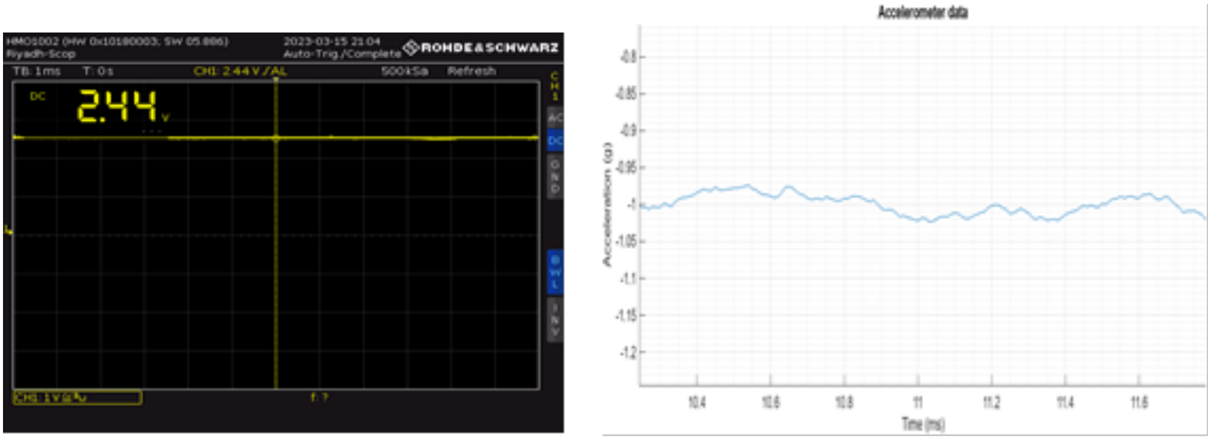
5.1. Static Test

Figure 5 shows the oscilloscope and platform readings. Figure (5.a) depicts the oscilloscope reading directly from the ADXL1022 sensor, which represents the output voltage in volts with a scale of 1 V/division and an accuracy of 10 mV. The x-axis of the sensor was placed vertically to the ground level. Therefore, the output acceleration is mostly 1 g as shown in Figure (5.b). On the other hand, Figure 6 shows the oscilloscope voltage reading and the acceleration in g when the sensor is rotated by 180o, which provides an acceleration of -1 g. Note that, all values were acquired with the activation of low pass filter to reduce the noise level and smoothen obtained data.



(a) **(b)**

Figure 5. ADXL1002 Output Voltage When it is Place Vertical to Ground. (a) The ADXL1002 Output Voltage Read by The Oscilloscope (b) The Acceleration Calculated in The Software in (g).



(a) **(b)**

Figure 6. ADXL1002 Output Voltage When it is Rotated by 180º (a) The ADXL1002 Output Voltage Read by The Oscilloscope (b) The Acceleration Calculated in The Software in (g).

Table 2 shows a sample of the acceleration values that were obtained from the software in comparison with actual values for both ±1 *g*.

Table 2 The Obtained Voltage Values for ∓1 *g*

No. of reading	Obtained values	
	+1 g	*1 g*
1	1.0024	-1.0014
2	1.0068	-1.0008
3	1.0006	-1.0002
4	0.9988	-1.0032
5	0.9964	-1.0014
6	0.997	-1.0002
7	1.0044	-1.002
8	1.0052	-1.0032
9	1.007	-1.0032
10	1.007	-1.0026

11	1.0076	-1.002
12	1.0094	-1.002
13	1.0052	-0.9982
14	1.0002	-1
15	0.9964	-1.0006
16	0.9934	-0.9994
17	0.9952	-0.9994
18	0.9914	-0.9994
19	0.9908	-1
20	0.9934	-0.9994

The error between the actual acceleration value and the measure value is illustrated in Figures 7 and 8 shown below. In the Figure 7, the error histogram is shown for a signal measured when the ADXL1002 is kept horizontally. The errors are mainly elapsed between -0.04 to 0.08 and the majority located between 0 to 0.04 g.

5.2. Dynamic Test

For dynamic test, a non-linear reciprocal movement was employed to evaluate the response of the system and compare the acceleration data obtained from the software to the actual voltage obtained from the oscilloscope. Figure 9 illustrates the actual voltage from the oscilloscope with a maximum voltage of 200 mV. According to the electrical sensitivity of the ADXL1002 (40 mV/*g*) and (1), this represents a maximum acceleration of about +5 *g*.

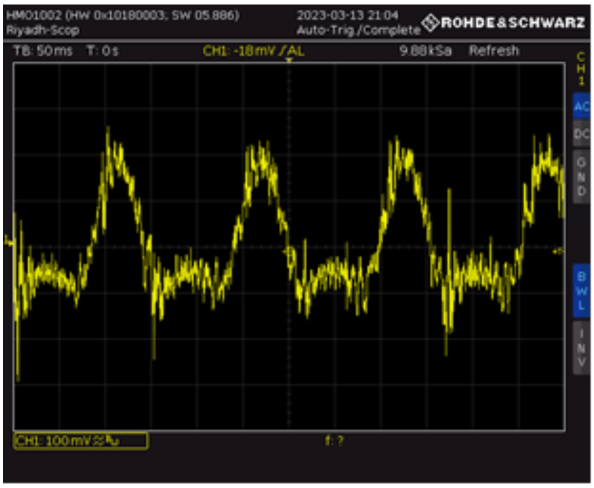


Figure 9. The ADXL1002 Output Voltage Read by the Oscilloscope for a Non-linear Movement.

Figure 10a shows the acceleration obtained by the software without the low pass filter. The data was collected using a sampling rate of 1000 sps. It is clear from the Fig. that the proposed system is able to provide an exact waveform in comparison with the actual oscilloscope signal. On the other hand, Figure 10b depicts the acceleration obtained from the system after applying the low pass filter. This offers a neat waveform by removing the high frequency components from the signal.

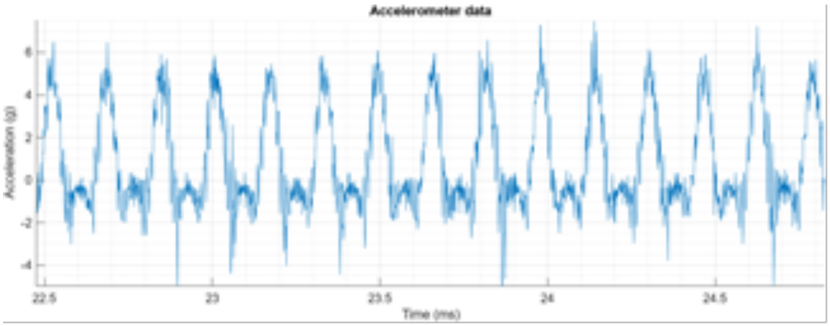


Figure 9 The ADXL1002 output voltage read by the oscilloscope for a non-linear movement.

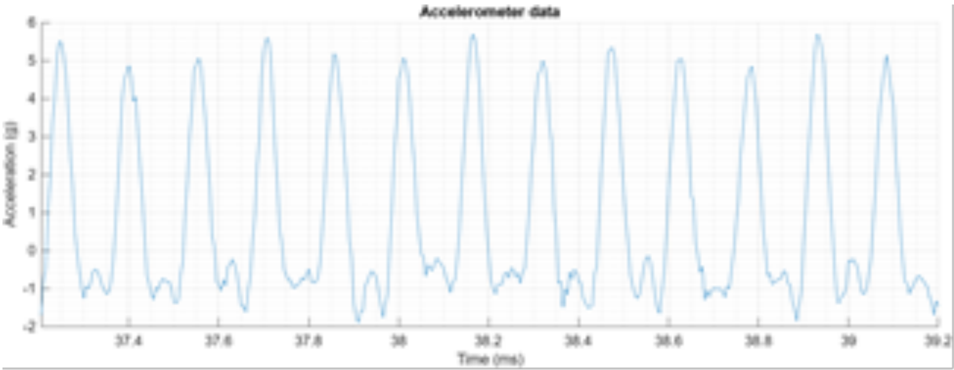


Figure 10. (a) The Acceleration Obtained From the Software for The Non-linear Movement Without Filter. (b) The Acceleration Obtained From the Software for the Non-linear Movement With Low Pass Filter.

6. Conclusion

The presented paper deals with the design and feasibility evaluation of the ADXL1002 accelerometer combined with stmf32F103C8T6. The specifications of the parts and the design of the electronic board are presented and illustrated. Results are obtained for the measurement of acceleration at the static condition (i.e. The accelerometer is hold horizontally and then flipped by 180o) to maintain ±1g. The accelerometer output voltage is measured by the oscilloscope and the acceleration is obtained by multiplying the output voltage by the designed sensitivity. Then the comparison of the measured acceleration and the actual (i.e. ±1g) is compared and the error was less than 6% for the majority of the measurements. Overall, the results confirmed the reliability of the electronic board and acquired measurements.

Declaration of Competing Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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Author Contributions

Riyadh A.Abbas design and conduct the programming of the electronic circuits. Hussein r. Al-Bugharbee supervise the testing process. Both authors has written the manuscript. and approved the final manuscript.

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