IJETST- Vol.||02||Issue||03||Pages 2084-2092||March||ISSN 2348-9480 2015

Open access Journal International Journal of Emerging Trends in Science and Technology

Applications of Accelerometer as a Vibration Detector

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ABSTRACT

In the present world scenario, the integration of various sensors to create a smart sensor is on the rise. This paper deals with the use of accelerometer as a vibration detector. The main focus of this is to reduce the complexity of the present systems and thus reducing the price. The accelerometer is able to detect the change in momentum generated in the three axial planes and this property gives the further advantage in detecting the vibrations produced in the specified field of interest. Several experiments have been conducted in this respect, he results analysed using proper pattern recognition software's and thus the inference drawn from them. Some of typical examples of vibrations produced by a moving train, minor vibrations produced by various household machines have been analysed. The fast response and the self-calibrating technique of this method is what keeps it at par from the other available algorithms.

Keywords: *Accelerometer, vibration sensor, vibrations, seismic reading, railway, microcontroller*

1. INTRODUCTION

In the modern era of autonomous machine, the development of control systems is on the rise. This calls out for better monitoring and calibration of the sensors used in the feedback of the plant, thus increasing the complexity of its circuit. This complexity in physical systems can be reduced by using better algorithms for proper interpretation of the data received.

Micro-electromechanical system (MEMS) accelerometers are widely used systems that are used to detect and measure the three dimensional static or dynamic forces that tend to change the momentum of a rigid body. This momentum results in producing vibration in that rigid body; which sometimes may be considered as 'desirable' while more often is 'undesirable' and causes loss in energy, fatigue in the system or in some cases causes fatigue in the system environment. The algorithm discussed in the subsequent part helps us to practically identify those undesirable vibrations while calibrating in real-life desired vibrations; taking in account of the various parameters affected by temperature variations, physical parameters and so on.

Vibrations produced in the various physical activities like vibrations in railway tracks, vibrations produced in the earth's crust (seismic activities), minute vibrations produced in human body have been the subjects of experiments performed and the results have been inferred from them.

2. ADXL335 ACCELEROMETER

The ADXL335 is a small, thin, low power, complete 3-axis accelerometer with signal conditioned voltage outputs. The product measures acceleration with a minimum full-scale range of ±3 *g*. It can measure the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion, shock, or vibration.

The user selects the bandwidth of the accelerometer using the CX, CY, and CZ capacitors at the XOUT, YOUT, and ZOUT pins. Bandwidths can be selected to suit the application, with a range of 0.5 Hz to 1600 Hz for the X and Y axes, and a range of 0.5 Hz to 550 Hz for the Z axis.

The functional block diagram of the ADXL335 is given as:

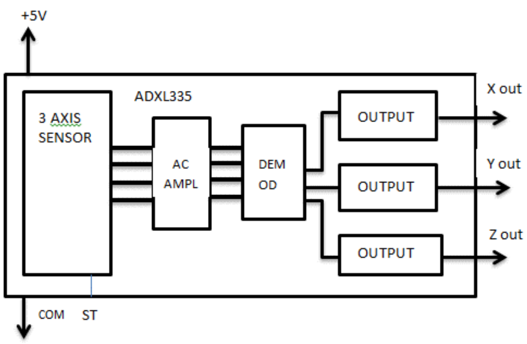

Figure-I. Functional block diagram of ADXL 335

The equation of bandwidth of the analog signal received is given by the equation:

$$F_{-3dB} = {}^{1}/_{2\pi} \times 32k\Omega \times C_{(x,y,z)}$$

Or simply

$$F_{-3dB} = 5\mu F / C_{(x,y,z)}$$

Table -I. Required bandwidth v/s capacitor

Capacitor(µF)	Bandwidth (Hz)
0.01	500
0.22	23
0.1	50
0.47	11
1	5

Typical noise that is associated with ADXL335 is given by:

$$Noise_{rms} = Noise\ Density.\sqrt{BW \times 1.6}$$

Table - II. Estimation of peak-to-peak noise

Peak-to-peak value	%time that noise exceeds nominal peak-to-peak value
2×rms	32
4×rms	4.6
6×rms	0.27
8×rms	0.006

3. ARDUINO

3.1. Arduino Development Board

Arduino is an open-source physical computing electronic platform based on 8-bit ATMEL AVR microcontrollers or 32-bit ATMEL ARM processors. The Arduino UNO development board has been used in developing this project. The development board provides us with a number of digital and analog input-output pins. The analog pins are directly connected to the A/D convertor pins of the AVR microcontroller. Pins are available for both parallel data transmission and serial data transmission. The analog pins of this development board has been used to read the analog values coming from the accelerometer and transfer this data serially to a computer database for processing. But for proper transferring of data between the Arduino and the computer they should have the same baud rate. The equation for calculating baud rate is given by:

$$Baud = \frac{fosc}{16(UBRR + 1)}$$

The baud rate required in our case is 9600. But UBRR value cause the actual baud rate to be slightly different from the expected value.

$$Error\ (\%) = \left(\frac{Baud\ Rate_{Closest}}{Baud\ Rate} - 1\right).100$$

The error rate in this case was less than 0.5%, which can be neglected.

3.2 Arduino Software Platform

Arduino integrated development environment (IDE) is across platform application which is written in Java as a base language for the processing programming language and wiring projects. Wiring is an open source electronics prototyping platform composed of a programing language, an IDE and a single board microcontroller. It is an easy to learn platform to introduce the programmers with software development.

Arduino programs are written in C and C++. It uses GNU tool chain and AVR Libc to compile programs to upload programs to the board.

4. MATLAB

MATLAB (MATrixLABoratory) was developed by MathWorks in the late 1970s.It was designed by Cleve Moler, the chairman of the computer science department at the University of New Mexico. It is a multi-paradigm numerical computing environment and is one of the fourth-generation programinglanguage. MATLAB allows manipulations, plotting of functions and data. It can even interact with programs written in other high level languages like C, C++, Java, etc.

The algorithm used in this project is written using MATLAB. The stable version of 2014a was used as the platform of the work.

5. BLOCK DIAGRAM

The block diagram representation of the system is shown below in the figure

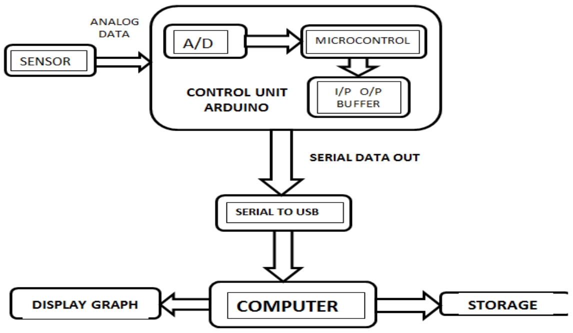

Figure-II. Block Diagram

The different components of the block diagram are explained below:

1. Sensor: The sensor is a device which converts the original signal into its electrical equivalent. The sensor considered in this project is the ADXL335 accelerometer.
2. Analog to Digital convertor: This circuitry is present within the microcontroller package of the Arduino. This is used to convert the analog signals into its digital equivalent signal.
3. Microcontroller: Microcontroller is a clock driver, register based electronic device which consists of a processor, a memory and input and output buffer present within itself. In this project the microcontroller is used as an interface between the sensor and the computer.
4. Input/output Buffer: This is the part of the memory where data is stored during the process of receiving or storing.
5. Serial to USB convertor: In most general laptops and desktops the RJ232 jack is not available so to get the serial data a serial to USB convertor has to be used.
6. Computer: It is the main server where all the processing is going to take place. The original algorithm is present in this machine.
7. Display and Storage: The data after being processed is either displayed or can be stored in any storage medium.

6. FLOW DIAGRAM

Flow diagram shows the flow of data from the input terminal to the output terminal.

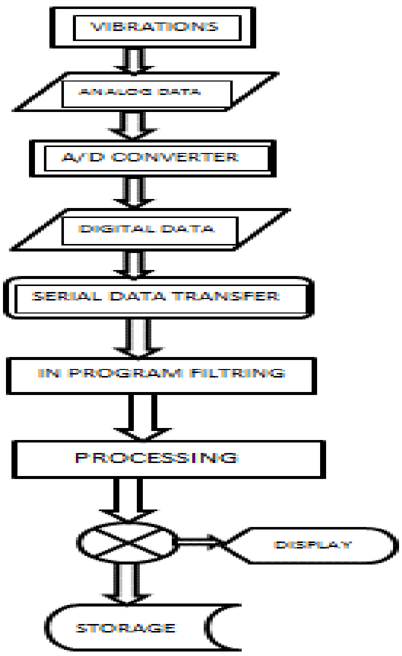

Figure-III. Functional diagram

Here we can see in the figure that the mechanical vibrations received by the sensor is first converted into an electrical signal by the transducer, the analog signal thus received is then passed through a A/D convertor to convert it into digital signal. The digital signal thus formed is passed to the algorithm for further processing. The algorithm first filters the undesired noise from the signal. Then the algorithm approaches an adaptive technique to calibrate itself to the present need of the surroundings. All the other signals that arrive at the algorithm after is time is first compared with that calibrated process and then processed accordingly.

7. ALGORITHM SEGMENTS

7.1 Serial communication

Serial communication is the process of sending the data bit-by-bit that is one bit at a time. But as we know that the processing speed of the microcontroller and the processor is not same, so before one could attempt any communication handshake between the two should be performed thus the first segment of the algorithm deals with setting up a perfect handshake between itself and the microcontroller. The main purpose of the handshake is to bring the two communicating devices on the same parameters before any actual transfer of data takes place. It is essentially needed in this case because the communication that takes place between the computer and the microcontroller is of asynchronous origin. The process used in this algorithm first sends a dummy signal to the microcontroller, if sent successfully the microcontroller replies by acknowledging it and giving a response showing that the serial communication has been set up perfectly.

7.2 Filtering and calibration

The second segment of the algorithm is concerned about filtering and adaptive calibration of the received signal. For this the accelerometer is kept in particular situations and their raw reading is read and stored. As this signal consists of the information about its initial setup and also the noise, this signal is used as a reference for the future signals received. This small approach in reading the signal not only filters the signal but also significantly increases the processing speed of the algorithm. This is an effective way of filtering as the noise level does not change during the entire process. The algorithm is also integrated with other sensors as an interrupt so that the device can calibrate itself if any parameter changer during the process. The bandwidth of the filter used in the project is 500 Hz. In addition to that a PID controller is placed in the algorithm to adjust the sensitivity of the device, whose parameter can be varied either manually or from any other source.

7.3 Data display and storage

The data thus received can be viewed either in a vector format or as a graphical plot. In vector format the three dimensional position of the accelerometer is shown, along with the representation of each of the axes of the accelerometer. The x-axis is represented in red colour, the y-axis is represented in blue colour and the z-axis is represented in the green colour and the resultant vector of all the three vectors are shown in black colour. The plot is drawn on a three dimensional graph.

On the other hand, the graphical representation of the accelerometer shows it as a signal wave. The x-axis is represented in red colour, the y-axis is represented in blue colour and the z-axis is represented in the green colour. The signals received can also be stored in the digital format or as an excel data format.

Table – III. Colour v/s axis

COLOUR	AXIS
Red	X
Blue	Y
Green	Z

8. FIRST PROJECT- SEISMIC ACTIVITIES:

8.1 Seismic activities

Seismic waves are waves of energy travelling through the Earth's mantle. Theses waves can have a several of origin for example earthquakes, explosion, volcanic eruptions etc. Apart from all of these various other small incidents can also give rise to minor waves like seismic waves are generated near a busy road. There are many types of seismic waves but in broad sense they are:

1. Body waves: Body waves travel through the interior of the Earth.
2. Surface waves: Surface waves travel through the surface of the Earth. These waves decay more slowly than the body waves.

8.2 History

The prediction of seismic waves is still an immature science. In the past various natural phenomenon were used to predict the arrival of an earthquake. The behaviour of the animals and insects changed just before an earthquake. Some research suggests that this is because they are much more sensitive to the P-waves then us humans. But the problem with them was that they were not able to give a prediction in the correct time for necessary precautions to be taken. Another research showed that the radon emission changes before the oncoming of an earthquake. There are reports of spikes in the concentrations of such gases prior to a major earthquake; this has been attributed to release due to pre-seismic stress or fracturing of the rock.

8.3 Present detection methods

Earthquakes are detected using a device known as a seismometer. The main principle of the seismometer is that it is used to pick up the vibrations from the earth. Information from three different seismometer are taken and compared to give the exact epicentre of the earthquake. Generally in a seismometer a mass is suspended from a spring and perpendicular motion of the earth's vibration produces inertia in that case which then vibrates in reference to the fixed mass suspended and the reading is recorded. The record thus obtained is known as seismogram.

But some of the defects of these methods are that the interpretation of the data becomes complex as along with the original signal various other signals like that of moving cars, trains produce noise. The variation in humidity and temperature also affects the efficiency of the seismometer.

8.4 Simulation Model

In the first project the various seismic activities were recorded. The setup was installed near various sources of vibrations and the reading were obtained from there. In the first case the setup was placed near a busy road, in the second case the setup was placed in a bridge. The simulation model is shown in the figure.

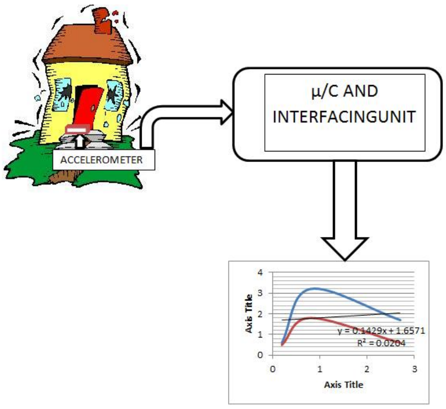

Figure-IV. Simulation model

8.5 Result

The graphs plotted from the above experiment is shown in the figure.

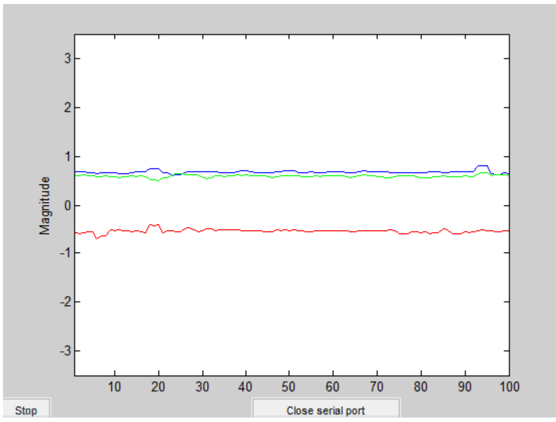

Figure-V. Vibrations due to small cars

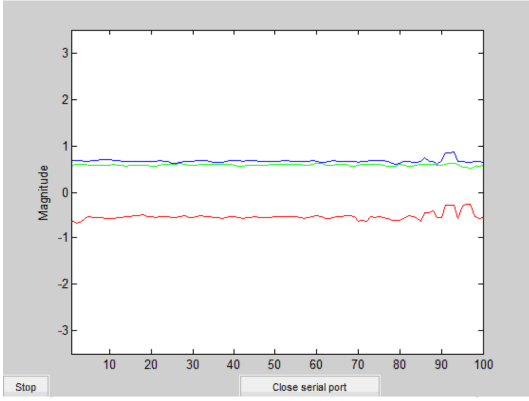

Figure- VI. Heavy traffic approaching

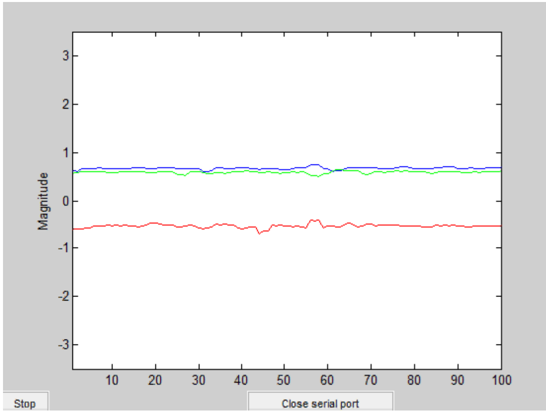

Figure- VII Vibrations due to mild traffic

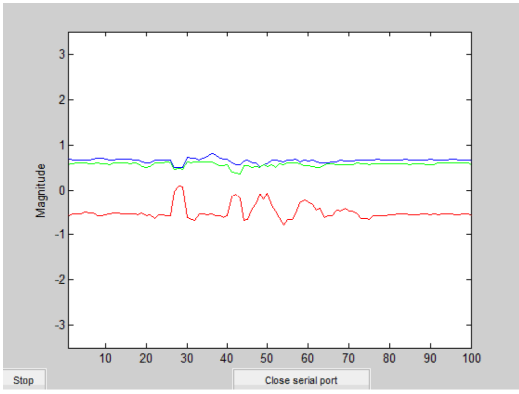

Figure-VIII. Vibrations due to bus

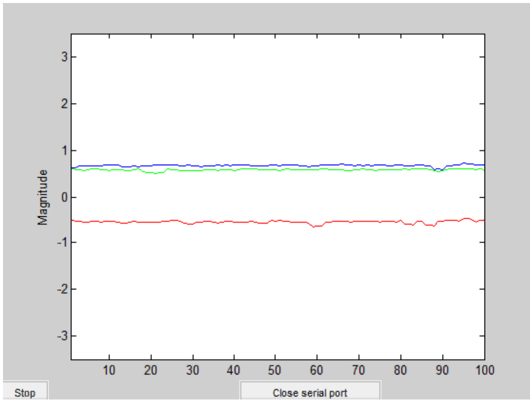

Figure- IX Vibrations due to continuous even traffic

8.6 Advantages of the suggested model

The advantages of the suggested model over the others are:

1. This method can be used for both major seismic waves, like earthquakes, and even minor seismic waves, like vibrations due to heavy traffic.
2. The calibration system enables the ability to shift from major seismic waves to minor seismic waves very fast.
3. Fatigue produced in a bridge can calculated by measuring the vibrations produced in various places of the bridge.

9. SECOND PROJECT- RAILWAY TRACK MONITORING SYSTEM

9.1 Vibrations in railway tracks:

The vibrations of a train running in the track reaches a certain point way ahead in time then the train. The vibrations thus generated if measured correctly is able to give a lot of precise information of the train. Details such as present speed of the train, its distance from that point can be easily determined with almost certain accuracy. Such system can thus be used for various applications like automation of railway crossings and warning systems. The vibrations can be detected even when the train is about a kilometre away.

9.2 Present works in this field

Motion sensors have found a various applications in the railway technology. Some of the examples are:

1. Bogie monitoring and diagnostic system for security and comfort
2. High speed tilt control system for improved passenger comfort
3. Position monitoring of magnetic levitation train
4. Closed loop control system
5. Health and Usage monitoring system
6. Shock monitoring during transport
7. Precise train positioning
8. Railway track monitoring for safety

9.3 Improvement from the previous techniques

The general disadvantage of the previous systems were that they lacked real time calibration. The algorithm ran into problem and could not differentiate between the signals coming from a train to that of a herd of animal walking on the track. This disadvantage of the previous system is removed in this algorithm.

9.4 Simulation Model

In the second project the system was fixed with the railway track and the readings were recorded. The simulation model of the system is shown below:

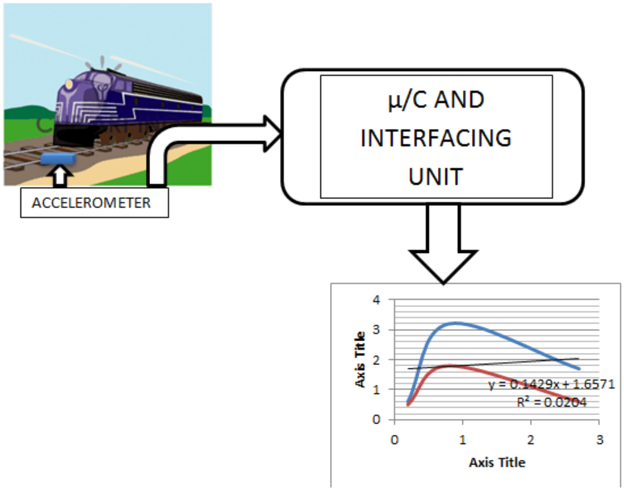

Figure-X. Simulation model.

9.5 Result

The graphs plotted from the above experiment is shown in the figure.

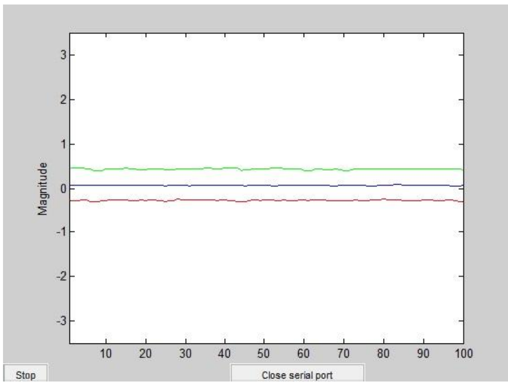

Figure – XI. Vibrations of crossing without train

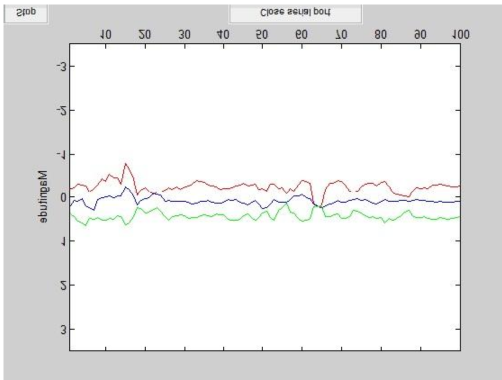

Figure- XII. Train approaching

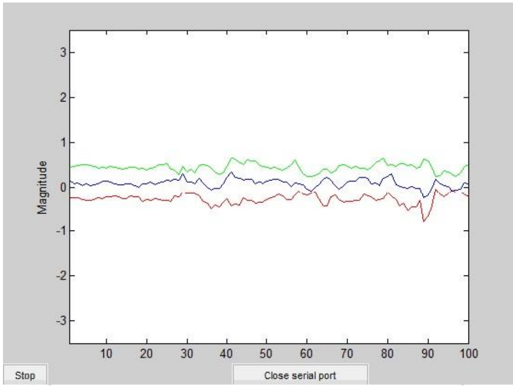

Figure- XII. Train passing by.

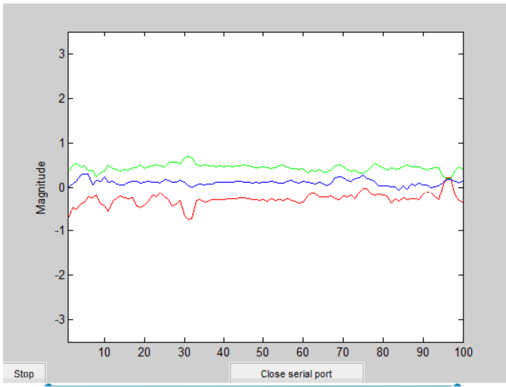

Figure- XIII Train departed

10. THIRD PROJECT – VIBRATIONS IN HUMAN BODY

10.1 Applications of accelerometer in a human body

Various movements that a human does can be accurately measured by using an accelerometer. An accelerometer can monitor the body movements and give desired results but in doing so care should be taken as to place the accelerometer in the place whose reading is to be taken. This concept of accelerometers are used in the sport watches. Accelerations proceeding by the heart signals, breathing movements and the snoring sounds are detected by an accelerometer attached to the skin.

Another application of the accelerometer is monitoring of patients, especially old. In such case the accelerometer is fitted to the body of the patient and continuous monitoring is done. In such case the readings get confusing as to whether the patient is falling or just sitting down. This type of misleading information can be avoided by using this system.

10.2 Simulation model

In this part an accelerometer is connected to a person and his readings of walking and sitting has been taken. The system model is shown below:

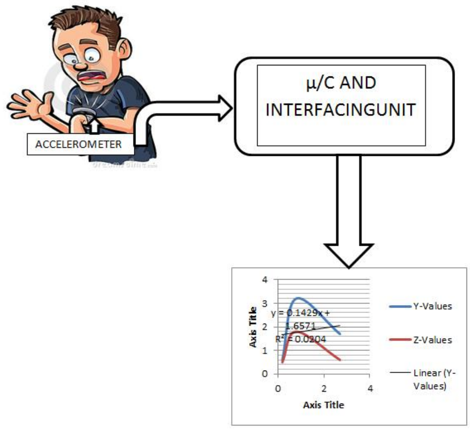

Figure- XV. Simulation model

10.3 Result

The graphs plotted from the above experiment is shown in the figure:

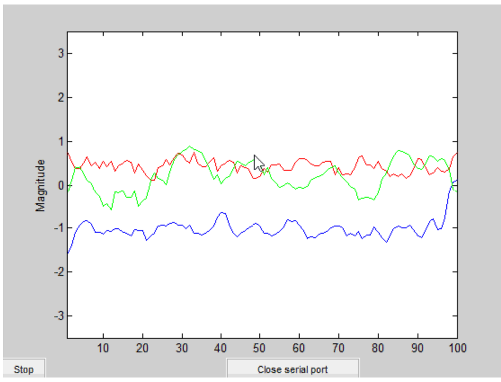

Figure-XVI. Man Walking

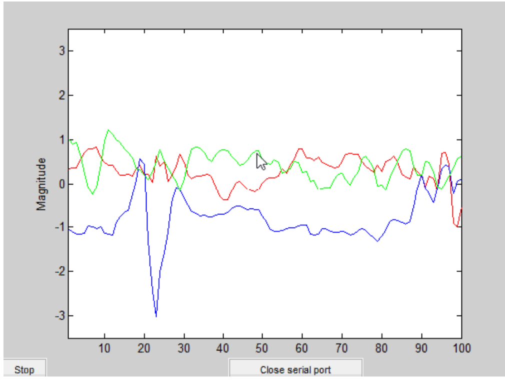

Figure- XVII Man falling down

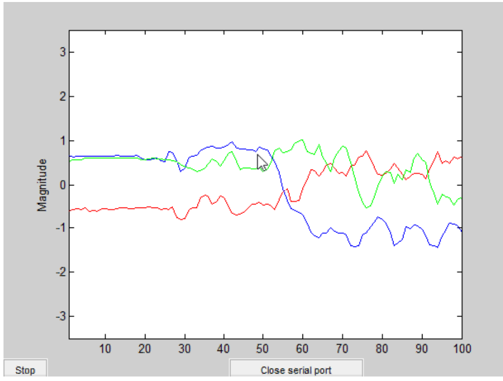

Figure- XVIII. Man sitting down

11. CONCLUSION

To conclude it can be said that the above algorithm work for minor as well as major vibrations by just changing the calibration and sensitivity of the device, and the major advantage of this system over the others presently available is that, it can perform this calibration on its own without human interference. It can either calibrate itself with respect to a fixed time set manually or by setting interrupts from other sensors.

Accelerometer can be used for a variety of uses and its performance is highly efficient. Accelerometer is a tool that is suitable for long-term monitoring of any system be it a living system like humans, a non-living machine like a train, or the surrounding.

12. PICTURES OF THE WORKING MODEL

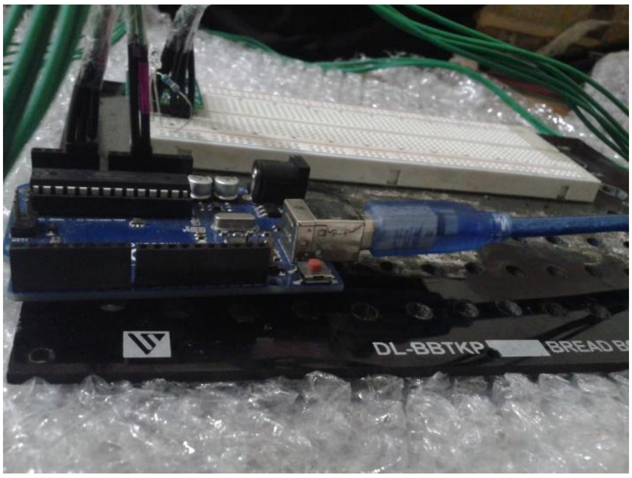

Figure- XIX. Side view

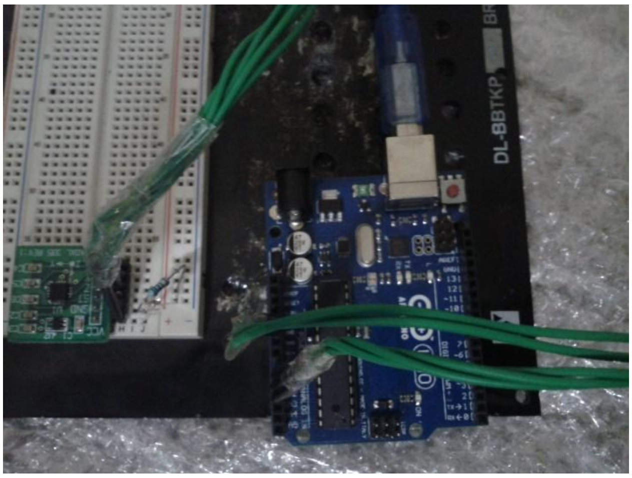

Figure –XX. Top view

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