AC 2010-1213: MEMS ACCELEROMETER INVESTIGATION IN AN UNDERGRADUATE ENGINEERING TECHNOLOGY INSTRUMENTATION LABORATORY

Dale Litwhiler, Pennsylvania State University, Berks

Dale H. Litwhiler is an Associate Professor at Penn State, Berks Campus in Reading, PA. He received his B.S. from Penn State University (1984), his M.S. from Syracuse University (1989) and his Ph.D. from Lehigh University (2000) all in electrical engineering. Prior to beginning his academic career in 2002, he worked with IBM Federal Systems and Lockheed Martin Commercial Space Systems as a hardware and software design engineer.

MEMS Accelerometer Investigation in an Undergraduate Engineering Technology Instrumentation Laboratory

Abstract

Accelerometers that are manufactured using micro electro-mechanical system (MEMS) techniques are becoming ubiquitous in many consumer and industrial products. The MEMS process allows for electro-mechanical devices to be produced very inexpensively. Because the MEMS accelerometer package also integrates the signal conditioning electronics, these devices can be implemented quite easily in many designs. For these reasons, it is important that engineering technology students become familiar with the operating principles and characteristics of MEMS accelerometer devices that they will likely encounter in their careers. As part of an undergraduate engineering technology instrumentation course, students at Penn State Berks investigate the characteristics and principles of operation of some low-g accelerometers. One device (±1.5g) is used as a tilt sensor. Such a device is very common in handheld consumer electronic devices to sense its orientation with respect to the earth's horizon. A plethora of applications can be built around this type of spatial orientation information. Familiar examples include display orientation (portrait or landscape) for video devices, and gaming control such as the Nintendo® Wii system. A second device (±40g) is investigated for its applications in vehicle motion measurement. Hands-on experience with these devices yields some unusual behavior (in both the students and the devices). This is the students' first encounter with electronic devices that are sensitive to their position on the laboratory bench. Simple apparatus are used to characterize and verify performance of the devices. This paper presents the laboratory apparatus and software as well as examples of assignments and student data analyses.

Introduction

Accelerometers have many practical uses in common consumer electronic devices. Micro electro-mechanical system (MEMS) manufacturing techniques have made accelerometers very inexpensive, compact and easy to incorporate into products. Game systems such as the Nintendo® Wii use accelerometers in the handheld controller to determine its position and motion.[1] This information is used by the game to create very realistic user interactions with the game. The Apple iPhone® and iTouch® devices also use accelerometers to determine the orientation of the device for use by applications such as games or just to rotate the display.[2] Some accelerometer applications are transparent to the user such as those used to detect freefall in devices containing spinning hard disk drive storage. When freefall is sensed, the hard disk drive read/write head is positioned to protect the storage device from the impact may be eminent.[3]

Because of the prevalence of accelerometers in common devices, engineering technology students are already aware of many of the uses for such components. In a third-year engineering technology instrumentation course, the students have the opportunity to quantitatively investigate accelerometer components. This is a three credit course with average enrollment of about twenty students. The course has lecture and laboratory components that are tightly coordinated. In the laboratory, the students work in teams of two or three persons. Each experiment is designed to take one laboratory period. Low-g devices manufactured by Freescale semiconductor are evaluated and calibrated by the students in the laboratory using simple, intuitive apparatus.

One accelerometer (±1.5g) is evaluated as a tilt sensor. The orientation of the device with respect to the surface of the earth is therefore used as a reference for its calibration. A second device (±40g) is investigated for its applications in vehicle motion measurement. This accelerometer is placed on a simple turntable centrifuge to produce the desired acceleration levels for calibration.

Device Testing

±1.5g Accelerometer

The Freescale MMA2260D, ±1.5g accelerometer is evaluated as a tilt sensor. The device used by the students has already been placed on a printed circuit board (PCB) along with other signal conditioning and protection devices as shown in the schematic of Figure 1. The PCB is housed in a small plastic enclosure as shown in Figure 2. As shown in Figure 2, a short wiring harness is used to connect to the enclosed PCB. The wiring harness is connected to a Labjack USB data acquisition unit to perform the measurements and provide a +5V power supply to the PCB.[4]

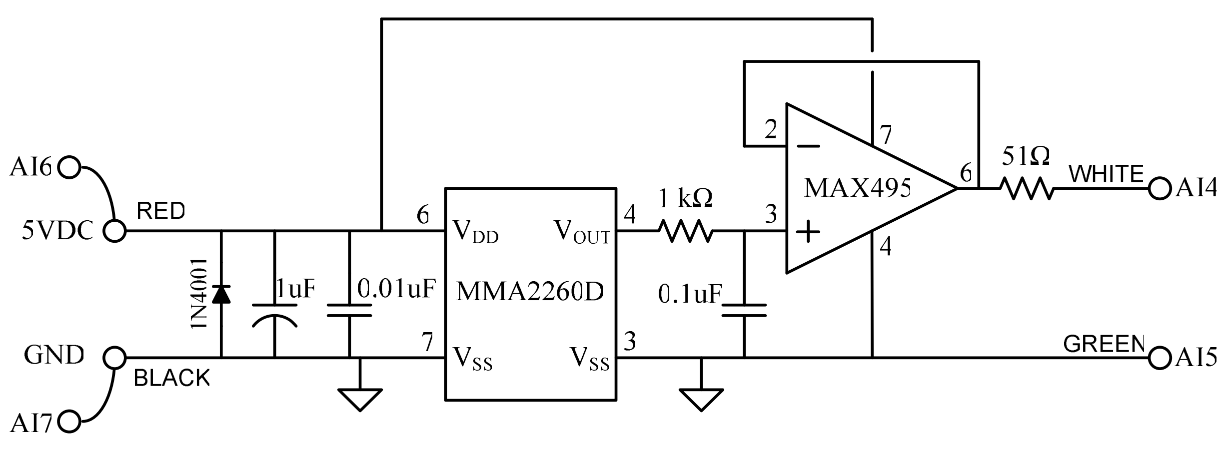

Figure 1. ±1.5g accelerometer PCB schematic

The MMA2260D enclosure is placed on the laboratory bench and a protractor is used to measure the angle of inclination as shown in Figure 3. The 0° tilt position is established using a simple bubble level. Small wooden spacers are used to raise the enclosure to the protractor's reference line. The output of the accelerometer is monitored via the LabView virtual instrument user interface shown in Figure 4. The MMA2260D is a ratiometric device therefore the important measurement is the *ratio* of the output voltage to the supply voltage, V_{DD}, as shown in Figure 4.

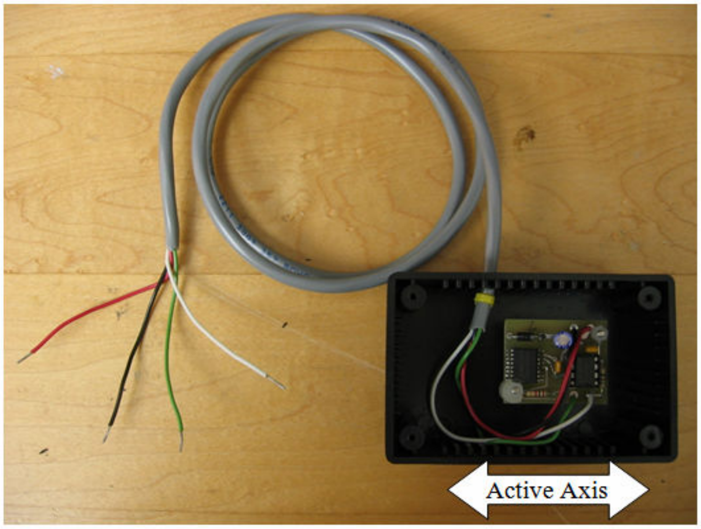

Figure 2. ±1.5g accelerometer PCB, enclosure, and wiring harness

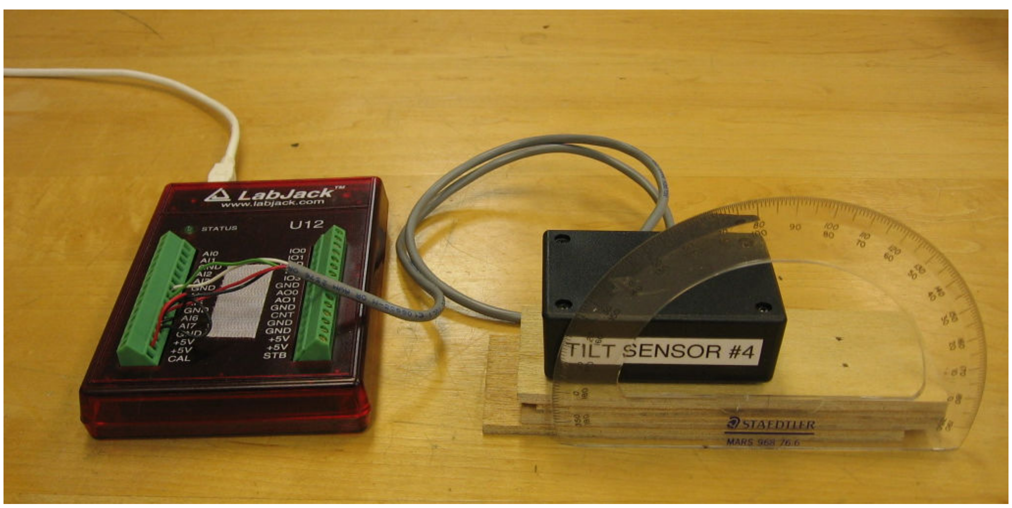

Figure 3. ±1.5g accelerometer inclinometer test setup

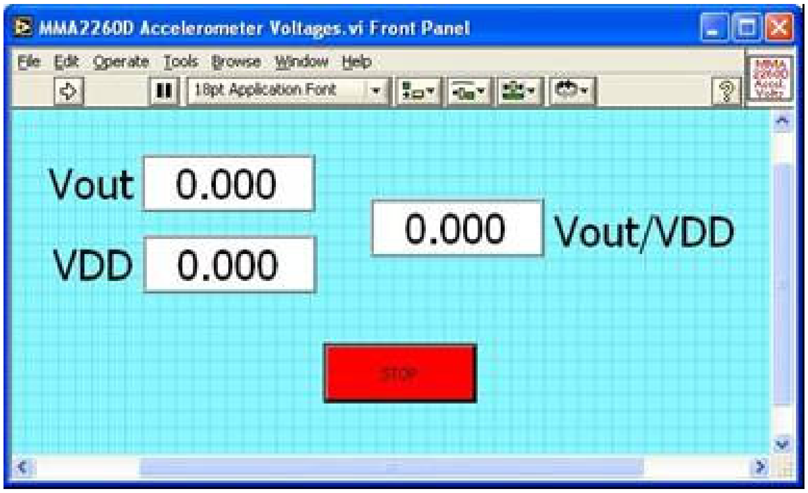

Figure 4. Tilt sensor measurement LabView user interface

The students set the accelerometer enclosure to various angles of inclination by simply propping up the appropriate side. The angle of inclination is measured using a protractor. The output of the accelerometer with respect to the angle of inclination is certainly not a linear relationship. Again, the students must think about the operation of the accelerometer and become comfortable with the data. The measured output is related to the angle by the following expression [5]:

$$\frac{Vout}{V_{DD}} = \frac{k \sin(\text{tilt angle}) + Vzg}{V_{DD}} \qquad (1)$$

In equation (1), k is the device sensitivity and Vzg, is the zero-g output voltage. The students are tasked with creating a data plot that produces a *linear* relationship from which useful information can be obtained. After a few trials and errors, most students arrive at a graph with the sine of the angle of inclination on the x-axis and $Vout/V_{DD}$ on the y-axis. The slope of the best-fit straight line (also known as the “trendline” in Excel) through the data is used to determine the device sensitivity, k. In this application, the sensitivity has units of volts/sin(θ) where θ is the tilt angle. Figure 5 shows a typical student-generated plot of tilt sensor data. The trendline slope of 0.2369 together with the measured V_{DD} of 5.01V results in a device sensitivity of 1.186 V/g. The published datasheet sensitivity of the MMA2260D is 1.14 to 1.26 V/g at 25°C.

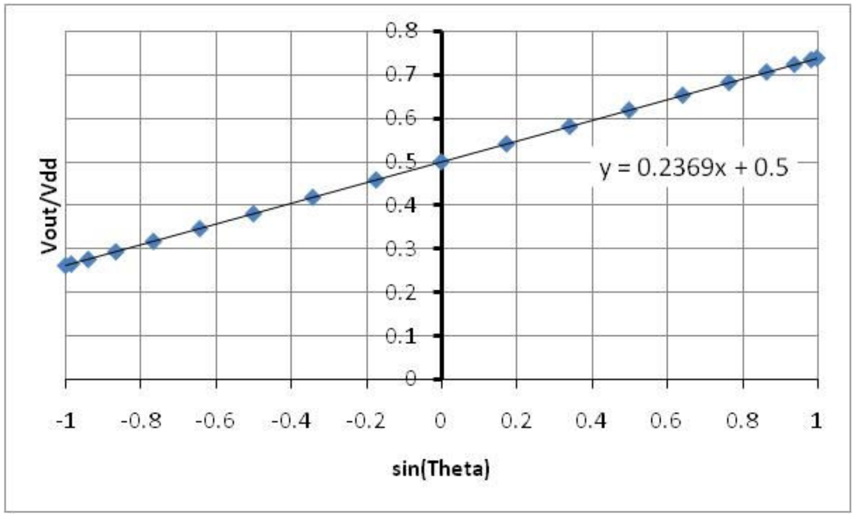

Figure 5. Plot of tilt sensor normalized output versus tilt angle.

±40g Accelerometer

The Freescale MMA2201D, ±40g accelerometer is investigated by the students for use in a model rocket to measure its acceleration during flight.[6] The accelerometer is mounted to a PCB which also contains passive filtering components per the datasheet recommendations as shown in Figure 6.[7] To exercise the full range of this device, it is placed on a variable speed turntable centrifuge. The centrifuge is comprised of a variable frequency drive AC motor and an aluminum platter as shown in Figure 7.

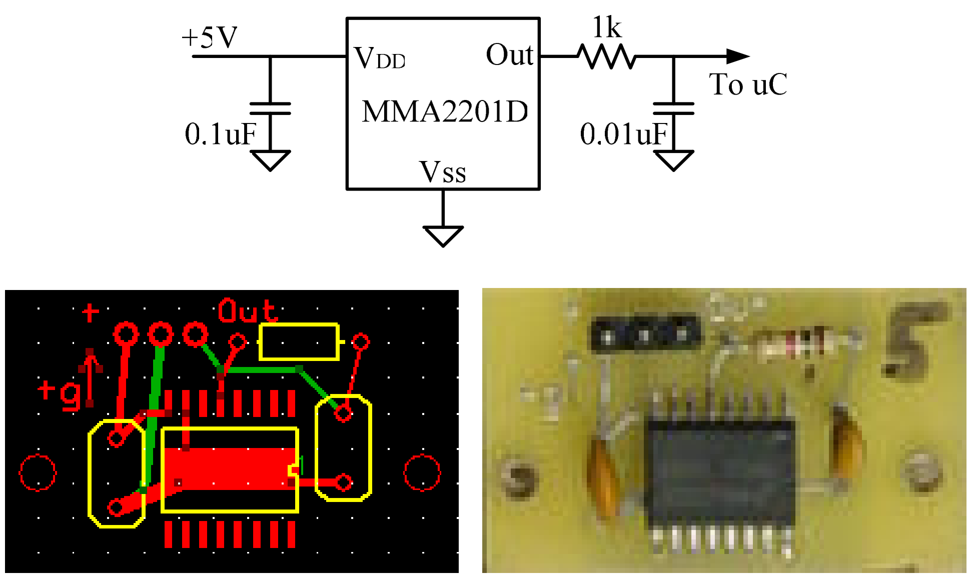

Figure 6. Accelerometer PCB schematic, layout, and photograph

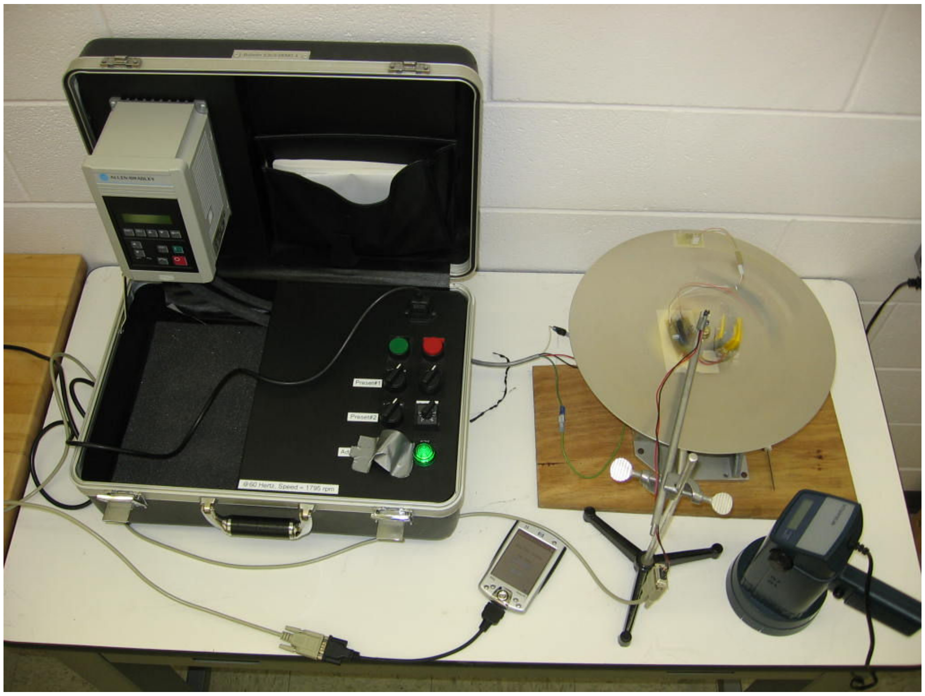

Figure 7. Variable frequency drive motor turntable centrifuge setup.

The variable frequency drive motor establishes a very stable speed of rotation required for testing the accelerometer. The diameter of the platter was chosen such that 40g centripetal acceleration would be experienced near its outer edge at a rotational speed that was reasonable for the motor and did not introduce unreasonable safety concerns. At a radial distance, R, of 6.0 inches from the center, 40g acceleration is experienced at 484 rpm from the following relationship:

$$n = 187.7\sqrt{\frac{g}{R}} \quad \text{rpm} \tag{2}$$

The output voltage of the accelerometer is measured by a 10-bit A/D converter of a PIC16F876 microcontroller. The same microcontroller A/D measurement technique is performed during the model rocket flight. The microcontroller is on another PCB which is also mounted to the spinning platter as shown in Figure 8. The microcontroller and accelerometer are powered by a 9V battery via a +5V regulator contained on the microcontroller PCB. The reference voltage for the A/D converter is the same +5V that powers the accelerometer. Because the accelerometer output is ratiometric, the resulting digital output of the A/D conversion is independent of supply voltage. To obtain both positive and negative acceleration data, the accelerometer PCB orientation is rotated 180° and the rotational speeds are again varied to exercise the full range of the device in the opposite acceleration polarity.

The A/D digital output is transmitted from the spinning platter by the microcontroller using an infrared LED and serial (RS232) encoding. An infrared phototransistor circuit is positioned above the platter to receive the serial data which is then received by a handheld computer (PDA) serial port. The serial data is interpreted and displayed on the PDA as a number ranging from 0 to 1023 (10 bits).

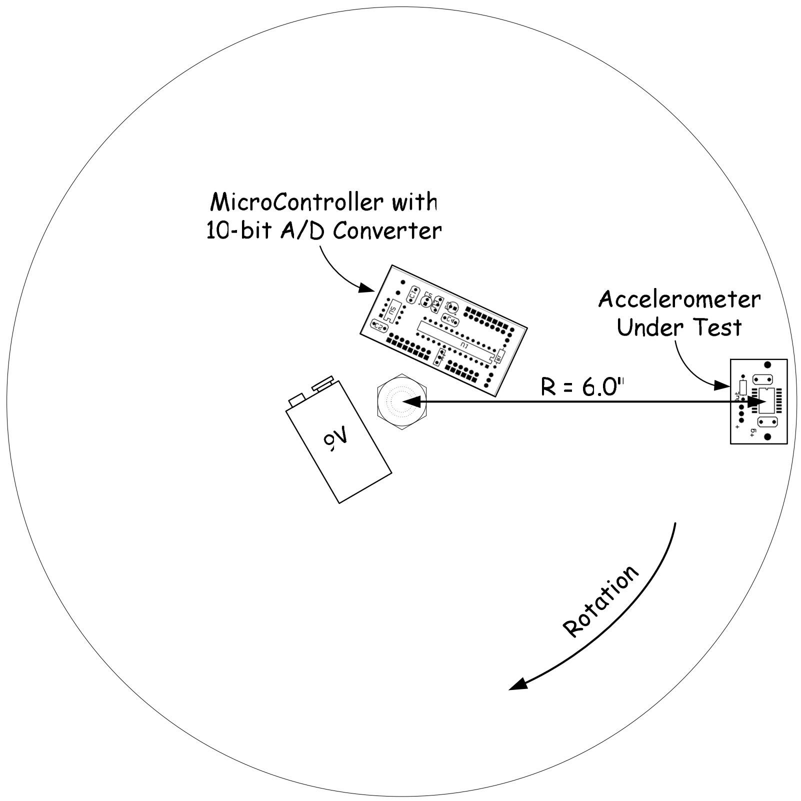

Figure 8. Centrifuge turntable PCB and battery mounting configuration

The students use a strobe light tachometer to measure the rotational speed of the centrifuge. The rotational speed, and thus the acceleration experienced by the accelerometer, is set by adjusting the frequency of the input drive. The students set the speeds to cover the full range of the device with enough points to get a meaningful calibration plot as shown in Figure 9. The maximum rotational speed is set in the motor controller such that the students cannot accidentally exceed safe limits (causing parts to fly off the turntable).

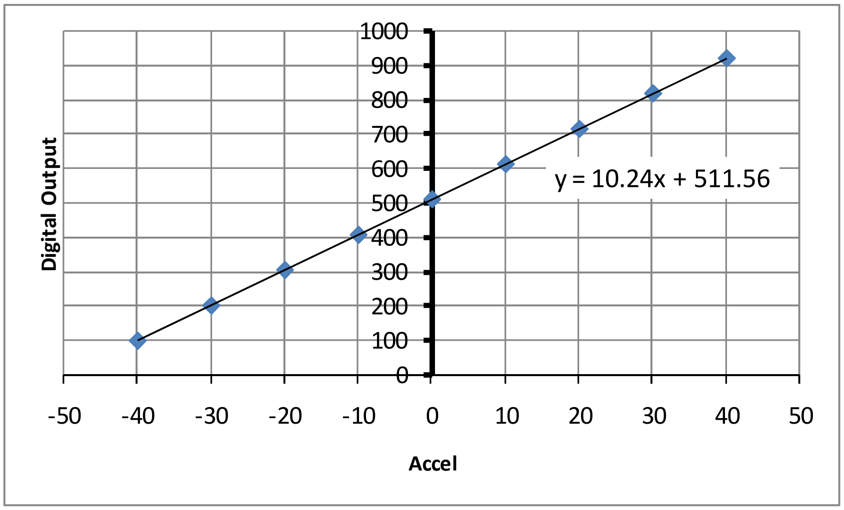

Figure 9. Plot of ±40g accelerometer centrifuge data

As shown in Figure 9, the students are urged to keep their plots in terms of the A/D digital output word because the actual flight data will also be in this form. The integer data from the model rocket flight can then easily be converted to acceleration by using the inverse of the trendline equation developed from the calibration procedure for the same accelerometer. Figure 10 shows a plot of the actual model rocket acceleration profile derived in the manner described.

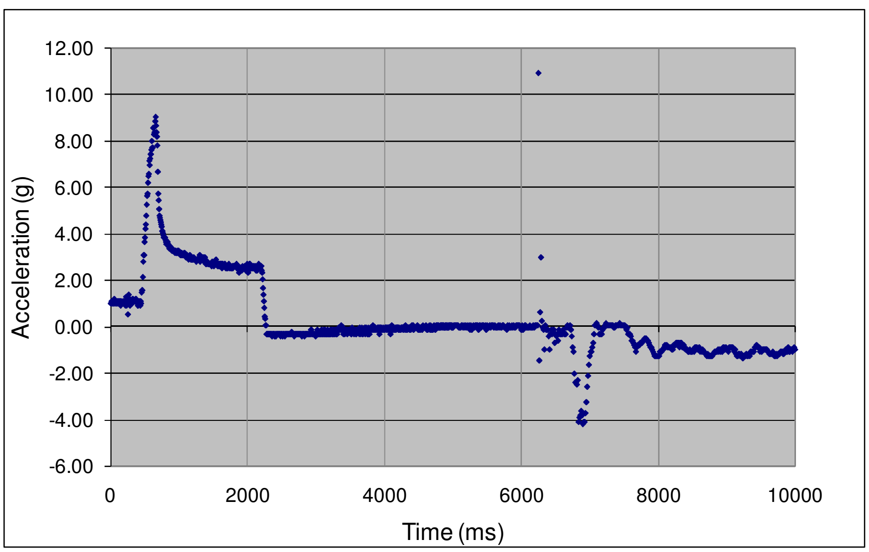

Figure 10. Actual model rocket accelerometer data plot

Conclusions

Through these exercises, the engineering technology students received a large amount of exposure to MEMS accelerometer devices. By using inexpensive devices that are already used in many familiar devices, the students could more easily appreciate the usefulness of and applications for these components.

The use of simple apparatus to evaluate the accelerometers helped the students to think in terms that were also familiar to them. The students were very comfortable with the concepts of sensing position with respect to the horizon as is done in many handheld games containing accelerometers as mentioned. The idea of centripetal force is also very familiar to anyone who has ever ridden an amusement park ride such as a merry-go-round or roller coaster. The simple turntable centrifuge was a micro-merry-go-round to which the students could easily relate and understand. It was also timely that many of the students were also studying variable frequency motor drives in a concurrent electrical machines course.

The results obtained in both investigations agreed very well with the published datasheet specifications. This type of correlation is very reassuring to the students that they have correctly performed the experiment. Also, by using their own data to later evaluate their rocket flight performance, the students had a vested interest in carefully characterizing their components.

Acknowledgements

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Bibliography

1. http://en.wikipedia.org/wiki/Wii_Remote
2. http://www.apple.com/iphone/iphone-3gs/high-technology.html
3. http://www.freescale.com/files/sensors/doc/app_note/AN3459.pdf?fsrch=1
4. Litwhiler, D. H. and Lovell, T. D., "USB Data Acquisition Units Provide New Measurement and Control Options for Engineering Technology Students," Proceedings of the American Society for Engineering Education Annual Conference and Exposition, 2005.
5. http://www.freescale.com/files/sensors/doc/data_sheet/MMA2260D.pdf
6. Litwhiler, D. H., "Using Rockets to Unify Topics in an Electro-Mechanical Engineering Technology Instrumentation Course," Proceedings of the American Society for Engineering Education Annual Conference and Exposition, 2006.
7. http://www.freescale.com/files/sensors/doc/data_sheet/MMA2201D.pdf.