12-8-2015

Design and Fabrication of an Instrumented Cane for the Blind

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Abstract

The most commonly used tool for navigation by the blind is the white cane. A greater understanding is essential in improving the design and performance of these canes. An existing cane was modified with integrated force and acceleration sensors, in order to study the relation between cane vibration characteristics and obstacle or drop-off detection. Data was gathered by these sensors, and then transmitted wirelessly to a computer workstation, where it was recorded and analyzed. Exertion of the forearm muscles was also measured. Care was taken to insure that the cane sensors and transmitter are ergonomically unobtrusive for the user. The accuracy of the force, vibration, and muscular data was verified using laboratory test cases, and preliminary results were collected during actual navigation conducted using this instrumented cane.

Disclaimer

This project report was written by students at Western Michigan University to fulfil an engineering curriculum requirement. Western Michigan University makes no representation that the material contained in this report is error-free or complete in all respects. Persons or organizations who choose to use this material do so at their own risk.

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1. Introduction

The white cane is one of the principal tools used for navigation by individuals suffering from blindness or low vision. It is swept across the path of the individual in order to check for objects and obstructions, and can also be used to determine characteristics of the walking surface. The department of Blindness and Low Vision Studies at Western Michigan University is performing ongoing research on the effectiveness of scanning techniques, cane properties, and how these properties can affect the ability of the user to detect an obstacle or drop-off.

One area of interest for future research is the importance of the vibrational characteristics of a cane to its effectiveness. The goal of this project was to design an instrumented cane in order to measure its vibration while in use. This cane will give insight into the resonance frequencies, damping, and transfer of vibration into the user's hand. These properties had already been measured for a wide range of canes in the WMU Noise and Vibration laboratory, by mounting a cane as a cantilever and measuring its acceleration response to a known impact.

The goal of this project was to design and fabricate an instrumentation setup that would allow researchers to gather vibration data while the cane is in use by a subject. Preliminary measurements with a human participant were obtained in order to show the effectiveness of the system. Through this project, data can be taken while navigating freely around a space, rather than only on a cantilevered beam affixed to a laboratory table. Requirements for the project included the ability to gather data with the same precision as previous laboratory experimentation, with components that are compact and easily carried by the user and are lightweight, not significantly changing the weighting or vibration characteristics of the cane being tested. The primary goal set for this project by researchers in the department of Blindness and Low Vision Studies was that the system work wirelessly. Removing the tether with a computer system allows greater freedom of movement for the participant, and testing of the cane in more realistic operating conditions.

A secondary objective of this project was to measure the muscular exertion of the forearm while the cane is in use. This data would give researchers insight on how the grip pressure effects drop off detection and the ability to navigate with a cane. The muscular exertion measurement system was also required to be wireless.

2. Background and Literature Review

There are several different types of white canes. They may differ in material, length, hollow/solid, handle, tip, and price. This project focuses on the traditional long cane, which is the primary mobility tool used to detect obstacles by the visually impaired. A long cane's length depends on the user's height, and typically extends from the floor to somewhere between the user's sternum and chin. Its standard diameter is ½ inch. Types of materials for the long cane include wood (typically poplar), aluminum, graphite, and fiberglass. Wooden canes are commonly solid, whereas other material varieties are usually hollow. Many canes are composed of a single rigid shaft, while others are telescoping and/or foldable. Types of cane tips include rolling tips, pencil tips, marshmallow tips, and glide tips. Their handles may be rubber (similar to a golf club grip), foam, wooden, or plastic. A long cane's price may vary from \$10 to \$115 USD. Figure 1 below shows several different canes with various handles and tips. Figure 2 below shows a folded cane and a retracted telescoping cane.

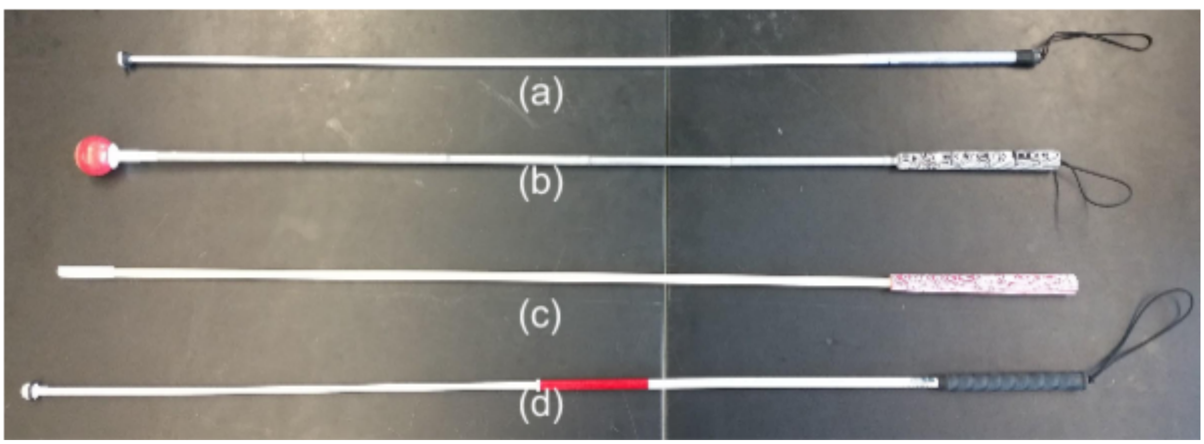

Figure 1: (a) Rigid fiberglass cane with a glide tip, (b) foldable aluminum cane with a roller-ball tip, (c) poplar cane with a pencil tip, and (d) telescoping cane with a marshmallow tip.

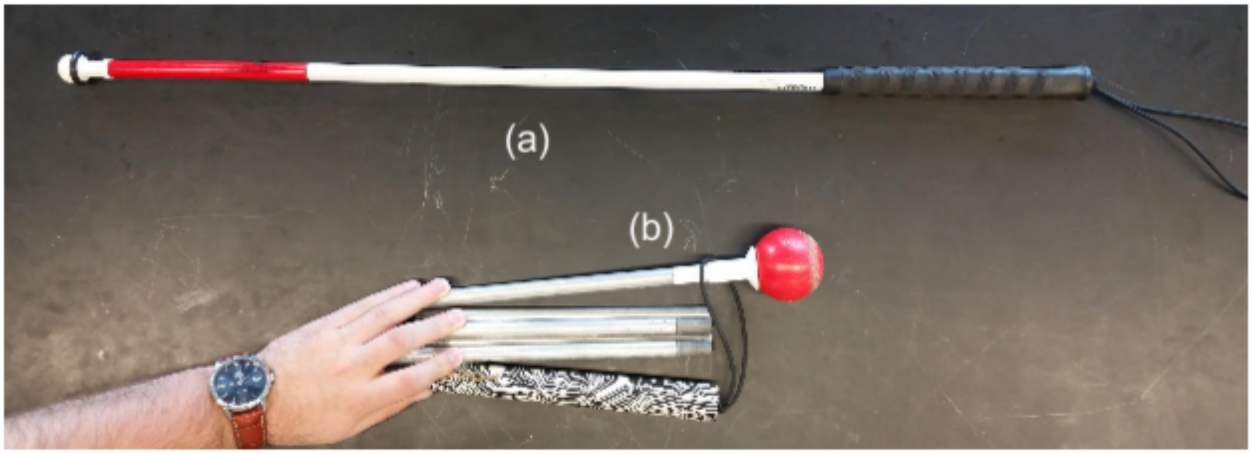

Figure 2: (a) Retracted fiberglass telescoping cane and (b) folded aluminum cane.

Cane performance is defined by user's ability to and ease of detecting obstacles and drop-offs while using it. Several correlations between cane properties and performance have been found. For example, the performance of a cane decreases linearly as its weight increases.[1] The distribution of the weight along a cane shaft, however, does not have a significant effect on the accuracy of cane manipulation. Cane weight does not have a significant effect on the discriminability of surface characteristics.[1]

A large improvement in the ability to navigate was noted after increasing the rigidity of the cane shaft, and the length of a cane has noteworthy effects on a user's ability to navigate down steps. Cane tips have been investigated as well, and were also found to have an impact on cane performance. A cane that was designed and fabricated based off of these findings was compared with a Typhlocane [1]. A Typhlocane, shown in Figure 3, is a patented cane design that is instrumented with a laser, photo sensor, and vibrators. The Typhlocane detects obstacles using the laser and photo-sensor, and then warns the user with vibrators in the handle. The simple cane, whose design was guided by these findings, performed significantly better than the Typhlocane.[2]

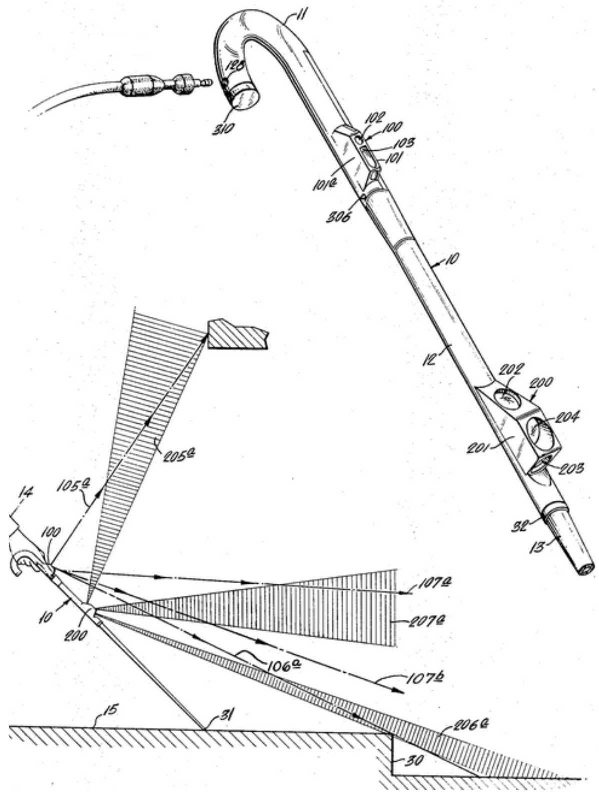

Figure 3: The Typhlocane was fixed with a laser, photo sensor, and vibrator to help detect obstacles.[2]

Furthermore, there has been study on using the sound of a cane tap to navigate. Schenkman and Jansson showed that tapping sounds from a long cane could be used for echolocation to detect and localize obstacles, although the task was difficult and success depended on the size of the obstacle. The frequency makeup of the sound showed no significant importance.[2] Schenkman found that the spectral content of the tapping sound was useful in identifying the ground material.[3]

There are many US patents for improvements to the long cane. Most of these aim to improve the user's ability to navigate or his visibility by others. One US patent (4062371 A, 1977) proposes adding a solar cell to a portion of the cane shaft to power a small lamp used as a beacon. This lamp increases the visibility of the user to others, thus increasing safety. A buzzer is used to signal to the user that the light is on.

There are several patents on the use of sensors attached to a cane to improve detection of obstacles that are either beyond the reach of the cane tip, or at levels above the ground. US Patent (US4280204 A, 1981) suggests the use of an electrostatic transducer to detect obstacles at

head or chest level. The user is alerted by an audible signal in an earpiece. US Patent (US20060028544 A1) performs the same function using an optical sensor; while US Patent (US20060129308 A1) proposes adding a Radio Frequency Identification (RFID) tag reader to a cane, allowing the user to follow a “trail” of preplaced markers. Another group of researchers attached optical and ultrasonic sensors to a cane, then communicated the presence of walls and obstacles to the user through haptic feedback.[5]

No patents were found that directly address the measurement of cane vibration. However, one patent from the sporting goods industry is of interest. Patent US7021140 B2, 2006 “Electronic measurement of the motion of a moving body of sports equipment” suggests rigidly mounting a gyroscope to a fly fishing rod. This is used to quantify the angular velocity of the rod during a cast, and the resulting data is used to coach the user. One could imagine attaching a gyroscope to a cane in order to teach scanning technique to a blind person. Because the WMU Blindness and Low Vision studies department has the capability to optically track cane position during experimentation, the use of a gyroscope in this project would not provide any additional useful information, so it was not considered here.

3. Scope and Project Requirements

The following section outlines the research completed at WMU prior to the start of this project, its limitations, and the resulting objectives and goals set for this design.

3.1 Benchmarking

Prior to our work, the WMU Noise and Vibration laboratory had completed preliminary testing of the vibration of four canes of different materials: poplar wood, 6061 aluminum, carbon fiber and a glass filled polymer. Each was 54 inches in length. The setup for this testing is shown in Figure 4. A cane was rigidly mounted to a lab table as a cantilever. An accelerometer was attached to the cane tip and just below the handle, then the cane was impacted at the tip with an instrumented hammer. Data from the hammer and accelerometers was collected by a computer where it was analyzed. In a second round of testing, the cane was held in the hand of the researcher as if it were in use for navigation, and either tapped at its tip with the instrumented hammer or hit on the ground.[7]

This laboratory setup used several components made by National Instruments. Two accelerometers and an impact hammer were connected to a NI-9234 module, which reads the analog values and outputs digital data. This module was attached through a wired chassis (via USB) to a lab computer running Smart Office Analyzer, software by M+P International. This software records and analyzes the data.

These experiments provided useful information that guided our design process. In the ground tap test, each material experienced peak acceleration in the range of 100-200 times the acceleration of gravity, giving us an idea of the range of accelerations that needed to be recorded. Likewise, the first four resonance frequencies of each cane, considered to be of greatest interest for research, fell below 500 Hz. All design alternatives had to be able to capture vibration in this frequency range, while measuring in the frequency range above 500 Hz was considered unnecessary. The Nyquist Theorem states that the sampling frequency must be at least twice the highest frequency of interest, so alternatives were selected that could sample force and acceleration data at a minimum of 1 kHz. By sampling more slowly, data that is important for analysis might be missed, while sampling at a higher rate would require managing unnecessarily large amounts of data.

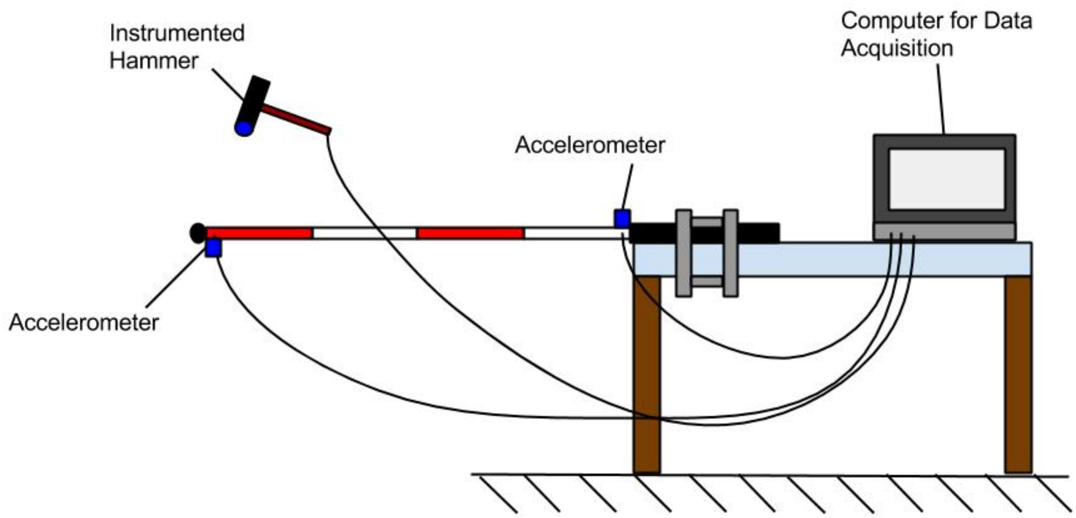

Figure 4: A schematic of the benchtop test setup of a cantilevered cane

3.2 Need for this Project

The testing conducted with a cantilevered cane was done under very restricted laboratory conditions which could be considered an oversimplification of the actual conditions present while navigating with a cane. Although bench-top testing is valuable for initial measurements, there is interest in measuring the response of a cane while it is being used. This will allow researchers to study the correlation between cane vibration characteristics and the detection of obstacles or drop-offs. The tap-testing is an improvement, as the cane is actually held in the hand of a participant, but it is still limited since the cane cannot move more than six feet away from the data acquisition system.

There are several requirements for an improved setup. First, it was required that the participant be free from any wired connection to a computer or data acquisition system. This would allow free motion around the test area without worrying about a tether cable, which could get stepped on, snagged or tangled, and in general, interfere with the motion of a subject. Desired wireless range was 50 to 100 feet from the receiver system, with capability for testing indoors or outdoors. The design alternatives presented below incorporated both Wi-Fi and Bluetooth. Infrared options were not considered, as they cannot operate in direct sunlight.

Another consideration is the comfort of the user. The participant is required to carry the transmitter system and battery, so these components must be light and compact enough so as to not fatigue or alter the natural motion of the user.

The solutions considered in this project aim to gather the same kinds of data as in previous laboratory experiments, by an easy to use wireless system. Specifically, they allow two to three accelerometers to be attached to the cane for vibration measurement, along with a force gauge to measure tip impact forces. These sensors are connected by wire to a module carried by the participant, and real-time acceleration and force data are transmitted to the data acquisition system. The acquired data is recorded by software on a computer.

Wireless sensors that would not require a separate transmitter module do exist. These were considered, but they were found to be impractical for this application. Wireless sensors are quite costly compared to the solutions proposed below; and they are all too large and heavy to provide a feasible solution. An illustration of the system discussed above is given in Figure 5.

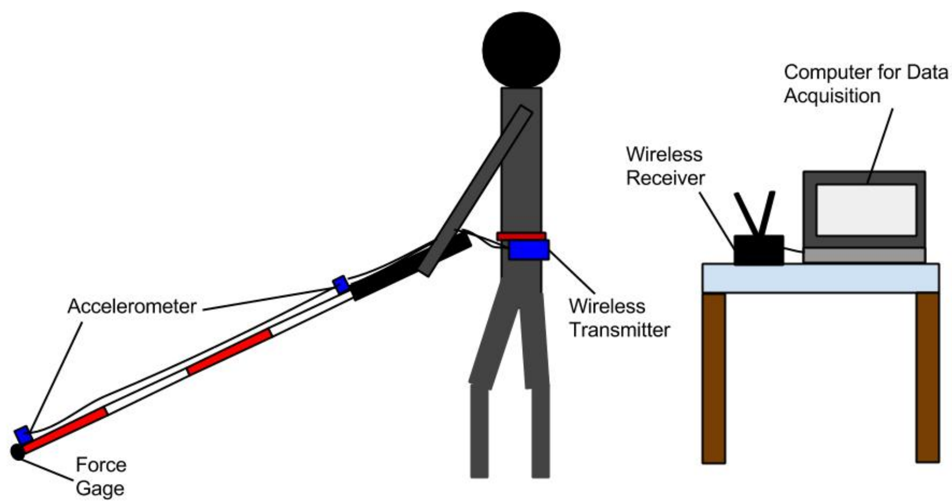

Figure 5: A schematic of the designed wireless data collection system

3.3 Secondary Objective - Muscular Exertion

Another research interest in this project is the muscle exertion in the arm of the cane user. It is possible that the grip intensity of the user impacts his ability to detect an obstacle, so a secondary objective was set to measure the exertion of the user while holding the cane. This component should also comply with the requirements listed above for the cane sensors: wireless, ergonomic, and lightweight.

Several methods were considered for collecting this information, such as instrumenting the cane grip with force or pressure sensors, or instrumenting a glove worn by the user. The main drawback of both of these methods is the complexity; as many as 10 or 20 sensors would be required to fully measure the grip exertion. Both design alternatives use technology that directly measures the exertion of the forearm muscle through the use of Electromyography (EMG) Sensors. These sensors are placed on the user's forearm and measure the voltage potential between two areas of the skin. This voltage potential changes slightly as the individual uses the muscles below the skin. A representative sensor using this technology is shown in Figure 6.

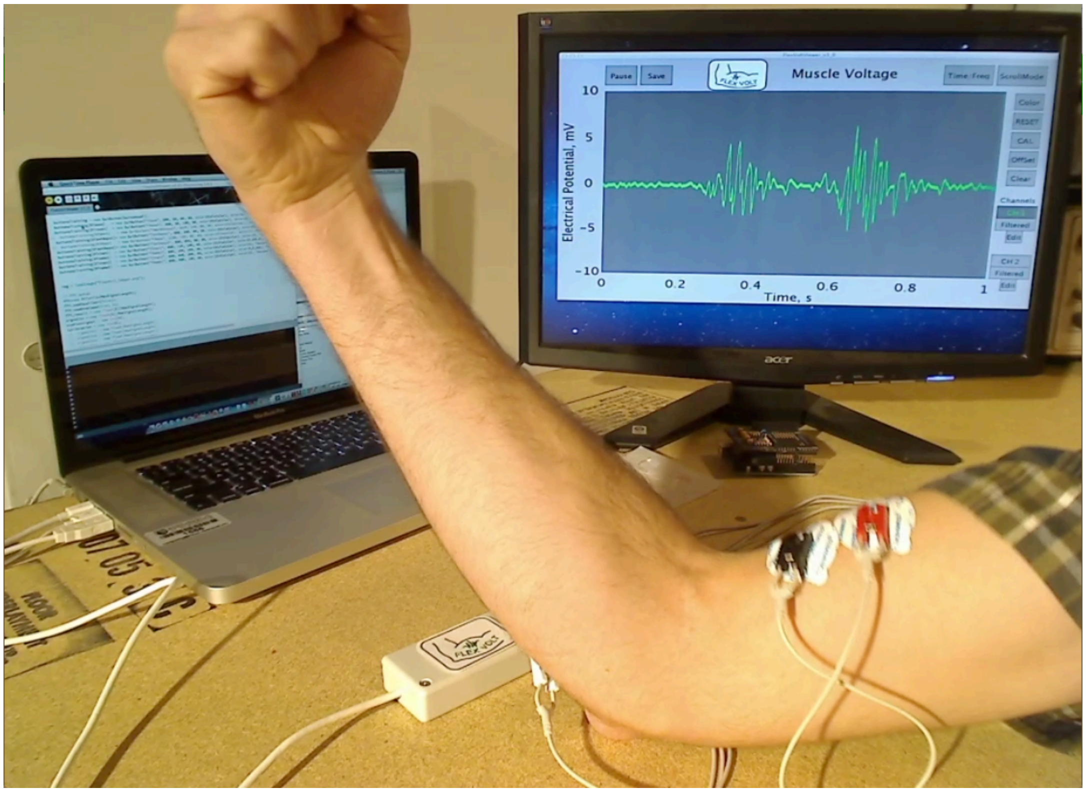

Figure 6: Electromyography sensors and data graph.

3.4 Deliverables

The objective of this project was to deliver a working and ready to use instrumented cane capable of measuring vibration and tapping force wirelessly from a computer station, while in use for navigation by a participant. Forearm muscular exertion data was also required.

4. Design Alternatives

This section discusses the design alternatives considered for this project. Several alternatives were developed for wirelessly transferring data, for measuring acceleration and force values, and for collecting EMG muscular exertion data. An estimation of the cost of each alternative is provided, along with the reasoning behind final design selections.

4.1 Wireless Data Transfer

4.1.1 National Instruments cDAQ-9191 CompactDAQ Wi-Fi Chassis

This is a wireless chassis made by National Instruments that connects a sensor module to a computer using Wi-Fi. It is compatible with a single NI-9234 module, enabling 4 channels of data collection. Prior to the start of this project, five of these modules were already owned by the WMU Noise and Vibration lab, reducing the investment required for this alternative. The chassis is shown in Figure 7.

Advantages:

- Compatible with NI-9234 module, which WMU already owns for vibration analysis.
- Includes driver software for lab computer
- Works with M+P International vibration analysis software that WMU already uses
- Cost: $379
- Power Requirements: 12 V DC, 6 W, 1.25 A max
- Estimated Battery Life: 8-12 hours (using $30 Talentcell Rechargeable 6000mAh Li-Ion; 3.81 x 10.2 x 8.8 in; 0.45 kg)[3]
- Size: 20.3 x 8.9 x 22.4 cm
- Weight (unloaded): 491 g
- Small and light enough to put on a belt. (Less intrusive)

Disadvantages:

- Maximum of four data channels.
- Requires battery power (sold separately, outside of National Instruments)

Figure 7: NI cDAQ-9191 Wi-Fi Chassis

4.1.2 National Instruments cDAQ-9184 CompactDAQ Chassis w/ Moxa AWK-3121 Wireless Transmitter

This is another wireless system sold by National Instruments. It includes a larger chassis for up to four modules (or 16 channels). This module is usually connected to a computer via Ethernet, so the Moxa transmitter is used to allow wireless communication. These are shown in Figure 8.

Advantages:

- Can hold up to 4 sensor modules, for up to 16 data channels of data
- Ability to measure strain, pressure, acceleration, force
- Compatible with NI-9234 module
- Includes driver software
- Works with M+P International software
- Compatible with multiple tri-axial accelerometers

Disadvantages:

- Cost: $1705
- Estimated Battery Life: 3-4 hours (using $30 Talentcell Rechargeable 6000mAh Li-Ion; 1.5 x 4 x 8.8 in; 1 lb.)
- Size: 6.4 x 8.8 x 17.8 cm + 5.4 x 13.5 x 10.5 cm

- Weight (unloaded): 1.5 kg
- System is large and could not be worn on a belt. It would likely be placed in a backpack

Figure 8: NI cDAQ-9184 CompactDAQ Chassis with MOXA AWK 3121 Wireless Transmitter

4.1.3 Arduino System

An Arduino is a small microcontroller that is popular in hobbyist electronics. It is inexpensive and can be set up to sample accelerometers or other sensors wirelessly. Figure 9 shows an Arduino microcontroller.

Advantages:

- System cost <$200
- Small, with low power consumption
- Modular and versatile

Disadvantages:

- Significant programming required
- Hobbyist level system, not designed for vibration analysis
- No professional support
- No available sensor for force measurement

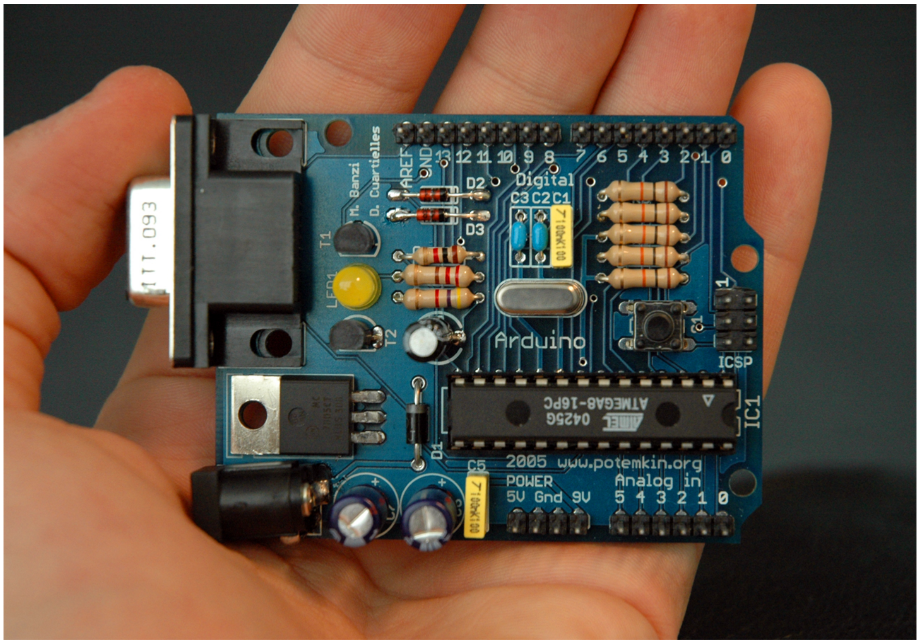

Figure 9: An Arduino microcontroller

4.2 Vibration and Force Measurement

This section outlines several of the sensors that were already owned by the Noise and Vibration laboratory, and a brief investigation of a mechanical impedance sensor.

4.2.1 PCB Piezotronics 288D01 Mechanical Impedance Sensor

This is a sensor designed to measure a force and acceleration together at the same point, eliminating the need for two sensors. None are owned by WMU. Figure 10 shows a mechanical impedance sensor.

Advantages:

- Measure both force and acceleration along the same axis, possibly eliminating the need for 2 sensors at the cane tip.

Disadvantages:

- Cost: $1115
- Only measure accelerations up to 50g (Previous cane vibration tests measured accelerations up to 200g)
- Weight: 19.2g; Size: 1.75 x 2.1 cm
- Uses 2 data channels

Figure 10: PCB Piezotronics 288D01 Mechanical Impedance Sensor

4.2.2 PCB Piezotronics 356B21 Tri-axial Accelerometer

Advantages:

- Accurate acceleration measurements along 3 axes, allowing for the most accurate vibration measurements
- Size: 1 x 1 x 1 cm
- Weight: 4 g
- Already owned by WMU

Disadvantages:

- Each accelerometer uses 3 channels, therefore only compatible with more expensive and bulky wireless data transfer option.

Figure 11: PCB Piezotronics 356B21 Triaxial Accelerometer

4.2.3 PCB Piezotronics 352C22 Uniaxial Accelerometer

Advantages:

- Very small (11.4 x 6.4 x 3.6 mm)
- Very lightweight (0.5 g)
- Already owned by WMU

Disadvantages:

- Fragile (especially the cord and connector)

Figure 12: PCB Piezotronics 352C22 Uniaxial Accelerometer

4.2.4 PCB Piezotronics 353B18 Uniaxial Accelerometer

Advantages:

- More robust than smaller sensors
- Already owned by WMU

Disadvantages:

- Weight: 1.8g
- Size : 18.8 mm tall x 7.14 mm wide

Figure 13: PCB Piezotronics 353B18 Uniaxial Accelerometer

4.2.5 PCB Piezotronics 208B02 Force gauge

Advantages:

- Already owned by WMU

Disadvantages:

- Weight: 22.7g
- Size 15.88 x 15.88 mm

Figure 14: PCB Piezotronics 208B02 Force gauge

4.3 Muscular EGM Measurement

Electromyography sensors will be used to measure the grip force used on the cane during navigation, in order to correlate grip strength with navigation success. Two options were considered.

4.3.1 BioRadio

This system utilizes up to four pairs of EMG sensors. The device has the ability to sample its sensors at up to 200 Hz while transmitting this data wirelessly via a Bluetooth connection to a computer, or it can sample as high as 16000 Hz and store this data using on-board memory. The system consists of a wireless transmitter connected by wires to the EMG sensors, which are placed directly on the skin. The transmitter is held by participant and runs on an internal rechargeable battery.

Advantages:

- Product support from subject matter experts
- Event marker to line up timestamps
- Power source included
- Software included

Disadvantages:

- Cost: $3490
- Sensors need to be individually placed on participant, and wired to the transmitter

4.3.2 Myo Armband

The Myo Armband is a hobbyist armband used to control things like PowerPoint presentations with hand and arm motion. The system is self-contained and transmits data wirelessly via Bluetooth. It uses an Inertial Measurement system that consists of a multi-axis accelerometer and gyroscope, along with eight EMG sensors, in order to read the position of the hand and arm of the user. Raw data from these sensors can be accessed using a developer toolkit. Figure 15 shows the BioRadio, while Figure 16 shows the Myo system.

Advantages:

- Compact system, no wires
- Easy-to-use
- Low Cost ($200)

Disadvantages:

- May require substantial programming
- No event marker

Figure 15: BioRadio alternative for monitoring muscle exertion

Figure 16: Myo armband alternative for monitoring muscule exertion

4.4 Analysis Software

Once the vibration data is streamed to a computer, it must be recorded and analyzed. Two software packages were considered for data acquisition.

4.4.1 M+P International Smart Office Analyzer

Smart Office Analyzer is a software package that is made for noise and vibration analysis. The WMU Noise and Vibration lab already owns a license for the software, and it is the same software package that was used for previous cane vibration testing. The advantage of using this software is that it is designed for analyzing vibration of structures, and there is no additional cost associated with using it.

4.4.2 National Instruments LabVIEW

LabVIEW is a software package made by National Instruments to interface and control hardware. Programs are written using a visual flowchart. This gives the user flexibility to write a program in any way it is needed, but writing these programs can be time consuming and require troubleshooting. WMU purchases an academic license for LabVIEW, so there is no cost to use it in this project.

4.5 Cost comparison

Table 1 reviews the candidate solutions and the required financial investment in new equipment for each for each option.

Table 1: Comparison of solution costs.

Option:	Component:	Cost:
1. cDAQ-9191 CompactDAQ Chassis		
	Wireless Chassis	$349
	Battery	$30
	Total:	$379
2. cDAQ-9184 CompactDAQ Chassis with Moxa AWK-3121 Wireless Transmitter		
	Chassis	$945.00
	Wireless Transmitter	$730
	Battery	$30
	Total:	$1705

3. Arduino System		
	Arduino Microcontroller	$25
	250g Analog Accelerometer (ea)	$30
	Bluetooth Module	$26
	Bluetooth usb module	$11
	USB battery pack	$30
	Total:	$122+
4. BioRadio EGM System		
	BioRadio System	$990
	EMG electrodes	~$35 (x10)
	"BioCapture" Software	$2150
	Total:	$3490
5. Myo Armband	Armband	$200
	Software Development Kit	Free
	Total:	$200
Optional Equipment:		
1. Linksys WRT54GL[8]	Wireless Router	$49.99
2. Model 288D01	Mechanical Impedance Sensor	$1115.00

4.5 Alternative Selection

A decision matrix is presented in Table 2. Each solution is rated on four criteria: The cost of the solution, the accuracy and reliability of the data it produces, its ease of use, both during setup and for the end user of the system, and the level of ergonomic accommodation it provides to the user. For example, the Arduino is cost effective and compact; however it is expected to take significant programming, and may produce data of lower quality because it is not intended for vibration analysis. The ratings of each component for each category represent the perception by the group members of how well that component meets the criteria outlined. The weighting factors represent the degree to which each criterion is believed to impact the overall success of the project.

Table 2: Decision matrix for system implementation

Criteria	Cost	Quality of Data	Ease of Use	Ergonomics	
Weighting (right)					Overall Satisfaction / 100
Concepts (below)	0.2	0.3	0.25	0.25	
Wireless Data Transfer:					
cDAQ-9191	80	80	100	80	85
cDAQ-9184 w/ AWK-3121	20	100	80	20	59
Arduino	100	50	20	70	42.5
Muscular EMG Measurement:					
Myo Armband	80	30	30	70	50
BioRadio EGM System	10	70	60	40	48
Smart Office Analyzer	100	100	80	n/a	70
LabVIEW	100	70	10	n/a	43.5

The Data Transfer solution selected for implementation was the cDAQ-9191. This provided four channels of wireless data, in a smaller and lighter package than the cDAQ-9184 with an external transmitter. Referencing the previous tabletop laboratory experiments which used one force gauge and two accelerometers, four channels of data acquisition is sufficient.

While the Arduino may be smaller and more versatile, it is not designed to collect high quality vibration data, so it was ruled out.

The EMG solution selected was the Myo armband. Although it is designed as a hobbyist level computer control device, it is compact and requires no loose wires on the participant. It also has a significantly lower cost than the BioRadio. Should the results produced by the Myo be interesting, the researcher could upgrade to the BioRadio in the future for higher quality data.

One PCB Piezotronics 208B02 force gauge was selected to be installed on the tip of the cane. This sensor will make contact with the ground in place of a traditional cane tip, allowing a measurement of the force used to strike the ground. Three of the PCB Piezotronics 352C22 were selected to be mounted on the cane shaft, with one at the tip, one at the mid-length, and the final one just below the grip. This accelerometer was used because it is the smallest and lightest option. By minimizing the mass of the sensors, the vibration characteristics of the cane are not significantly changed.

Smart Office Analyzer was selected as the analysis software to be used. Smart Office was already used in the Noise and Vibration Lab and was used for cane testing prior to this project. It is purpose built for vibration analysis and requires less programming when compared to LabVIEW. Smart Office also offers features like Frequency Response calculations and vibration spectrum, which may be difficult to implement in LabVIEW.

5. Implementation

Each component of the instrumented cane design was tested before data collection began. This section outlines how the components were tested, the results, as well as the installation of the components onto the cane and validation of the whole cane system.

5.1 Component Testing and Verification

5.1.1 Wireless Data Acquisition Setup

The first component tested was the NI-9191 wireless chassis. The chassis was installed using the quick start manual (see Appendix B). Data was gathered on all four channels using three 352C22 uniaxial accelerometers, one 208B02 force gauge, and the NI-9234 Module. Data was viewed in Smart Office. The ability to collect data was first confirmed with the wireless chassis hardwired to the computer with an Ethernet cord and powered with a standard 120V AC wall outlet. The Ethernet cord was then disconnected, and data was transferred to the computer with through a Linksys Wi-Fi router. Finally, a 12V battery was connected to the chassis, making the setup completely wireless. Because the battery is not made by NI, the battery power cord had to be spliced with an NI pin connector in order to connect it to the chassis. The ability to collect data with a completely wireless system was confirmed. All further validation was also performed wirelessly. Figure 17 shows the battery connected to the NI-9191 Chassis.

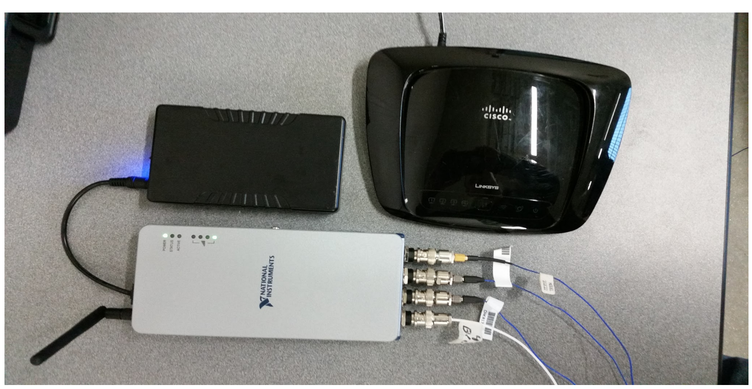

Figure 17: NI-9191 chassis connected to a 12V lithium ion battery. The NI-9234 analog input module is inserted in the chassis and equipped with 3 accelerometers and 1 force gauge (not shown). Top right is the Linksys router.

5.1.2 Sensor calibration

The accelerometers were calibrated using the PCB 394C06 Handheld Shaker, shown in Figure 18. This shaker vibrates at 1000 Hz with an RMS acceleration of 9.81 m/s^2. To calibrate an accelerometer, it is attached to the shaker and the output voltage is recorded. This value (in millivolts per g) is used as a basis of comparison when experimental data is collected.

Figure 18: PCB 394C06 Handheld Shaker

One limitation of the selected type of force gauge is that it will not measure static forces, but only dynamic ones. This is not of concern within the scope of this project, which deals with dynamic excitation of the cane. However, it does limit the way in which the gauge can be calibrated, because simply loading the sensor with a known mass will not produce a meaningful result. Instead, the force gauge is calibrated by application of Newton's Second Law:

$$F = m * a$$

In order to verify the nominal calibration value given by the manufacturer, the force gauge was mounted on an aluminum plate and placed on a flat table, pointing up. An iron bar of known mass (245g) was fitted with an accelerometer and dropped on the gauge from 3 inches above it. The measured deceleration of the bar as it comes to rest multiplied by the mass of the bar, is equal to the force of the gauge on the bar. This test confirmed the nominal calibration value given by the manufacturer to within 1% of the expected value. Figure 19 shows the test used to calibrate the force gage. Note that the rod is held in a PVC sleeve to guide it, so that it lands directly on the force gauge. Table 3 gives the measured calibration values for each sensor.

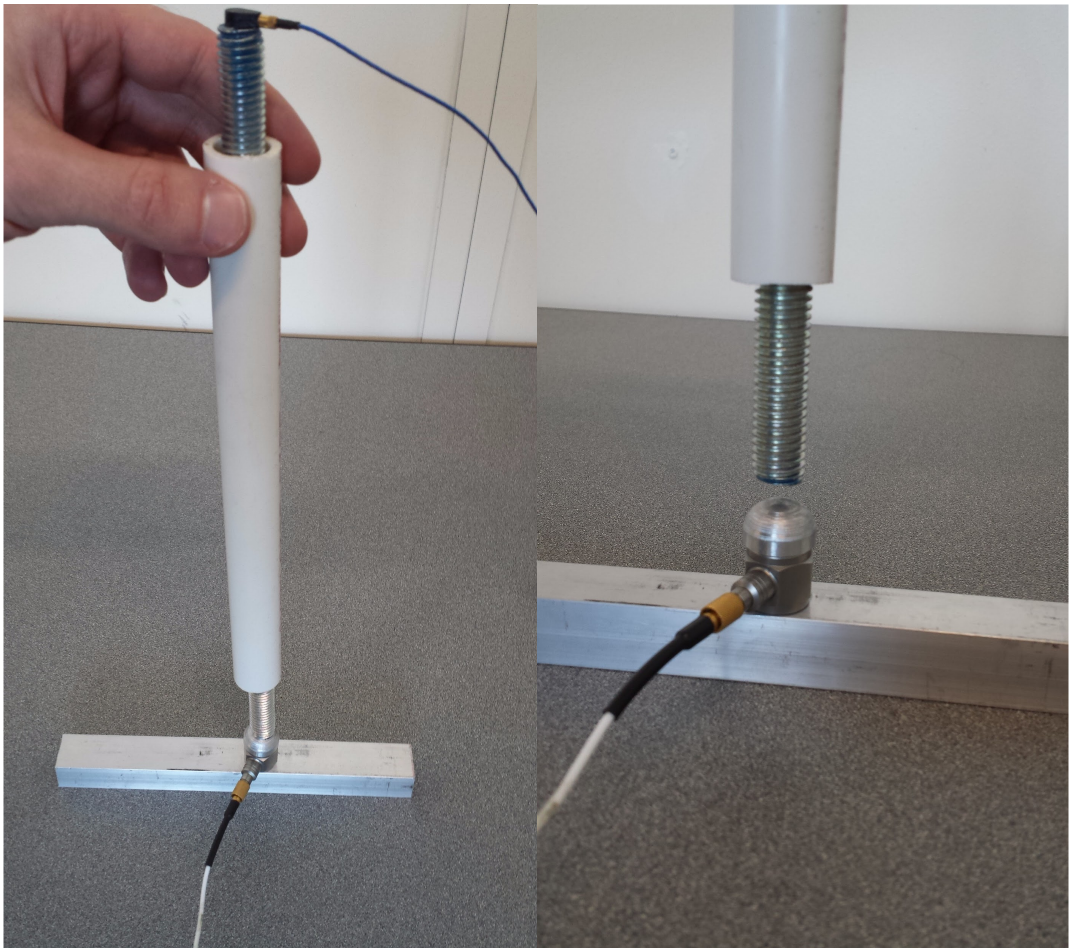

Figure 19: Test to verify nominal calibration of the force gauge

Table 3: Sensor calibration values at the time of this writing

Sensor	**Calibration value**
352C22 Accelerometer, SN 91717	10.162 mV/g
352C22 Accelerometer, SN 91719	10.048 mV/g
352C22 Accelerometer, SN 91720	10.037 mV/g
208B02 Force Gauge, SN 15252	11.241 mV/N

Another area of concern with the force gauge is its accuracy as it is impacted at an angle to its axis of measurement. In an ideal case, the force gauge would always be perpendicular to the ground, so that the value of the applied force is always accurately recorded. This is more difficult to achieve in practice, so the force gauge was tested with an oblique impact, at angles ranging from 0 to 90 degrees. The orientation of this angle measurement is shown in Figure 20.

The method is similar to the one used above to verify the force gauge calibration, but the plate with the mounted gauge was inclined at angles ranging from 10 to 90 degrees. The rod is still dropped vertically onto the gauge from a constant height of three inches. This arrangement is shown in Figure 21. Table 4 gives results, where each measurement is the average of three trials. The expected force value is again calculated using the measured acceleration of the rod:

$$F_{expected} = m * a * cos(\theta)$$

At angles larger than 40 degrees, the force gage produces sporadic results, including forces of negative magnitude. This data is not included in Table 4, as the gauge is clearly outside its useful angle range. For small angles (10 degrees or less), the gauge produces accurate force values. This result shows that the force gage will need to be mounted on the cane in a way that causes it to impact normal to the ground. However, variations in the impact angle of less than 10 degrees will not affect the validity of the output.

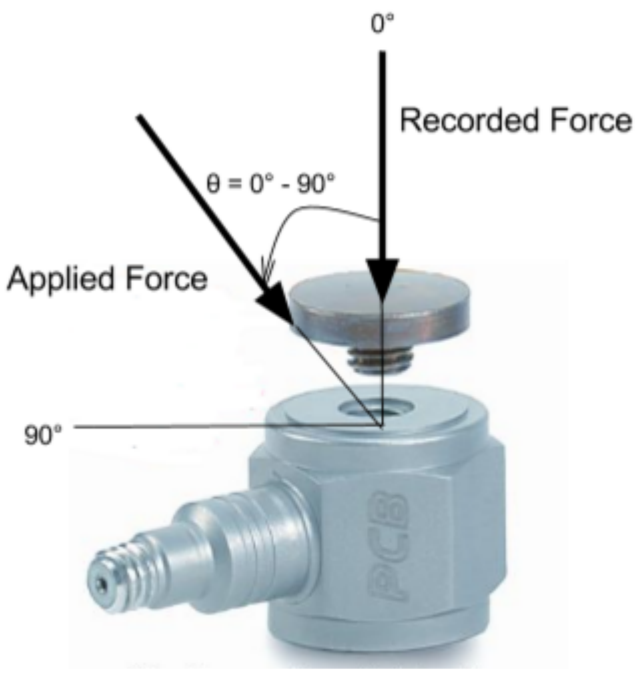

Figure 20: Force orientation for Oblique Impact test

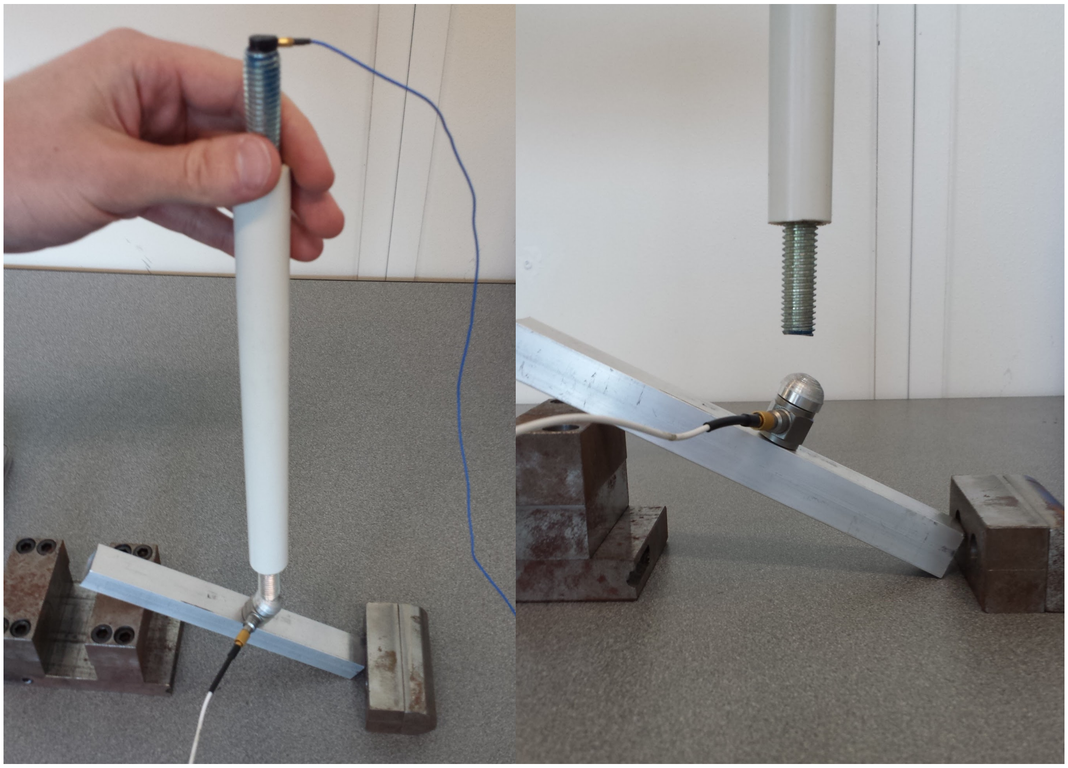

Figure 21: Measurement of the accuracy of force gauge to oblique impact

Table 4: Force gauge accuracy at an oblique angle. Results are the average of three trials.

Angle (degrees)	Force Measured (N)	Force Expected (N)	% Error
0	286.40	292.52	-2.09
10	184.85	182.44	1.32
20	132.88	144.89	-8.29
30	95.76	136.32	-29.76
40	110.65	133.65	-17.21

5.1.3 Myo Armband

The developers of the Myo armband have released a software package called “Myo Data Capture” which allows for data collection. The armband is programmed in C++. This package was implemented from the developer’s software market, and requires only that a Windows

computer has Microsoft Visual Studio 2013 run time available, in order to extract data from the C++ software.

Initial trials with the Myo show that the data from the EMG sensors is valid and that the program accurately records the data with no packet loss or Bluetooth interference from other devices. The data captured from the electromyography sensors and the data capture program only represent a relative "activation" of the muscle and contain no specific units of measure. This value may be difficult to correlate directly to a force value at the cane handle, but may be effective for qualitative comparisons between trials, and between participants.

Efforts to contact the developers of the Myo lead to a redirect to their forum where a developer states: "...the raw voltage output from the EMG sensors would consume too much power and significantly reduce battery length and performance." This is why the Myo uses a unit-less number indicating muscle exertion, rather than processing the measured voltage values.

The anatomy of the forearm includes 20 distinct muscular structures (as shown in Figure 22), so the Myo must be placed in the same location and orientation on the forearm whenever possible.

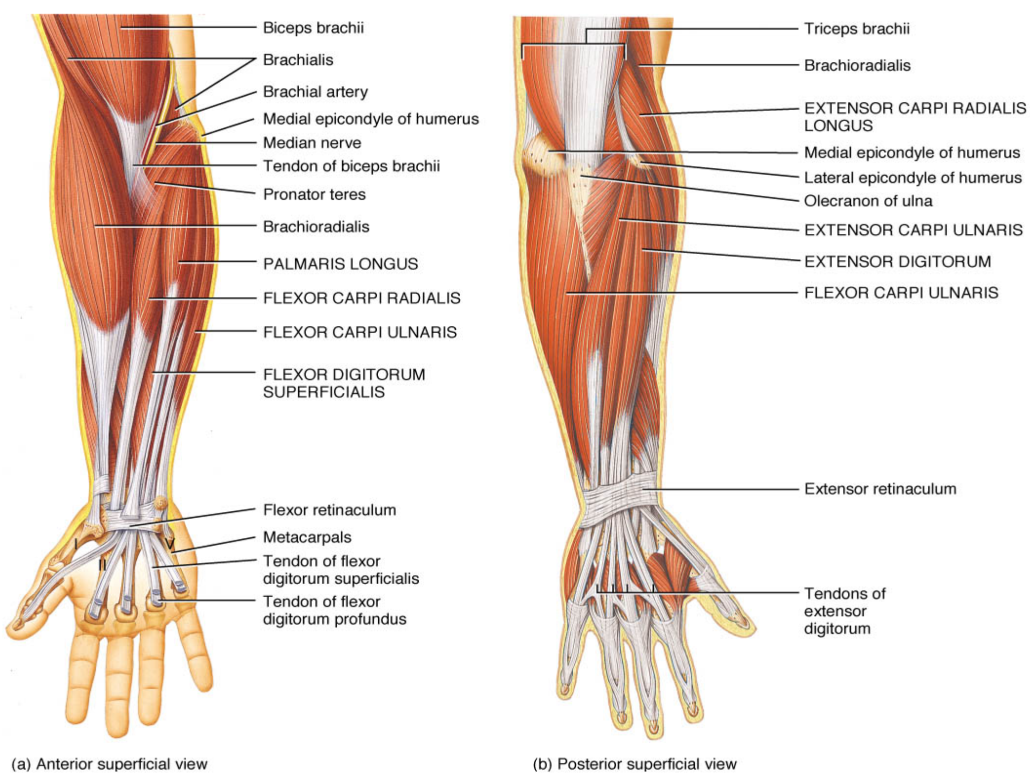

Figure 22: Internal view of the various muscles in the forearm

Myo Connect is the program Thalmic Labs uses to parse data coming from the armband for gesture recognition. The Myo Data Capture software redirects data streaming from the Myo Connect interface and compiles the data into a comma separated variable (.csv) file. A simple test was performed with the Myo armband and the tapping of a cane to validate that the system and software works as desired. In Figure 23, the cane taps are clearly shown as spikes in data values. The horizontal axis on the EMG data shows the UNIX timestamp for each point of data, in microseconds. The beginning timestamp for the test in Figure 23 is 1446653901184330, which correspond to 11/4/2015, 11:18:21 AM.

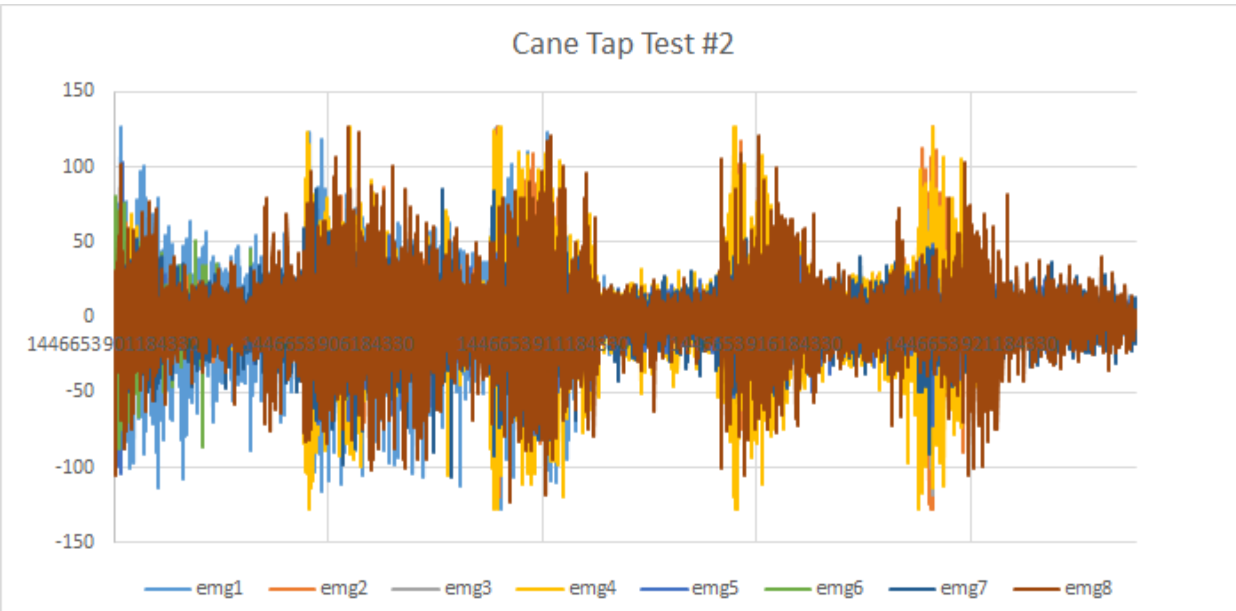

Figure 23: Simple cane tap with Myo Data Capture software

5.2 Cane Assembly

Finally, before the cane could be assembled, a blind cane had to be selected. At the recommendation of our industrial mentors, we selected an aluminum shafted cane that was cut to 54 inches in length. Aluminum was selected because it is light and rigid, and when compared to the fiberglass or wood canes tested previously, it produced the most consistent results. To measure the proper cane length for a user, it should reach from the ground to somewhere between the sternum and the chin of the user. A length of 54 inches is acceptable for most users, unless they are very tall or very short.

5.2.1 Initial Assembly and Verification of Sensor Range

Once the sensors were calibrated and the wireless data transfer had been set up, the cane was instrumented for an initial test. An accelerometer was placed on the cane tip and just below the hand grip, and the force gauge was placed at the tip, perpendicular to the length of the cane. The cane was held in the hand and tapped several times on the ground, so that the force gauge impacted normal to the floor surface. The taps were considered to be slightly harder than how the cane would be tapped while in use for navigation.

This test was performed to verify that the sensitivity range of the sensors was a good fit for the forces and accelerations experienced by the cane. Peak forces experienced at the cane tip were around 200 N, while the 208B02 force gauge is designed for maximum loads of 445 N (100 lbs.). Peak acceleration on the cane was near 300g, while the 352C22 accelerometers are rated for 800g maximum acceleration. In both cases, the data gathered in was within 30-50% of the maximum range of the sensors.

It is important that the sensor ranges are a good fit for the forces and accelerations being experienced by the cane. If the measurements are very low in the dynamic range of the sensors, the low sensitivity will lead to poor data accuracy. On the other hand, exceeding the rated limit of the sensors produces clipping, and the true force or acceleration values are not collected. Figure 24 shows a time record of the force gauge output, while Figure 25 shows a time record of the accelerometer output.

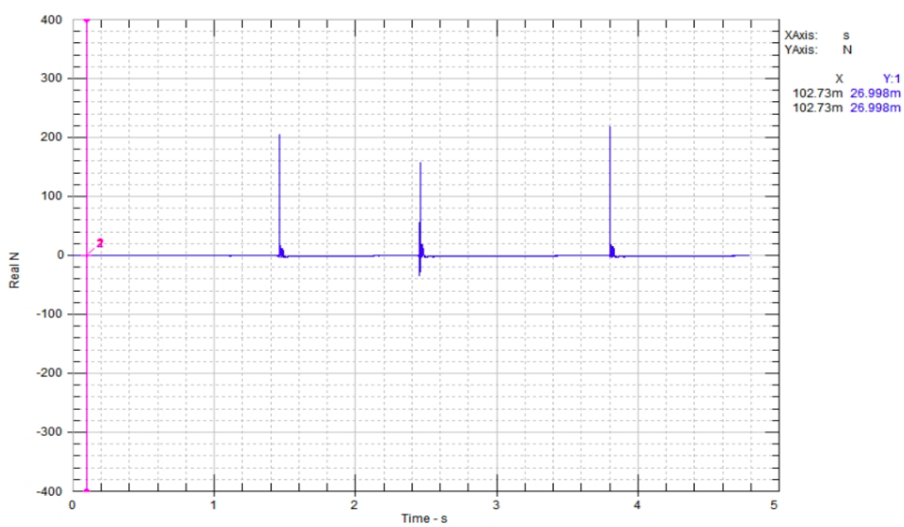

Figure 24: Data snapshots from initial sensor verification. Tap force peaked near 200 N.

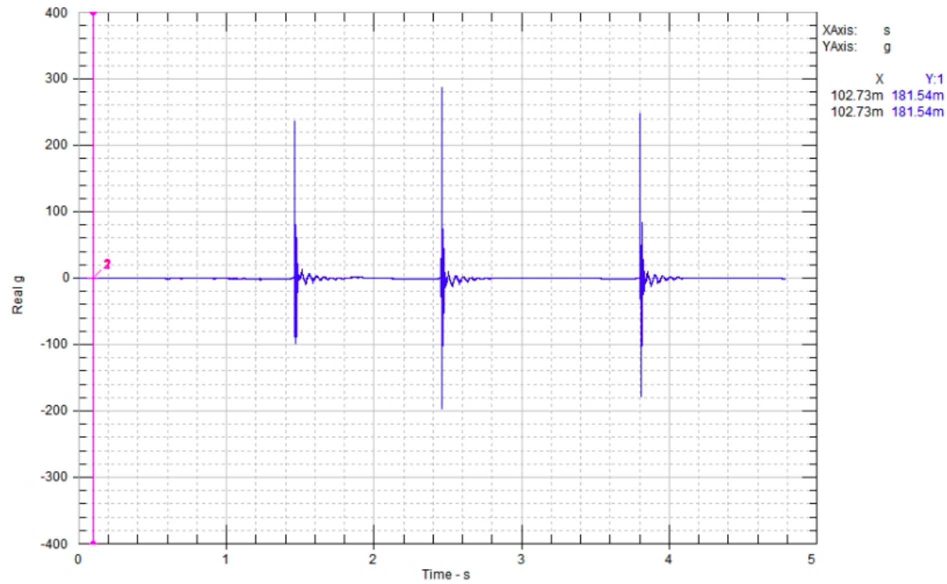

Figure 25: Data snapshots from initial sensor verification. Tip acceleration peaked near 300g.

5.2.2 Force Gauge Mounting

A requirement for mounting the force gauge is that it is positioned normal to the ground when the cane is being used, as shown previously. To keep it in that position, it must be mounted at an angle to the length direction of the cane. However, the angle that the cane makes with the ground changes with the height of the cane user. In order to mount the force gauge to the cane tip, several interchangeable tips were fabricated.

Figure 26 shows three common pencil tips for a blind cane. A pencil tip slides snugly onto the end of a cane, and is the component that actually makes contact with the ground. To mount the force gauge, several of these tips had a flat surface cut into them at different angles, and a threaded hole was added. During an experimental session the proper tip will be selected for a user based on his height, so that the force gauge impacts perpendicular to the ground. The tip is slid onto the cane, and the force gauge is screwed in place. This allows the sensor to accurately measure force for any user, regardless of height. The fabricated tips are shown in Figure 27, while a tip and force gauge is shown on the cane in Figure 28.

A hemispherical tip was machined from aluminum to be attached to the force gauge. Aluminum was selected because it is lightweight, and it will not grab the floor surface as a rubber or polymer tip may. The hemispherical shape contacts the ground consistently, even with small changes in the impact angle. Figure 29 shows the hemispherical tip, along with several

other tips provided by the sensor manufacturer. In general, a harder tip is used to excite higher frequencies than a softer tip, which preferentially excites lower frequencies. In this project, a rubber tip did not effectively excite the cane above 300 Hz, while a metallic tip excited the cane evenly up to 1000 Hz.

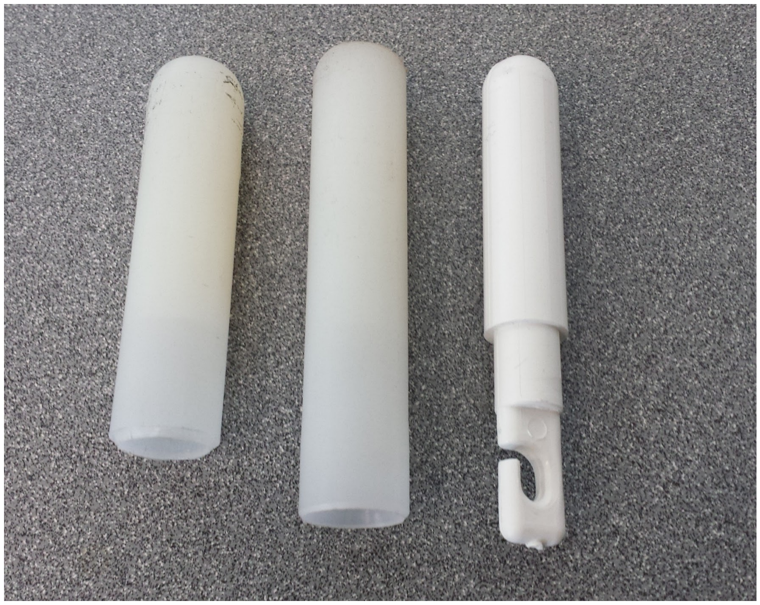

Figure 26: Three cane pencil tips

Figure 27: Interchangeable cane tips for force gauge attachment

Figure 28: The end of the cane, with a fabricated tip and force gauge attached

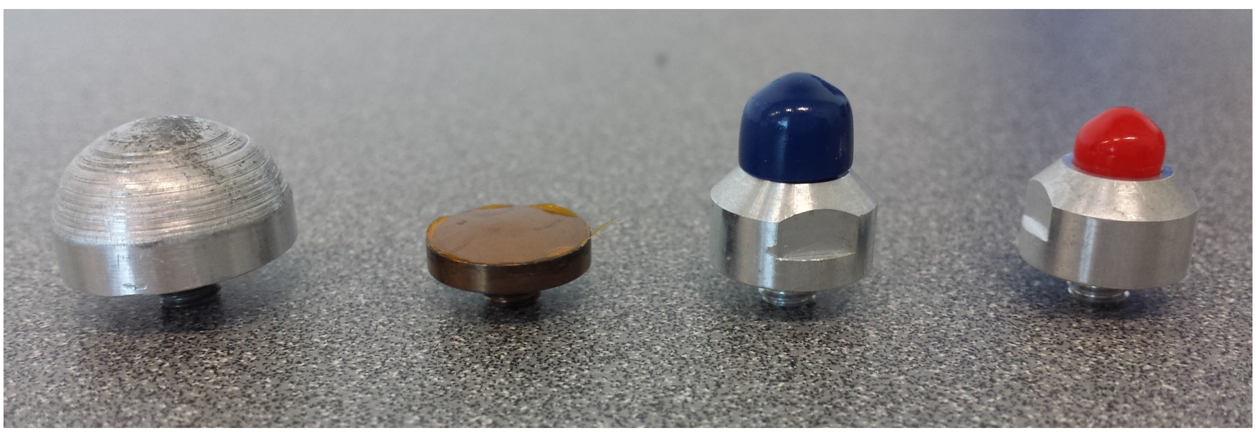

Figure 29: The custom hemispherical tip, far left, along with several manufacturer-supplied tips

5.2.3 Final System Assembly

After verifying that all of the sensors worked correctly, the final system was assembled. Three accelerometers were placed on the cane. These are on the end of the cane just above the interchangeable tip, just below the cane handle, and midway down the length of the cane between these two. All three are mounted in line with the force gage, on the side of the cane that faces the ground when in use. They were placed on the bottom side of the cane to keep them out

of the way of optical tracking markers, which have been used in the past by researchers in the Department of Blindness and Low Vision Studies.

The accelerometers are attached to the cane using Loctite super glue. The glue creates a firm bond to transmit vibration to the sensors, but is not so permanent that it would be difficult to move the sensors in the future. Cables from each sensor run up the side of the cane, and are secured by a band of electrical tape along the whole cane length. The final cane assembly is shown in Figure 30.

A fishing vest is worn by the user to hold the transmitter and battery pack. A backpack or hip pack was also considered. However, the transmitter is too large to comfortably fit on the belt, and there were concerns that a backpack strap could interfere with the natural range of motion of the user's arm. The vest has a large pocket on the back that holds the transmitter and battery, and the weight is spread evenly over a large area on the shoulders. The vest should not restrict arm motion, as it was designed to be worn while fishing, an activity that requires freedom of movement for casting. Figure 31 shows the fishing vest.

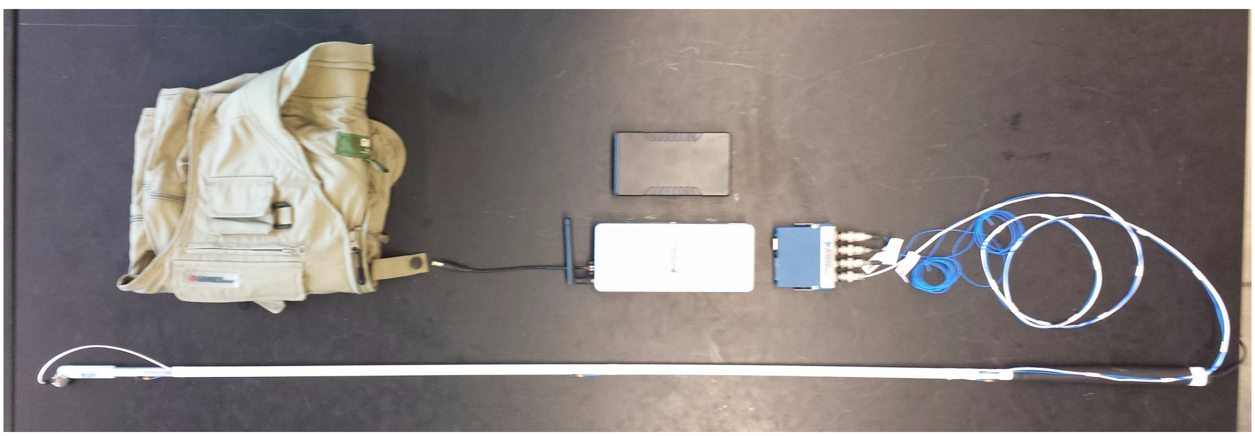

Figure 30: The final cane assembly

Figure 31: The fishing vest used to hold the transmitter and battery pack

5.3 Cane Vibration Characterization

Vibration analysis on the cane was performed in a laboratory setting, similar to the analysis done on other canes prior to the beginning of this project. First, the cane was cantilevered from a laboratory table and impacted at the tip with an external calibrated hammer to measure its frequency response. This was performed without the force gauge at the tip, as in the previous analysis. Next, the force gauge was added. Adding mass at the tip of the cane will change the vibration response of the cane, and it is important to know how adding instrumentation to the cane changes its vibration. Figure 32 shows the test setup.

Both of these tests were performed again while the cane was held by hand. By removing the rigid clamp at the handle, the boundary condition on that side changes along with the cane vibration. Finally, the cane was held in hand and excited by tapping it on the ground. The impact was measured by the force gage mounted on the cane instead of by an external impact hammer. These tests were performed in order to measure the degree to which this experimental setup changes the natural vibration of the cane.

Figure 33 gives the frequency response of the cane to an impact as measured in each of the five tests. Each plot shows the intensity of vibration on the vertical axis, against frequency on the horizontal axis. The blue line shows the vibration response at the cane tip, the red line shows the response at the midpoint of the cane, and the green line shows the response at the cane

handle. A peak in one of the traces indicates higher acceleration at that point for the given frequency. The peaks in the three traces line up at the natural resonant frequencies of the cane.

Note that when the force gauge is attached to the cane, the natural frequencies shift downward because of the added mass. Likewise, the natural frequencies shift downward when the cane is held in the hand, rather than cantilevered.

Figure 32: Cantilevered cane vibration test.

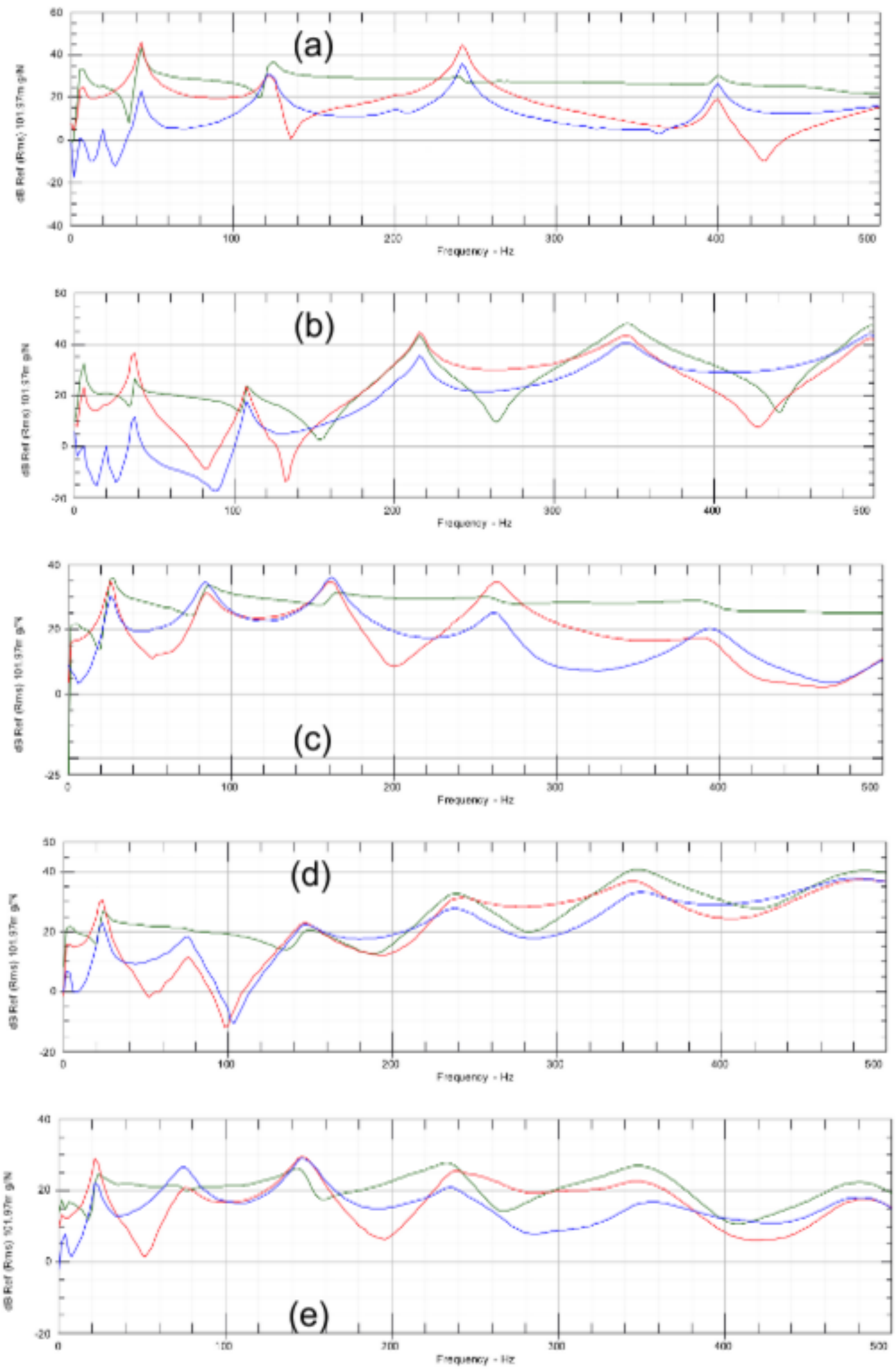

Figure 33: Frequency response of the instrumented cane when (a) cantilevered without the force gauge, (b) cantilevered with the force gauge, (c) hand held without the force gauge, (d) hand held with the force gauge, and (e) tapped on the ground.

5.4 Myo Armband Data Collection

Initial tests for the Myo armband were focused on creating testing techniques to minimize data background noise, and to ensure that the program performed as expected during experimental trials. For example, he data capture software is designed to create a new csv file when the current file becomes too large for the program to manage. This would have caused a problem with the data analysis if multiple files were created for each trial unexpectedly. A duration test was performed to be sure that the software would not split a file before a trial was concluded. Data was recorded for 10 minutes with a large muscle activation each minute. This is shown in Figure 34. The data was saved in a single file, showing that the program could handle greater than ten times the data typically needed for a trial, since testing trials with a participant are expected to last less than a minute.

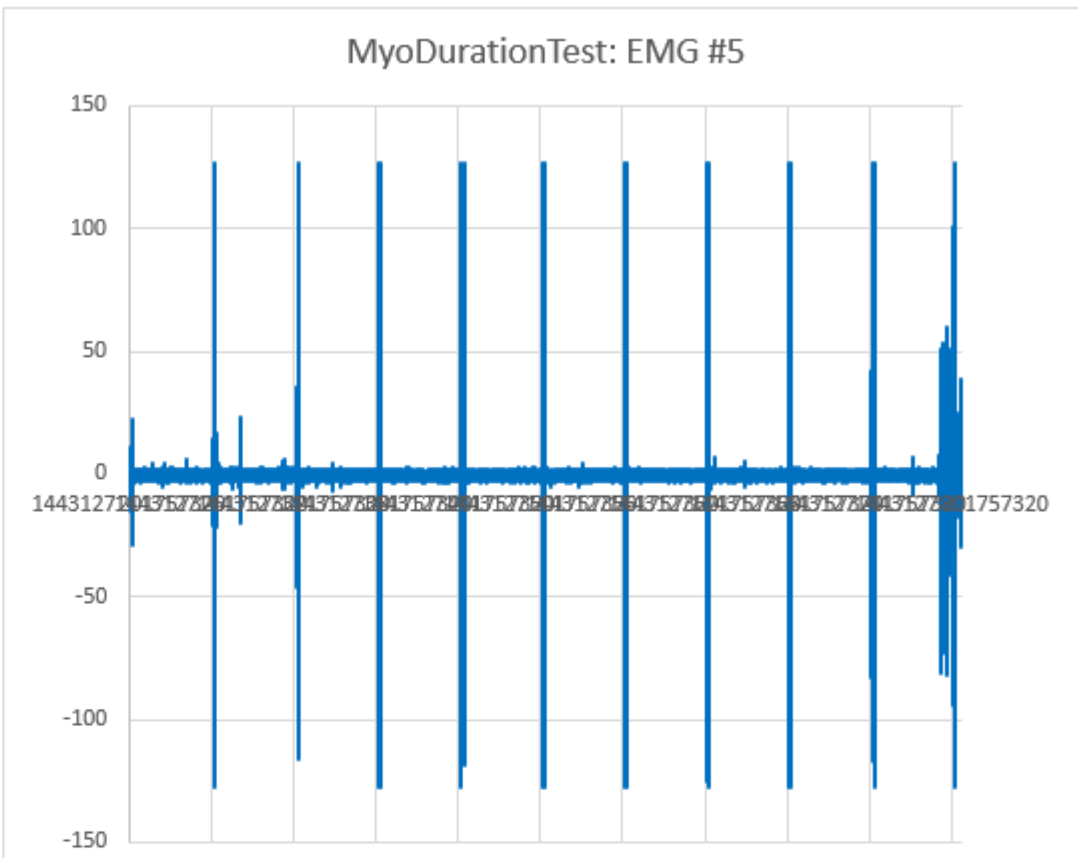

Figure 34: Myo data capture software duration test which lasts 10 minutes, with muscle activation every minute.

In order to establish a correlation between the Myo output and actual muscle exertion, two Gripmaster tools were used. The Gripmasters are shown in Figure 35 and require a known force in order to compress the device fully in the hand. The yellow Gripmaster provides 3lbs per finger while the red is 7lbs per finger. Tension was also addressed and a short test with a tension ball trainer was conducted but showed no significant results. A rubber band device was also explored for finger extension, but its results were inconsistent.

Figure 35: Gripmaster training tools for hand grip exertion.

The Gripmasters were used in several trials to determine the best way to calibrate the Myo before an experimental trial. There was some concern that the Myo would dynamically scale its non-dimensional output while it was in use. This would make it difficult to interpret the data, as an exertion value would not be correlated to the same force throughout the trial. Reaching out to the manufacturer did not provide any additional information.

Figure 36 shows a trial where the 3-pound Gripmaster was squeezed, followed by the 7-pound then the 3-pound again. All eight EMG sensors are displayed. In Figure 37, two of the channels are removed to make it easier to interpret the data. Note that the two peaks at the right and left of the figure are smaller in magnitude than the one in the center. This indicates that the data was not dynamically scaled while the test was ongoing.

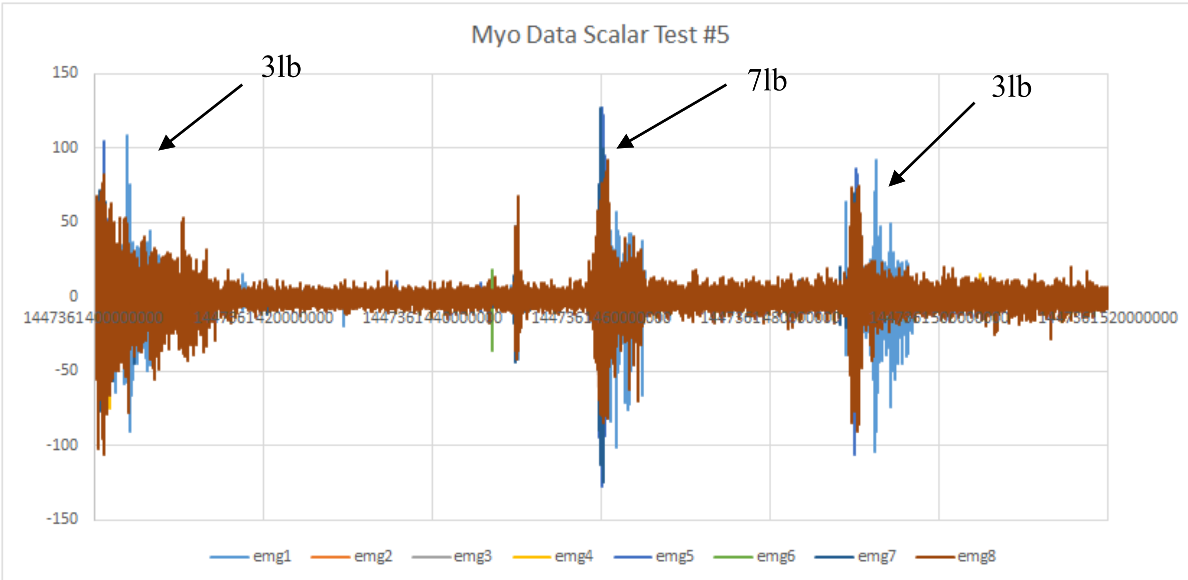

Figure 36: Data scaling test with a 3-7-3 lb. Gripmaster sequence.

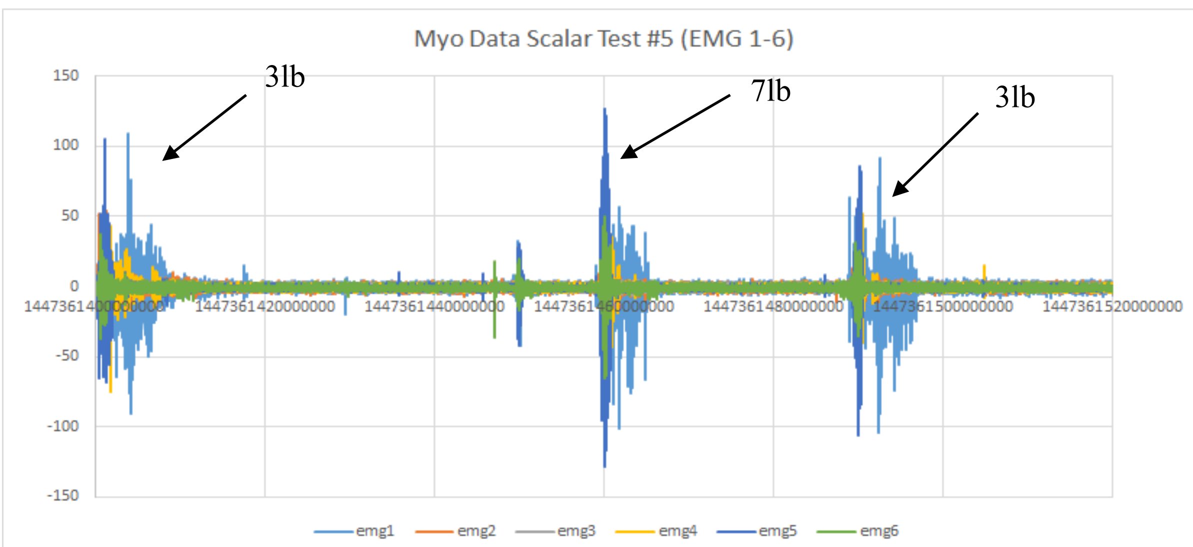

Figure 37: Data scaling test with a 3-7-3 lb. Gripmaster sequence, filtered to show six of the eight EMGs.

This test was performed again with two individuals consecutively, in order to investigate the validity of comparison between test participants. Figure 38 compares the results of the same test for two individuals. Although it may not be possible to correlate exact force values from one person to the next, this figure shows that comparison can be made qualitatively, as both plots are similar in structure.

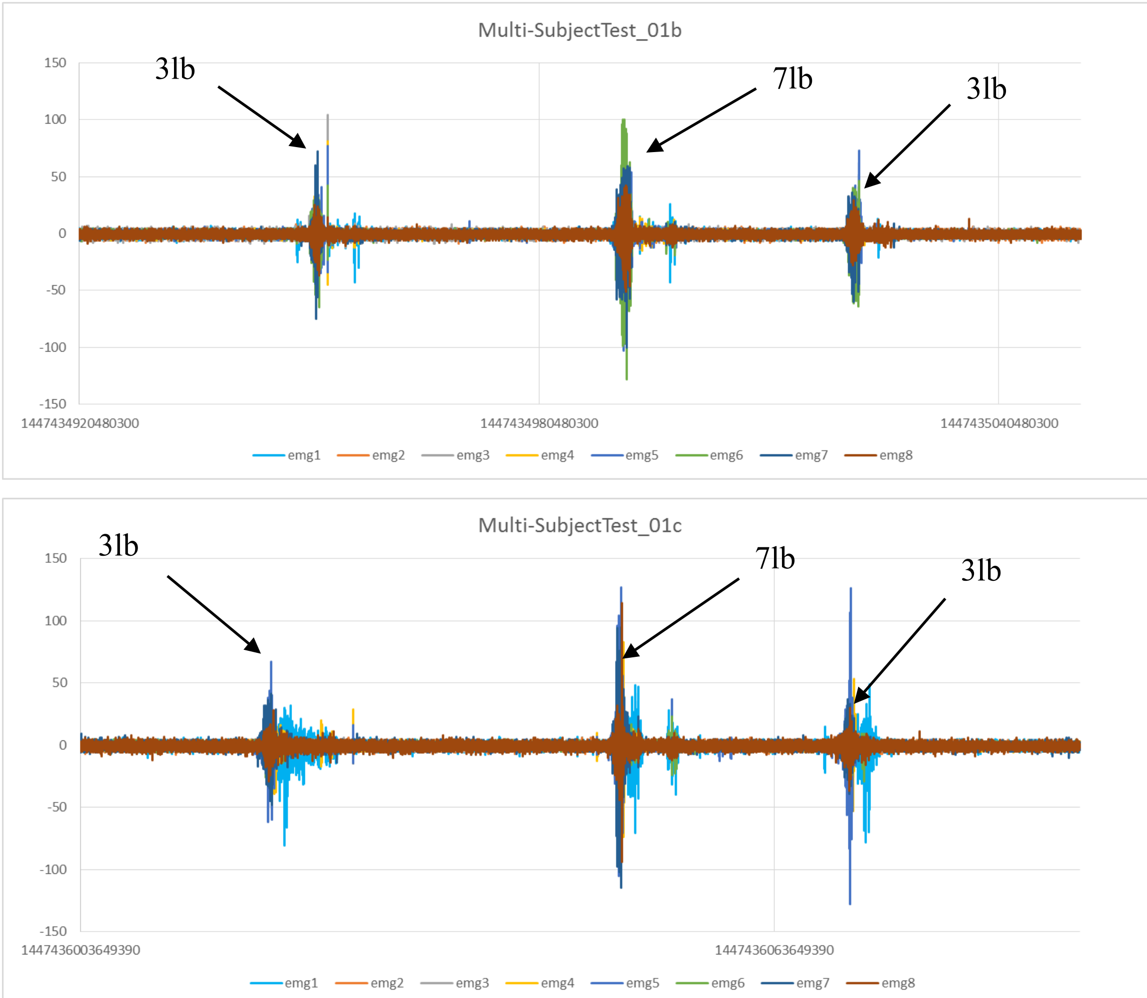

Figure 38: Scaling test with two participants

Electromyography sensors can be affected by a number of conditions such as air moisture, an individual's body mass index, and even metabolic rates. In one trial, the user experienced a muscle spasm that produced a noisy signal in one EMG sensor, while the other seven looked similar to the results in Figure 38.

Next, the Myo was tested in laboratory conditions while the user operated the instrumented cane. This was performed by an individual with good eyesight and no experience with cane navigation. The user was asked to give the cane a firm squeeze and tap on the ground at the beginning of the trial, in order to line up the EMG and vibration data. The squeeze also scales the initial range of the Myo outputs, reducing the noise level in the data. Figure 39 shows the Myo output from this test, while Figure 40 overlays that data with the output of the force gauge. There is good alignment between the moments of maximum muscular exertion and cane

impact on the ground. There also seems to be some alternation in the EMG channels that predominately make up the peak. This indicates that the cane is being swept back and forth.

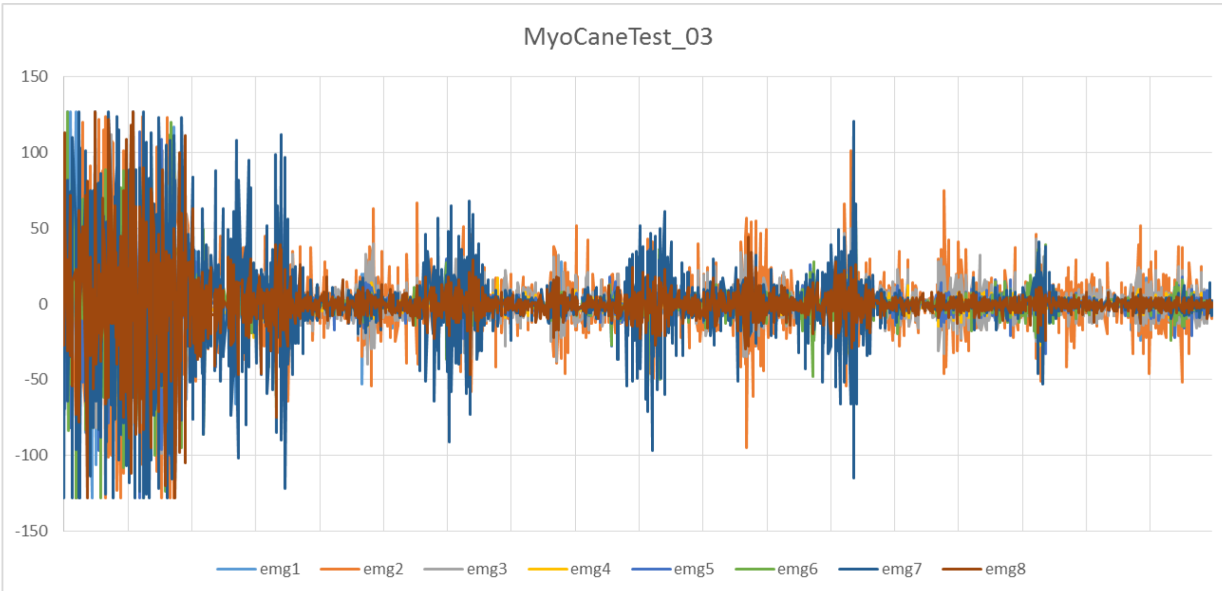

Figure 39: Initial cane testing with the Myo system (x-axis shows every half-second).

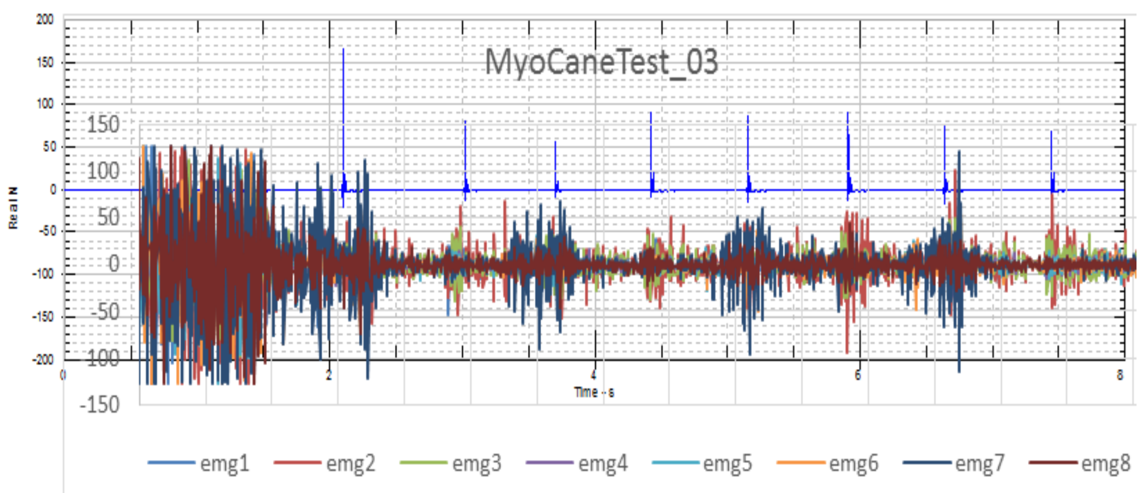

Figure 40: Overlay of Myo data with cane force gauge data.

6. Experimental Trials with Blind Participant

As a final confirmation of the effectiveness of the instrumented cane system, preliminary measurements were collected while the cane was being used by a blind participant. The trial took place at the WMU College of Health and Human Services, under the supervision of Drs. Kim and Wall Emerson, the industrial mentors for this project. This provided an opportunity to test the cane in an experimental environment, to verify that the results look reasonable, and to get some feedback from a blind user and from Drs. Kim and Wall Emerson.

6.1 Setup and Procedure

Four different conditions were tested: two methods of using the cane on two different walking surfaces. The first scanning method is the two-point touch technique. The cane is swung from side to side in front of the user, in an arc slightly wider than his shoulders. It is tapped once on the ground on each side of the arc. This has been the standard long cane technique for several decades[6]. The second scanning method is the constant contact technique, in which the cane tip is dragged across the ground, staying in contact with the surface.

The first walking surface tested was a raised wooden platform, covered with two layers of carpet. This platform was built to measure drop-off detection, and it is likely that this instrumented cane will be used there during ongoing experimentation. The second surface was concrete.

These four conditions were selected in order to give a wide range of excitation to the cane. It was expected that the hardness of the scanning surface and the force of the cane impact would each have a significant impact on the way in which the cane vibrated.

Prior to collecting data, the project background and aim was explained to the participant, along with an explanation of the instrumentation on the cane and Myo armband. He was then fitted with the vest and Myo armband, and given the instrumented cane. He was asked to keep the flat surface of the cane handle in the palm side of his hand to the best of his ability, as this kept the force gauge facing toward the ground. After fitting the armband, the participant was given the seven-pound Gripmaster to squeeze once, in order to scale the output measurements.

Smart Office Analyzer was set to record vibration data for 12 seconds after being manually triggered. The participant was asked to give the cane a firm tap on the ground at the

beginning of each trial, and to briefly squeeze the cane handle. This was to create a common feature in the vibration, muscular exertion, and optical tracking data in order to synchronize it, as these are each recorded separately.

Each condition was tested three times, in which the participant was asked to walk down a 30 foot long straight path with no obstacles. The 35 degree interchangeable cane tip was used. Figure 41 shows the participant using the instrumented cane on the carpeted platform.

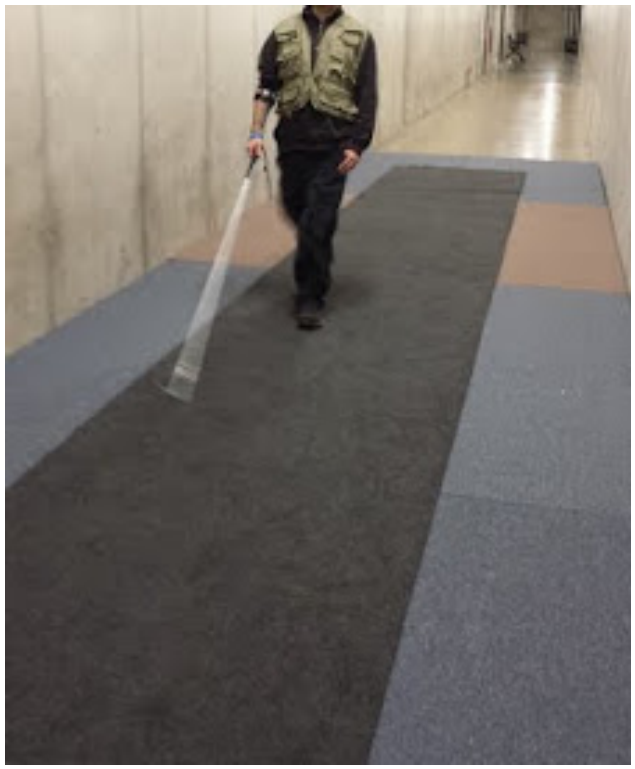

Figure 41: The participant with instrumented cane on the carpeted platform.

6.2 Results and Analysis

6.2.1 Vibration

Observations about the collected data show that the system is working correctly. For example, Figure 42(a) shows force measurement from trial 1 (two-touch on carpet) while Figure 42(b) shows force measurement from trial 4 (constant contact on carpet). Both trials show a clear tap at the beginning, and then look very different. The two-touch method shows a series of definite taps on the ground ranging in magnitude from 20 - 60 N, while the constant contact

method looks “noisier,” with no force values exceeding 10 N. This is the expected result, as the cane is excited with clear impacts in the first case and dragged across the ground in the second. Figure 43 shows the vibration response at the cane handle for each of these trials.

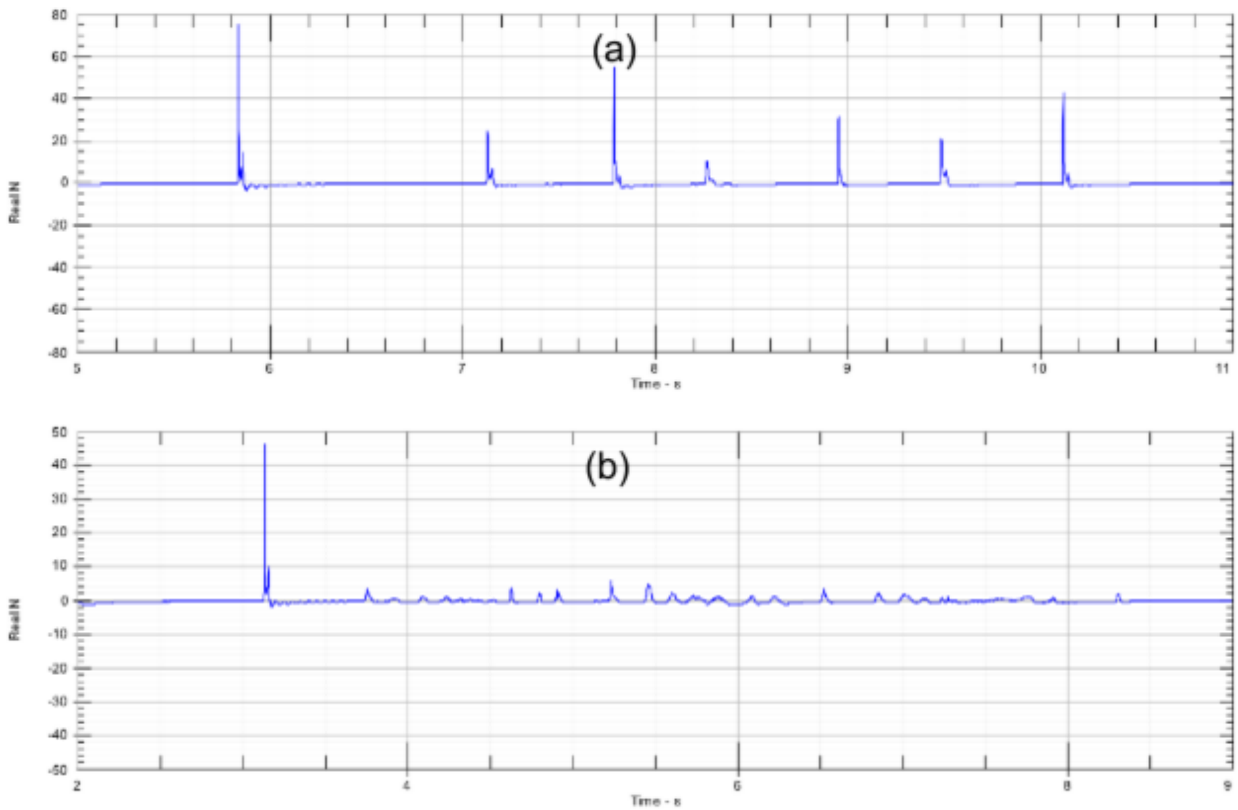

Figure 42: (a) Recorded force data from trial 1 (two-touch on carpet) and (b) trial 4 (constant contact on carpet).

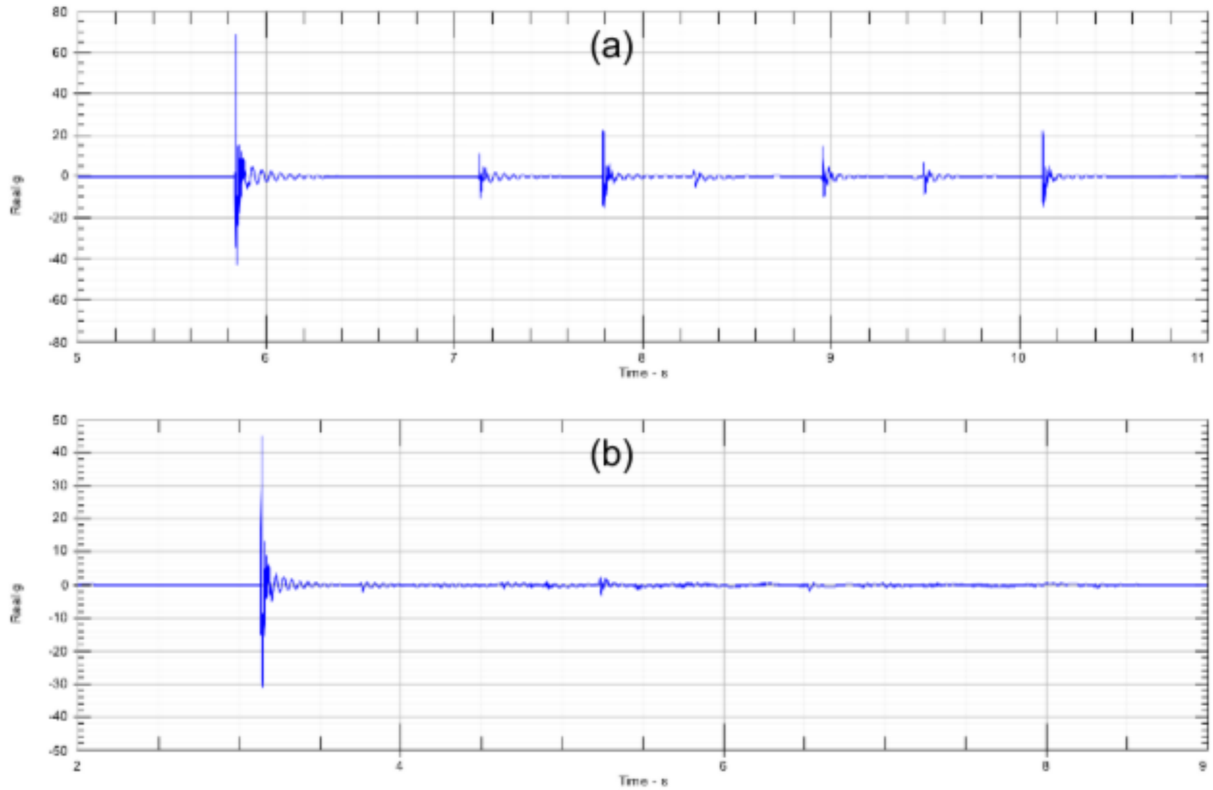

Figure 43: (a) Recorded acceleration data at the cane handle from trial 1 (two-touch on carpet) and (b) trial 4 (constant contact on carpet).

Smart Office can also be set to calculate the frequency content of an accelerometer. Figure 44 shows the known natural frequencies of the cane as determined in laboratory conditions (see Section 5.3), compared with the spectral content of an accelerometer during a constant contact trial on concrete. In both cases, resonance is observed near 20 Hz, at 70 - 75 Hz, and again at 140 - 150 Hz. The frequencies seem to be slightly lower in the participant trial.

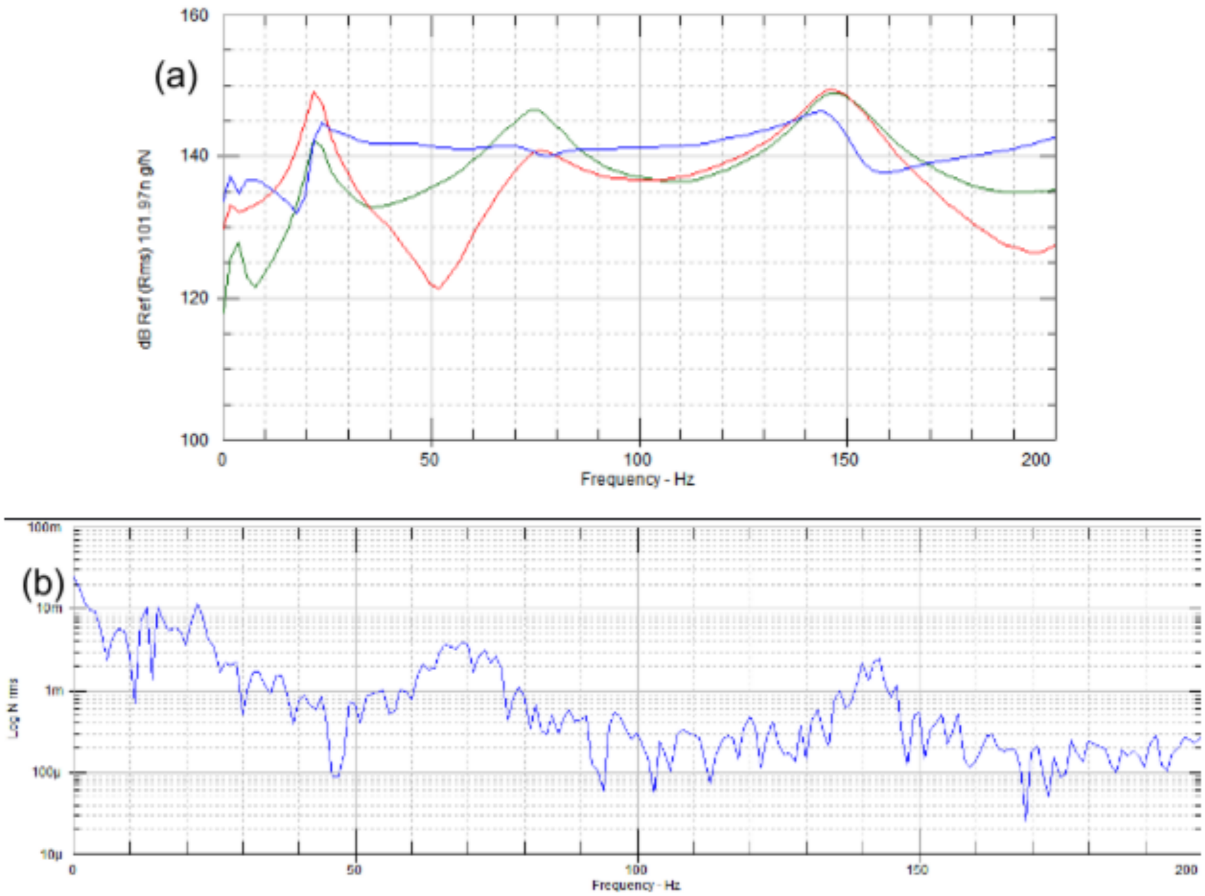

Figure 44: (a) Natural frequencies of the cane as determined in laboratory conditions; and (b) frequency content of an accelerometer during a constant contact trial on concrete

6.2.2 Muscle Exertion

Previous cane tests with the Myo armband suggested that the maximum muscle exertion occurred at the same time as the tap of the cane, and that each tap created a distinguishable spike in EMG activity. This seems to be the case with the blind participant as well, although muscle exertion is more comparable to the level seen during lateral and upward motion of the cane. Figure 45 compares EMG data (gray) with force gauge data (blue) for two trials. The two trials both show distinct peaks, which line up between the two sensors. Arrows show good points of comparison.

It is interesting to note that the EMG reading seems to "swell" before the cane tap, peak along with the tap, then "swell" back down. This repeats for each tap. This seems to indicate that the user is not actively bouncing the cane off of the ground during a tap. Rather, it is accelerated

with the forearm and swings across the body, then is decelerated by the forearm and is lightly touched to the ground at the extreme point of its arc.

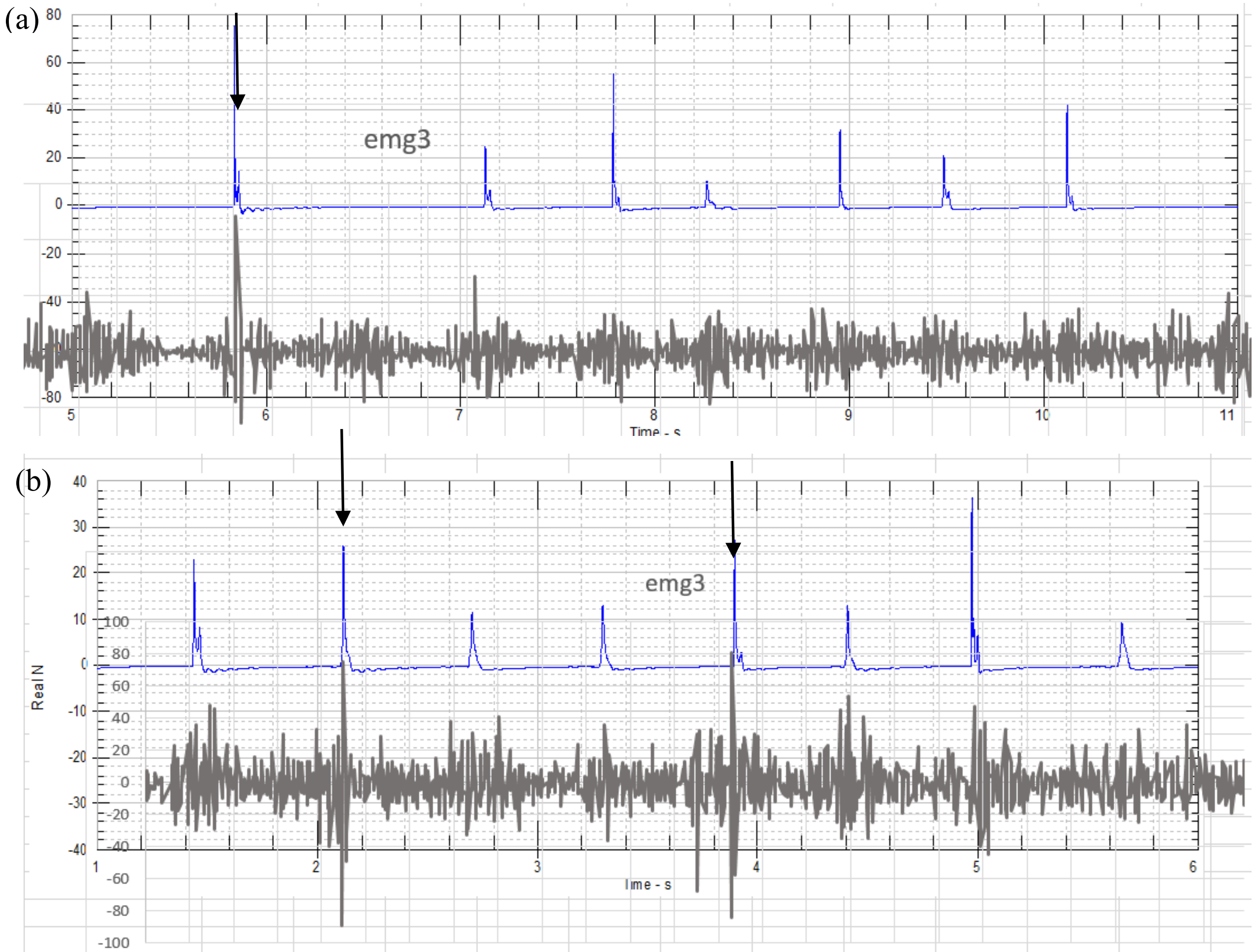

Figure 45: Myo armband (EMG 3) data and force gauge data plotted together with experienced cane user for (a) Trial 1 and (b) Trial 3

6.3 Assessment and Critique of the Experimental Trial

The outcome from the experimental trial was largely positive. There was a connectivity issue between the cDAQ-9191 Wi-Fi chassis and the laptop computer when the participant was first fitted with the system, which was fixed by manually re-connecting the chassis in the software. There were no other connectivity problems for the rest of the trial, in which the participant was up to 50 feet from the Wi-Fi router. The Myo armband also maintained good connection throughout the trial.

Two battery packs were brought to the trial, although each one was tested beforehand in the lab and was known to be able to power the cane in excess of 8 hours. Only one pack was used during data collection. Data was effectively collected wirelessly and the results correlate well with laboratory data. The vest makes the system ergonomically unobtrusive for the user.

The participant was enthusiastic about the project, and remarked that he thought that research into cane vibration and muscle exertion during use could positively affect him as a blind person. He said that the fishing vest was perfectly comfortable for the test, and that he felt that the Myo armband did not obstruct his cane use.

He did note that he did not like the cane itself and would not use it for general navigation, because of its weight. However, he recognized that this cane has added weight from instrumentation that is not typical, and thought that it was not too heavy for use in a research environment. This instrumented cane is made from aluminum, while the participant was used to using a lighter graphite cane. He also mentioned that he preferred a cane that was slightly longer.

The largest single addition of mass to the cane was from the force gauge, which is 22.7 grams. PCB Piezotronics does make a quartz force gauge with a suitable range and similar sensitivity with a mass of 10 grams (Model 201B03, shown in Figure 46). Further investigation would be required to determine whether this sensor would be suitable in this project. The 208B02 force gauge was selected for use in this project because of cost considerations, as the WMU Noise and Vibration Lab already owned it. The price of this 201B03 force gauge is $985.50.

Some mass could also be reduced by using a higher gauge wire to connect the force sensor to the data acquisition system, and by changing the cane material. The accelerometers weigh 0.5 grams each and were the least massive option available. They are not a feasible option for weight reduction.

Another objective of the data collection trial was to also collect data with the optical tracking system used by the department of Blindness and Low Vision Studies, in order to try to synchronize the collected data between the optical tracker, instrumented cane, and Myo armband. Unfortunately, the system had been sent to the manufacturer for repair and was not available on the day of data collection.

Figure 46: PCB Piezotronics quartz force ring, Model 201B03. This sensor has a 500 lb. range, 10mV/lb. sensitivity, and weighs only 10 g.

The Myo Band was chosen because of its low cost and built in ability to wirelessly transmit data through Bluetooth. This device outputs a number between 0 and 127, which is related to muscle exertion, although its exact correlation to muscle exertion is not well understood. Further investigation is required to directly relate this number to muscle excitation and grip force. It may be desirable to streamline Myo armband data analysis as well through programming since the software development package is now available from the developers.

7. Conclusions

The objective of this project was to incorporate vibration sensors into a blind cane in order to measure the vibration of the cane while it is in use for navigation. The cane was required to collect data without a tether cable connecting the participant to the acquisition system, and to be light and ergonomically unobtrusive to the user. Measurement of muscular exertion in the forearm while the cane is used was also required.

These objectives were met by installing three accelerometers down the length of an aluminum cane, along with a force gauge on the cane tip. These are connected to a National Instruments cDAQ-9191 wireless chassis that is powered by a small lithium-ion battery pack. The chassis and battery pack are carried by the cane user on his back, in the rear pocket of a fishing vest. The vest allows a full range of motion for the cane user, and keeps the transmitter out of the way. The transmitter sends the collected data to a computer station over a dedicated Wi-Fi network, where it is recorded using Smart Office Analyzer, a vibration analysis software. This system allows the cane user to move freely around an area while the vibration and impact force of the cane are recorded.

Muscle exertion was measured using a Myo armband. This is a consumer electronic product that allows a user to control a computer with hand and arm motions. It uses eight EMG sensors wrapped around the forearm to measure hand motion, and the raw output of these sensors can be accessed through an available developer pack. These sensors are used in this project to measure the exertion in the cane user's forearm. The armband transmits data wirelessly to a computer over a Bluetooth connection, where it is recorded using a script written by the developers.

The instrumented cane was validated in a laboratory environment, and then used to collect data with a blind participant as a proof of concept. Observations about the collected data indicate that the system is working correctly. Feedback from the blind user about the ergonomics of the system was positive.

Although there are some limitations in the data gathered by the Myo armband, qualitative comparisons allowed for a better understanding of the biomechanics required in the use of a cane for the blind. Data was captured both with a skilled cane user in the experimental trial, along with a new cane user in laboratory conditions.

8. Future Work

There are some possible areas of improvement for this instrumented cane system. For example, data collection is performed separately for the vibration sensors and Myo armband, and in the case that an optical tracking system is used; its results are recorded in separate software. This means it will typically take more than one researcher to gather data with a participant. One solution would be to write a script to trigger data acquisition on all three systems simultaneously, or to explore the possibility of logging all of the data in single software. LabVIEW may be considered, although it may require substantial code writing and troubleshooting.

Once the data is collected, it must be synchronized for analysis. A MATLAB code could be written to compile all of the results together. This way, a movement in cane position can be correlated with the simultaneous vibration of the cane, and compared to the forearm muscular exertion at that instant.

Perhaps the more exciting area of future work for this project is the research potential of this tool. This instrumented cane will allow researchers to ask questions about the dynamics action of the cane, and how this impacts the ability of the user to distinguish obstacles or drop-offs in front of him. For example, refer to Figure 43(a), which shows cane tip impact force during a two-touch trial.

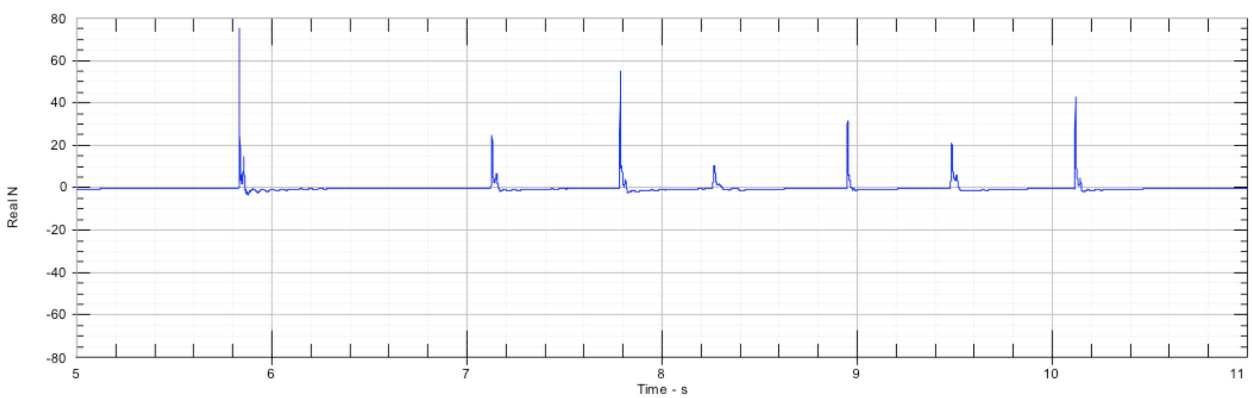

Figure 42: (a) Recorded force data from trial 1 (two-touch on carpet).

In this trial, the participant gave a deliberate tap at the beginning, then walked normally down the length of the runway. Note that the magnitude of the tap forces alternate between higher and lower values. This means that the blind user has a tendency to tap the cane harder on one side of the swing than he does on the other. One might ask if his swing is not symmetrical in

each direction. Furthermore, does the participant have higher discrimination to obstacles or drop-offs on one side than the other? And more broadly, how does the speed of the cane tip and the magnitude of the force on the ground affect the user's ability to detect a drop-off? Likewise, does it affect his ability to notice a change in the walking surface?

Figure 47 shows the cane tip force and handle vibration from trial 8, using the two-touch technique on a concrete surface. The deliberate tap at the start of the trial was very strong at around 360 N, while all other taps were less than about 80 N, a factor of four. However, when the magnitude of the handle acceleration is compared between the initial tap and the next three, they are found to be similar in magnitude. This suggests that for this cane material, the excitation force is not linearly related to the vibration felt in the handle. It may be the case that a soft tap is all that is required for navigation, because it produces a similar response to a harder tap, while requiring less muscle exertion by the user.

In the results from the Myo, it was difficult to determine where the cane touched the ground for the blind user, although it was clear when tested on people who were not experienced cane users. This suggests that the blind participant has a softer grip on the cane, so that its impact on the ground is not causing his forearm muscles to tense, as it would with somebody holding the cane more firmly. It could also be that with his experience in using a cane, he requires less muscle exertion to swing the cane. The relation between grip intensity and obstacle detection may be an area of future interest.

It is not uncommon for an experienced cane user to be able to tell the difference between different walking surfaces by feeling them with the cane. For example, a concrete sidewalk may feel different than an asphalt parking lot, which feels different than grass, packed dirt, or a smooth tile floor. This cane could be used in the future to study the differences in vibration as contact is made with each of these surfaces, in order to describe the way in which a user understands his walking surface.

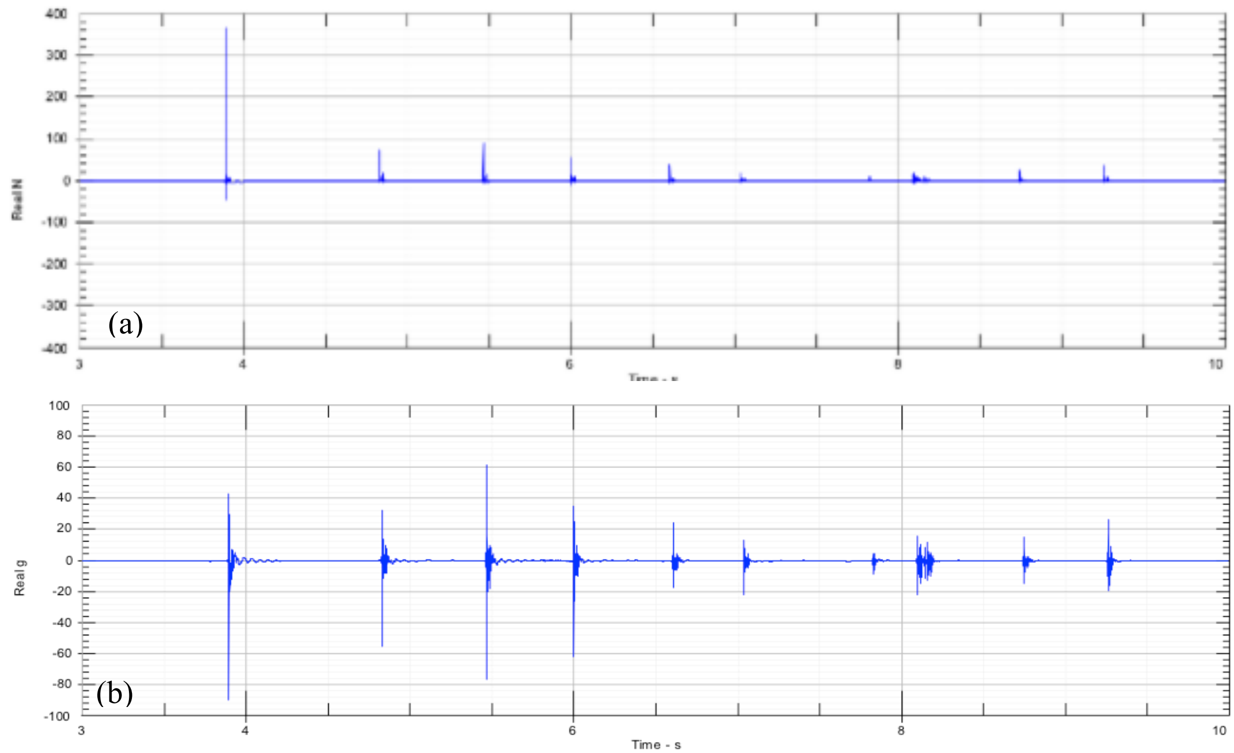

Figure 47: (a) Cane tip force from trial 8 (two-touch on concrete), and (b) acceleration of the cane handle from the same trial.

Finally, although this project uses an aluminum cane, the accelerometers and force gauge could easily be mounted onto any other cane of interest. The interchangeable mounting tips for the force gauge are of a standard inner diameter, the accelerometers are mounted with super glue, and cable management is done with electrical tape. Canes with different vibration characteristics could be tested under the same conditions for drop-off detection, in order to build a correlation between vibration parameters and cane effectiveness. Identifying the important factors for navigation, which may include certain resonant frequencies, damping level, or stiffness, can lead to the development of a cane that is optimized for use by the blind. This will increase the mobility and safety of those who rely on a cane for navigation.

9. References

Information about experimental setup and results from previous testing was gathered from conversation with the laboratory technician responsible for the testing.

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6. Kim, D. S., & Emerson, R. W. (2009). Drop-off Detection with the Long Cane: Effects of Different Cane Techniques on Performance. *J Vis Impair Blind, 103(9)*, 519-530.
7. Kim, Wall Emerson, Naghshineh and Auer "Drop-off detection with the long cane: Effect of cane shaft weight and rigidity on performance," *submitted* to the Ergonomics Journal (2015).

Appendices

Appendix A: Bill of Materials

*Denotes a component that was purchased for this project. Other components were previously owned by WMU or project members.

Part Number	Part Name	Description	Vendor	Qty	Cost
781497-01	NI cDAQ-9191	Wireless Chassis	National Instruments	1	$388*
763000-01	Power Cord, AC, U.S., 120 VAC, 2.3 meters	Power Cord	National Instruments	1	$9*
780702-01	2-Position Screw Terminal Kit for Power Supply Connection	Power Pin Connector for NI cDAQ-9191	National Instruments	4	$9*
779680-01	NI 9234	±5 V, IEPE and AC/DC Analog Input, 51.2 kS/s/ch, 4 Ch Module	National Instruments	1	$1823
352C22	Uniaxial Accelerometer	Miniature Piezoelectric Accelerometer	PCB Piezotronics	3	$510
208B02	Force Gauge	General Purpose Quartz Force Sensor	PCB Piezotronics	1	$415
146	WCIB Nylon Pencil Tip	White Cane Tip	sightconnection.com	5	$3*
N/A	Grip Strength Springs	3lb and 7lb	Amazon.com	2	$12*
WRT120N	Linksys Router	Wireless Router	Newegg.com	1	$115

Appendix A: Bill of Materials Continued

N/A	Fishing Vest	Large external pockets and size	Gander Mountain	1	$60*
N/A	Talentcell Rechargeable 6000mAh Li-Ion Battery Pack w/ Charger	12V Battery Pack	Amazon.com	2	$30*
N/A	Myo Armband	EMG Sensor	Thalmic Labs	1	$200*

Appendix B: NI cDAQ-9191 Wireless Chassis Quick Start

cDAQ Wireless Chassis

NI cDAQ-9191

Quick Start
Démarrage rapide
Erste Schritte
クイックスタート
시작하기
快速入门

Caution Before installing your device, read all product documentation to ensure compliance with safety, EMC, and environmental regulations.

Attention Avant d'installer votre périphérique, lisez toute la documentation se rapportant au produit pour vous assurer du respect des règles concernant la sécurité, la CEM et l'environnement.

Achtung Lesen Sie vor dem Anschließen des Geräts die Produktdokumentation, um sich über alle einzuhaltenden Sicherheitsvorschriften, EMV-Vorschriften und Umweltrichtlinien zu informieren.

注意 デバイスを取り付ける前に、すべての製品ドキュメントをお読みになり、安全、EMC、環境規制を遵守してください。

주의 디바이스를 설치하기 전에 모든 제품 관련 문서를 읽고 안전, EMC, 환경 규정을 준수하는지 확인하십시오.

警告 安装设备之前，请阅读所有产品文档，确保符合安全、EMC以及环境法规。

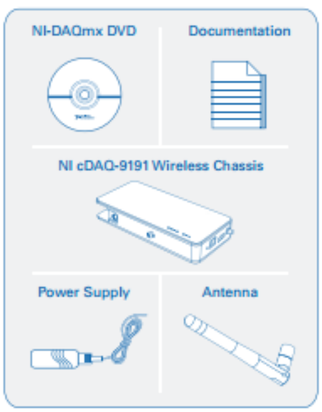
ni.com/gettingstarted

Printed in Hungary.

325667A-01 Jul11

NATIONAL INSTRUMENTS

Contents | Contenu | Inhalt
内容 | 내용 | 内容



Useful Links | Liens utiles | Nützliche Links
役に立つリンク | 유용한 링크 | 相关链接

Getting Started
ni.com/gettingstarted

NI cDAQ-9191 Documentation
ni.com/manuals ➪ 9191

Pinouts
In MAX, right-click module name

Examples
ni.com/info ➪ daqmxexp

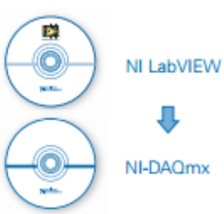
Software
ni.com/downloads

Demonstrations
ni.com/daq/videos

Services and Support
ni.com/services

Start Here | Commencez ici | Hier beginnen
開始 | 시작 | 入门

1



First, install application development software (if applicable). Then install NI-DAQmx driver software.

Commencez par installer le logiciel de développement d'applications (le cas échéant). Ensuite, installez le driver NI-DAQmx.

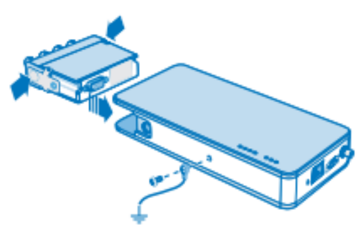
Installieren Sie zuerst die Entwicklungsumgebung (sofern zutreffend) und anschließend den NI-DAQmx-Treiber.

アプリケーション開発ソフトウェアをインストールします(必要な場合)。続いて、NI-DAQmxドライバソフトウェアをインストールします。

필요한 경우 우선 어플리케이션 개발 소프트웨어를 설치합니다. 그 다음 NI-DAQmx 드라이버 소프트웨어를 설치합니다.

先安装应用程序开发软件（如有需要），然后安装NI-DAQmx驱动软件。

2



Connect the cDAQ chassis to earth ground. Next, insert the module. Pinouts are available in the module documentation.

Connectez le châssis cDAQ à la terre, puis insérez le module. Les informations de brochage sont disponibles dans la documentation du module.

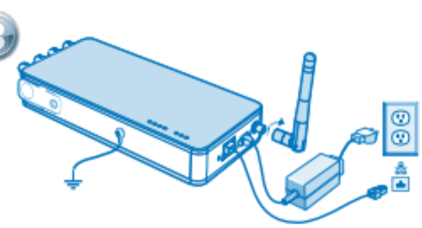
Erden Sie das cDAQ-Chassis über den entsprechenden Anschluss. Stecken Sie dann das Modul ein. Die Pinbelegung finden Sie in der Modulbeschreibung.

cDAQシャーシをアースに接続します。次に、モジュールを挿入します。ピン配列はモジュールのドキュメントで参照できます。

cDAQ 섀시를 접지에 연결합니다. 그 후, 모듈을 삽입합니다. 핀출력 다이어그램은 모듈 문서에서 찾을 수 있습니다.

将cDAQ机箱接地，然后插入模块。引脚信息见模块文档。

3



Connect the chassis to the PC network port or a network connection on the same subnet as the PC. Connect the antenna and power supply.

Connectez le châssis au port réseau du PC ou à une connexion réseau sur le même sous-réseau que le PC. Connectez l'antenne et le bloc d'alimentation.

Verbinden Sie das Chassis mit dem Netzwerkanschluss des PCs oder mit dem Subnetz, in dem sich der PC befindet. Schließen Sie die Stromversorgung und die Antenne an.

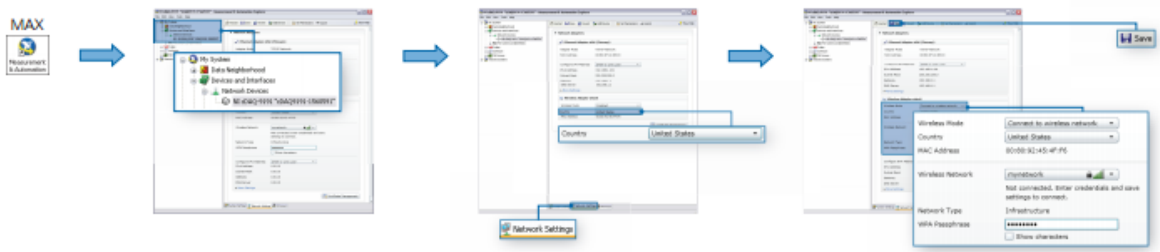
シャーシをPCネットワークポート、またはPCと同じサブネット上のネットワーク接続に接続します。アンテナと電源を接続します。

섀시를 PC 네트워크 포트 또는 PC와 같은 서브넷에 있는 네트워크에 연결합니다. 안테나와 전원 공급 장치를 연결합니다.

连接机箱至计算机的网络端口或与计算机位于同一子网内的网络连接。连接天线和电源。

Appendix B: NI cDAQ-9191 Wireless Chassis Quick Start Continued

4



Establishing a network connection may take several seconds. Open MAX. Expand **Network Devices** and select the chassis. If your device is not listed, refer to the *Measurement & Automation Explorer Help for NI-DAQmx*. On the Network Settings tab, select your country. For Wireless Mode, select **Connect to wireless network**. For Wireless Network, select a network from the scanned list or select **Other Network** and enter settings. Click **Save**.

L'établissement d'une connexion réseau peut prendre plusieurs secondes. Ouvrez MAX. Développez **Périphériques réseau** et sélectionnez le châssis. Si votre périphérique ne figure pas dans la liste, reportez-vous à l'*Aide Measurement & Automation Explorer pour NI-DAQmx*. Sur l'onglet Paramètres réseau, sélectionnez votre pays. Pour le mode sans fil, sélectionnez **Se connecter à un réseau sans fil**. Pour obtenir le Réseau sans fil, sélectionnez un réseau dans la liste de balayage ou sélectionnez **Autre réseau** et entrez les paramètres. Cliquez sur **Enregistrer**.

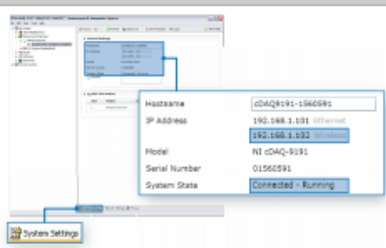
Das Herstellen einer Verbindung kann einen Moment dauern. Öffnen Sie MAX. Erweitern Sie die Kategorie **Netzwerkgeräte** und klicken Sie das Chassis an. Wenn das Gerät nicht angezeigt wird, lesen Sie bitte die Hilfe zum Measurement & Automation Explorer für NI-DAQmx. Wählen Sie auf der Registerkarte "Netzwerkeinstellungen" Ihr Land aus. Klicken Sie unter "Drahtlose Verbindung" auf **Mit drahtlosem Netzwerk verbinden.** Wählen Sie unter "Drahtloses Netzwerk" ein Netzwerk aus oder klicken Sie auf **Anderes Netzwerk** und füllen Sie die erforderlichen Felder aus. Klicken Sie auf **Speichern**.

ネットワーク接続が確立するには数秒かかります。MAXを起動し、**ネットワークデバイス**を展開してシャーシを選択します。デバイスが表示されていない場合は、『*NI-DAQmx用Measurement & Automation Explorerヘルプ*』を参照してください。ネットワーク設定タブで国名を選択します。ワイヤレスモードでは、**ワイヤレスネットワークに接続**を選択します。ワイヤレスネットワークでは、スキャンしたリストからネットワークを選択するか、**他のネットワーク**を選択して設定を入力します。**保存**をクリックします。

네트워크가 연결되는데 몇 초 이상 소요될 수 있습니다. MAX를 열고 **네트워크 디바이스**를 확장한 후 섀시를 선택합니다. 디바이스 리스트에 디바이스가 없는 경우, *NI-DAQmx*를 위한 *Measurement & Automation Explorer* 도움말을 참조하십시오. 네트워크 셋팅 탭에서 국가를 선택합니다. 무선 모드로 사용하려면 **무선 네트워크에 연결**을 선택합니다. 무선으로 연결하려면 스캔 리스트에서 네트워크를 선택하거나 **다른 네트워크**를 선택하고 셋팅을 입력합니다. **저장**을 클릭합니다.

建立网络连接可能需要一段时间。打开MAX，展开**网络设备**并选择机箱。若用户设备未被列出，请查看*NI-DAQmx*的*MAX*帮助。在网络设置选项卡上选择所在国家。无线模式下，选择**连接至无线网络**。从扫描列表中选择一个无线网络或选择**其他网络**并输入设置，单击**保存**。

5



On the System Settings tab, verify that the chassis has a wireless IP address and the System State reads ***Connected - Running***.

Sur l'onglet Paramètres système, vérifiez que le châssis a une adresse IP sans fil et que l'État du système indique ***Connecté - Démarré***.

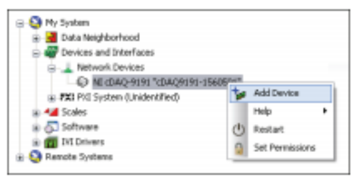
Prüfen Sie auf der Registerkarte "Systemeinstellungen", ob das Chassis eine Drahtlos-IP-Adresse hat und der Systemstatus ***Verbunden - Wird ausgeführt*** lautet.

システム設定タブで、シャーシにワイヤレスIPアドレスが割り当てられ、システム状態が***接続－実行中***であることを確認します。

시스템 셋팅 탭에서 섀시가 무선 IP 주소를 가지고 있고 시스템 상태가 ***연결됨 – 실행 중***을 표시하는지 확인합니다.

在系统设置选项卡上，验证机箱是否具有无线IP地址，系统状态为***已连接—运行***。

6



Right-click the chassis and select **Add Device**.

Cliquez avec le bouton droit sur le châssis et sélectionnez **Ajouter le périphérique**.

Klicken Sie mit der rechten Maustaste auf den Chassis-Namen und wählen Sie **Gerät hinzufügen**.

シャーシを右クリックして、**デバイスを追加**を選択します。

섀시에서 마우스 오른쪽 버튼을 클릭하고 **디바이스 추가**를 선택합니다.

右键单击机箱并选择**添加设备**。

7

Wait for the icon to turn from white to blue.

Attendez que l'icône passe du blanc au bleu.

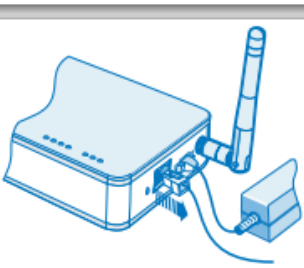
Warten Sie, bis sich das weiße Symbol in ein blaues geändert hat.

アイコンが白から青に変わるのを待ちます。

아이콘이 흰색에서 파란색으로 바뀔 때까지 기다립니다.

等待按钮由白色变为蓝色。

8



Disconnect the Ethernet cable from the chassis. **Note:** Your PC must be connected to a network that can access the chassis at its wireless IP.

Déconnectez le câble Ethernet du châssis. **Remarque** : Votre PC doit être connecté à un réseau pouvant accéder au châssis à partir de son adresse IP.

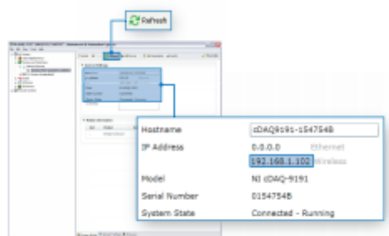
Trennen Sie das Ethernet-Kabel vom Chassis. **Hinweis:** Ihr PC muss mit einem Netzwerk verbunden sein, in dem das Chassis über seine Drahtlos-IP erreichbar ist.

シャーシからイーサネットケーブルの接続を解除します。**メモ:** PCをワイヤレスIPでシャーシにアクセス可能なネットワークに接続している必要があります。

섀시에서 이더넷 케이블의 연결을 해제합니다. **노트:** 섀시의 무선 IP에 접근할 수 있는 네트워크에 PC가 연결되어 있어야 합니다.

断开机箱的以太网连接。**注意：**计算机必须连接至能够访问机箱无线IP地址的网络。

9



Click **Refresh**. Verify that the Ethernet IP address is 0.0.0.0 and the wireless IP address remains unchanged from Step 5.

Cliquez sur **Actualiser**. Vérifiez que l'adresse IP Ethernet est 0.0.0.0 et que l'adresse IP sans fil ne diffère pas de celle de l'étape 5.

Klicken Sie auf **Aktualisieren.** Prüfen Sie, ob die Ethernet-IP-Adresse 0.0.0.0 lautet und die Drahtlos-IP-Adresse sich gegenüber Schritt 5 nicht geändert hat.

更新をクリックします。イーサネットIPアドレスが0.0.0.0で、ワイヤレスIPアドレスが手順5から変わっていないことを確認します。

새로 고침을 클릭합니다. 이더넷 IP 주소가 0.0.0.0이고 무선 IP 주소가 이전 5단계의 주소와 같은지 확인합니다.

单击**刷新**。验证以太网IP地址是否为0.0.0.0，且无线IP地址从步骤5开始一直保持不变。

10

Take your first measurement in MAX. Right-click the module and select **Test Panels**. Click **Start** to verify measurement functionality.

Prenez votre première mesure dans MAX. Faites un clic droit sur le module et sélectionnez **Panneaux de test**. Cliquez sur **Démarrer** pour vérifier la fonctionnalité de la mesure.

Führen Sie die erste Messung im MAX durch. Klicken Sie das Modul mit der rechten Maustaste an und wählen Sie **Testpanels**. Klicken Sie zum Prüfen des Moduls auf **Start**.

MAXで最初の測定を実行します。モジュールを右クリックして**テストパネル**を選択します。**開始**をクリックして、測定機能を確認します。

MAX에서 먼저 측정을 해봅니다. 해당 모듈에서 마우스 오른쪽 버튼을 클릭하고 **테스트 패널**을 선택합니다. **시작**을 클릭하여 측정 기능을 확인합니다.

在MAX中进行初次测量。右键单击模块并选择**测试面板**，单击**开始**，校验测量功能。

Appendix C: ABET Questionnaires

<u>Assessment of Program Outcome # 5</u>

<u>ME 4800</u>

The MAE faculty members have identified "**<u>An ability to design a system, component, or process to meet desired needs within realistic constrains such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability"</u>** as one of the student outcomes for both mechanical and aeronautical engineering programs. As part of your design project, we ask you to answer the following questions. You are required to submit the completed form with your final report in ME 4800. In your final report, please include the page references in response to each question below.

Evaluation of student outcome "**<u>An ability to design a system, component, or process to meet desired needs within realistic constrains such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability"</u>**

1. This project involved the design of a: **system / component / process**

   Description:

This project involved the design of an instrumented cane for the blind. The instrumentation of the cane measures force at the tip of the cane and vibration throughout the cane. The instrumented cane was designed to be wireless. A system for muscle exertion measurements was also selected. See page 10 for more information on the design of this system.

2. The **need:**

Researchers are interested in studying the correlation between cane vibration characteristics and the detection of obstacles or drop-offs. A wireless, instrumented cane crucial in carrying out this research. The resulting research of this cane has the potential to improve the quality of and safety of visually impaired people worldwide. The need of this project is outlined further on page 7 of this report.

3. The **constraints:** (Explain and justify any constraint that was relevant to the project. At least 3 constrains mores be addressed.)

Economic:

Although hard budget numbers were not in place, the cost of components was a primary deciding factor in the design of the instrumented cane. The cost of every component was taken in to consideration. Many components were chose because they were already owned by Western Michigan University. Also, the Myo armband was chosen because of its low cost. Cost comparisons of components can be found on page 19 of this report.

Ergonomic:

Deliberate care was taken in this project to ensure that the end result would be unobtrusive, comfortable, and user-friendly. Users of the cane must be able to use the cane as naturally as possible. Excess weight, wires, or size would prevent the user's ability to use the cane in a normal manner; and therefore make the resulting measurements and research less valid. Constraints and considerations may be seen in pages 6-9 and 10-22 of the report.

Lightweight and Wireless:

It was imperative that this project be made lightweight and wireless. The user of the cane must be un-tethered in order to effectively gather data. Care was also taken to be sure that the system could be used outside, allowing more possibilities in the future research applications of the cane. The sensors chosen needed to be lightweight not only for ergonomic reasons, but also to ensure that the vibration characteristics of the cane remained true. Constraints and considerations may be seen in pages 6-9 and 10-22 of the report.

4. Is there a potential for a new patent in your design? Explain and compare with related patents.

To our knowledge, an instrumented cane of this kind has never been made. It is possible to patent this design, but this project will be used for research and not to make money; therefore a patent would be extraneous. Instrumented canes aimed to directly help visually impaired people have been patented. For example, the Typhlocane was patented in 1970. This cane is equipped with lasers, photo-sensors, and vibrators to warn the user of obstacles and drop-offs. Another example is US patent 4280204 A. This cane implements an ultrasonic sensor and an earpiece to alert the user obstacles above the ground such as a low lying tree branch. Additional examples and explanations may be seen in pages 4-5 of this report.

Assessment of Program Outcome #9

ME 4800

The MAE faculty members have identified "**A knowledge of contemporary issues**" as one of the program outcomes for both mechanical and aeronautical engineering programs. **Contemporary issues are any issues that you hear on the news related to new and old products and their safety, new innovations, technologies, standards and regulations in general.** As you develop your proposal for your senior design project, we ask you to start answering the following questions. These questions will guide you in the development of ideas you need to include in your proposal and final project reports. You are required to submit the completed form with your final proposal in ME 4790 and again with your final report in ME 4800. In your proposal and report, please include page references in response to each question below.

Evaluation of program outcome "**A knowledge of contemporary issues**"

1. Why is this project needed now?

Little vibration and force data has been gathered to find the ideal designs and materials for canes for the blind. Doctors Kim and Wall are performing ongoing studies for visually impaired individuals and have recognized the need for this data. An instrumented cane for the blind will provide the ability to wirelessly acquire vibration and force data. Their goal is to correlate this data to factors such as drop off detection, in order to determine which properties grant optimal cane materials and designs. The need of this project is outlined further on page 7 of this report.

2. Describe any new technologies and recent innovations utilized to complete this project.

N/A

3. If this project is done for a company—how will it expand their potential markets?

N/A

---how will it improve satisfaction of the company's existing customers?

---identify the competitors for this kind of a product, compare the proposed design with the company's competitors' products.

4. How did you address any safety and/or legal issues pertaining to this project (e.g., OSHA, EPA, Human Factors, etc.)?

We do not foresee any safety or legal issues. Care has been taken with the use of research results, some of which have not been published.

5. Are there any new standards or regulations on the horizon that could impact the development of this project?

No.

6. Is there a potential for a new patent in your design? Please document related patents.

There are several existing patents for instrumented systems in the sporting goods industry. One uses an array of accelerometers and gyroscopes attached to a fly-fishing rod to help teach technique to new fisherman. Another patent uses pressure sensors along the fingers and palms in an attempt to quantify the feel of a good swing with a golf club. Our system is being developed for academic research and we do not foresee a commercial market for it, so at this time we do not expect to patent it. Additional examples and explanations may be seen in pages 4-5 of this report.

Assessment of Program Outcome #12

ME 4800

The MAE faculty members have identified "**An understanding of the impact of the engineering solutions in a global, environmental and societal context**" as one of the program outcomes for both mechanical and aeronautical engineering programs. As you develop your proposal for your senior design project, we ask you to start answering the following questions. These questions will guide you in the development of ideas you need to include in your proposal and final project reports. You are required to submit the completed form with your final proposal in ME 4790 and again with your final report in ME 4800. In your proposal and report, please include page references in response to each question below.

Evaluation of program outcome "**An understanding of the impact of the engineering solutions in a global, environmental and societal context**"

1. Is this project useful outside of the United States? Describe why it is or is not-provide details.

Yes, this project is useful in any place where research for the blind and visually impaired is conducted.

2. Does your project comply with US and/or international standards or regulations? Which standards are applicable?

N/A

3. Is this project restricted in its application to specific markets or communities? To which markets or communities?

This product is restricted to blindness and low vision research.

4. If the answer to any of the following is positive, explain how and, where relevant, what were your actions to address the issues?
   a. Air quality?
      N/A
   b. Water quality?
      N/A
   c. Food?

N/A

d. Noise level?

N/A

5. Does this project impact:

a. Human health?

This project has the potential to improve human health by decreasing the chances of injuries for blind and low vision people. The data may lead to improvements in cane design, along with the way canes are used.

b. Wildlife?

N/A

c. Vegetation?

N/A

Does this project improve:

a. Human interaction?

N/A

b. Well-being?

An instrumented blind cane has the potential to improve the wellbeing of the blind and low vision population. Doctors Kim and Wall hope to correlate the data gathered from the project to safety factors such as drop off detection. The end goal is to improve cane materials and designs, in turn improving the wellbeing of blind and low vision people. Improvements may also be made in the way these canes are used.

c. Safety?

By gathering vibration and force data from canes for the blind, safety for the blind and low vision population will likely improve. Cane vibration and force data may be related to the users' ability to detect objects and drop offs. Undetected objects and drop offs can lead to injuries. This data may give way to improvements in cane materials and designs, as well as the way these canes are used; ultimately improving the safety of blind and low vision people.

d. Others?

N/A

Assessment of Program Outcome #13

ME 4800

The MAE faculty members have identified "**A recognition of the need for, and ability to engage in life-long learning**" as one of the program outcomes for both mechanical and aeronautical engineering programs. As you develop your senior design project, we ask you to start answering the following questions. These questions will guide you in the development of ideas you need to include in your final project reports. You are required to submit the completed form with your final report. Please include the page numbers of the report that addresses the answers to the following questions.

Your responses will be used in the Evaluation of student outcome "**A recognition of the need for, and ability to engage in life-long learning**"

A well-organized team brings necessary backgrounds and talents together that are needed to successfully execute the design process. Each team member plays an important role on the design team. Individual members must be prepared to gain any additional skills necessary, and improve existing skills during project execution. Your response to the questions below will be evaluated for our ability to convey the need for lifelong learning and your ability to be creative in recognizing the need and acquiring the requisite knowledge.

For each team member:

1. List the skills you needed to successfully execute your responsibilities on the project as outlined in ME 4790.

Aaron Dean: Success with this project required an ability to learn and solve problems independently, good communication with team members, suppliers and mentors, and foresight about potential obstacles and challenges.

James Bowman: To be successful, this project required great diligence. Team members had to be able to work in their free time with each other and individually to assure deadlines are met. Communication between team members was vital.

Nathan Wortman: This project required both time and effort in order to be sure the group has considered all aspect of the challenges presented. Communication between members was our greatest tool while we found innovative solutions for finding the needed information.

2. List how you gained the requisite skill, or enhanced you existing skill, to the benefit of your design team and the project.

Aaron Dean: I gained the skills needed through personal research, careful planning of upcoming tasks, and through the help of our faculty and industry mentors.

James Bowman: I did my own research online, and sought advice from Dr. Naghshineh and National Instruments. Dr. Naghshineh was great at managing our project and ensuring our success. We all tried to be available for necessary group work as much as possible and worked individually as well.

Nathan Wortman: I worked closely with the mentors we had with this project and reached out to other professors at WMU when needed. This was augmented with personal research based on the systems we decided to implement.

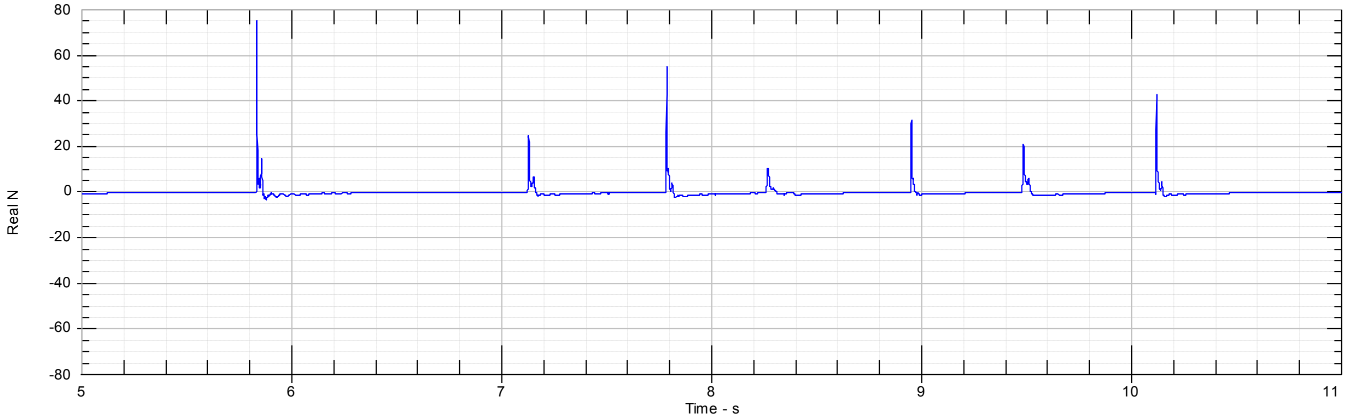
Appendix D: Time record data with blind participant

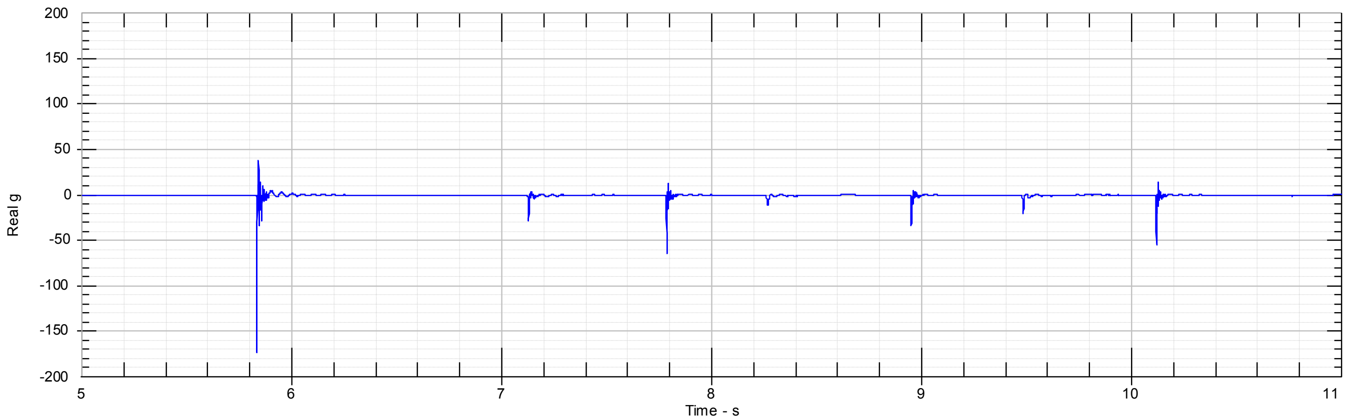
The following pages show all of the time record data collected with the instrumented cane and blind participant. There were 12 trials performed, with the following conditions:

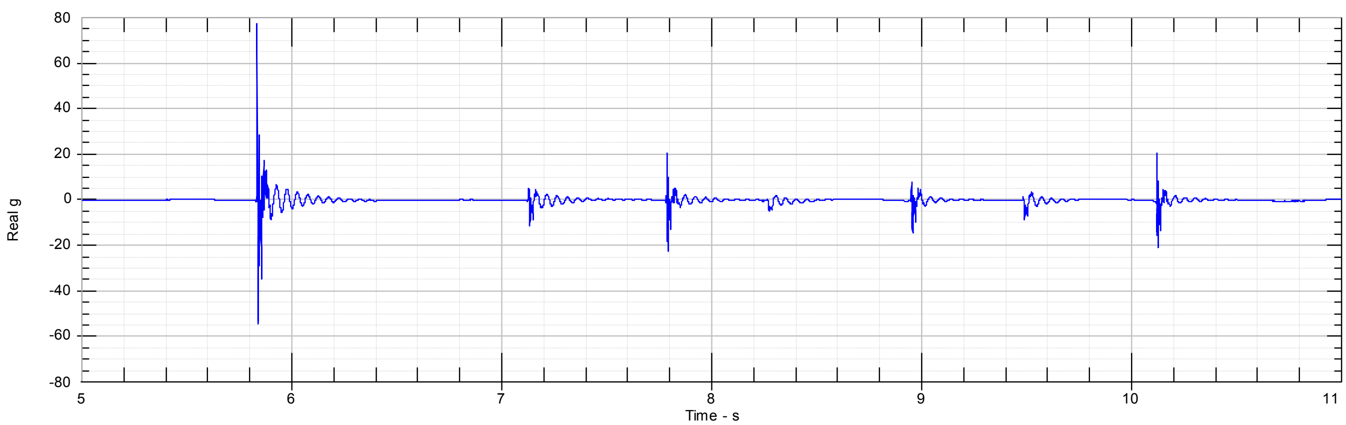
Trial 1 - Trial 3	Two-touch method on carpet
Trial 4 - Trial 6	Constant contact method on carpet
Trial 7 - Trial 9	Two-touch method on concrete
Trial 10 - Trial 12	Constant contact method on concrete

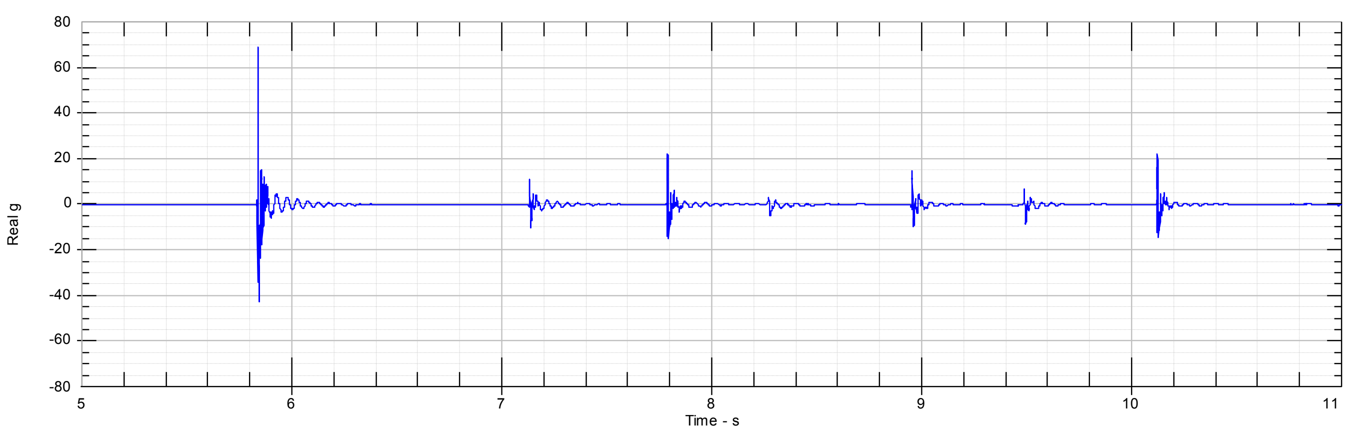
Each trial is displayed on a new page. For a given trial, the first plot shows the response of the force gauge against time. The second plot shows acceleration at the cane tip, the third shows acceleration at the midpoint of the cane, and the fourth shows acceleration at the cane handle. Although each trial was recorded for 12 seconds, these plots have been scaled to show only the data gathered while the cane was in use. This was usually four to six seconds.

Trial 1 – Two Touch on Carpet

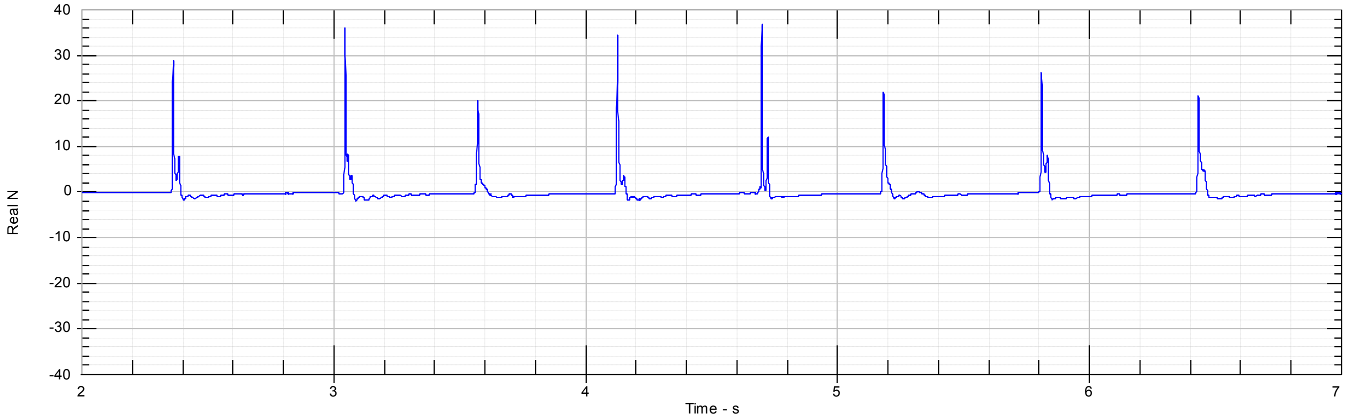


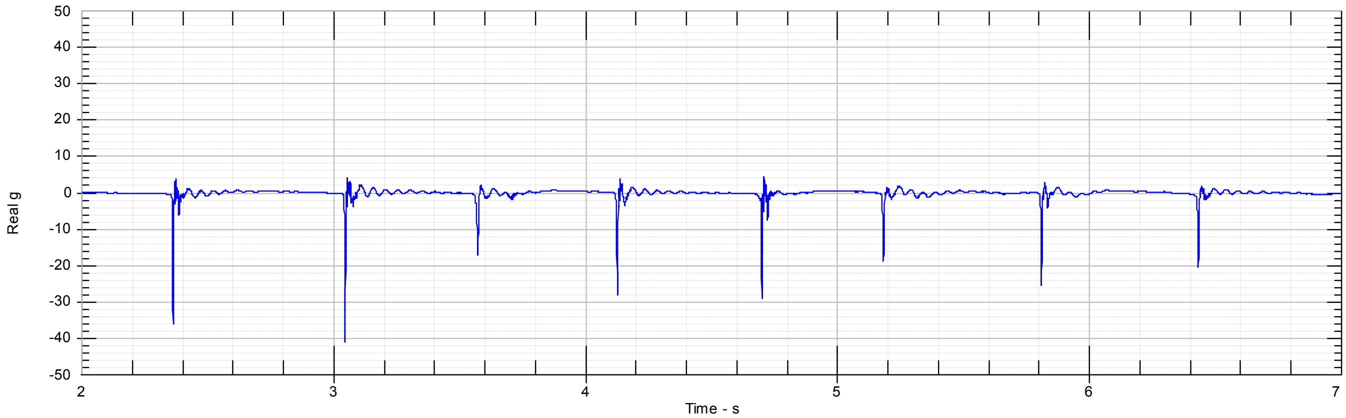


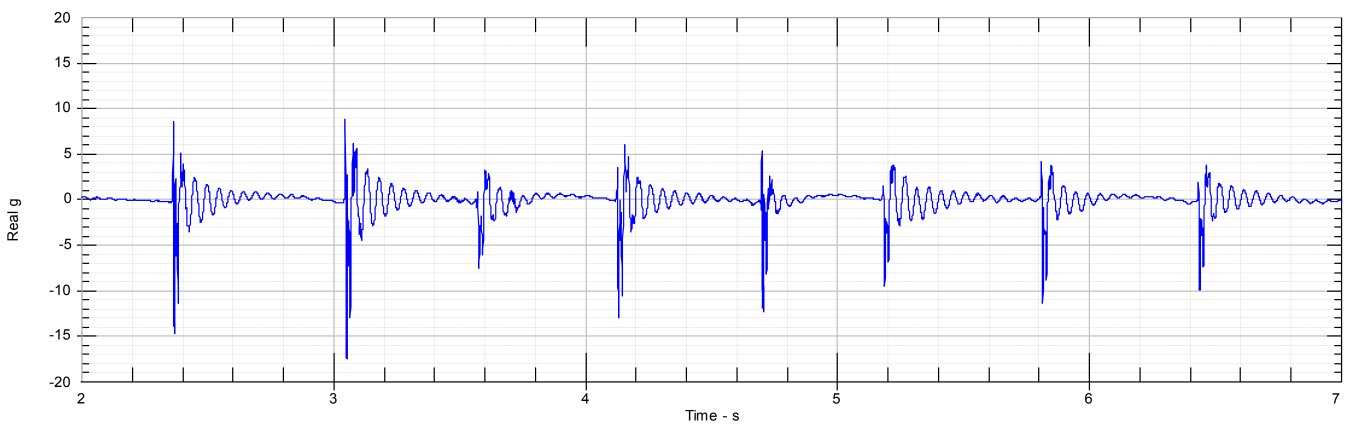


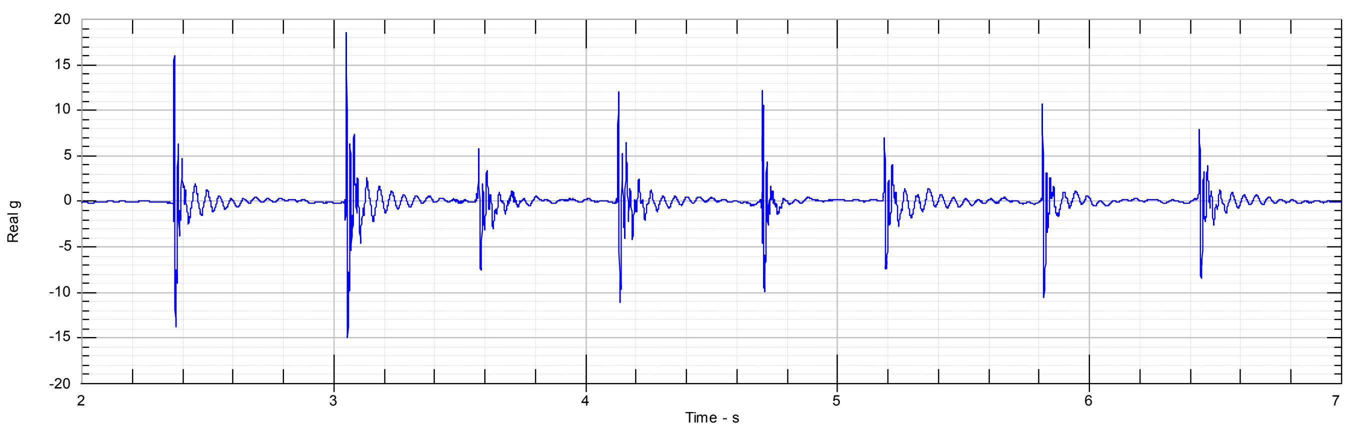


Trial 2 – Two Touch on Carpet

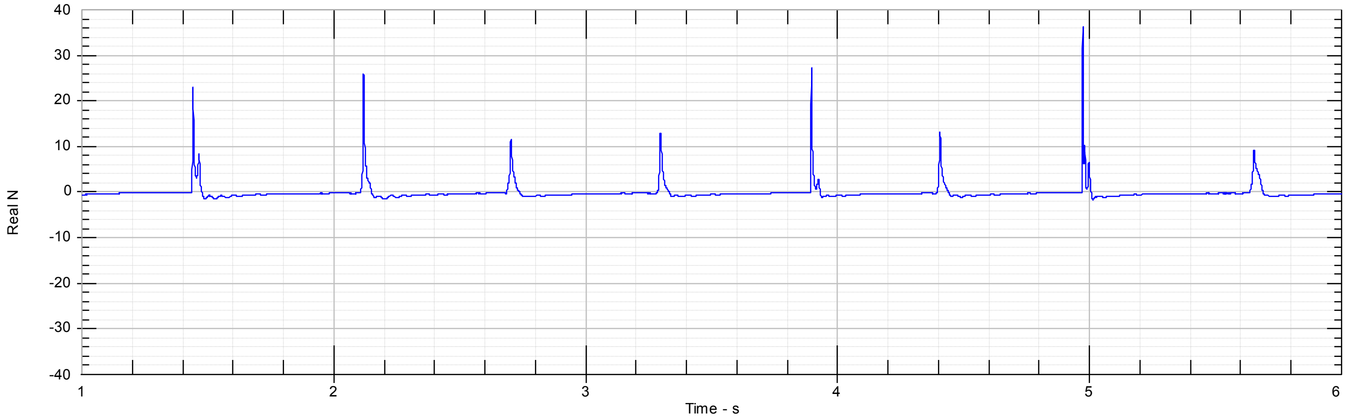


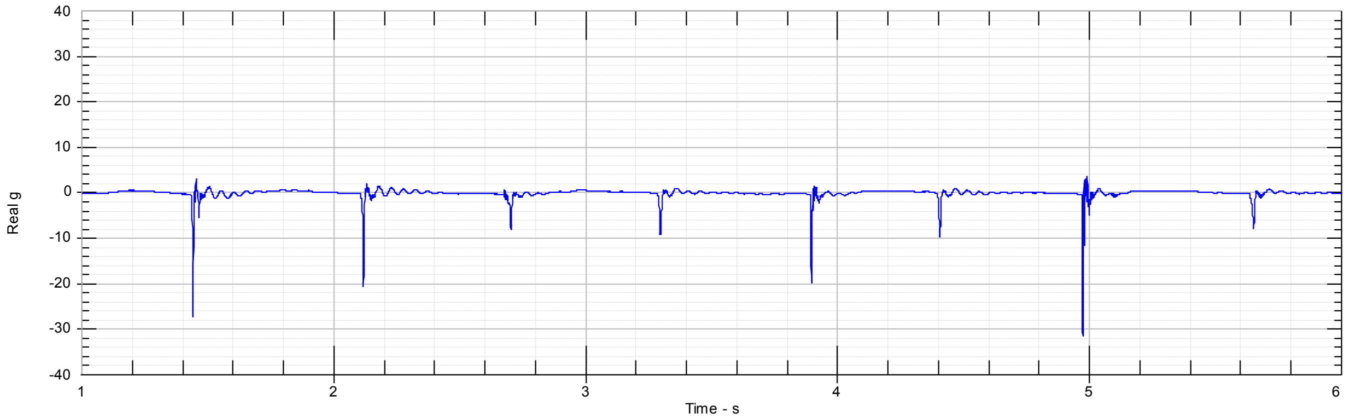


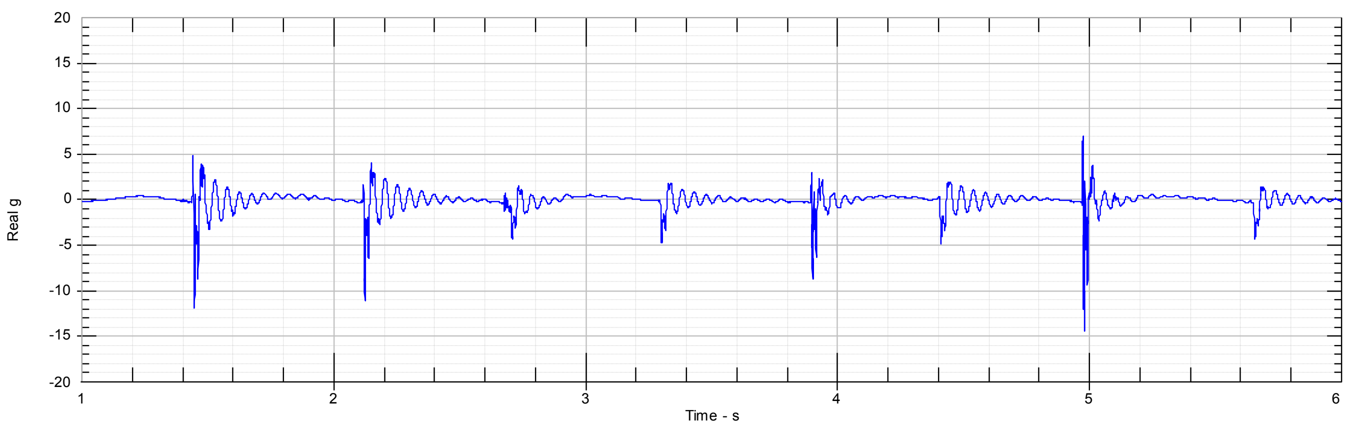


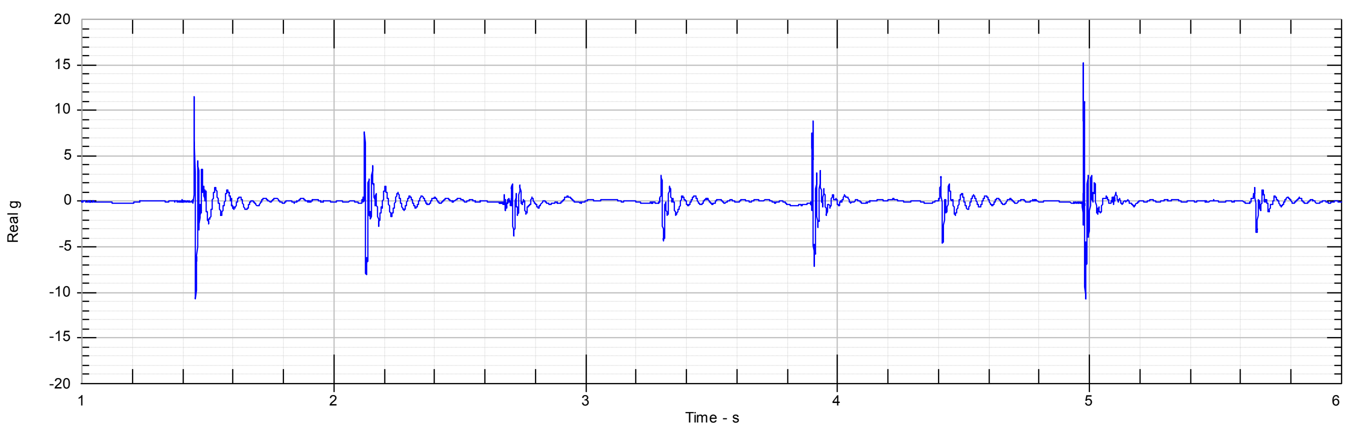


Trial 3 – Two Touch on Carpet

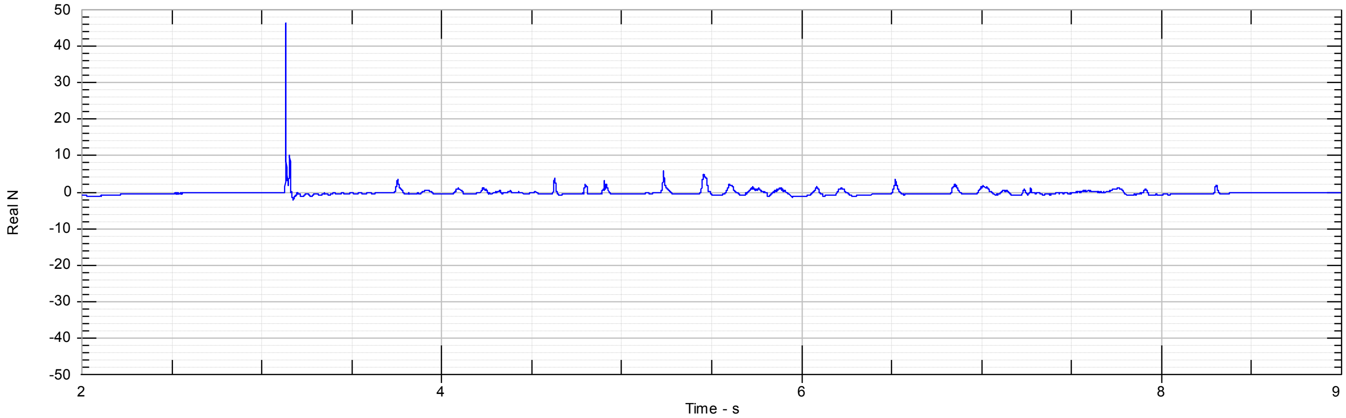


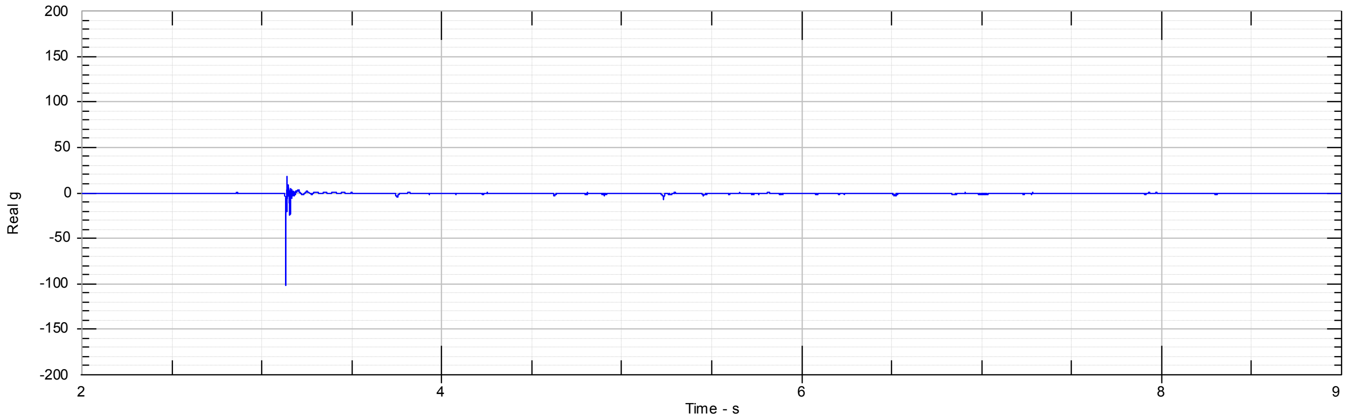


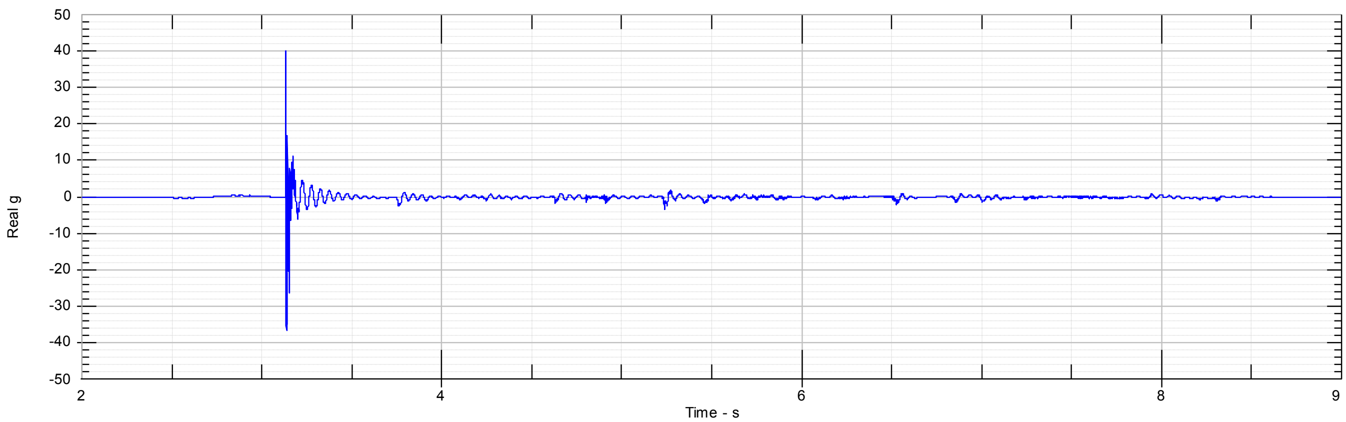


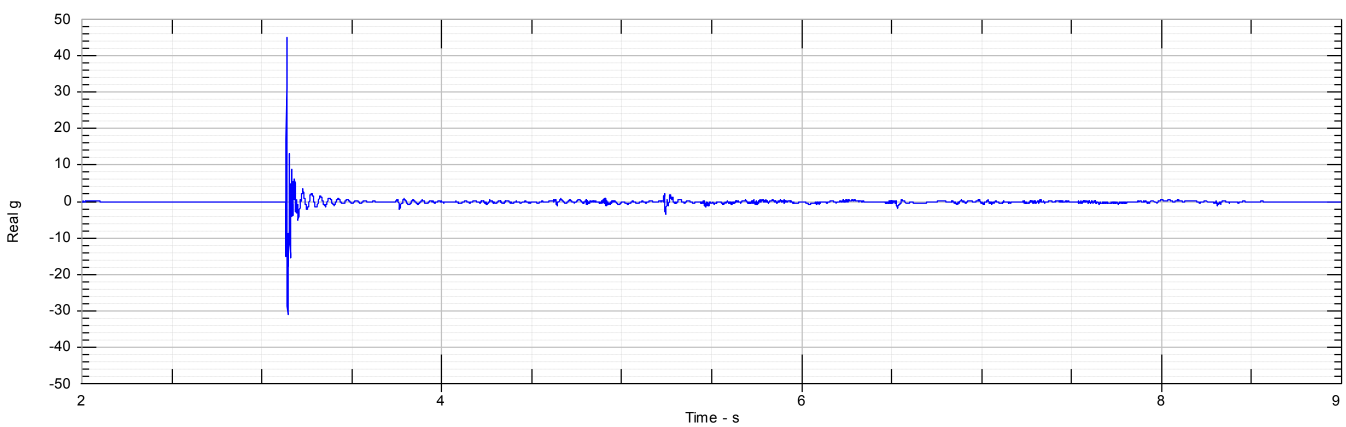


Trial 4 – Constant Contact on Carpet

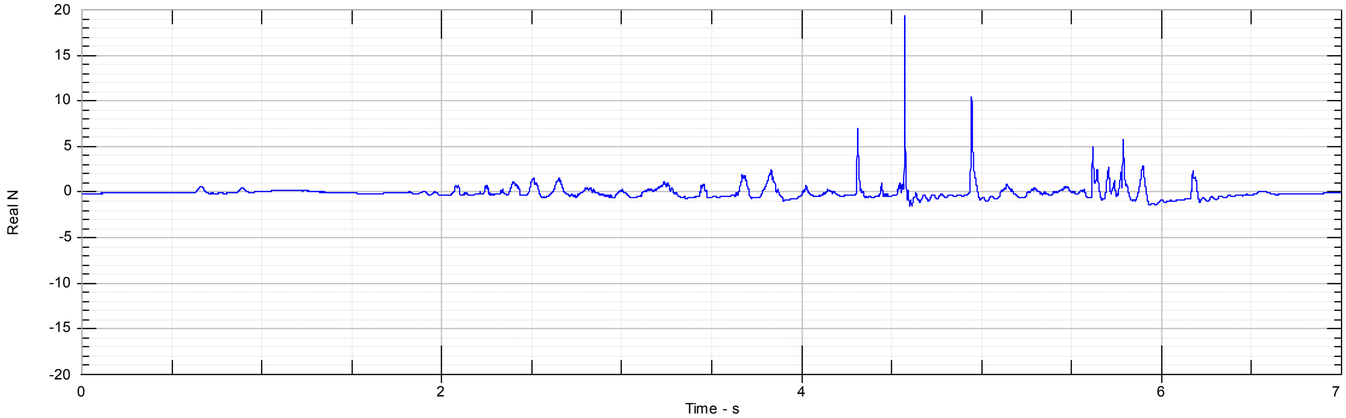


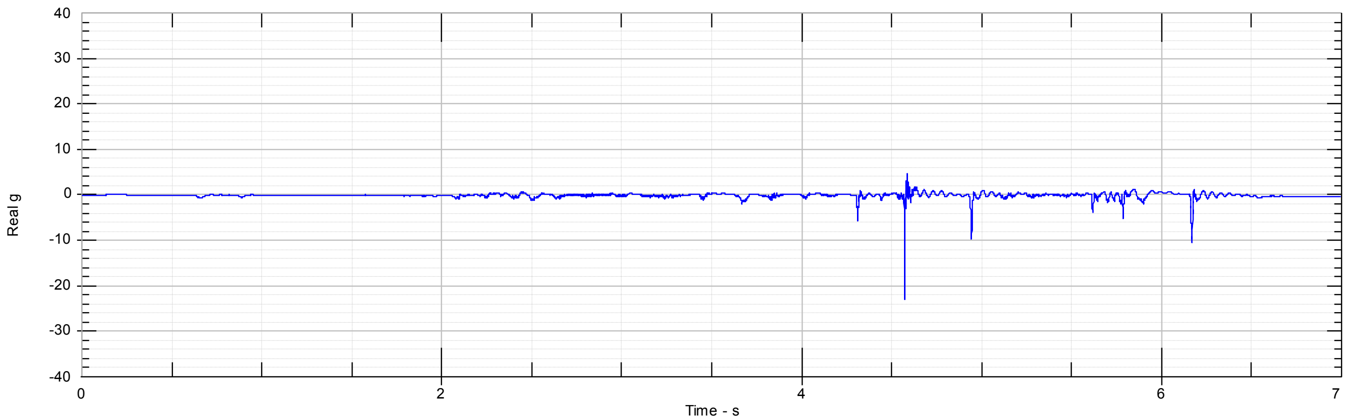


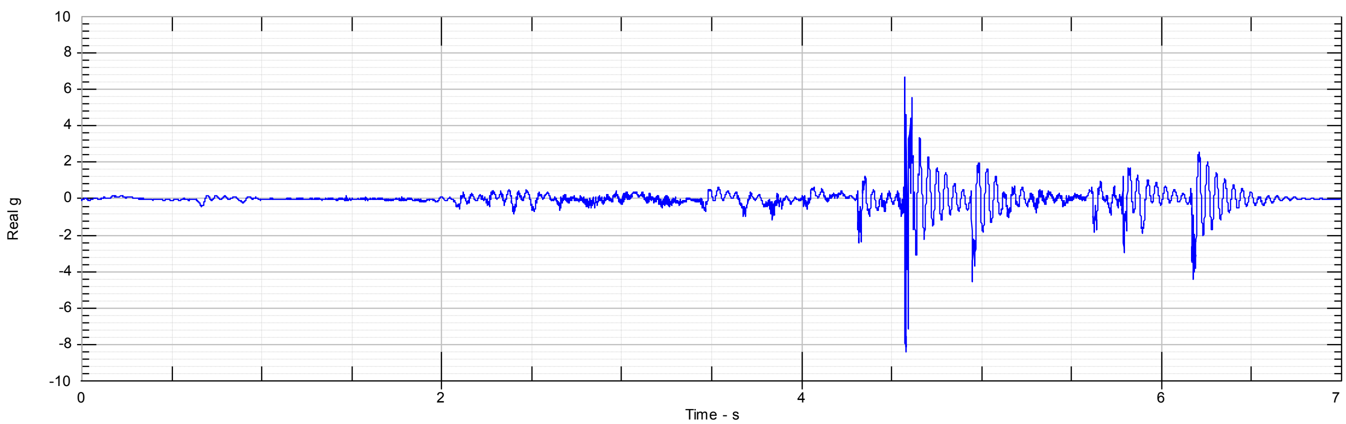


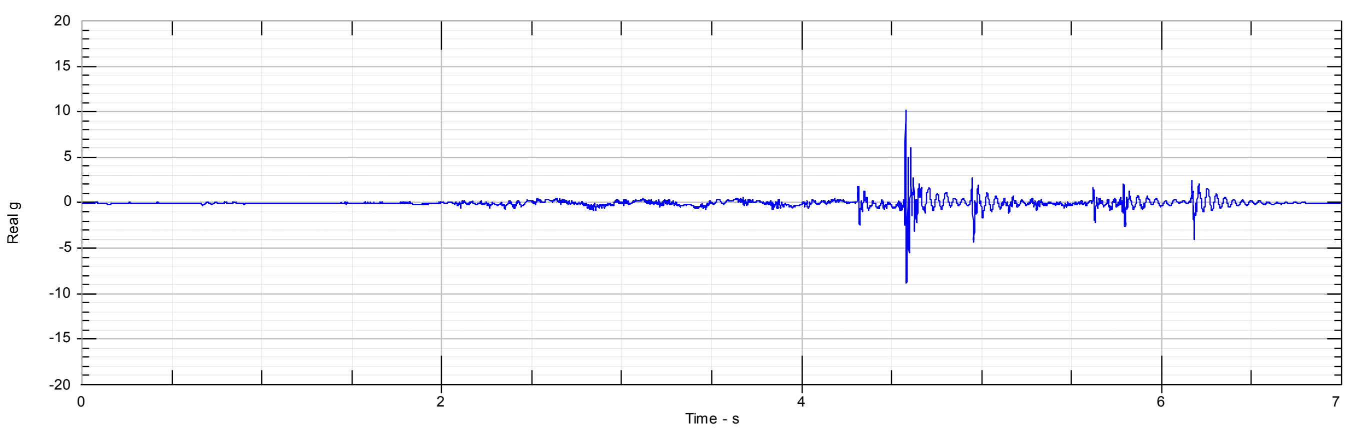


Trial 5 – Constant Contact on Carpet

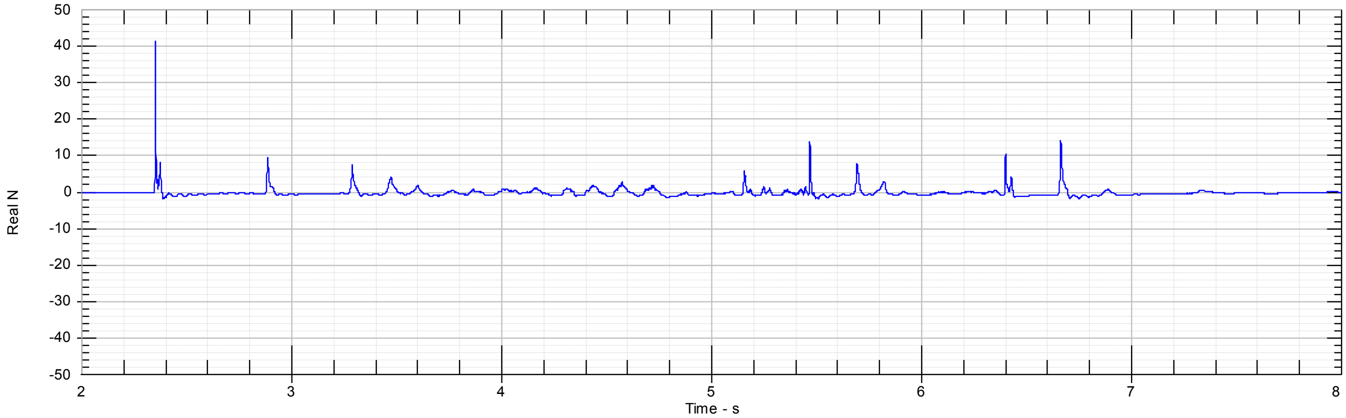


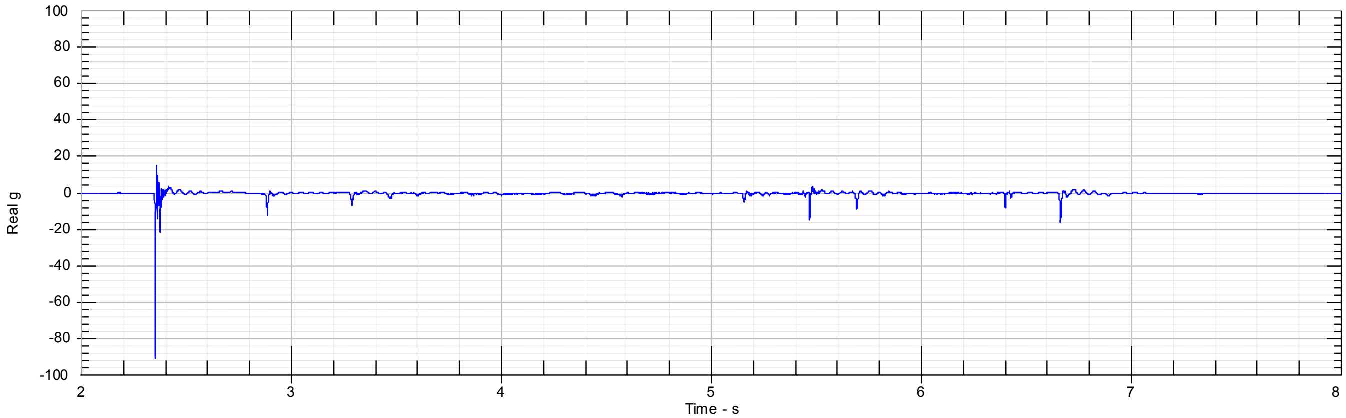


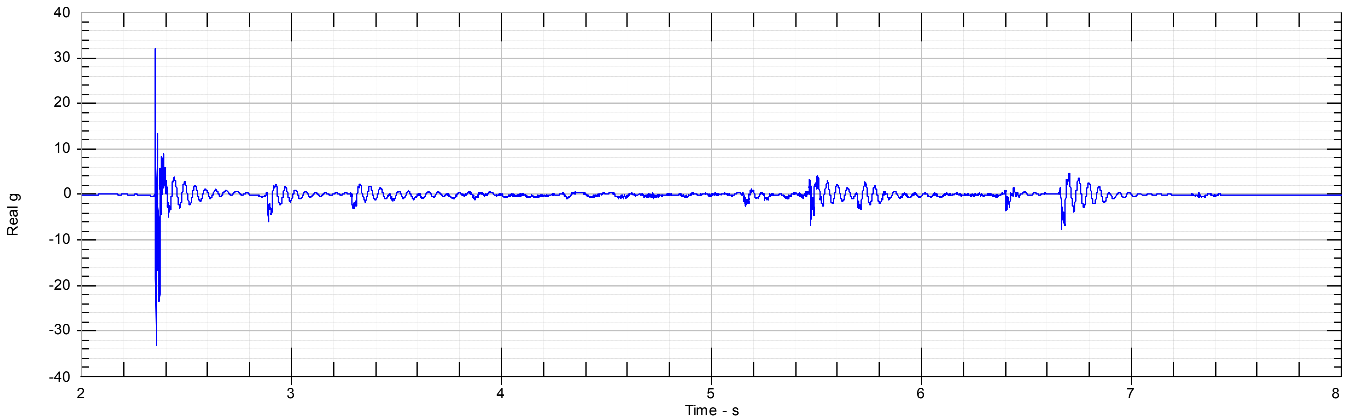


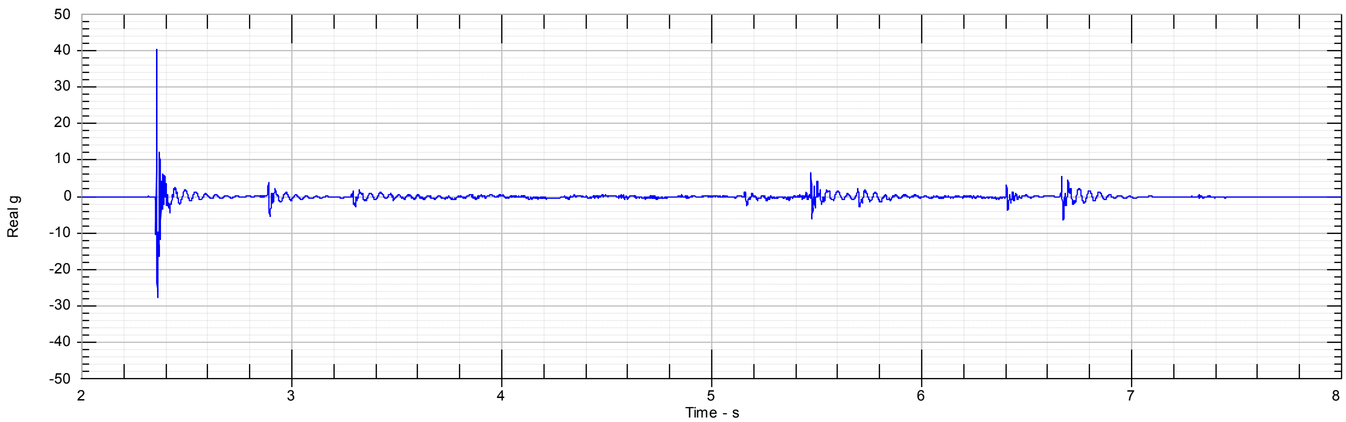


Trial 6 – Constant Contact on Carpet

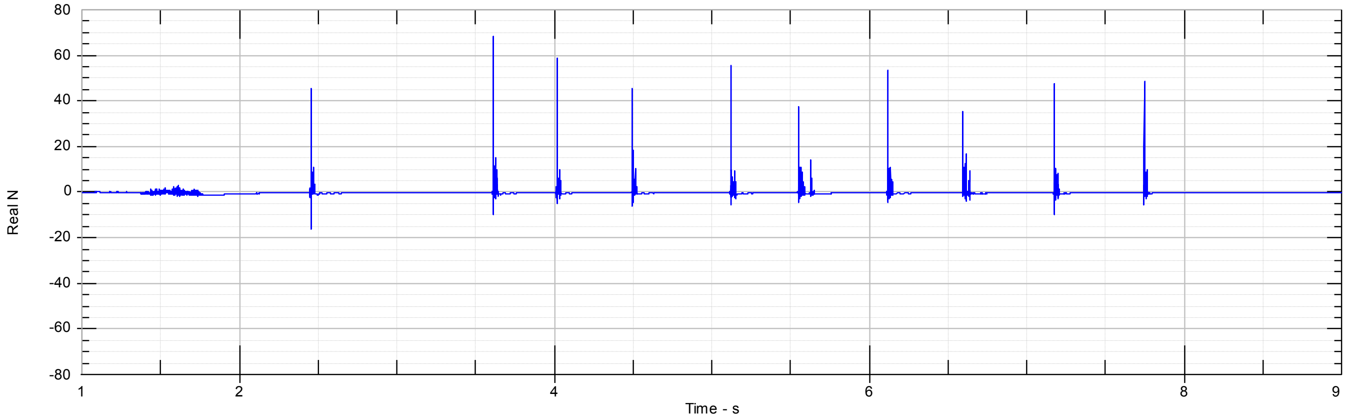


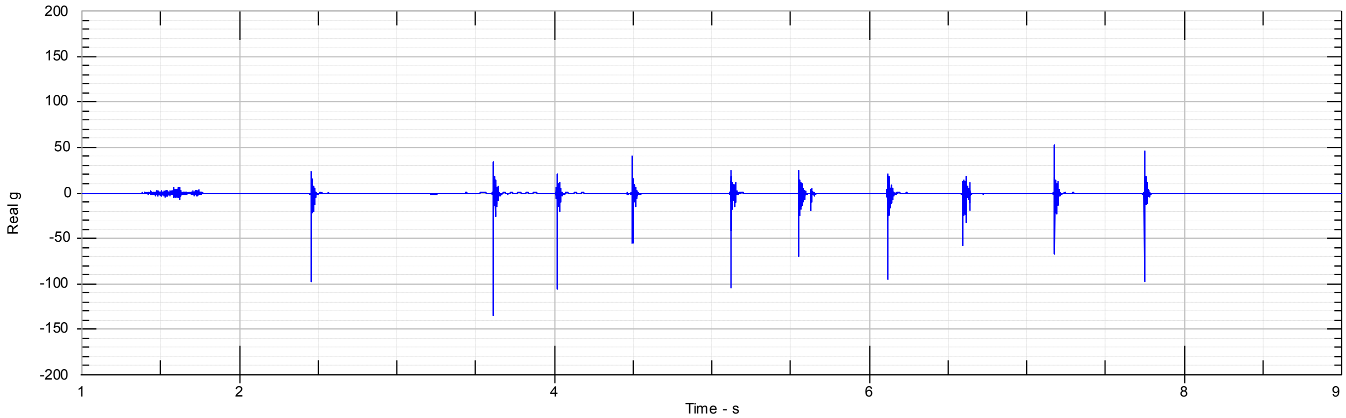


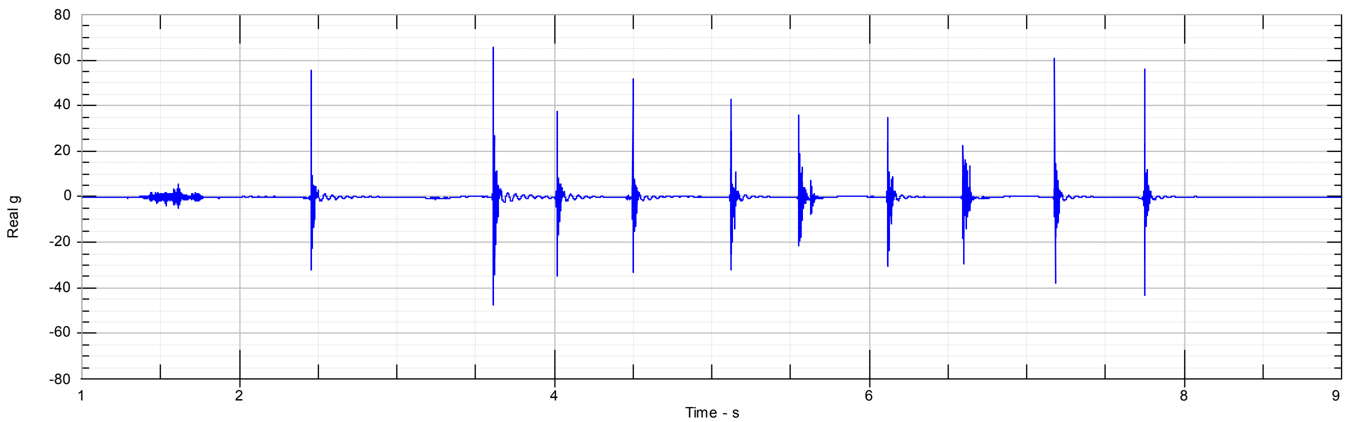


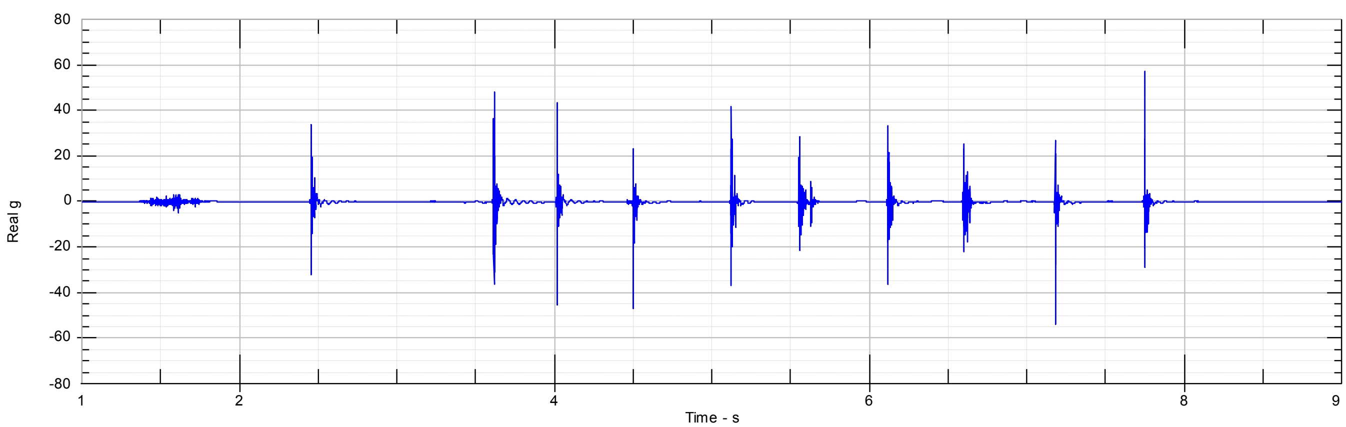


Trial 7 – Two Touch on Concrete

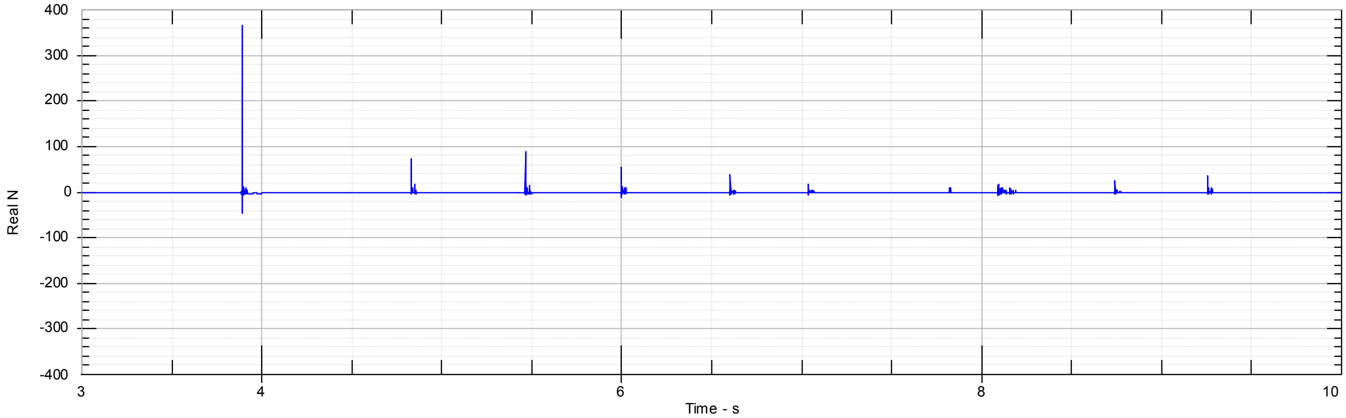


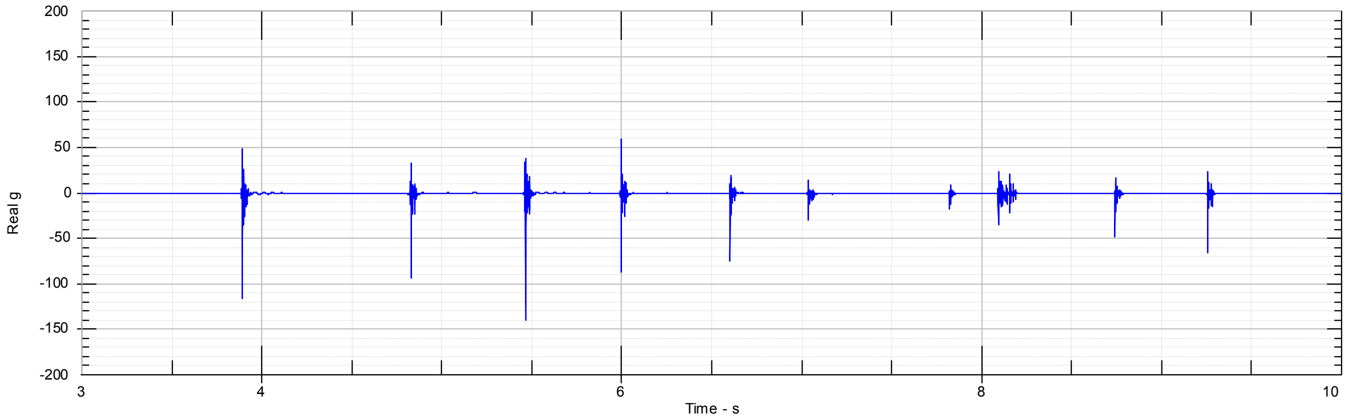


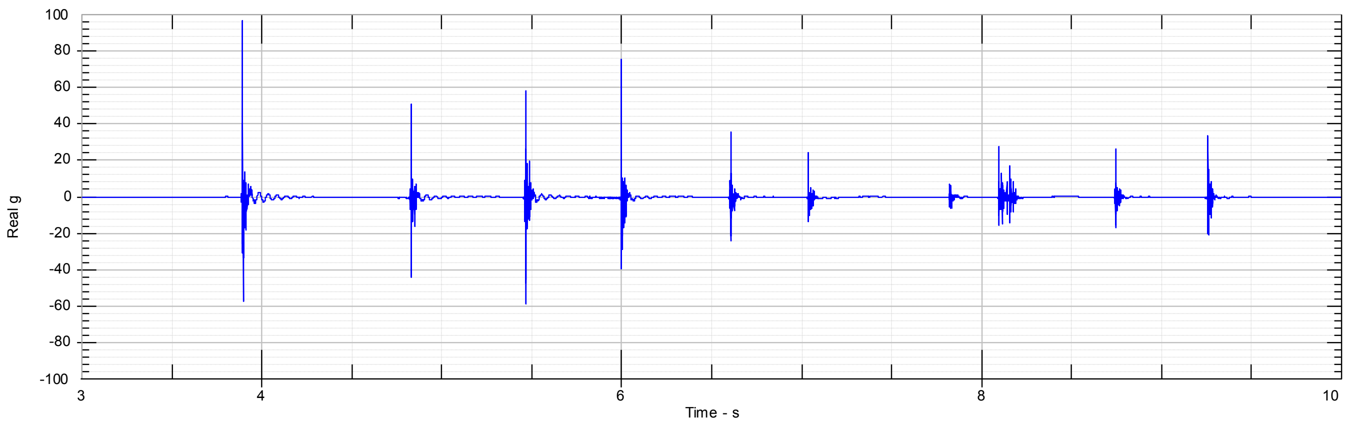


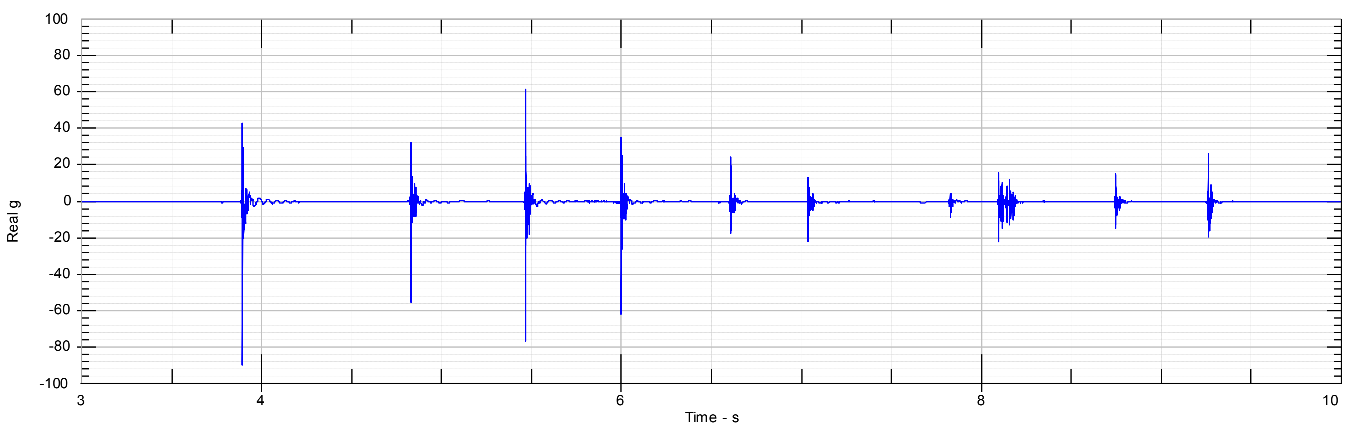


Trial 8 – Two Touch on Concrete

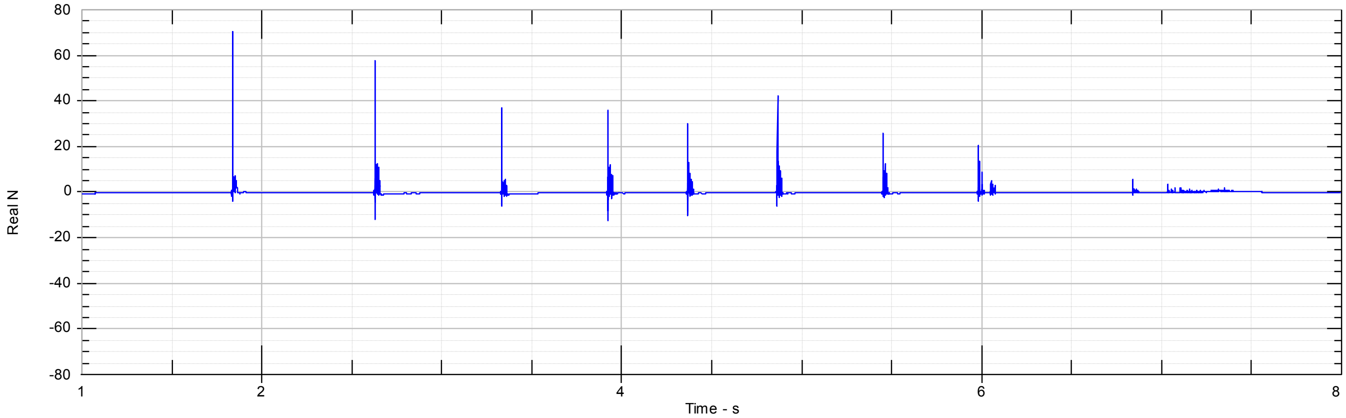


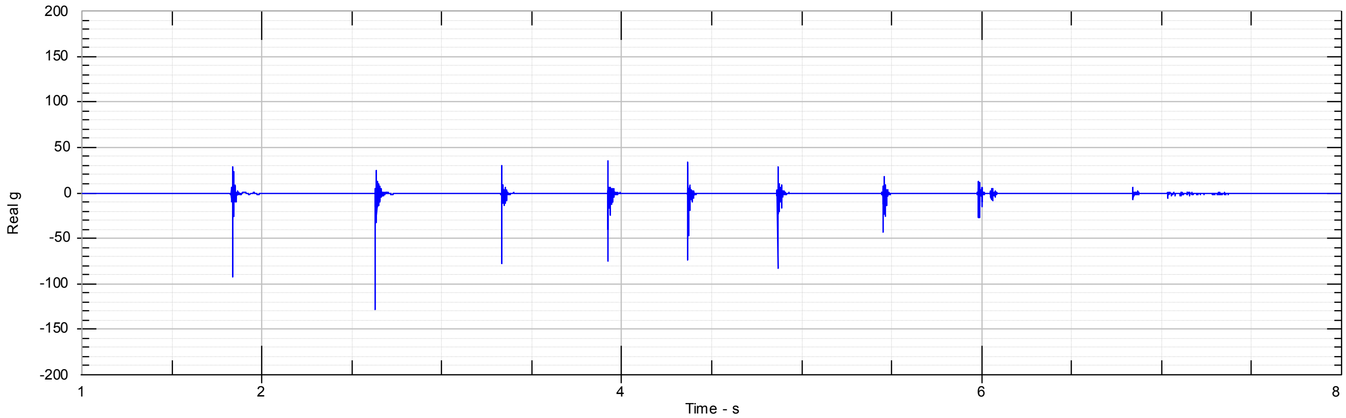


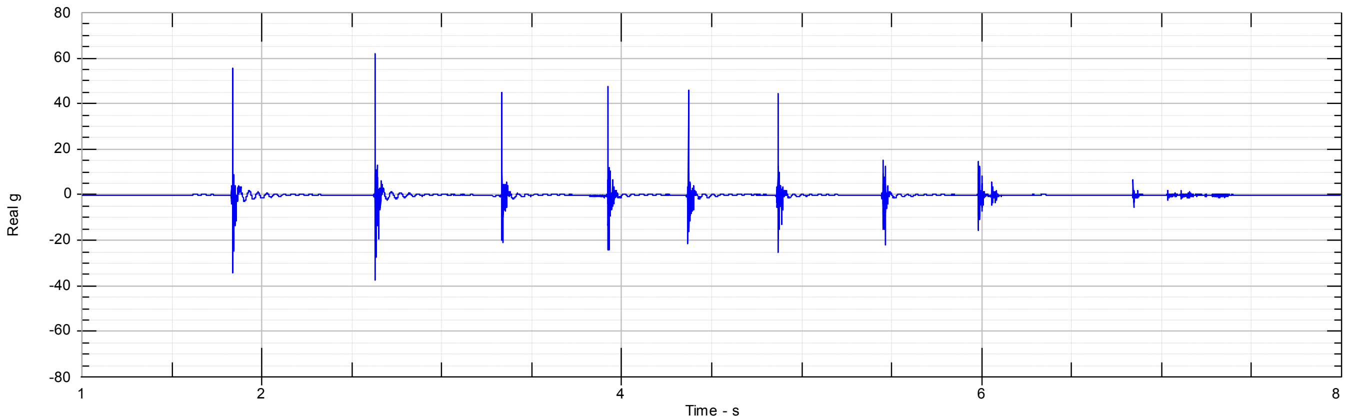


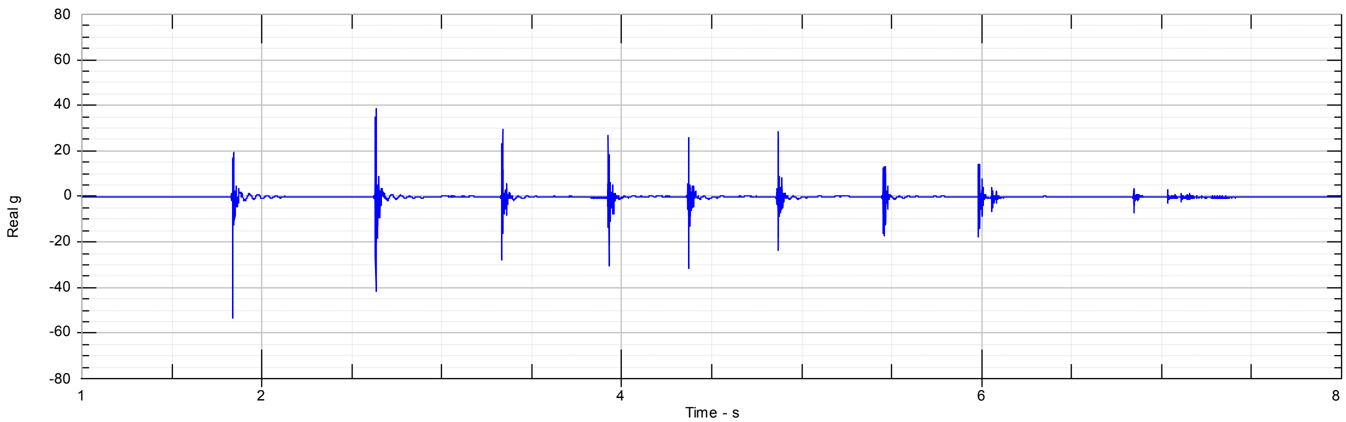


Trial 9 – Two Touch on Concrete

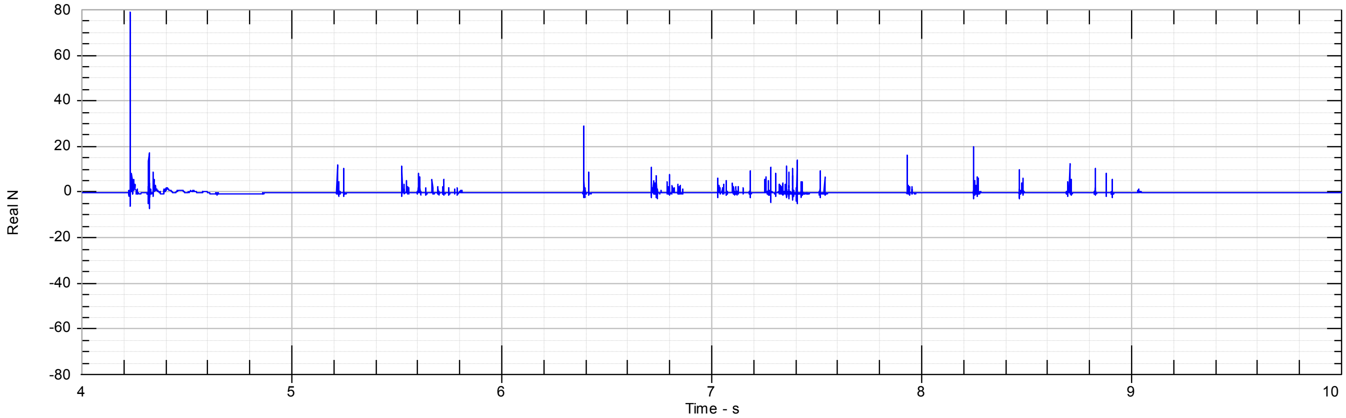


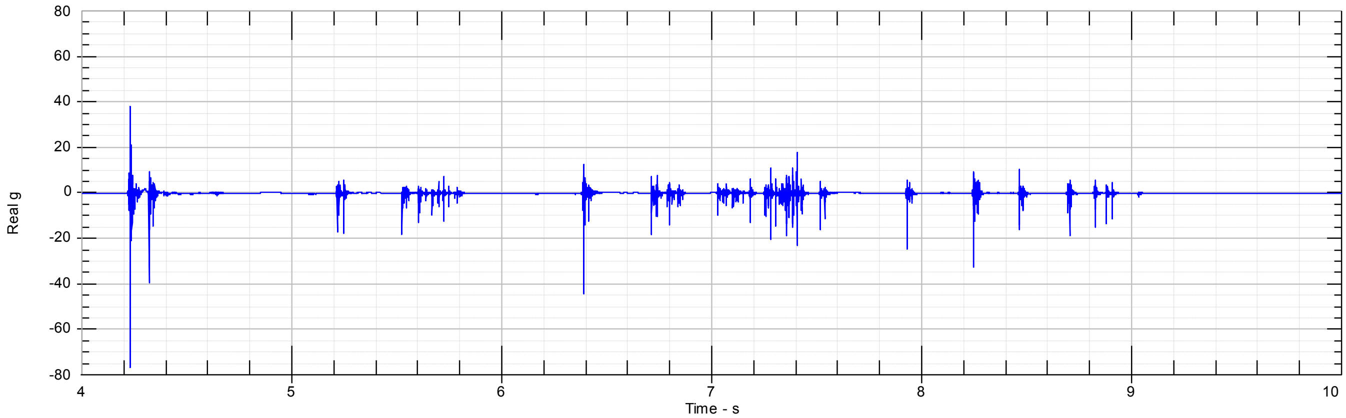


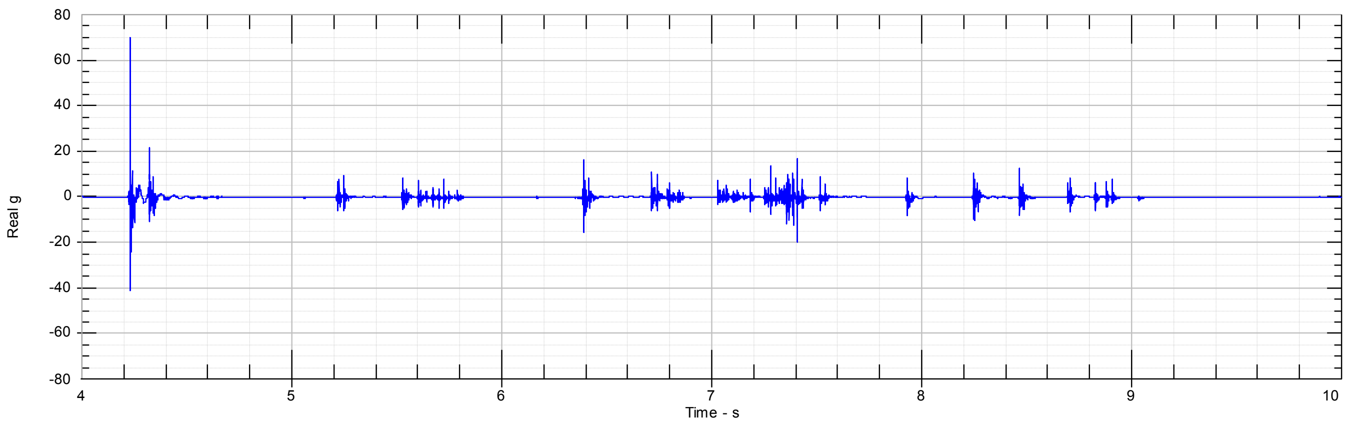


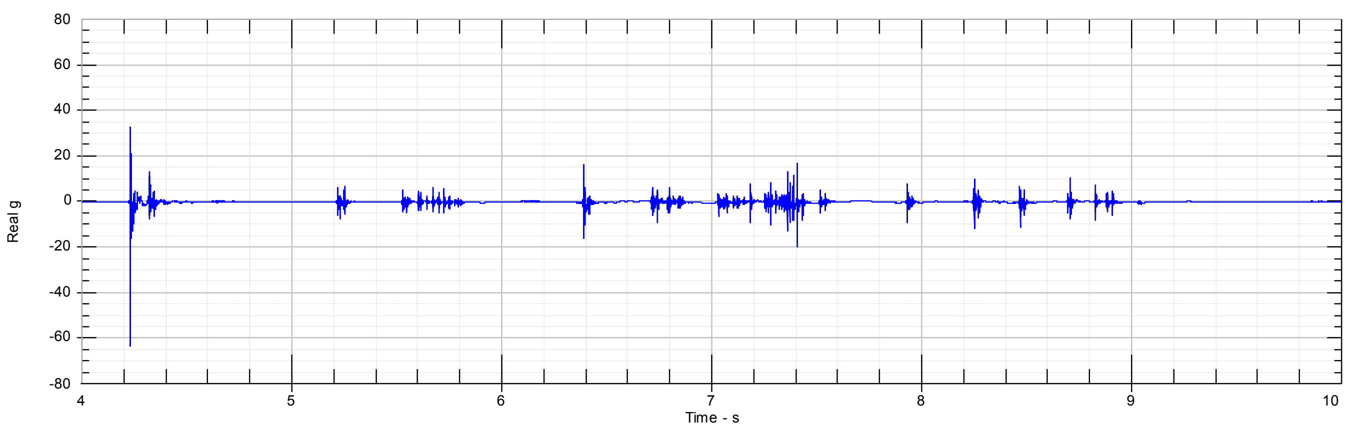


Trial 10 – Constant Contact on Concrete

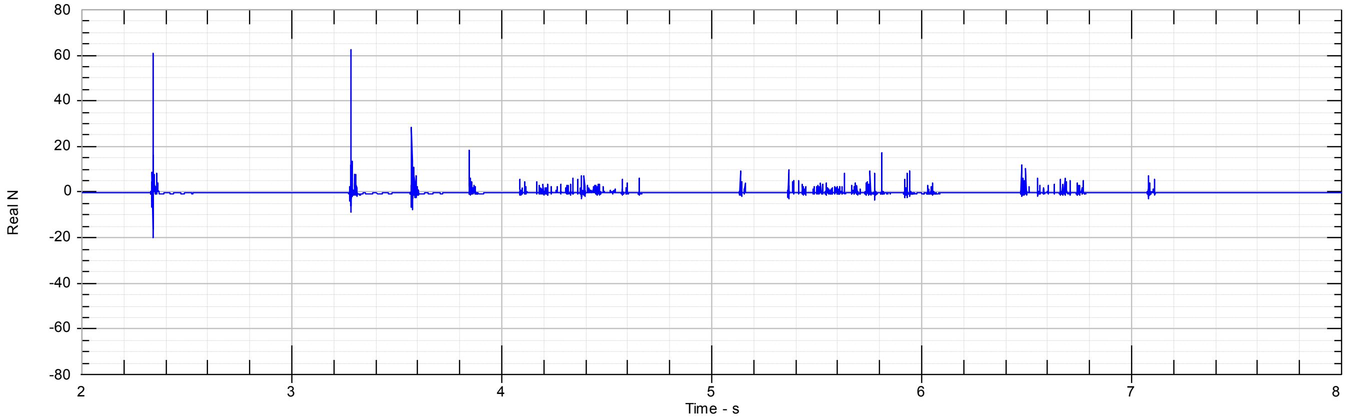


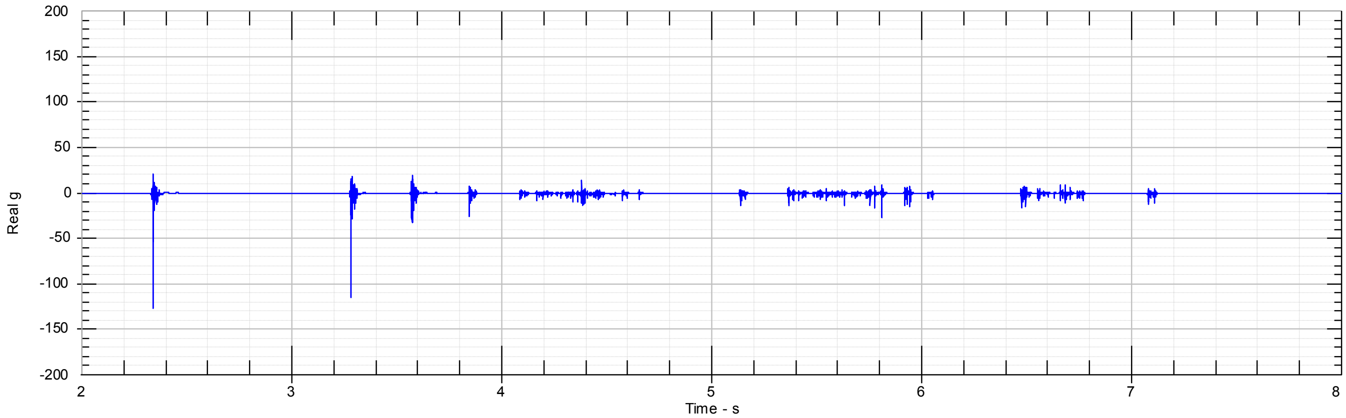


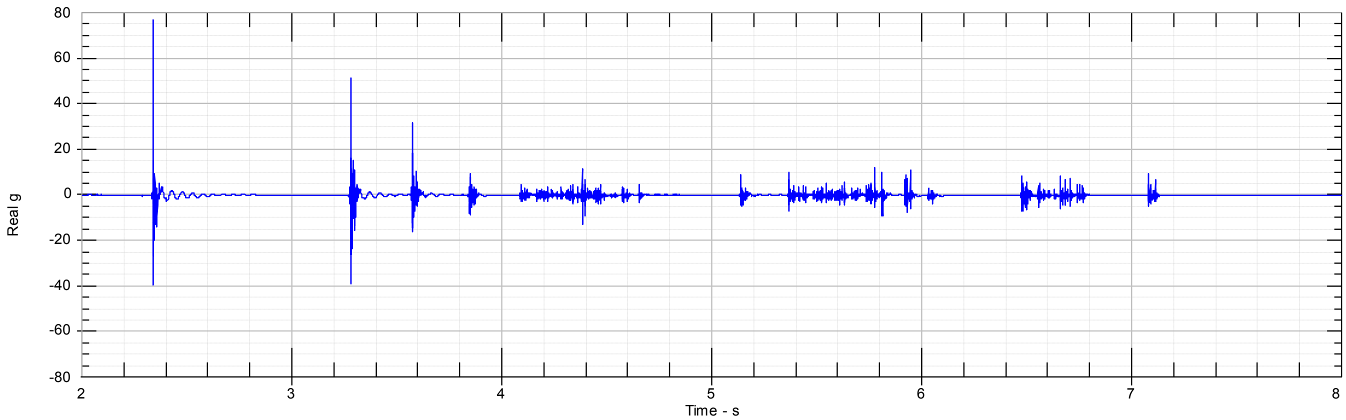


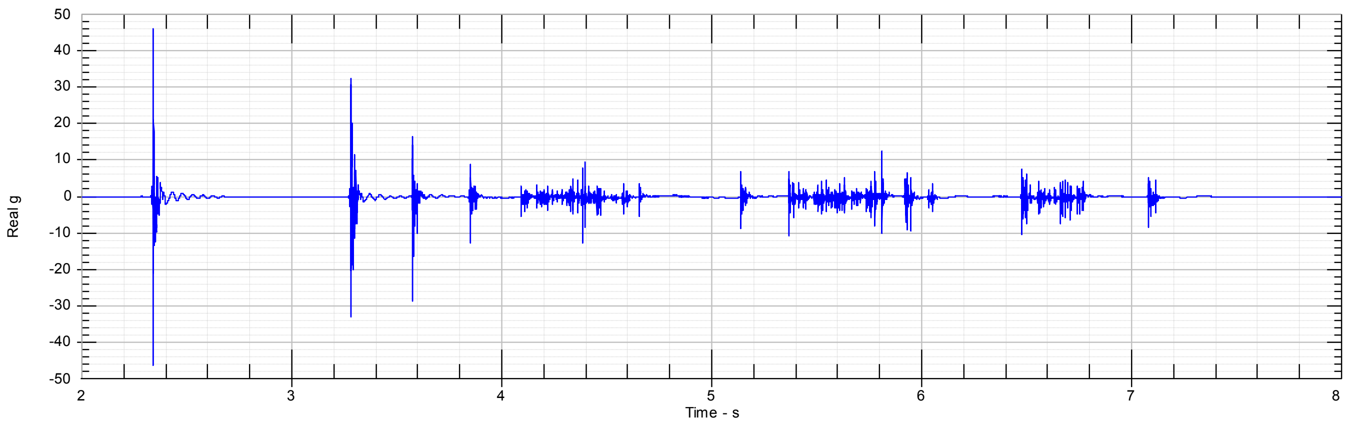


Trial 11 – Constant Contact on Concrete

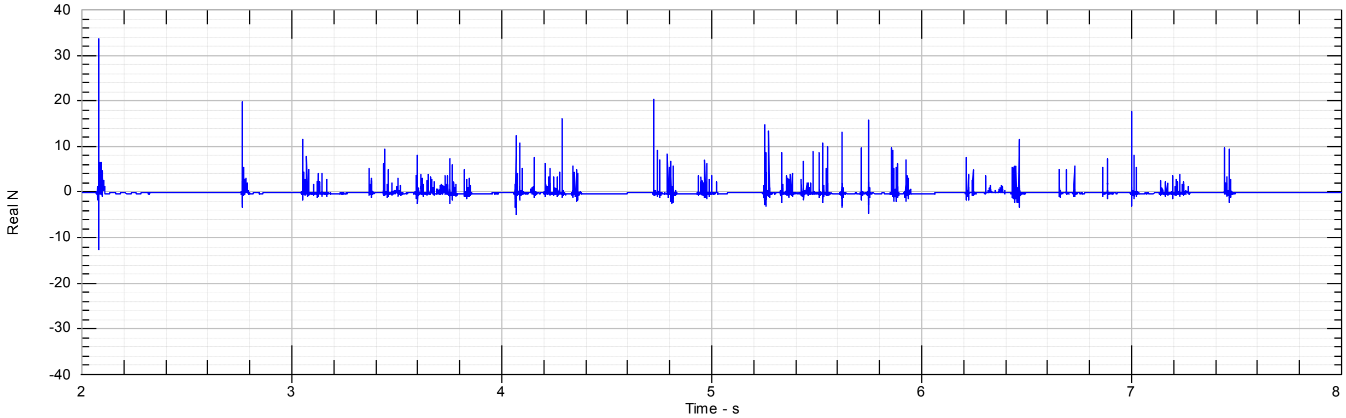


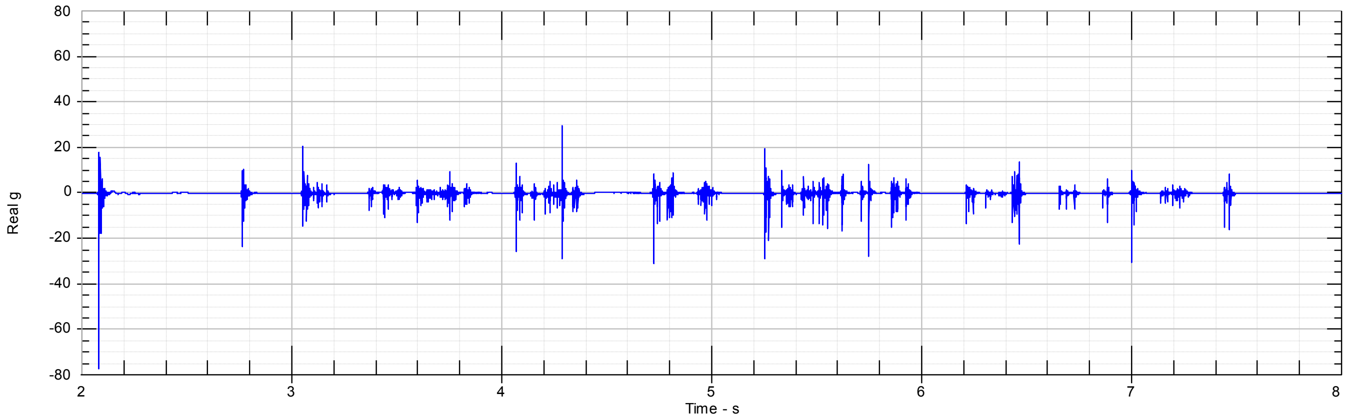


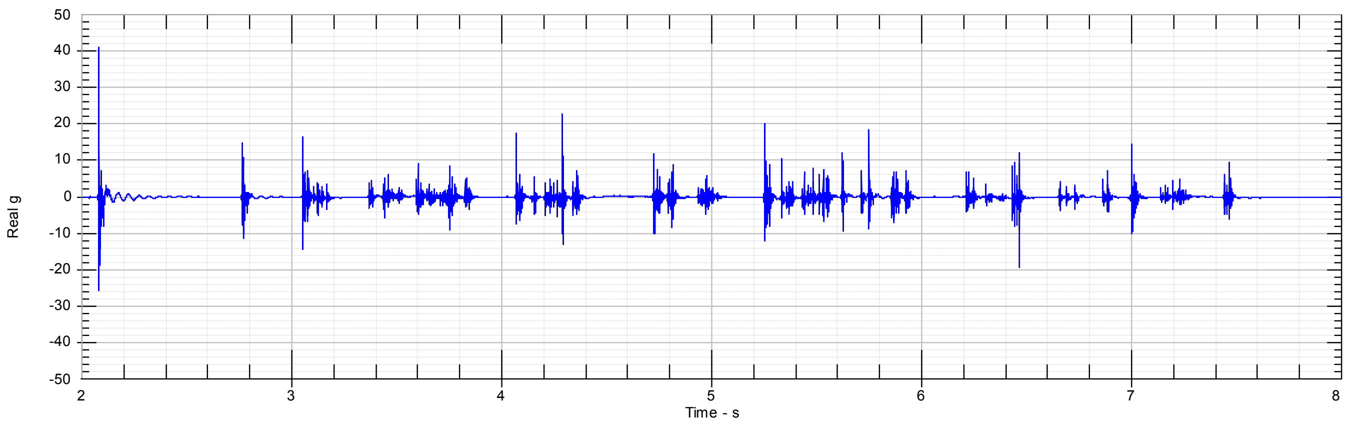


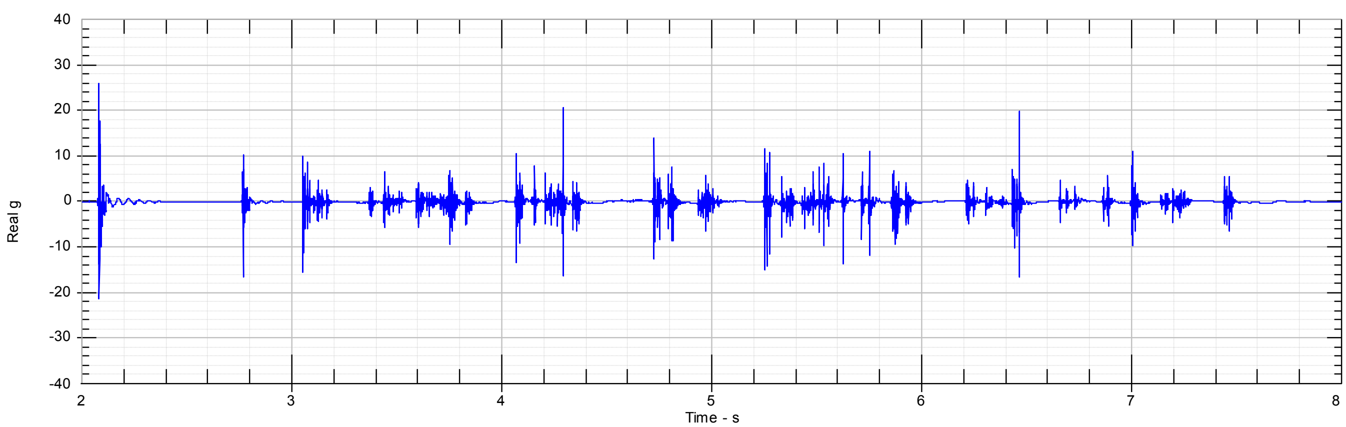


Trial 12 – Constant Contact on Concrete







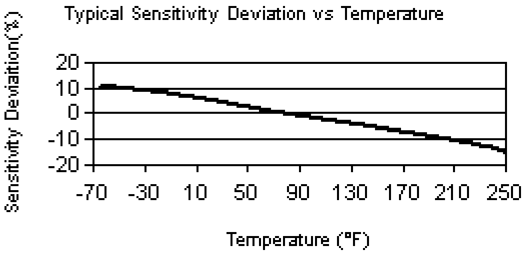


Appendix E: Datasheets

Model Number 352C22	ICP® ACCELEROMETER	Revision: H ECN #: 42346

Performance	ENGLISH	SI	
Sensitivity(± 15 %)	10 mV/g	1.0 mV/(m/s²)	
Measurement Range	± 500 g pk	± 4900 m/s² pk	
Frequency Range(± 5 %)	1.0 to 10,000 Hz	1.0 to 10,000 Hz	
Frequency Range(± 10 %)	0.7 to 13,000 Hz	0.7 to 13,000 Hz	
Frequency Range(± 3 dB)	0.3 to 20,000 Hz	0.3 to 20,000 Hz	
Resonant Frequency	≥ 50 kHz	≥ 50 kHz	
Broadband Resolution(1 to 10,000 Hz)	0.004 g rms	0.04 m/s² rms	[1]
Non-Linearity	≤ 1 %	≤ 1 %	[2]
Transverse Sensitivity	≤ 5 %	≤ 5 %	
Environmental			
Overload Limit(Shock)	± 10,000 g pk	± 98,000 m/s² pk	
Temperature Range(Operating)	-65 to +250 °F	-54 to +121 °C	
Temperature Response	See Graph	See Graph	[1]
Electrical			
Excitation Voltage	18 to 30 VDC	18 to 30 VDC	
Constant Current Excitation	2 to 20 mA	2 to 20 mA	
Output Impedance	≤ 300 Ohm	≤ 300 Ohm	
Output Bias Voltage	7 to 12 VDC	7 to 12 VDC	
Discharge Time Constant	1.0 to 3.5 sec	1.0 to 3.5 sec	
Settling Time(within 10% of bias)	<3 sec	<3 sec	
Spectral Noise(1 Hz)	800 µg/√Hz	7840 (µm/sec^2)/√Hz	[1]
Spectral Noise(10 Hz)	250 µg/√Hz	2450 (µm/sec^2)/√Hz	[1]
Spectral Noise(100 Hz)	60 µg/√Hz	590 (µm/sec^2)/√Hz	[1]
Spectral Noise(1 kHz)	50 µg/√Hz	490 (µm/sec^2)/√Hz	[1]
Spectral Noise(10 kHz)	40 µg/√Hz	392 (µm/sec^2)/√Hz	[1]
Electrical Isolation(Base)	>10^8 Ohm	>10^8 Ohm	
Physical			
Size (Height x Length x Width)	0.14 in x 0.45 in x 0.25 in	3.6 mm x 11.4 mm x 6.4 mm	
Weight	0.017 oz	0.5 gm	[1]
Sensing Element	Ceramic	Ceramic	
Sensing Geometry	Shear	Shear	
Housing Material	Anodized Aluminum	Anodized Aluminum	
Sealing	Epoxy	Epoxy	
Electrical Connector	3-56 Coaxial Jack	3-56 Coaxial Jack	
Electrical Connection Position	Side	Side	
Mounting	Adhesive	Adhesive	

CE [3]



All specifications are at room temperature unless otherwise specified.
In the interest of constant product improvement, we reserve the right to change specifications without notice.

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OPTIONAL VERSIONS

Optional versions have identical specifications and accessories as listed for the standard model except where noted below. More than one option may be used.

NOTES:
[1] Typical.
[2] Zero-based, least-squares, straight line method.
[3] See PCB Declaration of Conformance PS023 for details.

SUPPLIED ACCESSORIES:
Model 030A10 Coax Cable, 10 ft (3 m), 3-56 plug to 10-32 plug. (1)
Model 039A27 One-piece removal tool for Models 352C22, 357C10, 352A21, & 357A09 (1)
Model 080A109 Petro Wax (1)
Model ACS-1 NIST traceable frequency response (10 Hz to upper 5% point). (1)

Entered: AP	Engineer: JJB	Sales: WDC	Approved: JJB	Spec Number:
Date: 12/16/2013	Date: 12/16/2013	Date: 12/16/2013	Date: 12/16/2013	**10668**

PCB PIEZOTRONICS
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Model Number 208C02	ICP® FORCE SENSOR	Revision: H ECN #: 34989

Performance	ENGLISH	SI	
Sensitivity(± 15 %)	50 mV/lb	11,241 mV/kN	
Measurement Range(Compression)	100 lb	0.4448 kN	
Measurement Range(Tension)	100 lb	0.4448 kN	
Maximum Static Force(Compression)	600 lb	2.669 kN	
Maximum Static Force(Tension)	500 lb	2.224 kN	
Broadband Resolution(1 to 10,000 Hz)	0.001 lb-rms	0.004 N-rms	[1]
Low Frequency Response(-5 %)	0.001 Hz	0.001 Hz	[2]
Upper Frequency Limit	36,000 Hz	36,000 Hz	[3]
Non-Linearity	≤ 1 % FS	≤ 1 % FS	[4]
Environmental			
Temperature Range	-65 to +250 °F	-54 to +121 °C	
Temperature Coefficient of Sensitivity	≤ 0.05 %/°F	≤ 0.09 %/°C	
Electrical			
Discharge Time Constant(at room temp)	≥ 500 sec	≥ 500 sec	
Excitation Voltage	20 to 30 VDC	20 to 30 VDC	
Constant Current Excitation	2 to 20 mA	2 to 20 mA	
Output Impedance	≤ 100 Ohm	≤ 100 Ohm	
Output Bias Voltage	8 to 14 VDC	8 to 14 VDC	
Spectral Noise(1 Hz)	0.000135 lb/√Hz	0.000603 N/√Hz	[1]
Spectral Noise(10 Hz)	0.0000276 lb/√Hz	0.000123 N√Hz	[1]
Spectral Noise(100 Hz)	0.0000096 lb/√Hz	0.0000427 N/√Hz	[1]
Spectral Noise(1000 Hz)	0.0000021 lb/√Hz	0.0000095 N/√Hz	[1]
Output Polarity(Compression)	Positive	Positive	
Physical			
Stiffness	6 lb/µin	1.05 kN/µm	[1]
Size (Hex x Height x Sensing Surface)	0.625 in x 0.625 in x 0.500 in	15.88 mm x 15.88 mm x 12.7 mm	
Weight	0.80 oz	22.7 gm	
Housing Material	Stainless Steel	Stainless Steel	
Sealing	Hermetic	Hermetic	
Electrical Connector	10-32 Coaxial Jack	10-32 Coaxial Jack	
Electrical Connection Position	Side	Side	
Mounting Thread	10-32 Female	Not Applicable	
Mounting Torque(Recommended)	16 to 20 in-lb	181 to 226 N-cm	

CE [5]

All specifications are at room temperature unless otherwise specified.
In the interest of constant product improvement, we reserve the right to change specifications without notice.

OPTIONAL VERSIONS

Optional versions have identical specifications and accessories as listed for the standard model except where noted below. More than one option may be used.

N - Negative Output Polarity

W - Water Resistant Cable

NOTES:
[1]Typical.
[2]Calculated from discharge time constant.
[3]Estimated using rigid body dynamics calculations.
[4]Zero-based, least-squares, straight line method.
[5]See PCB Declaration of Conformance PS023 for details.

SUPPLIED ACCESSORIES:
Model 080A81 Thread Locker (1)
Model 081B05 Mounting Stud (10-32 to 10-32) (2)
Model 084A03 Impact Cap (1)
Model M081A62 Mounting stud, 10-32 to M6 x 1, BeCu with shoulder (2)

Entered:	Engineer: MJK	Sales: KWW	Approved:	Spec Number:
Date:	Date: 2/11/2011	Date: 2/11/2011	Date:	**8467**

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