B.Eng (Hons)

Mechanical Design Engineering

Final-Year Project 2015/16

TITLE: AUTOMATIC WEARABLE POSTURE BALANCE METER FOR ELDERLY (15008)

NAME: KHOO DING XUAN, ALOYSIUS
UoG MATRICULATION No.: 2167469K

FIRST SUPERVISOR: Dr ALAN WONG
SECOND SUPERVISOR: Dr MARTIN MACAULEY

School of Engineering

Acknowledgement

I would like to express my most sincere gratitude and appreciation to the following people that have helped me throughout this journey and the completion of the final year project.

First of all, I would like to express my deepest thanks to my first supervisor, Dr Alan Wong, who patiently guided me throughout the development of the project. Without the advice and encouragement rendered to me, the project would not have been completed successfully.

I would like to thank my second supervisor, Dr Martin Macauley from University of Glasgow, for his valuable feedback, advice to manage the progress orderly and how to do organize my report.

I am also grateful to Dr Alfred Tan, Dr Ben Soon, Dr Meredith Yeung who held the weekly Healthcare Engineering Cluster meeting and fellow friends and classmates for their constructive feedback throughout the course for the development of my project.

Special thanks to Dr Alan Wong for the opportunity to present to the physiotherapists and nurses at Kwong Wai Shiu Hospital for their survey and comments to further improve on this project, as well as to loan the swaymeter from Singapore General Hospital that helped to compare with the prototype.

Abstract

Postural sway is currently measured using a modified Nintendo Wii Board (Nintendo, Japan) [7] and the manual swaymeter [6]. There are several limitations to their use; long set-up time, high cost, lacking in portability and poorly understood outcomes. The objective of this project is to propose a light-weight and wearable device to quantify the postural sway of elderly people and those with balance deficits.

This project utilizes a prototype device to communicate with a computer laptop via wireless connection, using accelerometry technology. The accelerometer sensor reads the static measurements of the acceleration due to gravity of a postural sway in tilt angles. The tilt angle measurements are in the mediolateral (x axis) and anteriorposterior (y axis) direction over a defined period of time, for example, 30 seconds. The outputs include graphical displays, direction capture and maximum angles from each axis. The prototype is worn by the person around the waist level. Quantifies sway similarly as the swaymeter, where patient is required to be tested on a foam rubber mat of a medium density in quiet stance for 30 seconds. Hence measuring postural sway using this prototype device overcomes the issue of set-up time, cost, protability and meaningfulness of clinical outcomes. The device was light-weighting, measuring 200 grams.

Furthermore, tests were conducted to compare this prototype device and the commonly used manual swaymeter. Ten participants, whos ages ranged from 20 to 72 years old, were tested on both methods. Correlation coefficients were calculated showing strong relationship between the two methods ($r = 0.798$ to 0.873), suggesting that the prototype device could potentially replace the manual swaymeter currently used by clinicians. However, potential limitation of the device includes recording jerk motion spikes on the graph, which could provide spurious maximum reading on postural sway. Further research and development of the prototype device is needed. In conclusion, this light-weight and wearable prototype device could validly quantify postural sway in elderly people or those with balance deficits by measuring maximum postural tilt angles in both mediolateral and anteriorposterior axes.

Table of Contents

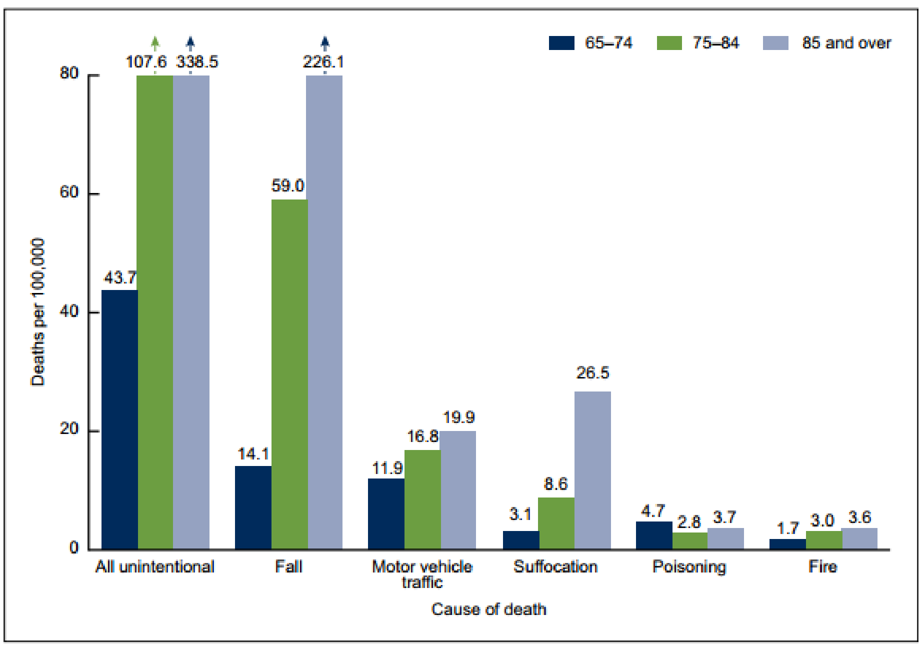
Table of Figures

Tables

Introduction

Postural control is the primary support for the ability to stand and walk freely, and maintain the equilibrium and orientation in a gravitational environment [1]. Poor postural control can result in an increased risk of falling while one engages in the different daily activities [2]. In one study involving Singaporean elderly residents(401 participants, 21% response rate), the prevalence of falls among those aged 60 years and above was 17.2% [3]. Approximately $^1/_3$ of these elderly fallers had recurring falls [3]. Besides old age, postural control can also be weakened by dieases, such as Parkinson's disease, which then leads to higher prevalence of falls [4]. Falls in elderly may lead to higher mortality than motor vehicle accidents, as shown in Table 1, where accidental deaths from falls in people aged 65 years and above are higher than those from motor vehicle accidents [5].

Table 1 Death rates, by age group and cause of death among adults aged 65 and over: United States, 2012–2013 [5].



Thus, postural control is an important measure for elderly persons. This report aims to describe the background and approach to designing a prototype light-weight and wearable device that can objectively quantify postural sway in elderly persons or people with balance problems

Postural Instability

The balance system of a person declines with age or as a result of diseases, leading to poor balance control and subsequent accidental falls [2, 4-7]. Poor postural stability has been shown to be a risk factor for falls among elderly persons, particularly standing or walking on uneven surfaces or in the presence of environmental hazards, such as slippery floor or poor lighting [1-2, 4-8]. Studies have in fact demonstrated that fallers have 33-34% larger postural sway than non-fallers [8].

According to Chan and colleagues [3], postural sway measurements could be valuable in identifying elderly people or persons with balance deficits as a fall prevention strategy. Several studies have in fact shown the people with postural instability are prone to fall [8, 9]. A prospective study of 100 adults aged between 62 and 96 years has shown that the quadratic mean of the mediolateral displacement, while having the participants stood blindfolded, is predictive of a fall in the following 12 months, with an accuracy of 67% [9].

Posture Sway

Posture defines an upright orientation of the human body with respect to the Earth, and it is a vertical angular measurement [10]. Good postural balance enables the human body to maintain a dynamic control. This naturally prevents accidental fall. Any person who is standing still on a supporting surface will not be absolutely still. He or she will experience front and back (anteriorposterior), and side to side (mediolateral) postural sway. Figure 1 below shows the swaying movement at five different points over time, W and R will remain the same during quiet standing. The human body standing pivoted at the ankle is similar to the inverted pendulum, providing estimation of the static acceleration with respect to gravity [10].

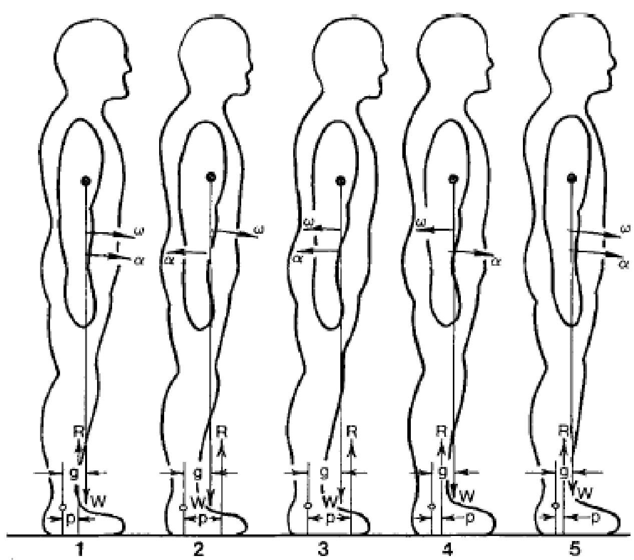


Figure 1 Subject swaying back and forth while standing quietly on a force platform [9].

Literature Review

In the following sections, different tools used to measure postural control will be reviewed.

Force Platform

The force platform, (Figure 2) is commonly employed to assess for postural control as well as baseline for rehabilitation [11-15]. It measures the ground force reaction and moment using the strain gauge load transducer [14]. The position and orientation of the strain gauge can be determined based on the desired output [14]. In one study involving 28 healthy participants, reliability and validity of the force platform was established, demonstrating that the force platform was sensitive and able to discriminate steadiness among participants [11] postural balance data acquired by the force platform has further been shown to have predicted value for subsequent fall among older people [12]. However some of the limitations of the force platform are its high cost, time taken in measurement and calibration, and unavailability in most clinics [11, 13].

Figure 2 The Force Platform [14].

Nintendo Wii Board

Some researchers have adapted Nintendo Wii board (Nintendo, Japan, Figure 3). For calculation of body sway parameters [7]. This measures the centre of pressure, which serves as a portable substitute for the force plate. Setting up the Wii board can be very complex as the device is meant for gaming purposes, hence there is difficulty in calibrating the board with the computer for the forces in x and y axes [7].

Figure 3 Nintendo Wii Board [7].

Swaymeter

Clinicians and researchers with limited resources do not have equipment like force plates and motion analysis laboratories to measure ground reaction forces. Hence the manual swaymeter (Figure 4) is an alternative [6]. The swaymeter does not require electronics or any computer processing, because the assessment can be conducted in different health care facilities and settings. Many local clinics use the swaymeter to measure patients' postural sway. This is achieved by strapping an extended metal to a pencil to map out the postural sway tracing on a graph paper (Figure 5), before manually measuring the area [6]. An elderly person standing still may experience anteroposterior (front-to-back) and mediolateral (side-to-side) postural sway. The larger the area on the graph paper, the greater the postural sway, and therefore the poorer the postural balance or stability [4]. The manual estimation of the area of postural sway tracing is subject to rater's bias and is not objective. Nevertheless, the swaymeter is simple and inexpensive, but requires considerable amount of time to set up.

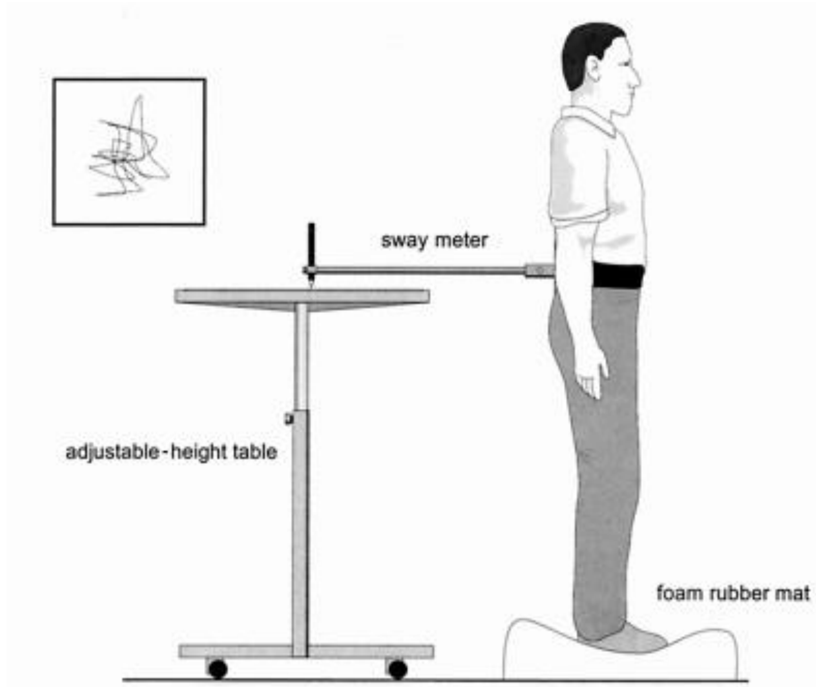


Figure 4 Swaymeter [1].

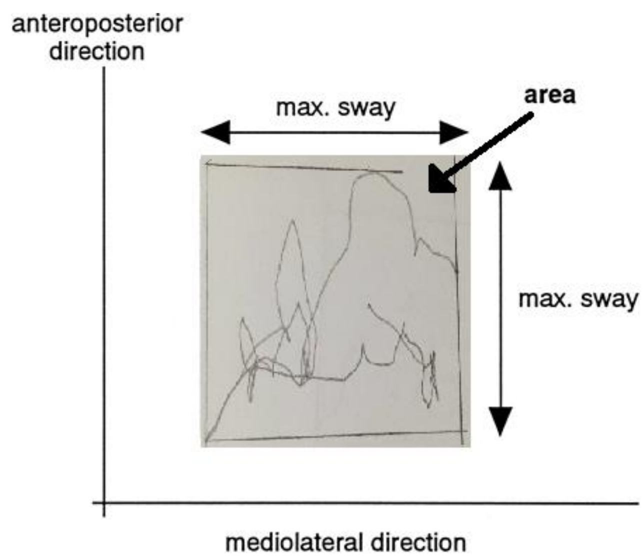


Figure 5 Postural sway tracing measurement

MTX Xsens Sensor

Finally, some researchers have developed the use of motion tracking as a means to record postural sway [4]. In one study participants wore the MTX Xsens sensor (Figure 6) on the posterior superior iliac spine (PSIS) at the lumbar spine level of L5 [4]. The sensor will record streamed data to a laptop wirelessly via Bluetooth technology. In the horizontal plane comparing the force plate measures with MTX Xsens sensor, figure 7 below shows the size and jerkiness traces to be large for mild untreated Parkinson's disease person and even larger in the moderate and untreated Parkinson's disease person. Results have demonstrated that using a body-worn accelerometer measuring postural sway has to be sensitive, valid and reliable for patients with Parkinson's disease [4].

Figure 6 MTx Xsens human motion tracker [4].

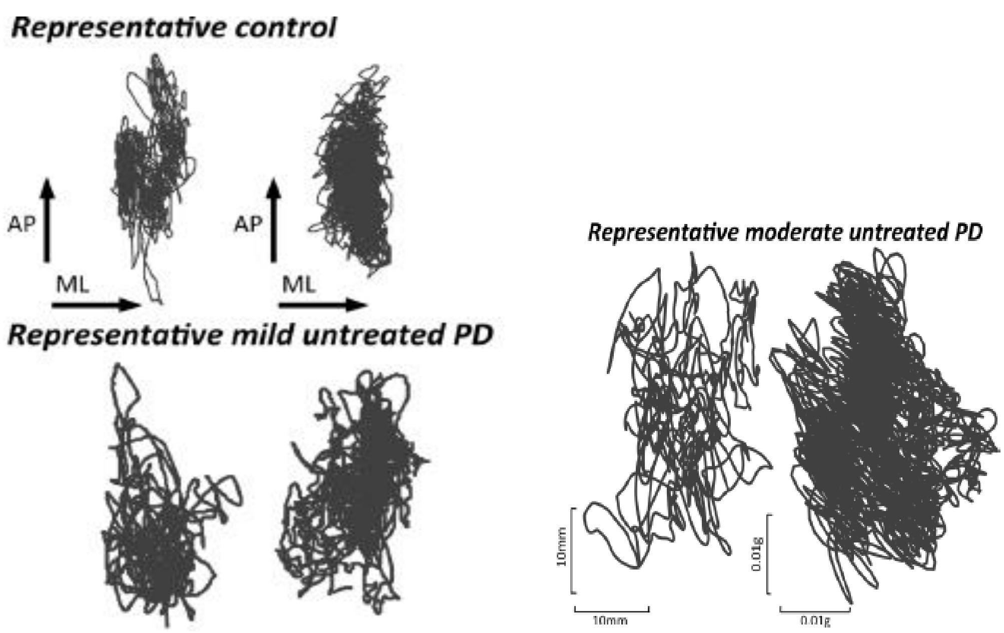


Figure 7 Centre of pressure (left panel) and acceleration (right panel) traces in the horizontal plane for three representitive subjects [17].

Similarly the correlations between the force platform and MTx Xsens sensors for person with multiple sclerosis (rho = 0.804 – 0.378), have a wide range of values which indicates both are highly correlated [13]. MTX Xsens sensors placed on the sternum, sacrum, right and left lower leg and lumbar spine level L5 have been compared, but only those from the lumbar spine can be used for analysis as it provides the most consistent result obtained from the accelerometer [15]. However, the MTX Xsens has been discontinued from the market since 31st August 2014 [17-20]. There are similar products from Xsens that substitutes the MTX model, now known as the MTi-1 a semiconductor chip on a printed circuit board which requires further wiring to power up the board and a protection casing, which cost approximately S$1,000 or more. Another model, known as MTw Arwinda, is rather well equipped with rechargeable battery, wifi wireless functions, comes with specially designed straps. This model comes with 6 ready to use motion trackers and a charging port which cost up to more than S$7,000 [20]. Since the late 1990s, literature supporting validation of the use of such motion trackers to measure postural sway has emerged, however its widespread adoption in clinics is not feasable because of the high cost and the complex computing required in calibrating the device before usage [17-21].

Accelerometer

A sensor known as an electro-mechanical device is able to measure static and dynamic forces of acceleration. Depending on the amount of static forces due to gravity it can identify the angle the device has tilted with respect to the ground. Dynamic forces of vibration and movements can analyze how the device moves [18]. Piezo-electric crystal-type accelerometers are deemed to be large and clumsy, thus development trend has been towards the field of microelectronics and micro electro-mechanical systems accelerometer [19], which can now be found in many popular application such as mobile devices, vehicles and aircrafts [18-19].

Micro Electro-Mechanical Systems or MEMS is a term coined around 1989 by Prof. R. Howe [17]. MEMS are mechanical devices that are built on a semiconductor chips, ranges from size 20 micrometers to 1 mm with components. This helps to lower cost, based on the low material usage, small size and common application in many mechanical purposes, such as the video game controller and mobile phone [19].

The capacitive-type MEMS accelerometer has been commonly used. It is known for having high and accurate sensitive measurements as well as transduction mechanism, but it basically is insensitive to temperature, hence the capacitive type is more robust and stable as compared to the others available in the market [19].

Aims and objectives

The foregoing background literature review suggests that there is a variety of methods available to clinicians and researchers to measure postural stability in people. However, most are either costly or subjective in measurements. Therefore this project aims to develop a low-cost method for measuring postural sway.

One major issue in measuring the postural sway with the use of a manual swaymeter in clinics would be the long set up time and unreliable measurement method, hence creating inconsistency in obtaining the measurements. Different clinicians and researchers have different methods to calculate the postural sway, as they consider different sway-related measures. There has been no consensus as to which specific sway-related measures should be used in obtaining the measurements [4]. Hence, this project also aims to devise a tool which collects data that can be processed and translated into clinically meaningful and understandable outcomes for research, rehabilitation and assessment.

Decreasing the hassle in set-up and reducing the amount of complex computing are important goals that need to be incorporated into the design of a new measurement tool for postural sway. Devising a wearable belt gadget with adjustable straps that can cater to the varying sizes of different individuals is another aim of this project. The device can be used at one's convenience regardless of the environment or setting. An accelerometer sensor is valid and reliable and can acquire static measurements ranging from a healthy individual, to one with postural instability (e.g. patients with Parkinson disease).

Methodology

Figure 8 shows the implemented method using the accelerometer to acquire swaying measurement.

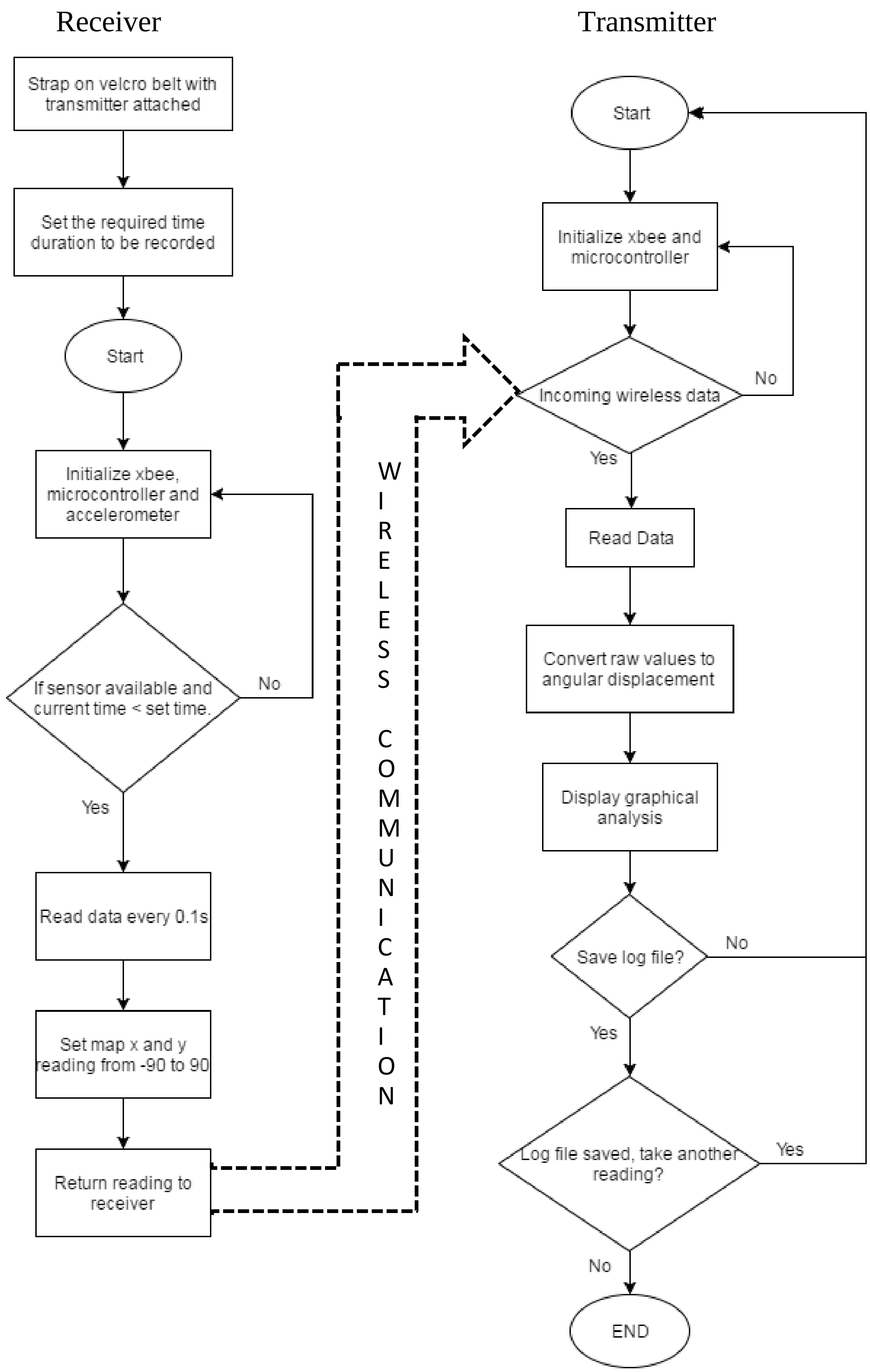


Figure 8 Prototype System flow

As shown in figure 6, is the system flow of the method implemented. Secure the Velcro belt on the subject waist and attach the transmitter on the belt at the back of the waist, follow by setting the desired time required for the measurement. When adjustment is done, switch on the power button of the transmitter and run the program with the receiver attached to a computer or laptop, graphical analysis of the measurement will be displaying in real time. Once the test has ended, the user can choose to restart the test, click on a button to save the current log file or end the program.

Implementation Process

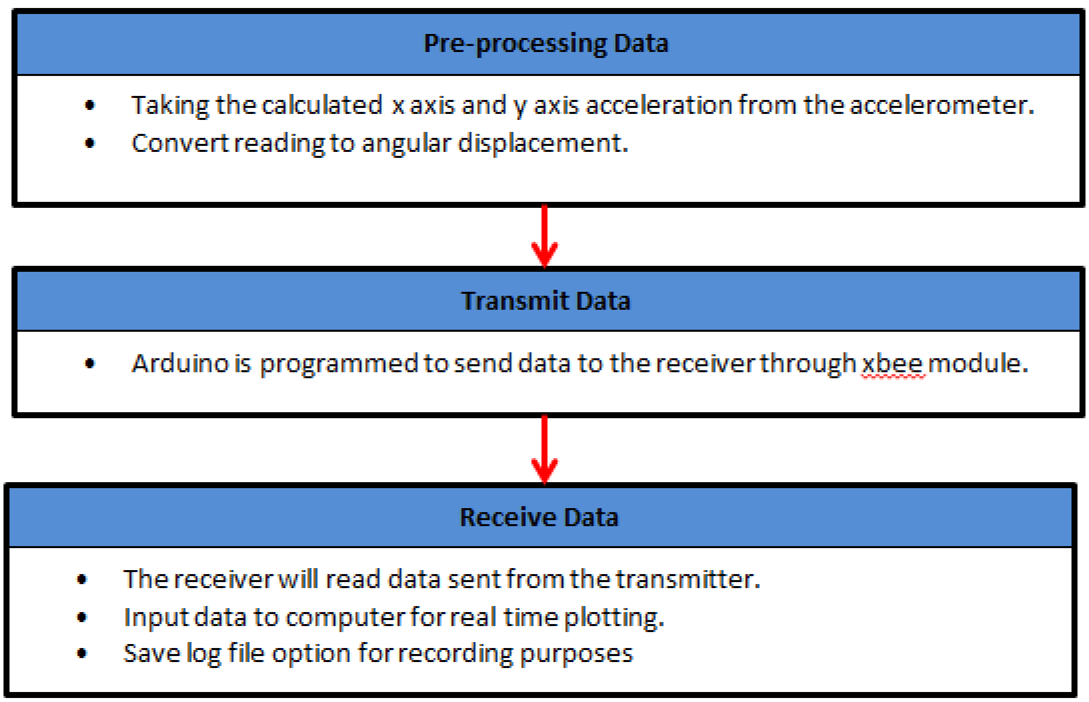


Figure 9 Implementation process flow

The process will begins by reading the calculated x and y axis from the accelerometer while ignoring the z axis, which is not required. Value of the readings will be converted into angular displacement before sending the data to the receiver wirelessly through the paired Xbee module. The receiver will read any incoming wireless data from the transmitter, data will be transferred out to the computer and display graphical results in real time. If user clicks on the log button, a log file will be saved which can be open using text document.

Design Concept

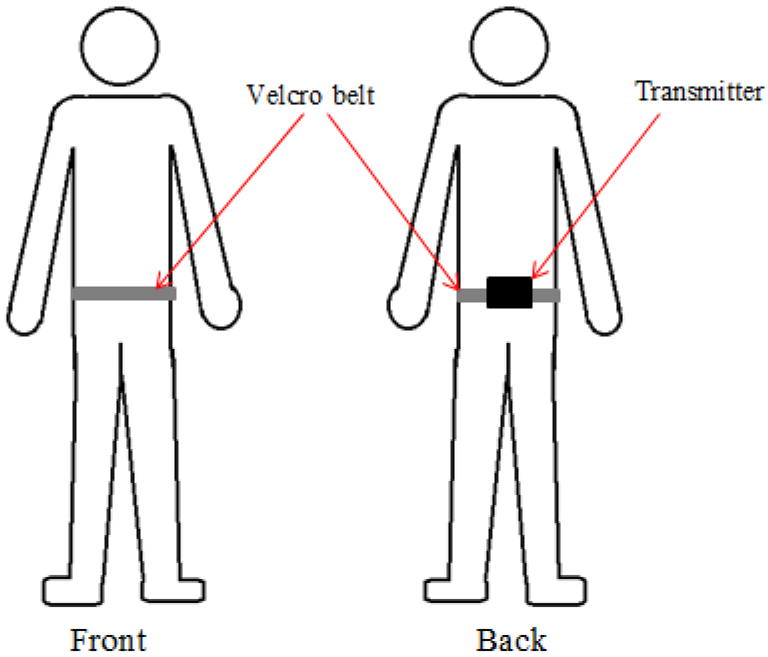


Figure 10 Design concept for prototype

The design concept in figure 8 illustrates an idea of how to measure postural sway. The transmitter will be placed on the Velcro belt at the posterior superior iliac at lumbar the level of L5 [17], the primary measurement will be read by the accelerometer sensor inside the transmitter programmed with the Arduino 1.6.6 software to transmit to the receiver to display graphical analysis using the Processing 3 software.

Tilt Motion

There has been no consensus to which sway related measures should be considered [4]. Therefore there are many different methods to measure a posture sway. Taking a sway motion of a body standing straight up is similar of an inverted pendulum, hence able to evaluate the motion by calculating the static acceleration due to gravity [9]. Since the accelerometer can measure both static and dynamic accelerations [21], illustration in figure 9 shows how the sensor calculate the static acceleration of the subject's tilt motion can now measure postural sway. This project requires an accelerometer sensitive enough to pick up tilt motions.

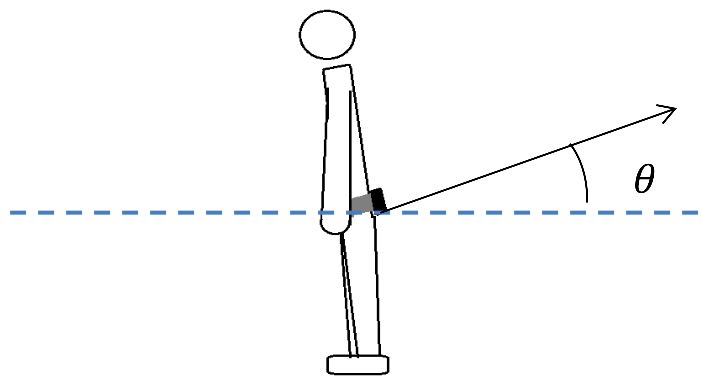


Figure 11 Example of a subject swaying forward.

Tilt measurement

Figure 10 shows the example of an accelerometer placed perpendicularly with respect to the earth and figure 11 shows the example when an accelerometer is being tilted.

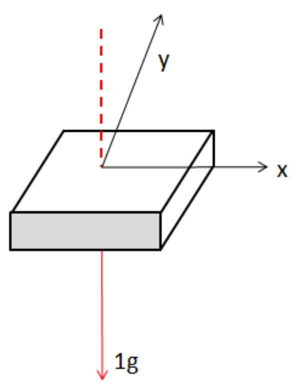


Figure 12 Accelerometer Orientation

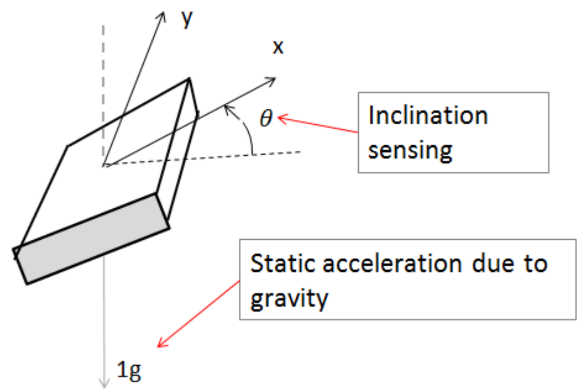


Figure 13 Tilt orientation of accelerometer

The tilted accelerometer illustrates the calculation of a single axis. Showing how the accelerometer is able to calculate static measurements, the x axis elevates where there is an inclination sensing which will affect the acceleration. According to the sine of the angle θ between the x axis and the horizontal plane, the output acceleration is [23]

$$x_{output}[g] = 1g \ * \ \sin(\theta)$$

However in this project, measuring the postural sway will be in angular displacement instead of g-force, hence:

$$\theta = sin^{-1}\left(\frac{x_{output[g]}}{1g}\right)$$

Hardware Architecture and Material

The project architecture compromises of a computer or laptop, USB cable, Arduino Nano, Sparkfun Redboard, 2 XBee modules, Xbee wireless shield, Xbee USB adapter, 3 axis capacitive accelerometer sensor, box casing, velcro belt and 9v battery refer to Appendix for hardware components. The goal of the project is to apply the use of low powered capacitive accelerometer, 12 bits resolution to measure postural sway.

Accelerometry

The principle of a force balance capacitive accelerometer has a capacitive divider a two capacitors connected in series with a common central plate. As shown in figure 10, during rest the two capacitors are equal in value, with the voltage output of the central plate at zero. Where there is acceleration being applied, the central plate will move towards one of the fixed plates causing the distance between the capacitors and the central plate to be different shown in figure 11, producing a signal at the central plate. The amplitude of the output signal will change with respect to the acceleration applied to the sensor [26]. Hence under static conditions, the output of the accelerometer reflects the degree of tilt in the device, which can be determined, and corrected for using basic trigonometry [27].

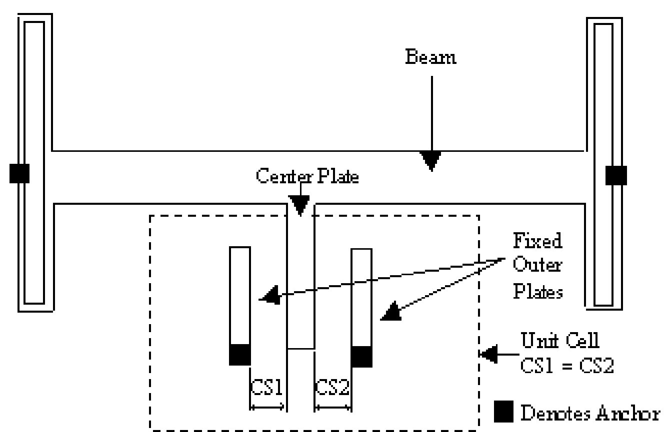


Figure 14 Diagram of the sensor at rest [26].

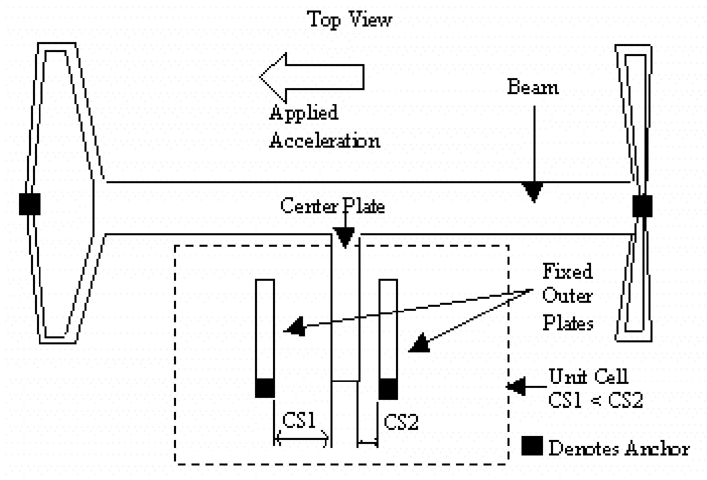


Figure 15 Sensor responding to applied acceleration [26].

Hardware Architecture and Data Collection

Transmitter Hardware Circuit

The figure below shows the schematic diagram and the connections of the transmitter circuit.

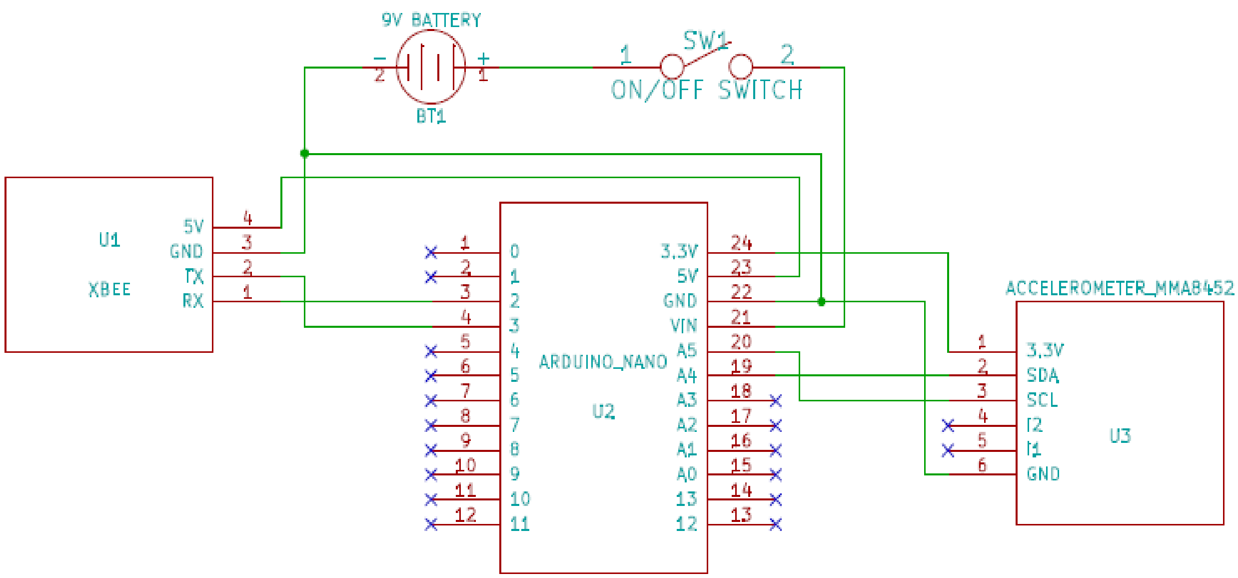


Figure 16 Transmitter hardware circuit.

System Flow

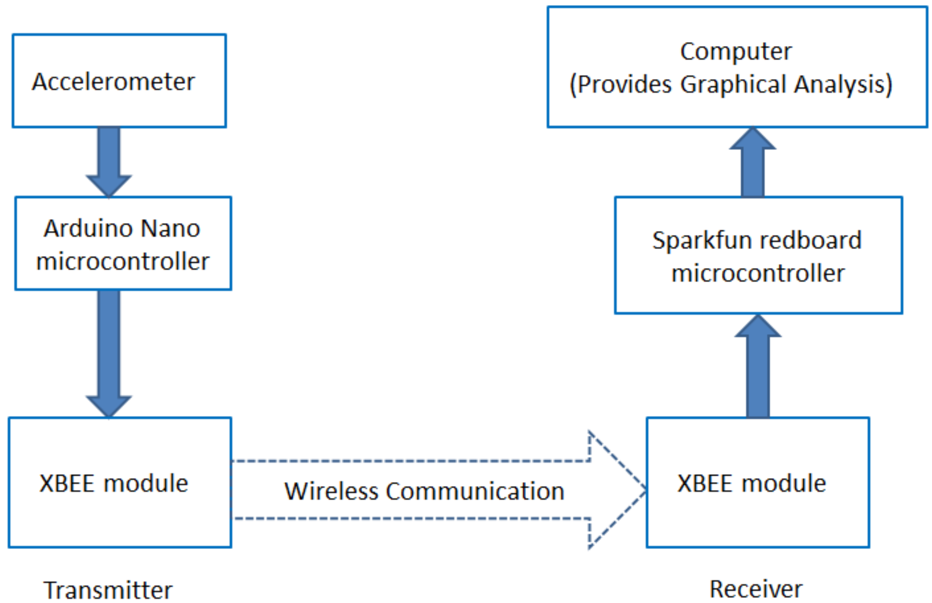


Figure 17 System Flow Architecture.

Transmitter Device

1. 3 axis Accelerometer sensor: Read static acceleration.
2. Arduino Nano: Collect reading from the sensor.
3. Xbee USB adapter: For Arduino board to communicate with Xbee module.
4. Xbee: Transmit data to the paired Xbee.

When the transmitter device is switched on, it will start reading for any static acceleration, while the microcontroller is programmed to collect the values from the sensor and send it to the Xbee module to constantly send data out.

Receiver

1. USB cable: To help the microcontroller communicate and send data with the computer
2. Sparkfun Redboard: To collect incoming data from the Xbee to send it to the computer.
3. Xbee wireless shield: For the Redboard to communicate with the Xbee
4. Xbee: Transmit data to the paired Xbee.

The receiver will be powered up by connecting it to the computer with the USB cable, the microcontroller is programmed to start reading for any incoming wireless data. When there is any data received, it will be sent to the computer.

Wireless Communication

The X-CTU software is used to configure both Xbee modules in the same network in order to pair up both devices. A baud rate of 9600 is set for the serial communication between both Xbee to communicate wirelessly.

Baud rate is a block bits that is sent over a serial line in communication at a certain rate, as known as bit per second (bps). Consist of different bits which are the start bit, stop bit, parity bit and data bit. The typical communication rates are 1200, 2400, 4800, 9600, 14400, 19200, 38400, 57600, 115200, 1280000 and 256000 baud rate. As the baud rate increases, the rate in sending out signal increases too. If the baud rate is too fast, the clock and sampling periods cannot keep up, thus causing errors and unreliable readings [25].

Figure 18 A serial frame. Some symbols in the frame have configurable bit sizes [25].

I²C Interface

An I^2C interface provides reliable data because it is noise free and able to support up to 1008 slave devices by using two wires. It can also support multi-master system to have more than one master to communicate with every device on the bus [28]. The MMA8452Q accelerometer will communicate with the microcontroller through the serial clock line (SCL) and the serial data line (SDA) as shown in the diagram below.

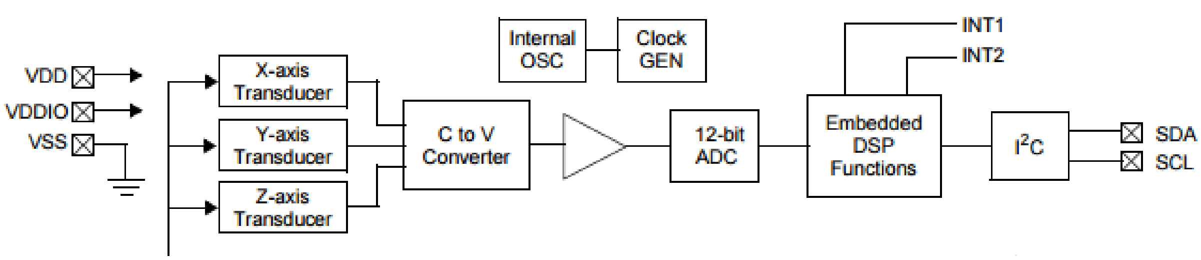


Figure 19 Block diagram of MMA8452Q function [29].

Final Prototype Device

Figure 20 Transmitter Hardware.

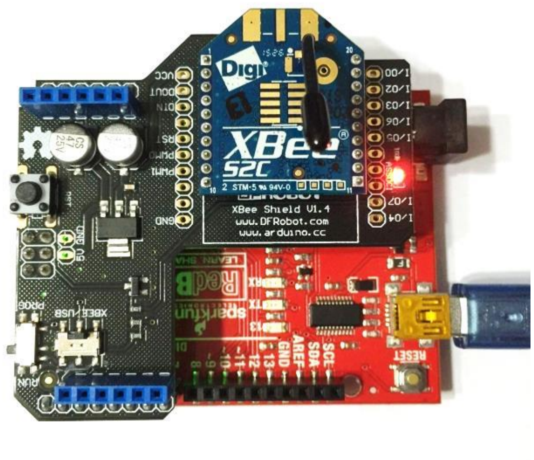


Figure 21 Receiver Hardware.

Figure 17 and 18 shows all components being assembled according to specific hardware circuit, for the use of accelerometer sensor to measure postural sway. The final prototype device is light in weight and portable.

Figure 22 Prototype fitted on subject (Back view)

Figure 23 Prototype fitted on subject (Side view)

Figure 19 and 20 shows subject fitted with the velcro belt and the transmitter attached on it, doing the standard quiet standing test standing on the rubber foam mat for postural sway measurement.

Software

Graphical Analysis

The software used to display the graphical analysis is Processing 3. Displaying two types graph in real time, on the left side of the Accel Grapher shows the angular displacement against time. Shown in the graph has a limit of -90 to 90 degrees, when the subject is moving forward or to the right, the angular displacements is in negative value. While subject moving backwards or to the left, the angular displacement is in positive value, front and back will be represented in yellow color while left and right is represented in blue color.

Figure 24 Accel Grapher, graphical analysis design using Processing 3.

- On the right side of the Accel Grapher from the bottom right, labelled max_xneg, max_xpos, max_yneg and max_ypos will record only the maximum angular displacement of the front, back, left and right of the subject taken during the test.
- On the right side with a cross labelled front, back, left and right is the motion capture graph, there will be a red line displayed during the test in real time showing the motion of the subject and leaving grey traces of the motion recorded during the test.

• On the top right of the labelled xpos and ypos will display the current angular displacement of the subject. The xpos and ypos will display positive or negative value to discriminate between fron, back, left and right.

• The white rectangle box labelled log, is a button that can save up a data log as a text document with all the readings taken during the test for assessment purposes.

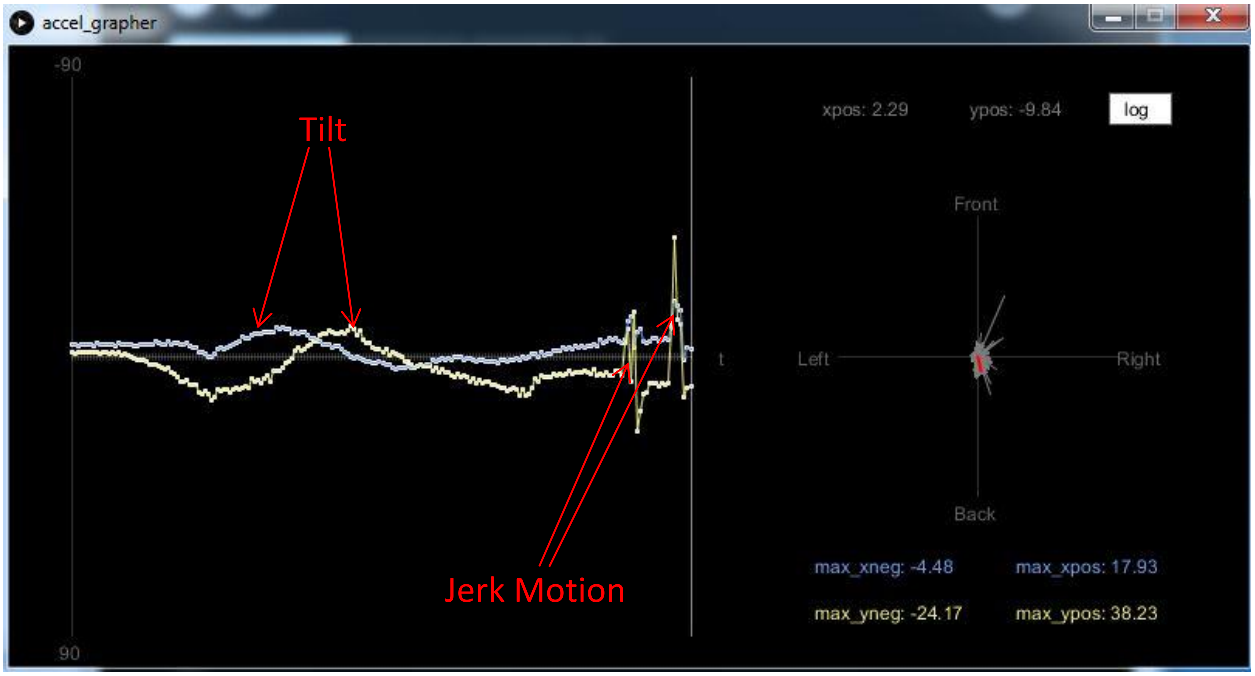


Figure 25 Graph results shown in Accel Grapher.

As shown in figure 22 is a test result from a postural sway test, blue color represents the left and right motion and yellow represents front and back motion. The graph on the left shows a linear wave which represents a tilting motion when the subject sway, the spike shown at the end of the graph represents jerk motion when the subject experiences near falling and pulls back using their waist.

Test

The swaymeter has been used by many local clinics and hospitals. Ten volunteers were recruited as subjects to undergo postural sway measurements using the manual swaymeter and the prototype. All subjects are healthy, except for subject (10), who had an ankle sprain at the time of testing. All subjects were tested according to the standard postural sway protocol, that is, quiet standing on a rubber foam mat of medium density for 30 s.

Results and Discussion

Results are shown in (table 3) were taken from the swaymeter by measuring displacement length of the anteroposterior and mediolateral 2D drawing. Results shown in (table 4) were taken from the prototype by calculating the difference between the front and back, right and left angular displacement.

Table 2 Subjects age and gender

Subject	Age	Gender
1	*48*	female
2	*76*	male
3	*19*	male
4	*21*	female
5	*21*	female
6	*26*	male
7	*73*	female
8	*25*	male
9	*48*	male
10	*25*	Female

Table 3 Results taken from the swaymeter

Swaymeter			
Subject	Anteroposterior	Mediolateral	Setup time
1	*3.1cm*	7.5	6min 36s
2	*5.1cm*	7.9	4min 20s
3	*2.1cm*	2.4	4min 10s
4	*2.2cm*	7.5	3min 15s
5	*2cm*	1.5	2min 47s
6	*2.2cm*	2.8	3min
7	*3.5cm*	6.2	4min 21s
8	*2.5cm*	4.9	3min 15s
9	*2.3cm*	3.4	6min 40s
10	*4.7cm*	5.4	3min 27s
Mean			4mins

Table 4 Results taken from the prototype

Prototype			
Subject	Front & Back tilt	Left and Right tilt	Setup time
1	*4.92°*	6.2	1min 30s
2	*9.76°*	7.5	1min
3	*6.85°*	3.25	47s
4	*5.44°*	4.84	50s
5	*3.78°*	3.16	30s
6	*5.36°*	3.65	1min 5s
7	*7.65°*	5.19	42s
8	*4.31°*	6.6	45s
9	*4.92°*	4.63	1min 16s
10	*11.25°*	6.24	2min
Mean			63s

A Pearson product-moment correlation coefficient was calculated to measure the linear correlation between the swaymeter and the prototype measurements in terms of 2D mapping and angular displacement. The formula used to calculate is as follows:

$$\boldsymbol{Correlation}\ (\boldsymbol{x},\boldsymbol{y}) = \frac{\sum(\boldsymbol{x}-\overline{\boldsymbol{x}})(\boldsymbol{y}-\overline{\boldsymbol{y}})}{\sqrt{\sum(\boldsymbol{x}-\overline{\boldsymbol{x}})^2\sum(\boldsymbol{y}-\overline{\boldsymbol{y}})^2}}$$

r (Anteroposterior, Front and Back tilt) = 0.873 (3 significant figure)

r (Mediolateral, Right and Left tilt) = 0.798 (3 significant figure)

The results from the tests have demonstrated that the swaymeter and the prototype were highly correlated; both results were more than 0.5 close to 1. From the above tables 2 and 3, to set up the prototype appears to be faster than the swaymeter. The Velcro belt was able to fit the body sizes of all the volunteers, whilst the sensor was able to detect the slightest sway movement.

There are two types of graphical outputs, as shown in the figure 24 and 25 below. The graphs show that the prototype is able to discriminate between postural sway of young adults and elderly persons. This observation indeed agrees with current research findings that show that postural sway is greater in elderly than younger people [2]. Similarly, the prototype appears to be sensitive in identifying persons with support balance affected by injury, such as ankle sprain (figure 28), this shows that a person with low peroneal muscle strength demonstrates a larger sway area [27].

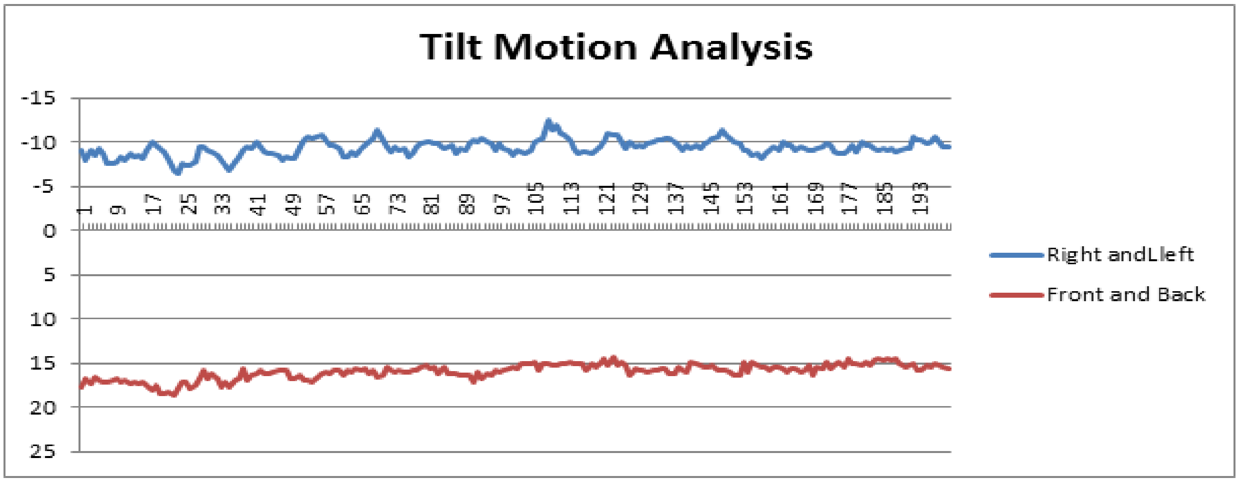


Figure 26 Tilt motion of a healthy young subject.

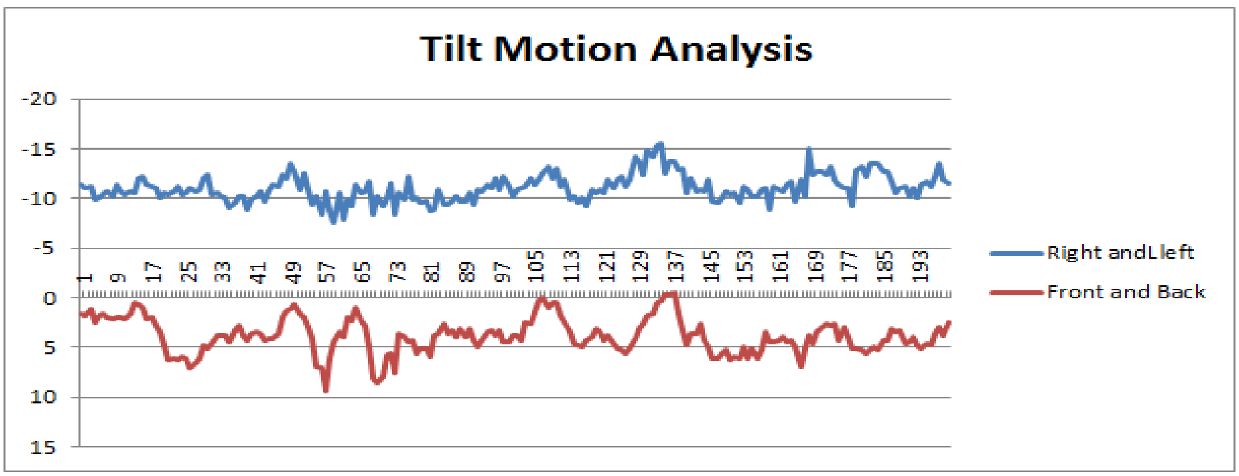


Figure 27 Tilt motion of a healthy an elderly subject.

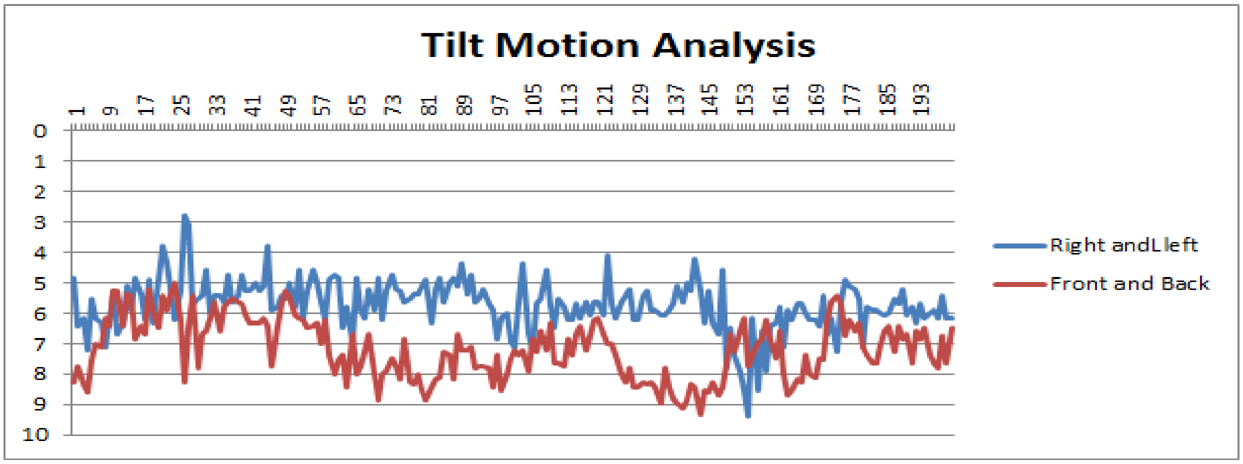


Figure 28 Tilt motion of a young subject with sprained ankle.

Limitation

The prototype was proved to be accurate for being able to discriminate between young and elderly subjects, there is no right or wrong way for measuring a postural sway, however there was no opportunity to test on elderly who are prone to fall or patients with Parkinson disease. The prototype still requires more tests on young and elderly subjects, to identify if there is improvement shown before and after rehabilitation.

Strength

The prototype is able to attain a near 1 correlation with the current swaymeter commonly used by clinics and hospitals. The components found in the prototype are inexpensive and are easily available, simple hardware and circuitry helps to rectify fix any issues easily. The design and concept is flexible and does not have complex computing thus it is able to be further improve to fit a wide range of functions.

Conclusion

There are many other methods to measure postural sway; however the use of an accelerometer to measure postural sway is considered inexpensive, lightweight and portable alternative, made easy for physiotherapist to do assessment on patients during home rehab or visits.

Future development

Future development could address the limitations discussed above. Some of the consideration might be further studies to develop normative data for healthy individuals. These could then be used as normative reference for rehabilitation goals for patients with postural balance deficits.

Secondly, the prototype has potential to create a task-profiling system that identifies different amplitude and frequency characteristic of postural sway in variety of tasks, for example, reaching for shelves, picking up items from the floor or walking on an uneven surface.

Thirdly, more prototypes can be used for measuring the postural sway all at the same time, showing analysis at the chest, waist, and both ankles which all plays a part when a person is swaying. Showing the cause of the postural sway, thus rehabilitation or medication can be arranged to help the root of the problem.

Lastly, the prototype works wirelessly, hence utilizing the accelerometer's full potential to measure dynamic acceleration, as an alternative over the moving platform. The addition of the gyroscope sensor; Gait analysis help to provide information of how a person walks, which is risk factor to how a person could fall, the combination of both accelerometer and gyroscope can provide more detailed analysis as well as gait rehabilitation as well.

References

[1] Lord, Stephen R., Hylton B. Menz, and Anne Tiedemann. "A physiological profile approach to falls risk assessment and prevention." Physical therapy83, no. 3 (2003): 237-252.

[2] Era, P., P. Sainio, S. Koskinen, P. Haavisto, M. Vaara, and A. Aromaa. "Postural balance in a random sample of 7,979 subjects aged 30 years and over." Gerontology 52, no. 4 (2006): 204-213.

[3] Chan, K. M., W. S. Pang, Chye Hua Ee, Y. Y. Ding, and P. Choo. "Epidemiology of falls among the elderly community dwellers in Singapore."Singapore medical journal 38, no. 10 (1997): 427-431.

[4] Mancini, Martina, Arash Salarian, Patricia Carlson-Kuhta, Cris Zampieri, Laurie King, Lorenzo Chiari, and Fay B. Horak. "ISway: a sensitive, valid and reliable measure of postural control." Journal of neuroengineering and rehabilitation 9, no. 1 (2012): 1.

[5] Kramarow, Ellen, Li-Hui Chen, Holly Hedegaard, and Margaret Warner. "Deaths From Unintentional Injury Among Adults Aged 65 and Over: United States, 2000–2013." NCHS data brief 199 (2015): 1-8.

[6] Sturnieks, Daina L., Ria Arnold, and Stephen R. Lord. "Validity and reliability of the Swaymeter device for measuring postural sway." BMC geriatrics 11, no. 1 (2011): 1.

[7] Clark, Ross A., Adam L. Bryant, Yonghao Pua, Paul McCrory, Kim Bennell, and Michael Hunt. "Validity and reliability of the Nintendo Wii Balance Board for assessment of standing balance." Gait & posture 31, no. 3 (2010): 307-310.

[8] Lord, Stephen R., and Sally Castell. "Physical activity program for older persons: Effect on balance, strength, neuromuscular control, and reaction time." Archives of Physical Medicine and Rehabilitation 75, no. 6 (1994): 648-652.

[9] Maki, Brian E., Pamela J. Holliday, and Anne K. Topper. "A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population." Journal of gerontology 49, no. 2 (1994): M72-M84.

[10] Winter, David A. "Human balance and posture control during standing and walking." Gait & posture 3, no. 4 (1995): 193-214.===[5]

[11] Goldie, Patricia A., T. M. Bach, and O. M. Evans. "Force platform measures for evaluating postural control: reliability and validity." Archives of physical medicine and rehabilitation 70, no. 7 (1989): 510-517.

[12] Piirtola, Maarit, and Pertti Era. "Force platform measurements as predictors of falls among older people–a review." Gerontology 52, no. 1 (2006): 1-16.

[13] J. M. Huisinga, M. Mancini, and F. B. Horak, "do we really need a force platform?: accelerometry to measure postural sway in healthy and pathological populations," in http://www.asbweb.org/. [Online]. Available: http://www.asbweb.org/conferences/2013/abstracts/126.pdf. Accessed: Apr. 6, 2016.

[14] Berme, Necip. "Multi-component force and moment measuring platform and load transducer." U.S. Patent 6,354,155, issued March 12, 2002.

[15] "GP Musculoskeletal system modeling lab," in University of Connecticut. [Online]. Available: http://msml.uconn.edu/amti-uconn-collaboration-project/. Accessed: Apr. 6, 2016.

[16] Kamen, Gary, Carolynn Patten, C. Duke Du, and Steven Sison. "An accelerometry-based system for the assessment of balance and postural sway." Gerontology 44, no. 1 (1998): 40-45.

[17] F. Chollet and Hb. Liu, "“A (not so) short Introduction to Micro Electromechanical Systems," in memscyclopedia.org, 2015. [Online]. Available: http://memscyclopedia.org/Document/IntroMEMS.pdf. Accessed: Apr. 6, 2016.

[18] "A beginner’s guide to accelerometers," in Dimension Engineering LLC. [Online]. Available: http://www.dimensionengineering.com/info/accelerometers. Accessed: Apr. 6, 2016.

[19] Andrejašic, Matej. "Mems accelerometers." In University of Ljubljana. Faculty for mathematics and physics, Department of physics, Seminar. 2008.

[20] Xsens, "Home - Xsens 3D motion tracking," Xsens 3D motion tracking. [Online]. Available: https://www.xsens.com/. Accessed: Apr. 7, 2016.

[21] C. J. Fisher, "Using an Accelerometer for Inclination Sensing," in ANALOG DEVICES. [Online]. Available: http://www.analog.com/media/en/technical-documentation/application-notes/AN-1057.pdf. Accessed: Apr. 8, 2016.

[22] J. 0, "Serial communication," in Spark Fun. [Online]. Available: https://learn.sparkfun.com/tutorials/serial-communication/rules-of-serial. Accessed: Apr. 8, 2016.

[23] LaPierre, Charles M. "Persona1 Navigation Systern for the Visually Impaired." PhD dissertation, Carleton University, 1998. [24] Xsens, "Home - Xsens 3D motion tracking," Xsens 3D motion tracking. [Online]. Available: https://www.xsens.com/. Accessed: Apr. 7, 2016.

[24] Kavanagh, Justin J. "Lower trunk motion and speed-dependence during walking." Journal of neuroengineering and rehabilitation 6, no. 1 (2009): 9.

[25] SFUPTOWNMAKER, "I2C," in Spark Fun. [Online]. Available: https://learn.sparkfun.com/tutorials/i2c. Accessed: Apr. 9, 2016.

[26] Freescale Semiconductor. (2015, Jun.). "MMA8452Q 3-Axis, 12-bit/8-bit digital accelerometer” www.NXP.com, 2015. [Online]. Available: http://cache.nxp.com/files/sensors/doc/data_sheet/MMA8452Q.pdf?fpsp=1&WT_TYPE=Data%20Sheets&WT_VENDOR=FREESCALE&WT_FILE_FORMAT=pdf&WT_ASSET=Documentation&fileExt=.pdf. Accessed: Apr. 9, 2016.

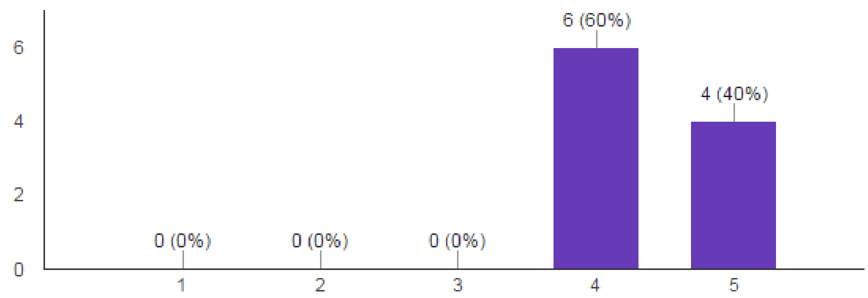
[27] Leanderson, J., A. Wykman, and E. Eriksson. "Ankle sprain and postural sway in basketball players." Knee Surgery, Sports Traumatology, Arthroscopy 1, no. 3-4 (1993): 203-205.

Appendix A

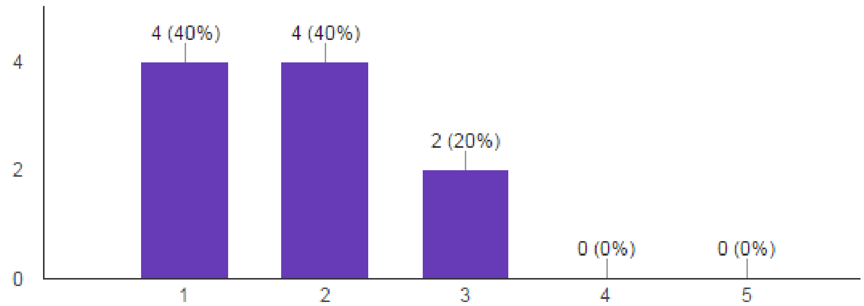
<u>Survey</u>

Automatic Wearable Posture Balance Meter For Elderly, a total of 10 surveys done by physiotherapists from Kwong Wai Shiu Hospital after my presentation, following statements are rated on scale of 1 (strongly disagree) to 5 (strongly agree).

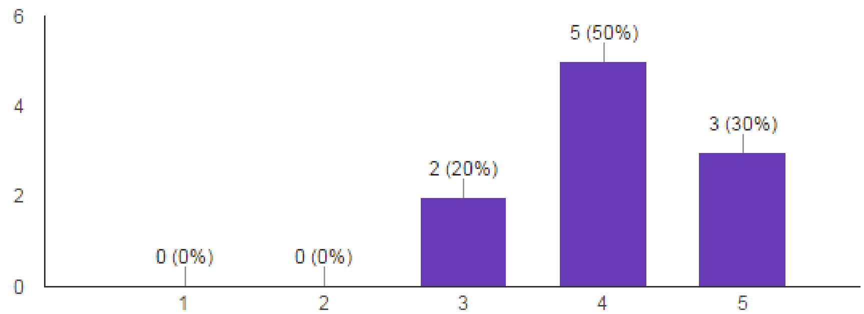
The set-up for the balance measurement is fast and easy. (10 responses)



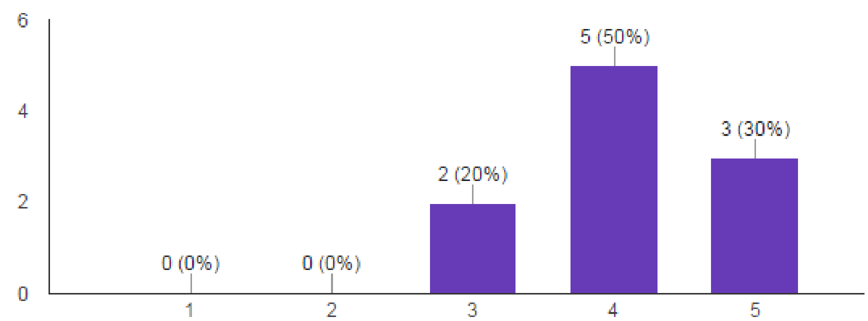
Patients will find the measuring test tiring. (10 responses)



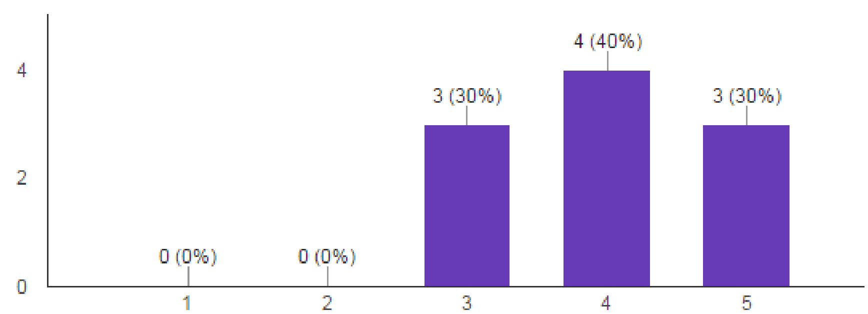
The analysis provides help for rehabilitation. (10 responses)



The analysis provides help for assessment. (10 responses)

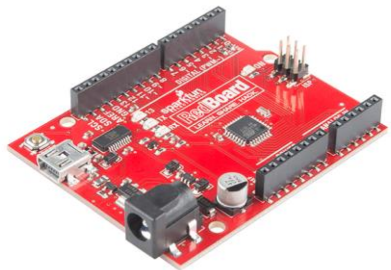


You are willing to use the device on your patients. (10 responses)



Appendix B

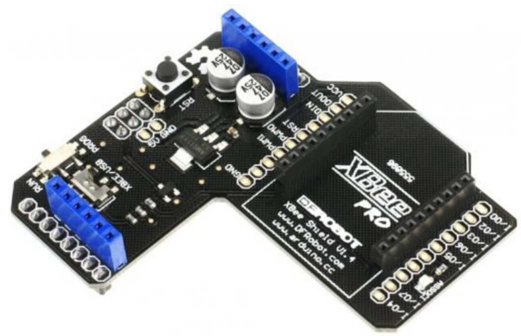
Hardware Components



SparkFun RedBoard - Programmed with Arduino

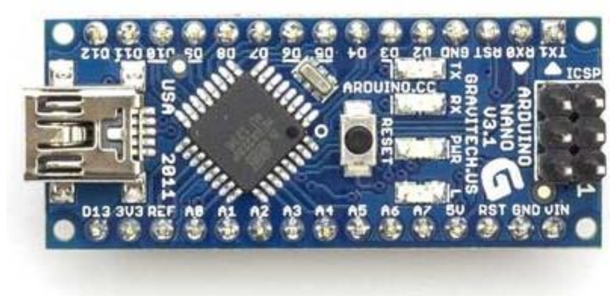
Triple Axis Accelerometer Breakout - MMA8452Q

XBee 3mW Wire Antenna – Series 2C (ZigBee Mesh)

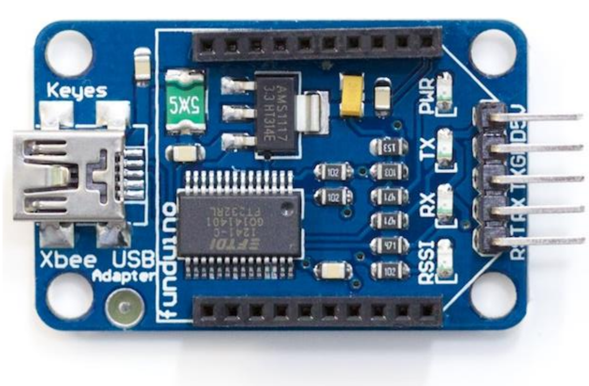


DFrobot - Xbee Shield for Arduino

USB cable



Arduino Nano 3.0 Usb Microcontroller



Funduino Xbee USB Adapter

Electrical 9V Battery Holder Case Box

Rocker Switch (Round)

Velcro Belt

Appendix C

Transmitter Arduino program code

```
// include libraries

#include <SoftwareSerial.h>

#include <Wire.h>

#include <SparkFun_MMA8452Q.h>


// declare variables

float xReading, yReading;

long lastReadTime;


// declare objects

SoftwareSerial xbee(2, 3);

MMA8452Q accel;


void setup()

{

	// for debugging

	Serial.begin(9600);

	// initialize xbee

	xbee.begin(9600);

	// initialize accelerometer

	accel.init();

}


void loop()
```

```
{
	// read data every 0.1 sec
	if (millis() - lastReadTime > 100){
		// if data coming in from sensor
		if (accel.available()){
			// read sensor
			accel.read();
			// map x reading to -90 90
			xReading = mapfloat(accel.cx, -1.0, 1.0, -90.0, 90.0);
			// map y reading to -90 90
			yReading = mapfloat(accel.cy, -1.0, 1.0, -90.0, 90.0);

			xbee.print(xReading);
			xbee.print(",");
			xbee.println(yReading);

			Serial.print(xReading);
			Serial.print("\t");
			Serial.println(yReading);
		}
		lastReadTime = millis();
	}
}

float mapfloat(float x, float in_min, float in_max, float out_min, float out_max)
{
	return (x - in_min) * (out_max - out_min) / (in_max - in_min) + out_min;
```

```
}
```

Receiver Arduino program code

```
// declare variables
String data;

void setup()
{
	// for data output
	Serial.begin(9600);
}

void loop()
{
	// if incoming wireless data
	if (Serial.available()){
		data = "";
		while (Serial.available()){
			// read data
			char c = Serial.read();
			data += c;
			delay(2);
		}

		// dump data out for processing
		Serial.print(data);
	}
}
```

Accel Grapher Processing 3 program code

```
import processing.serial.*;

Serial my_port;

//USER DEFINED SETTINGS
String PORTNAME; //define port name in settings.txt file. Follow the name seen in the Arduino IDE under ports.
int SAMPLESIZE; //define sample size in settings.txt file. Must be a factor of 400.

float[][] vals;
int array_index;
float max_xpos, max_xneg, max_ypos, max_yneg;
float raw_xpos, raw_ypos;
String in_string;
boolean is_done;

void setup()
{
    size(800, 400);
    String textlines[] = loadStrings("settings.txt");

    //printArray(Serial.list());
    //print("port name: ");
    //println(textlines[0]);
    PORTNAME = textlines[0];
    my_port = new Serial(this, textlines[0], 9600);

    SAMPLESIZE = int(textlines[1]);
    //println("Sample size: " + SAMPLESIZE);
```

```
    vals = new float[SAMPLESIZE][2];

    my_port.clear();
    //my_port.bufferUntil('\n');

}

void draw()
{
    background(0);

    draw_graph_outlines();

    update_graphs();

    show_extreme_values();

    check_if_done();

    fill(255);
    //text(mouseX + "," + mouseY, mouseX, mouseY);

    button_update();

    println(array_index);
}

void serialEvent(Serial my_port)
```

```
{
    if (!is_done)
    {
        if (my_port.available() > 0) in_string = my_port.readStringUntil('\n');

        if (in_string != null) {

            in_string = trim(in_string);
            //println("in_string: " + in_string);

            String[] numbers_string = split(in_string, ',');

            try
            {
                raw_xpos = float(numbers_string[0]);
                raw_ypos = float(numbers_string[1]);

                record_data();

                array_index = (array_index+1)%(SAMPLESIZE + 1); //update the array index
            }
            catch (Exception e)
            {
                e.printStackTrace();
            }
        }
    }
}
```

```
void record_data()
{
    if (!Float.isNaN(raw_xpos) && !Float.isNaN(raw_ypos))
    {
        vals[array_index][0] = -raw_xpos;  //translating to the y-axis, so must invert as well
        vals[array_index][1] = -raw_ypos;  //invert the y-axis from Cartesian to computer

        update_extreme_values();

        //println("array index: " + array_index);

        //if (array_index == 0)
        //{
        //      println("zero index: " + vals[array_index][0] + "    " + vals[array_index][1]);
        //}
    }
}

void update_extreme_values()
{
    if (raw_xpos >= 0 && raw_xpos > max_xpos) max_xpos = raw_xpos;
    if (raw_xpos < 0 && raw_xpos < max_xneg) max_xneg = raw_xpos;
    if (raw_ypos >= 0 && raw_ypos > max_ypos) max_ypos = raw_ypos;
    if (raw_ypos < 0 && raw_ypos < max_yneg) max_yneg = raw_ypos;
    //println(max_xpos + " " + max_xneg + " " + max_ypos + " " + max_yneg);
}
```

```
void show_extreme_values()
{
	textAlign(LEFT);
	fill(117, 158, 242);
	text("max_xpos: " + max_xpos, 650, 340);
	text("max_xneg: " + max_xneg, 520, 340);
	fill(240, 242, 117);
	text("max_ypos: " + max_ypos, 650, 370);
	text("max_yneg: " + max_yneg, 520, 370);

	fill(125);
	text("xpos: " + raw_xpos, 525, 45);
	text("ypos: " + raw_ypos, 620, 45);
	//text("array_index: " + array_index, 525, 50);
}

void check_if_done() {
	 if (array_index == SAMPLESIZE) is_done = true;
}
```

Button Processing 3 program code

```
boolean mouse_over = false;
color button_curr_color, button_default_color = color(255),
	button_highlight_color = color(100), button_activated_color = color(255, 0, 0);

PrintWriter pw;

boolean over_rect(int x, int y, int width, int height)
{
```

```
    if (mouseX >= x && mouseX <= x+width &&
        mouseY >= y && mouseY <= y+height)
    {
        return true;
    } else
    {
        return false;
    }
}

void write_log_file()
{
    if (pw != null)
    {
        pw = null;
    }

    int year = year(); int month = month(); int day = day(); int hour = hour(); int min = minute(); int sec =
second();

    pw = createWriter( str(day)+"_"+str(month)+"_"+str(year)+"__"+str(hour)+"_"+str(min)+"_"+str(sec) );

    for (int i=0; i<array_index; i++)
    {
        pw.println(vals[i][0] + " " + vals[i][1]);
    }

    pw.flush();
```

```
        pw.close();
}

void button_update()
{
        strokeWeight(1);
        stroke(100);
        fill(button_curr_color);
        rect(710, 30, 40, 20);

        mouse_over = over_rect(710, 30, 40, 20);

        if (mouse_over)
        {
                button_curr_color = button_highlight_color;
        } else
        {
                button_curr_color = button_default_color;
        }

        fill(0);
        text("log", 720, 45);
}

void mousePressed()
{
        if (mouse_over)
        {
```

```
        button_curr_color = button_activated_color;

        write_log_file();
    }
}
```

Graph Processing 3 program code

```
 void draw_graph_outlines()
{
    //lines
    strokeWeight(1);
    stroke(255, 255, 255, 50);

    //text
    fill(100);
    textAlign(CENTER, CENTER);

    //time graph
    pushMatrix();
    translate(40, height/2);
    line(0, -180, 0, 180); //axes
    line(0, 0, 400, 0);

    for (int i=0; i<SAMPLESIZE; i++) //tick markers
    {
        line( (i*1.0/(SAMPLESIZE-1))*400, 2, (i*1.0/(SAMPLESIZE-1))*400, -2);
    }
    popMatrix();
```

```
    text("-90", 40, 10);
    text("90", 40, 390);
    text("t", 460, 200);

    //burst graph
    pushMatrix();
    translate(625, height/2);
    line(-90, 0, 90, 0);
    line(0, 90, 0, -90);
    popMatrix();

    text("Right", 730, 200);
    text("Left", 520, 200);
    text("Front", 625, 100);
    text("Back", 623, 300);
}

void update_graphs()
{
    //time graph
    pushMatrix();
    translate(40, height/2);

    //moving ticker line
    stroke(255, 255, 255, 125);
    strokeWeight(1);

    int ticker_index = 0; //always 1 behind the array index because array index updated before this is called
```

```
	if (array_index>0) ticker_index = (array_index - 1);

	else if (array_index == 0) ticker_index = SAMPLESIZE - 1;


	line( ( (ticker_index)*1.0 / (SAMPLESIZE-1) )*400, -180, ( (ticker_index)*1.0 / (SAMPLESIZE-1) )*400,
180);


	//data points

	for (int i=0; i<SAMPLESIZE; i++)

	{

		noFill();

		stroke(255);

		ellipse( ( i*1.0 / (SAMPLESIZE-1) )*400, vals[i][0]*2, 2, 2);

		ellipse( ( i*1.0 / (SAMPLESIZE-1) )*400, vals[i][1]*2, 2, 2);




		if (i>0)

		{

			stroke(117, 158, 242); //color for the xpos

			line( (i*1.0 / (SAMPLESIZE-1) )*400, vals[i][0]*2, ((i-1)*1.0 / (SAMPLESIZE-1) )*400, vals[i-
1][0]*2 );

			stroke(240, 242, 117); //color for the ypos

			line( (i*1.0 / (SAMPLESIZE-1) )*400, vals[i][1]*2, ((i-1)*1.0 / (SAMPLESIZE-1) )*400, vals[i-
1][1]*2 );

		}

	}

	popMatrix();


	//burst graph

	pushMatrix();
```

```
    translate(625, height/2);

    for (int i=0; i<SAMPLESIZE; i++)
    {
        stroke(125);
        strokeWeight(1);
        line(0, 0, -vals[i][0], vals[i][1]); //invert back the xpos values since previously was inverted
    }

    stroke(255,0,0); //latest always on top
    strokeWeight(2);
    line(0,0, raw_xpos, -raw_ypos);

    popMatrix();
}
```