Development of Arm Exo-skeleton for Bicep Brachii Muscle

By

GOH LI YING

FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Development of Arm Exo-skeleton for Bicep Brachii Muscle

by

Goh Li Ying

A project dissertation submitted to the
Electrical & Electronics Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Approved:

____

A.P. Dr. Irraivan a/l Elamvazuthi
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

August 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

____
GOH LI YING

ABSTRACT

This report presents the study on design of arm exoskeleton for stroke rehabilitation purpose. The mechanical design of the exoskeleton focuses on few aspects of the arm exoskeleton which are length and the design of the exoskeleton and motor specification. Besides, the experiment of obtaining surface electromyography (sEMG) signal for repetition training for physiotherapy patient purpose is carried out to observe the difference in amplitude and muscle signal of different subjects (four males and four females) due to the amount of training and the angle of the training. The signals are filtered and the average of the root mean square of the data is compared.

ACKNOWLEDGEMENTS

First, I would like to thanks Universiti Teknologi Petronas for providing sufficient research materials to ease the research of my project. The nice and quiet environment contributes to the life of me as an undergraduate student.

Secondly, I would like to express my utmost gratitude to my supervisor, Dr Irraivan Elamvazuthi for his patience and sincere guidance towards me. Dr Irraivan has shared with me a lot of his experience in the robotic field throughout his research years that helps in inspiring me in my project.

Next, I would like to sincere appreciation to the master student of my supervisor, Ku Nurhanim. She is very willing to help me in any doubt throughout my project and share her experiences throughout her industry and researches experience.

Besides, I thank all my friends and lecturers that contribute to the success of my project. Their participation in the experimental part of the project is highly appreciated. Last but not least, I would like to thank my family the most. I am very thankful for having their moral support by my side always throughout my undergraduate student’s life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

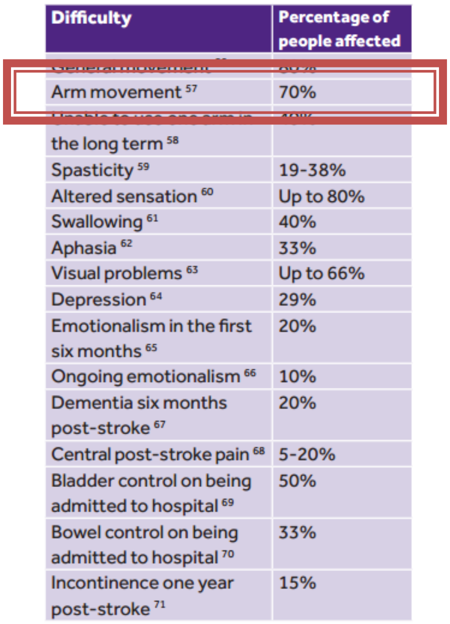
BMI	Body Mass Index
EMG	Electromyography
RMS	Root Mean Square
sEMG	Surface Electromyography

CHAPTER 1

INTRODUCTION

1.1 Exo-skeleton

World Health Organization states that 15 million people suffer from stroke around the global every year. Among all the stroke patients, 5 million of fatality cases and 5 million are permanently disabled [1]. More than half of the stroke survivors are left disabled and need to depends on others for everyday activities [2]. Exo-skeleton that first appears in 1956 [3] is the hope for disable people because it is able to help in the process of rehabilitation for stroke patients. Exo-skeleton is a robotic mechanism that can help physically disabled person to move their weak body parts near to normal by controlling the input for the robots. Many researchers have been done on different body parts but arm exo-skeleton has just started its milestone in this research field due to the complicated of the joints and muscles at the arm, wrist and fingers. There are different types of input to control exoskeleton and in this project, the input will be focused on surface Electromyography because it can obtain the muscle activities directly from the individual and hence produce higher accuracy and efficiency of exoskeleton.



Difficulty	Percentage of people affected
General movement	80%
Arm movement [57]	70%
Unable to use one arm in the long term [58]	40%
Spasticity [59]	19-38%
Altered sensation [60]	Up to 80%
Swallowing [61]	40%
Aphasia [62]	33%
Visual problems [63]	Up to 66%
Depression [64]	29%
Emotionalism in the first six months [65]	20%
Ongoing emotionalism [66]	10%
Dementia six months post-stroke [67]	20%
Central post-stroke pain [68]	5-20%
Bladder control on being admitted to hospital [69]	50%
Bowel control on being admitted to hospital [70]	33%
Incontinence one year post-stroke [71]	15%

Figure 1: Effects of Stroke [2]

In this project, focus is put on arm exo-skeleton due to the reason that 70% of stroke patients have arm movement difficulty and are unable to use one of their arm in long term.

1.2 Problem Statement

An arm exoskeleton will be developed to support the arm of a stroke patient. By evaluating and record the electrical activity produced by skeletal muscles, EMG signals can be obtained by using EMG sensors. By amplifying the signals, the muscle strength of the patient can be determined whether there is any improvement. In this project, focus will be given to test on normal healthy person to observe the improvement in muscle strength after doing few repetitions on different angle for training rehabilitation purpose.

The problem statements of this project are:

i) The facilities of rehabilitation for stroke patients are limited in hospitals and the cost for therapists is high

ii) Low efficiency of therapy sessions due to too many patients

In this project, the arm exo-skeleton prototype will be built and the analysis on the improvement of muscle strength using arm-exoskeleton of 8 different subject of healthy person in the same age group of different gender is carried out.

1.3 Objectives

- To design an arm exo-skeleton to help in movement for stroke patient
- To analyze the improvement in muscle strength of different subjects (in term of gender and BMI) after few times of training on his/her arm by using the built arm exo-skeleton.

1.4 Scope of Study

In this project, a simple prototype of arm-exoskeleton will be built to assist in helping stroke patients to do rehabilitation for their arm. After the prototype is built, EMG sensor will be placed at the biceps brachii of the subject as shown in Figure 2. By using the assistance of the built arm-exoskeleton, the signals from the sensor are acquired and analyzed to determine the muscle strength improvement of the subject after several trainings.

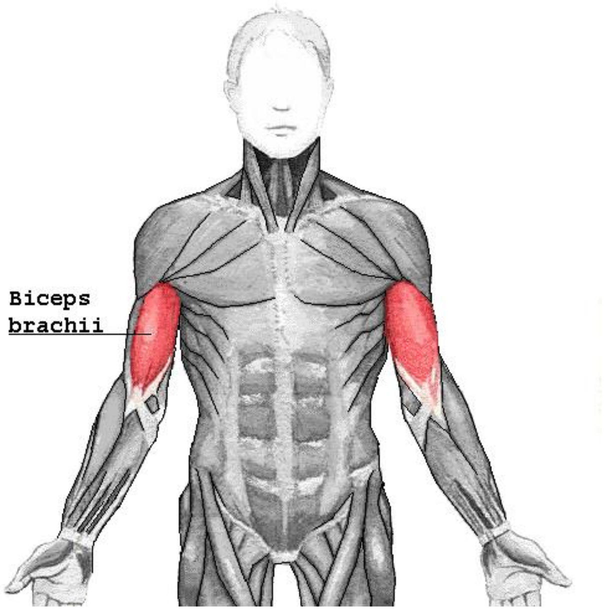


Figure 2: Biceps Brachii

CHAPTER 2

LITERATURE REVIEW

2.1 Exoskeleton

Figure 3 shows some examples of exoskeleton in giving extra strength for human in daily life or for rehabilitation purpose. Exoskeleton is divided into two parts which are upper limb and lower limb. The first draft of exoskeleton prototype will be shown in the results section at later part and flexion and extension of elbow joint which are being shown in Figure 4 is given importancy to support the movement of the arm. In this project, EMG signal is used to control exoskeleton. Other related researches have been done in this particular biomedical engineering field with other input signals such as sensors but this project aimed to use the direct muscle signals (EMG signals) from the patients to achieve the best accuracy for the exoskeleton and give the best rehabilitation for each patient.

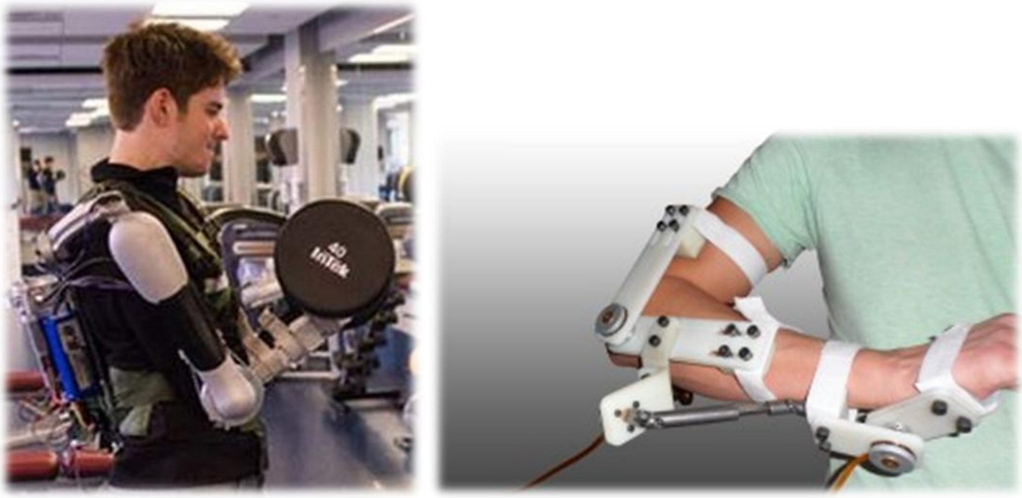


Figure 3 Example of Exoskeleton[4] [5]

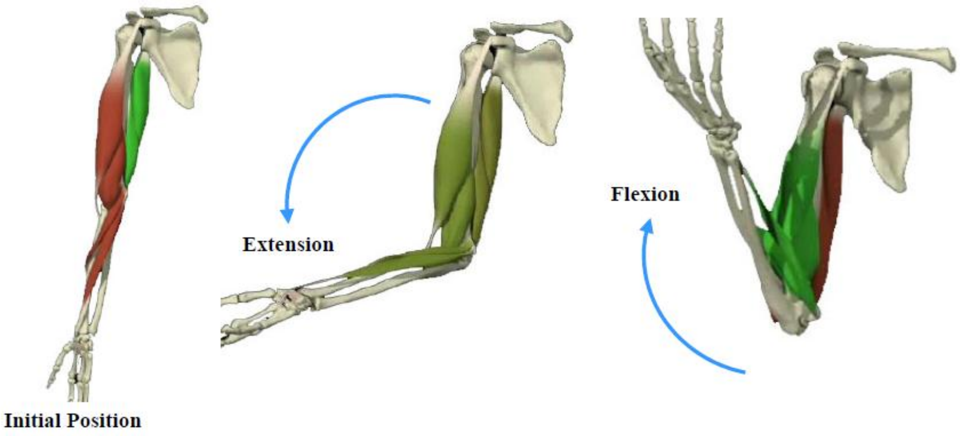


Figure 4: Elbow joint (flexion/extension)[6]

2.2 Surface Electromyography (sEMG)

In this project, electromyography (EMG) acts as the input for controller and it is able to detect the electrical potential produced by the muscle cells during their activities such as contracting and resting[7]. Due to the direct contact of EMG sensors with the human's muscle, EMG is one of the suitable control methods for exoskeleton. [8]There are two types of EMG signals which are:

i) Surface EMG where the EMG signals can be monitored through the electrode that is placed on the skin surface of the muscles.
ii) Intramuscular EMG where the EMG signals can be detected from inside of the muscles through a needle electrode that is put through the skin.

EMG signals obtained from different person are varies and even the same person with the same motion will produce different EMG signals. This may be caused by various factors such as tiredness, dizziness or sleepiness of the particular person.[7] Since EMG signals are able to predict the human motion, it is suitable to be used as the input for controller but researchers must take care of the properties of the EMG signals when plan to use EMG signals as the input to a controller since the signals are very sensitive.

Intramuscular EMG signals are difficult to be implemented widely due to its complicated procedures.[7] It is also not practical to use intramuscular EMG signals often because of its usage of needle to obtain signals from muscle activities. Instead, surface EMG (sEMG) is normally being applied in the medical and rehabilitation because of its non-invasive and painless method to acquire the signals of muscle activities.[7, 9] Hence, sEMG will be discussed in this project only due to its common usage in the particular field. The method of measuring sEMG is shown in Figure 5.

EMG signals are used in diagnosis of neurological and neuromuscular problems and research areas including motor controls and movement disorder. The elderly people, injured patient and physically disable person see hopes through the development of EMG signals in the medical and rehabilitation field for exoskeleton.

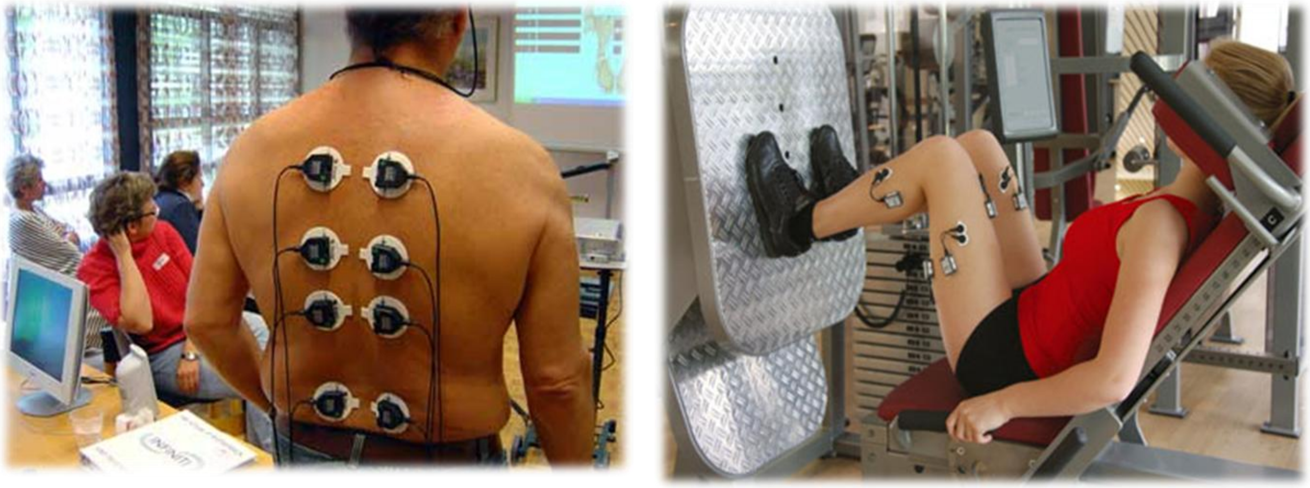


Figure 5: Method of measuring sEMG [9, 10]

2.2.1 Principle of Signal Extraction From Muscle

Figure 6 shows how muscle activity produces signal that can be detected through skin of human. Motor neuron is generated from the brain and through sensory nerve root and motor nerve root, motor neuron will directly or indirectly control the muscles. The signal that is created from the neuron will produce a potential difference which can be detected by the sEMG sensors that will be attached to the skin of the patients.

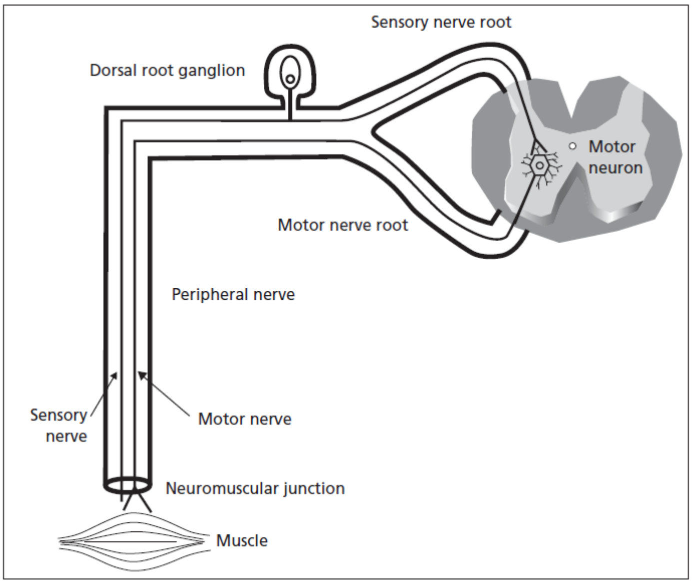


Figure 6: Motor Unit Diagram[11]

Figure 7 shows the process of converting the signals that are detected through the EMG sensors to the production of graph that is produced in the analysis software. The muscle signals will be first amplified and filtered. The raw sEMG signals will be obtained and viewed in the analysis software.

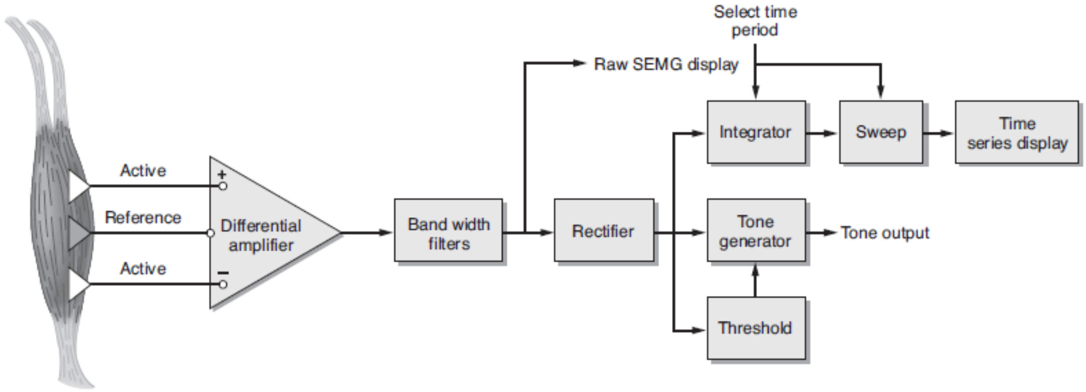


Figure 7: Block Diagram of sEMG Instrument[12]

2.2.2 Advantages of sEMG

- Provides a safe, easy and non-invasive method
- Enables patients to observe the muscle energy while at rest and varies over movement of the muscle
- Provides information to clinicians and researchers about the muscle function and dysfunction.

2.3 Filter Comparison

In this project, the sEMG signal will be filtered using two filters which are Butterworth filter and Chebyshev filter. The results from the filters will be analyzed. The comparison between the two filters used in this project is in Table 1.

Table 1: Comparison of Filters

Characteristics	Butterworth	Chebyshev
Pass Band	Flat	Has Pass Band Ripple
Roll-off rate	Poor	Better

Butterworth filter has the flattest pass-band (Figure 8) while Chebyshev filter has some pass band ripple (Figure 9). In term of roll-off rate, Butterworth has a poor performance in this characteristic. As the ripple increase, the roll-off becomes better. Despite having a poor roll-off rate, Chebyshev has a sharper roll-off. In this project, the signals are filtered using both filters to observe the difference in the output after each filter.[13]

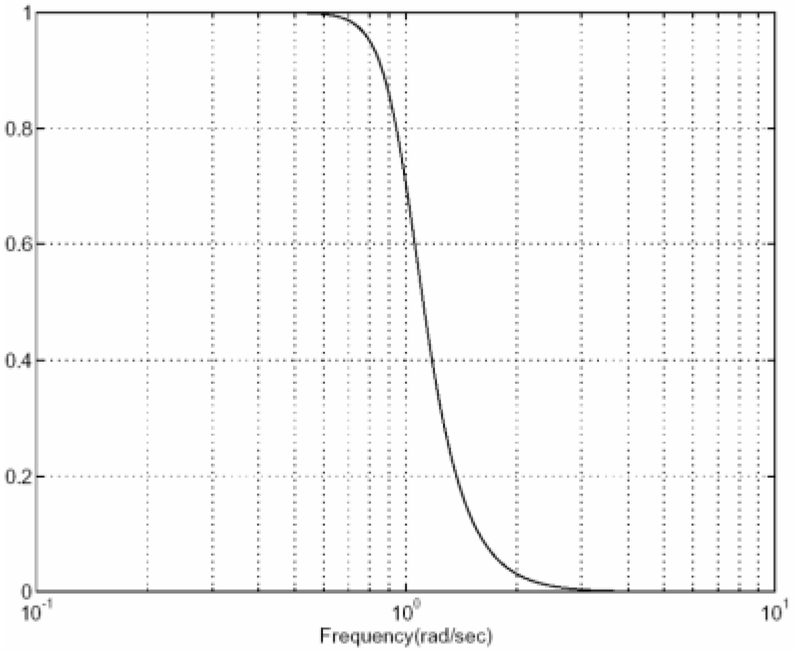


Figure 8: Frequency Response of Butterworth Filter[13]

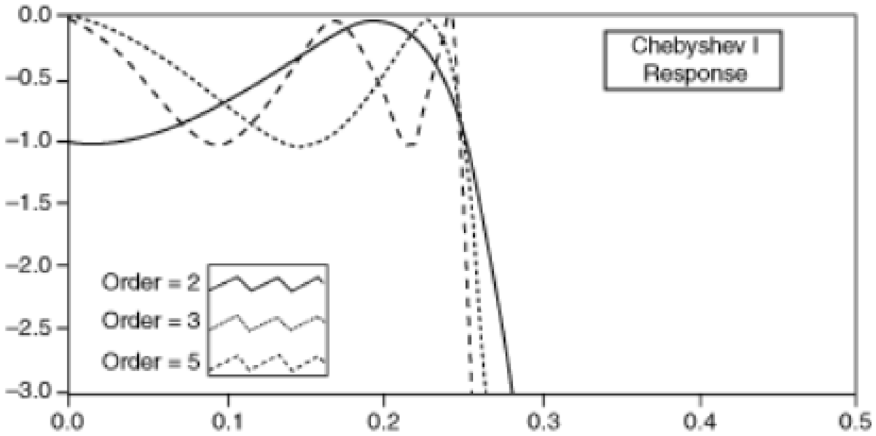


Figure 9: Frequency Response of Chebyshev Filter[13]

2.4 Related Work

In Table 2, Jacob Rosen et al had done research on integration of human arm with powered arm exoskeleton and by using EMG as the primary command signal for the exoskeleton [19]. Kazuo Kiguchi et al stated that since EMG signals of human muscles are significant to know how the user intends to move, it is used as the control for the robotic exoskeleton. [20] In D.S. Andreasen research, a EMG based control system is implemented to provide the appropriate amount of assistance and resistance to progress a patient's recovery. [21]. Besides, Christian Fleischer et al computed the intended motion by converting calibrated EMG signals into muscle forces to animate the human model. [22]. R.A.R.C Gopura and Kazuo Kiguchi presented the EMG-based fuzzy-neuro control method with multiple controllers and the method of adaption of the controllers. [23]. In 2010, Zeeshan O Khokar et al presented the use of pattern of recognition of EMG signal to estimate the torque applied by a human wrist [24] while in 2011, Michal A. Mikulski proposed EMG signals to maximize the user's intuitive control over the exoskeleton system[25]. At the same year, Jose M. Ochoa et al did research on monitoring EMG signals to ensure active participation of the user and to provide feedback of EMG patterns for the user by practicing grasp-and-release tasks. [26] For the lower limb research, H.He and K.Kiguchi proposed that sEMG signals are used as the input information for controller to assist in the lower-limb motions of physically weak people [27] and in 2008, Zhang Zhen et at did a study on human ankle movement based on sEMG signals.

Many researchers have proven that EMG signal is a suitable and effective input to control exoskeleton in term of upper limb or lower limb and to monitor the human muscle since EMG signal is obtained directly from the surface of the skin of human. Although exoskeleton research has been carried out for a long time, the research on usage of EMG signal as a method of controlling exoskeleton has only been started decades ago. Hence, it is a good approach to use EMG signal to produce an effective and efficient arm exoskeleton for the purpose of rehabilitation for stroke patients.

Table 2: Literature Review on EMG Signal Research on Exoskeleton

No	Year	Author	Description
1	2001	Jacob Rosen et al[19]	EMG signal as control for powered-exoskeleton to integrate human arm
2	2004	Kazuo Kiguchi et al[20]	EMG signal controlled robotic exoskeleton to assist human upper-limb motion
3	2005	D. S. Andreasen[21]	EMG signal control on a prototype robotic system for neuro-logical impairments rehabilitation
4	2005	Christian Fleischer et al[22]	Method of calculating intended motion of joints is presented by using EMG signal.
5	2008	R.A.R.C. Gopura and Kazuo Kiguchi[23]	Human forearm and wrist motion assist exoskeleton robot by using control method of EMG-based fuzzy-neuro.
6	2010	Zeeshan O Khokhar et al[14]	EMG signal pattern recognition to approximate the torque put on by human wrist
7	2011	Michał A. Mikulski[15]	EMG signal usage on exoskeleton for rehabilitation of human upper limb
8	2011	Jose M. Ochoa et al[18]	Development of digit extension active assistance for grasp-and-release tasks by monitoring EMG signals
9	2007	H.He, K.Kiguchi[16]	EMG signal control on exoskeleton as assistive equipment for weak lower limb patient
10	2008	Zhang Zhen et al[17]	EMG signal studies on movement of human ankle

CHAPTER 3

METHODOLOGY

3.1 Specification of Motor and Exoskeleton

The torque of the motor can be related to the weight of lifting capacity by the following equation:

Torque = Force * Position Vector

Force = Mass * Acceleration (gravity = 9.81m/s^2)

The lifting capacity for wrist, elbow and shoulder are different since each of them will support other body parts that are considered as part of the lifting load. According to [24], the motor that used to actuate each part of the exoskeleton is shown. With reference to Table 3, further survey on the motors to be used is in the progress.

Table 3: Specification of Motor [24]

Joints of Exoskeleton	Achieved Torque
Shoulder	30Nm
Elbow	6Nm
Wrist	4Nm

In term of specification of arm exoskeleton, the length of each section of the arm is calculated according to the height of individual[25]. By assuming standard height (H) for a patient is 170cm, the length of the exoskeleton is built with reference to Table 4.

Table 4: Length of Exoskeleton[25]

	Length	
Parts of Exoskeleton	Reference	Exoskeleton Design
Forearm	0.186H = 31.6cm	31cm
Elbow	0.146H = 24.8cm	23cm

3.2 Hardware and Software

3.2.1 Tetrix Kit

Tetrix Kit would be used to build the exoskeleton. An example of a robot frame is shown in Figure 10 that made up of different component from the Tetrix Kit.

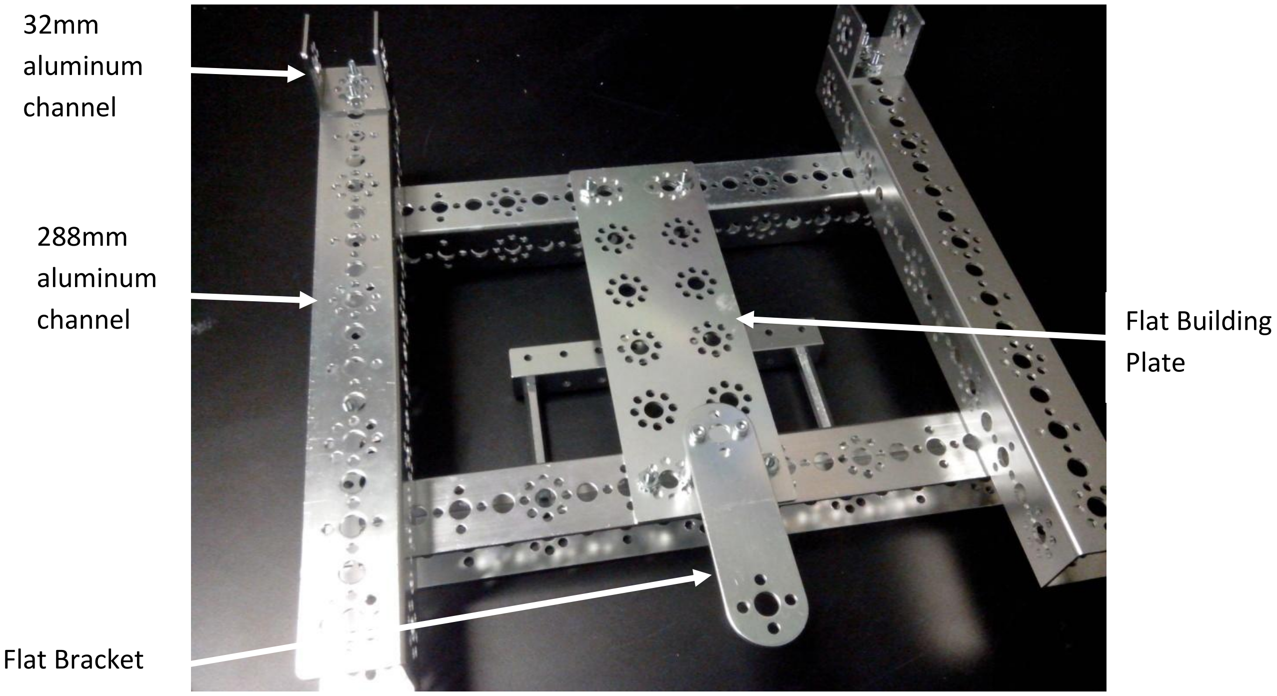


Figure 10: Frame of the Basic Robot of Tetrix Kit

3.2.1.1 Motor

The motor specification in Figure 11 is studied. The rated voltage for the motor used in Tetrix is 6-13.8V. The no load current and no load speed are 0.19A and 11000±10% rpm. Surveys are made through other references and the suitability of the motor is determined. °C

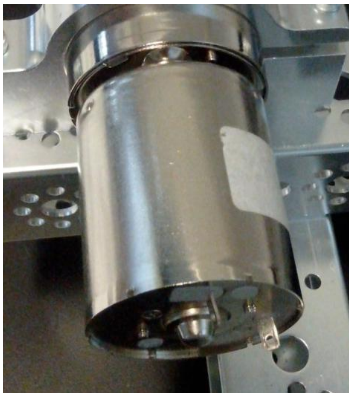


Figure 11: Motor of current exoskeleton

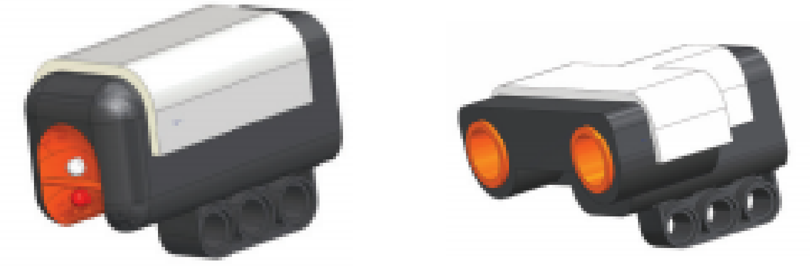
3.2.1.2 Controller

The main CPU of the controller consists of 32bit ARM7 microcontroller, 256Kbytes FLASH, 64Kbytes RAM while the motor controller consists of 8-bit AVR microcontroller, 4Kbytes FLASH, 512 byte RAM. The Controller is shown in Figure 12. Details of other specifications can be obtained in [26]

Figure 12: NXT Brick Controller

3.2.1.3 Sensors

Figure 13 shows the electronic components (Sensors) used in the project.



Light Sensor

Ultrasonic Sensor

Touch Sensor

Sound Sensor

Figure 13: Types of Sensors

3.2.2 Discussion

The exo-skeleton would be developed base on the hardware and software discussed in the preceding sections. The building compartment of Tetrix and the controller and the servo motor from Lego Mindstorms will be used to build the exo-skeleton. The NXT controller will be the brain for the exo-skeleton while the NXT servo motor from the Lego Mindstorms and motor from the Tetrix will be in charge of the rotation part of the joints of the arm exoskeleton.

3.3 EMG Signal Acquisition and Processing

i) Figure 14 shows EMG Sensor is being placed on biceps brachii of subjects

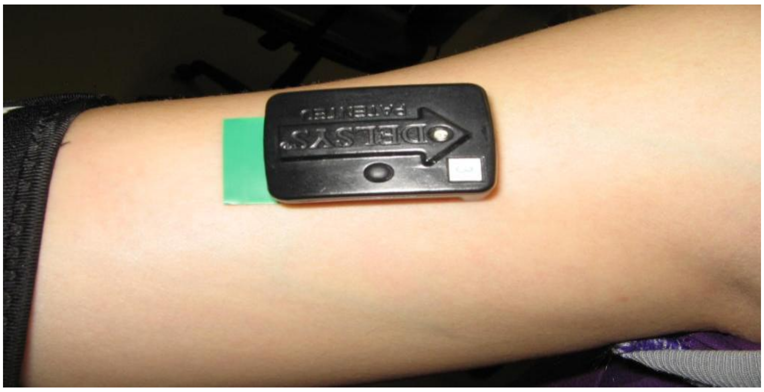


Figure 14: EMG Sensor Placement

ii) Figure 15 shows exoskeleton is attached to the arm of subject

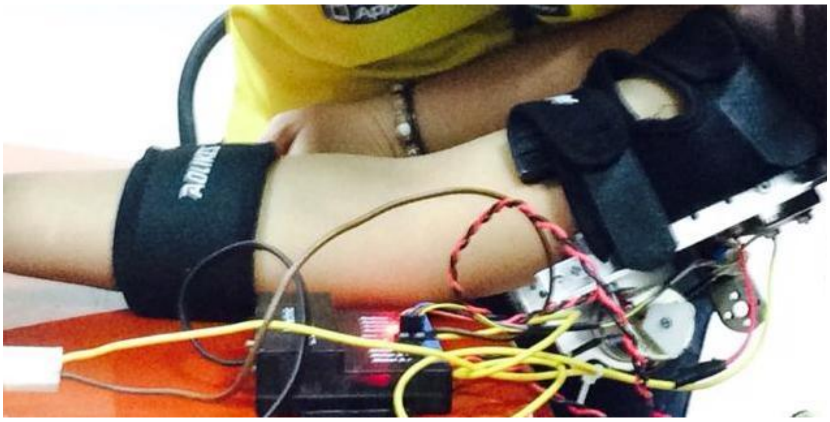


Figure 15: Exoskeleton on Subject

iii) Figure 16 shows the connection between controller and exoskeleton is set up

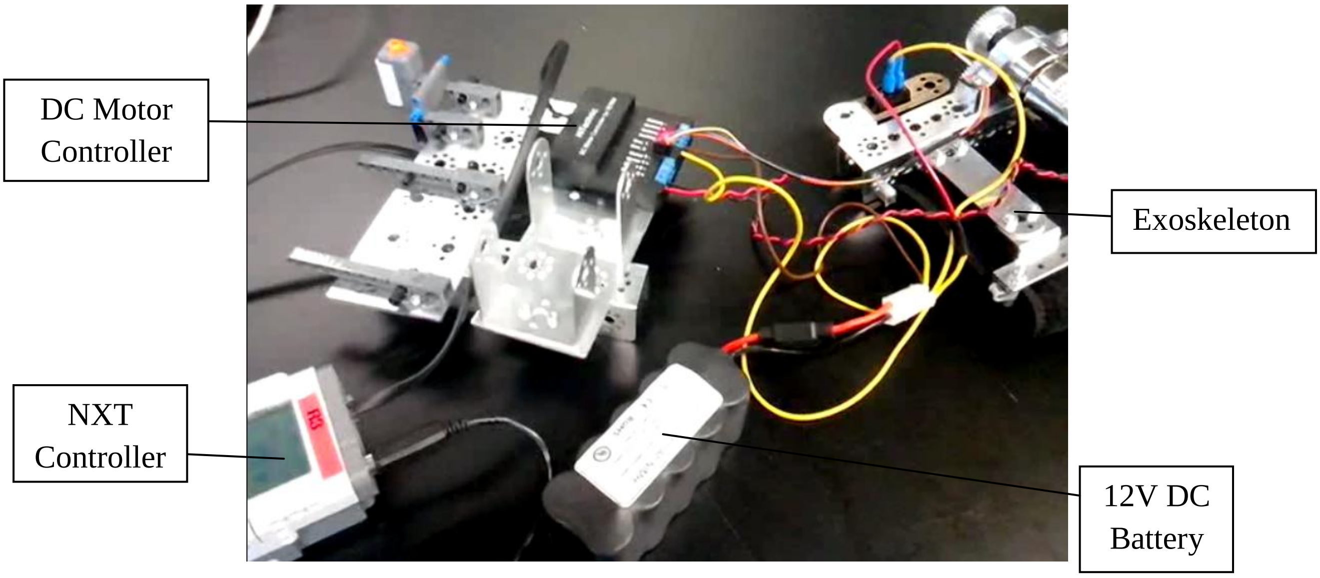


Figure 16: Connection of Controller and Exoskeleton

iv) Figure 17 shows the sEMG Acquisition system display

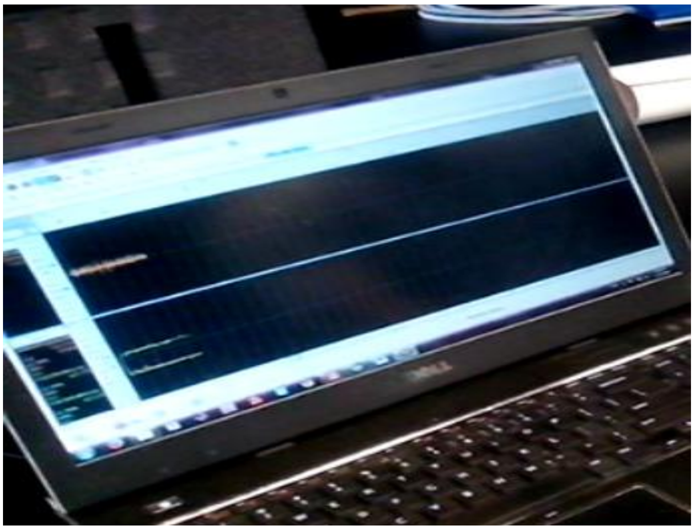
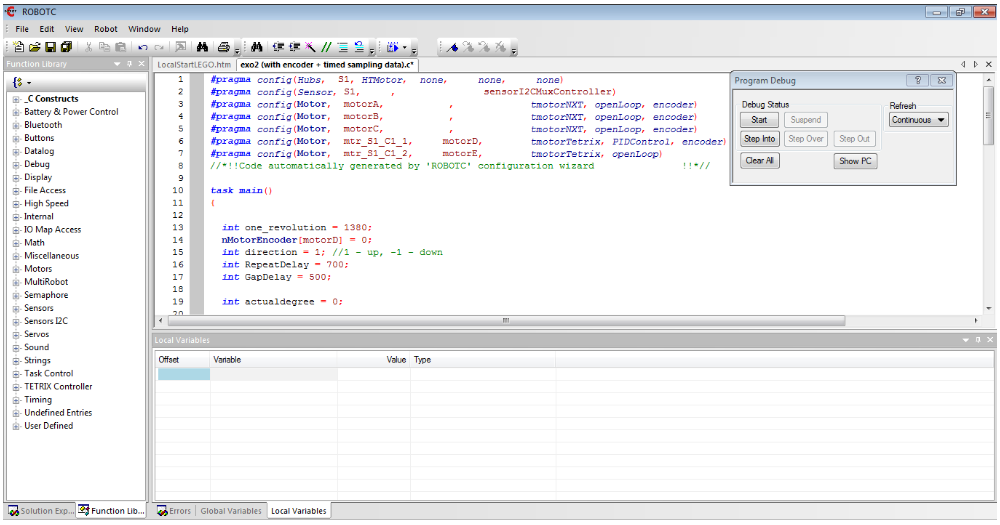


Figure 17: sEMG Acquisition System

v) Figure 18 shows the ROBOTC display of program for NXT controller



```
#pragma config(Hubs,  S1, HTMotor,  none,     none,     none)
#pragma config(Sensor, S1,     ,               sensorI2CMuxController)
#pragma config(Motor,  motorA,          ,             tmotorNXT, openLoop, encoder)
#pragma config(Motor,  motorB,          ,             tmotorNXT, openLoop, encoder)
#pragma config(Motor,  motorC,          ,             tmotorNXT, openLoop, encoder)
#pragma config(Motor,  mtr_S1_C1_1,     motorD,       tmotorTetrix, PIDControl, encoder)
#pragma config(Motor,  mtr_S1_C1_2,     motorE,       tmotorTetrix, openLoop)
//*!!Code automatically generated by 'ROBOTC' configuration wizard               !!*//

task main()
{

  int one_revolution = 1380;
  nMotorEncoder[motorD] = 0;
  int direction = 1; //1 - up, -1 - down
  int RepeatDelay = 700;
  int GapDelay = 500;

  int actualdegree = 0;
```

Figure 18: ROBOTC Program Display

vi) Figure 19 shows the sensor on biceps brichii is turned on and connect wirelessly to the system

Figure 19: Delsys Wireless EMG System

vii) Figure 20 shows the process of acquiring EMG signal with exoskeleton as assistive equipment

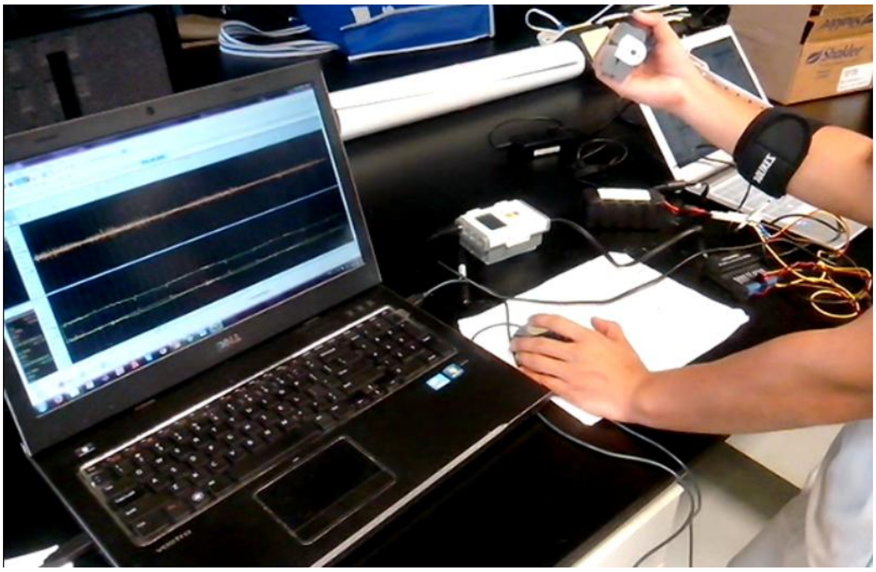
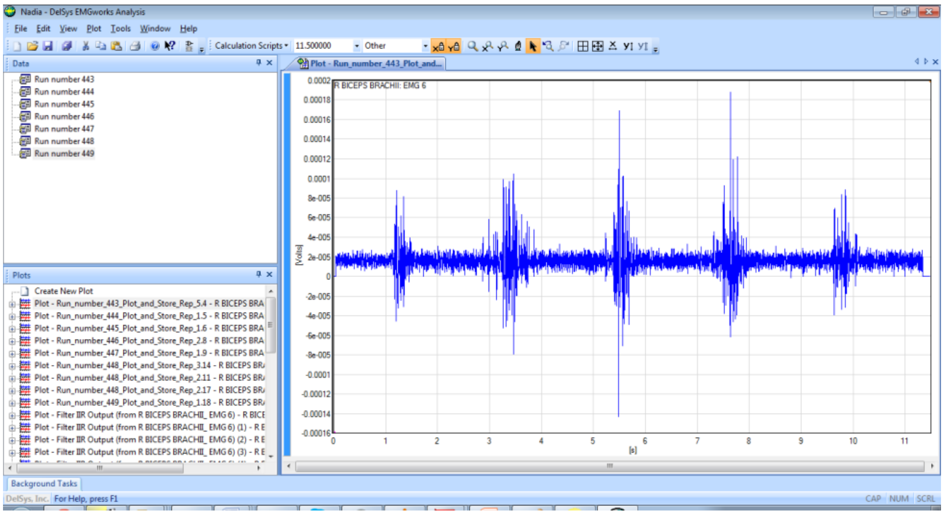


Figure 20: Process of Acquiring sEMG Signals

viii) Figure 21 shows raw EMG signals data analysis

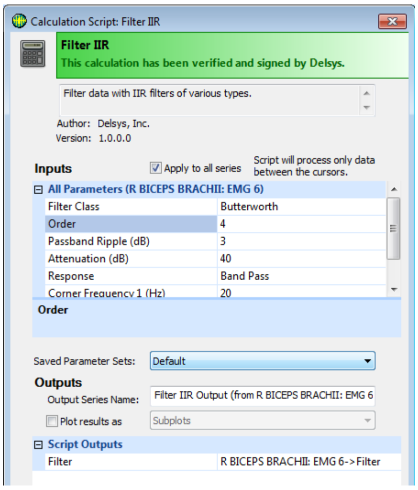


Run number 443
Run number 444
Run number 445
Run number 446
Run number 447
Run number 448
Run number 449

Plot - Run_number_443_Plot_and_Store_Rep_5.4 - R BICEPS BRA
Plot - Run_number_444_Plot_and_Store_Rep_1.5 - R BICEPS BRA
Plot - Run_number_445_Plot_and_Store_Rep_1.6 - R BICEPS BRA
Plot - Run_number_446_Plot_and_Store_Rep_2.8 - R BICEPS BRA
Plot - Run_number_447_Plot_and_Store_Rep_1.9 - R BICEPS BRA
Plot - Run_number_448_Plot_and_Store_Rep_3.14 - R BICEPS BR
Plot - Run_number_448_Plot_and_Store_Rep_2.11 - R BICEPS BR
Plot - Run_number_448_Plot_and_Store_Rep_2.17 - R BICEPS BR
Plot - Run_number_449_Plot_and_Store_Rep_1.18 - R BICEPS BR
Plot - Filter IIR Output (from R BICEPS BRACHII_ EMG 6) - R BICE
Plot - Filter IIR Output (from R BICEPS BRACHII_ EMG 6) (1) - R E
Plot - Filter IIR Output (from R BICEPS BRACHII_ EMG 6) (2) - R E
Plot - Filter IIR Output (from R BICEPS BRACHII_ EMG 6) (3) - R E

Figure 21: Raw sEMG signals

ix) Figure 22 shows the process of filtering raw EMG signal



Filter IIR

This calculation has been verified and signed by Delsys.

Filter data with IIR filters of various types.

Author: Delsys, Inc.

Version: 1.0.0.0

Inputs ☑ Apply to all series

Script will process only data between the cursors.

All Parameters (R BICEPS BRACHII: EMG 6)

Filter Class	Butterworth
Order	4
Passband Ripple (dB)	3
Attenuation (dB)	40
Response	Band Pass
Corner Frequency 1 (Hz)	20

Order

Saved Parameter Sets: Default

Outputs

Output Series Name: Filter IIR Output (from R BICEPS BRACHII: EMG 6

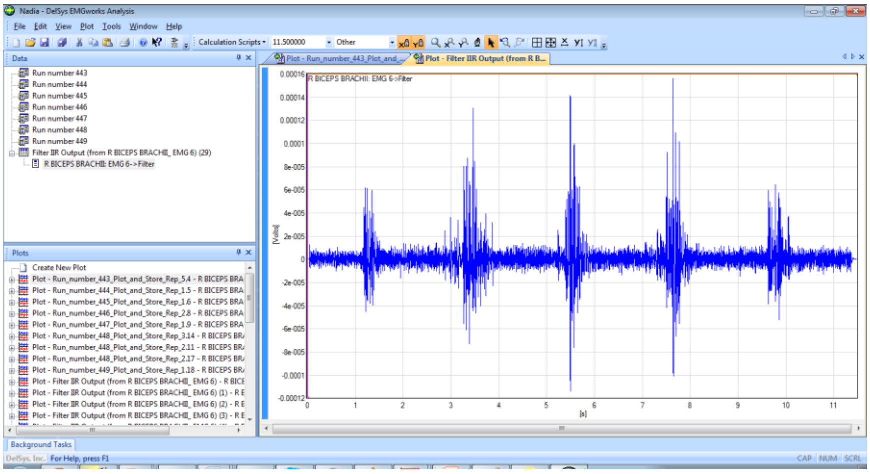
☐ Plot results as Subplots

Script Outputs

Filter	R BICEPS BRACHII: EMG 6->Filter

Figure 22: Signals Filtering

x) Figure 23 shows the Filtered Signal

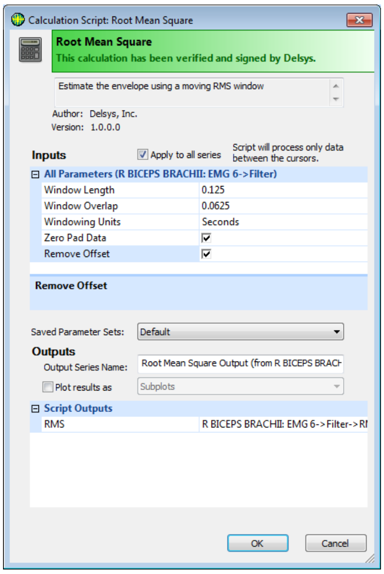


- Run number 443
- Run number 444
- Run number 445
- Run number 446
- Run number 447
- Run number 448
- Run number 449
- Filter IIR Output (from R BICEPS BRACHII_ EMG 6) (29)
  - R BICEPS BRACHII: EMG 6->Filter

- Create New Plot
- Plot - Run_number_443_Plot_and_Store_Rep_5.4 - R BICEPS BRA
- Plot - Run_number_444_Plot_and_Store_Rep_1.5 - R BICEPS BRA
- Plot - Run_number_445_Plot_and_Store_Rep_1.6 - R BICEPS BRA
- Plot - Run_number_446_Plot_and_Store_Rep_2.8 - R BICEPS BRA
- Plot - Run_number_447_Plot_and_Store_Rep_1.9 - R BICEPS BRA
- Plot - Run_number_448_Plot_and_Store_Rep_3.14 - R BICEPS BR
- Plot - Run_number_448_Plot_and_Store_Rep_2.11 - R BICEPS BR
- Plot - Run_number_448_Plot_and_Store_Rep_2.17 - R BICEPS BR
- Plot - Run_number_449_Plot_and_Store_Rep_1.18 - R BICEPS BR
- Plot - Filter IIR Output (from R BICEPS BRACHII_ EMG 6) - R BICE
- Plot - Filter IIR Output (from R BICEPS BRACHII_ EMG 6) (1) - R E
- Plot - Filter IIR Output (from R BICEPS BRACHII_ EMG 6) (2) - R E
- Plot - Filter IIR Output (from R BICEPS BRACHII_ EMG 6) (3) - R E

Figure 23: Filtered Signals

xi) Figure 24 shows the process of obtaining RMS from the filtered signal



Root Mean Square

This calculation has been verified and signed by Delsys.

Estimate the envelope using a moving RMS window

Author: Delsys, Inc.
Version: 1.0.0.0

Inputs ☑ Apply to all series — Script will process only data between the cursors.

⊟ All Parameters (R BICEPS BRACHII: EMG 6->Filter)

Window Length	0.125
Window Overlap	0.0625
Windowing Units	Seconds
Zero Pad Data	☑
Remove Offset	☑

Remove Offset

Saved Parameter Sets: Default

Outputs

Output Series Name: Root Mean Square Output (from R BICEPS BRACH

☐ Plot results as Subplots

⊟ Script Outputs

RMS	R BICEPS BRACHII: EMG 6->Filter->RI

Figure 24: Signals RMS Function

xii) Figure 25 shows the RMS of the signal

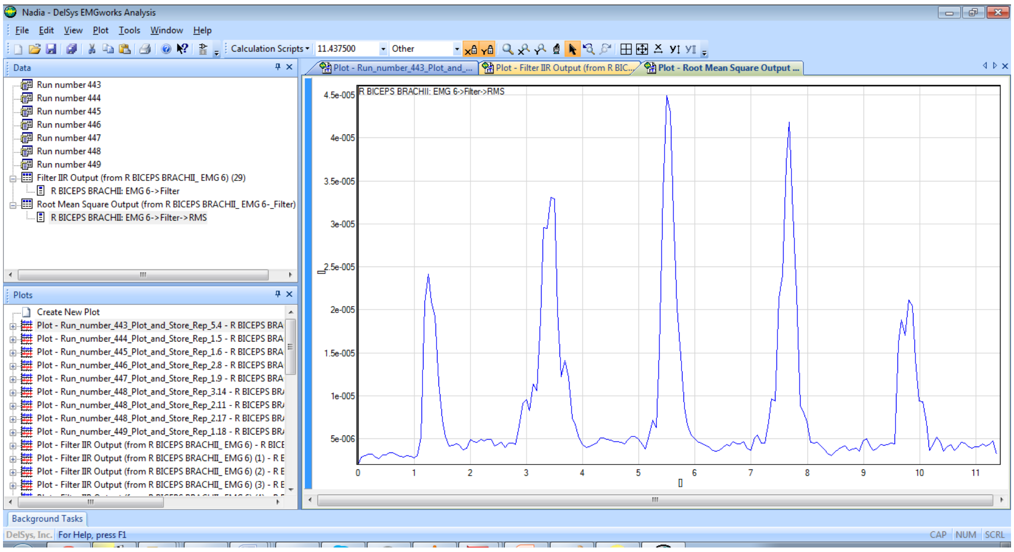
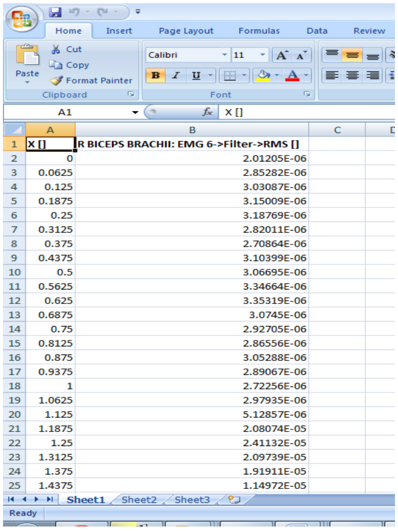


Figure 25: RMS of Signals

xiii) Figure 26 shows the RMS data is export to Excel file for further analysis and graph production



	A	B
1	X []	R BICEPS BRACHII: EMG 6->Filter->RMS []
2	0	2.01205E-06
3	0.0625	2.85282E-06
4	0.125	3.03087E-06
5	0.1875	3.15009E-06
6	0.25	3.18769E-06
7	0.3125	2.82011E-06
8	0.375	2.70864E-06
9	0.4375	3.10399E-06
10	0.5	3.06695E-06
11	0.5625	3.34664E-06
12	0.625	3.35319E-06
13	0.6875	3.0745E-06
14	0.75	2.92705E-06
15	0.8125	2.86556E-06
16	0.875	3.05288E-06
17	0.9375	2.89067E-06
18	1	2.72256E-06
19	1.0625	2.97935E-06
20	1.125	5.12857E-06
21	1.1875	2.08074E-05
22	1.25	2.41132E-05
23	1.3125	2.09739E-05
24	1.375	1.91911E-05
25	1.4375	1.14972E-05

Figure 26: Excel Data Analysis

3.4 ROBOTC Software

3.4.1 Description of Coding

One revolution for 12V Tetrix DC motor is equal to 1380. The initial position of encoder is set to 0. The exoskeleton will repeat its movement until ‘count’ achieve its respective number. While the motor have not achieved its targeted angle, the motor will keep moving on a power of 20 which is assigned by user. When the motor achieve its target in forward movement, the motor is then move in reverse direction to its next target angle. Hence, the movement of the exoskeleton is repetitive. The nxtDisplayTextLine will display the current angle of the motor while the writeDebugStream will display the angle of the motor in the ROBOTC debug window so that user is able to analyse the data in future.

3.4.2 Flowchart

Figure 27 shows the flow chart of the ROBOTC Program

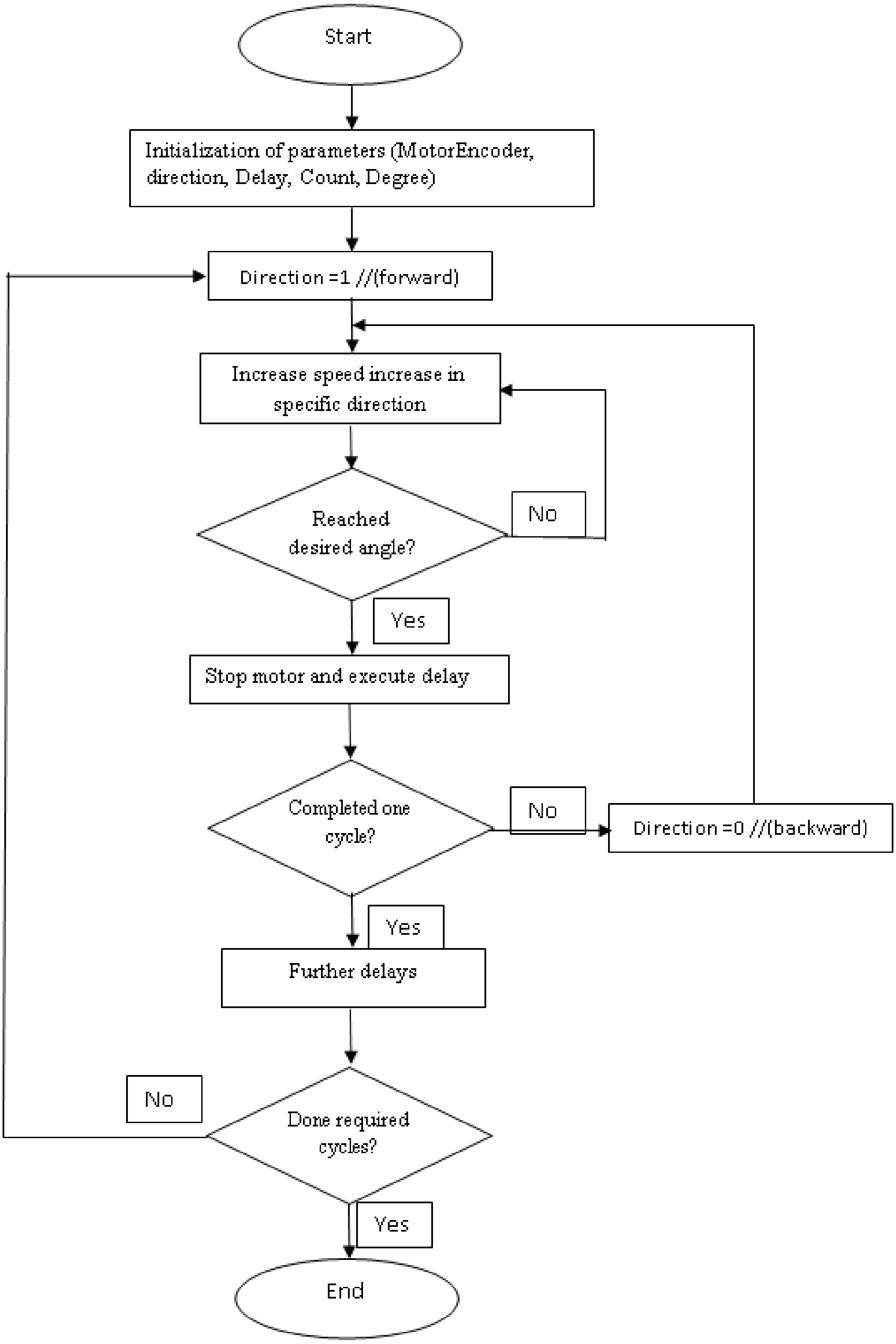


Figure 27: Flow Chart of Program

3.4.3 Coding

```
#pragma config(Hubs,  S1, HTMotor,  none,     none,     none)
#pragma config(Sensor, S1,     ,               sensorI2CMuxController)
#pragma config(Motor,  motorA,          ,             tmotorNXT, openLoop, encoder)
#pragma config(Motor,  motorB,          ,             tmotorNXT, openLoop, encoder)
#pragma config(Motor,  motorC,          ,             tmotorNXT, openLoop, encoder)
#pragma config(Motor,  mtr_S1_C1_1,     motorD,        tmotorTetrix, PIDControl,
encoder)
#pragma config(Motor,  mtr_S1_C1_2,     motorE,        tmotorTetrix, openLoop)
//*!!Code automatically generated by 'ROBOTC' configuration wizard               !!*//

task main()
{

    int one_revolution = 1380;
    nMotorEncoder[motorD] = 0;
    int direction = 1; //1 - up, -1 - down
    int RepeatDelay          = 500;
    int GapDelay = 500;
    int actualdegree = 0;
    int angle =1/12; //1/12 (speed 115) = 30 degree, 1/6(speed 230) = 60degree, 1/4(speed
345) = 90 degree



    clearDebugStream();
    for (int count=1;count<=5;count++)//Time of Repetition
    {
            for (int updown=1;updown<=2;updown++) //up 3 times, down 3 times
            {
                            if (updown<=1)
                                    direction = 1;
                            else direction =-1;

                                    nMotorEncoder[motorD]=0;

                                    while
(direction*nMotorEncoder[motorD]<=one_revolution*angle) //
                                    {
                                    motor[motorD]=direction*20;
```

```
                                        nxtDisplayTextLine(1, "Enc=%d ",
                                        nMotorEncoder[motorD]);
                                        nxtDisplayTextLine(2,"Time=%d ms", time1[T1]);
                                        writeDebugStream("%d",time1[T1]); // Time
                                        writeDebugStream(" %d", nMotorEncoder[motorD]);//
Angle of Motor
                                        writeDebugStreamLine(" %d", actualdegree);//Actual
Degree of Motor
                                        wait1Msec(10);
                                        }


                                        motor[motorD]=0;
                                        wait1Msec(GapDelay);

         }
         wait1Msec (RepeatDelay);

   }


}
```

CHAPTER 4

RESULTS & DISCUSSION

4.1 Mechanical Section

1. The CATIA design of arm exoskeleton

a) Figure 29 shows the side view of the exoskeleton for 30 Degree

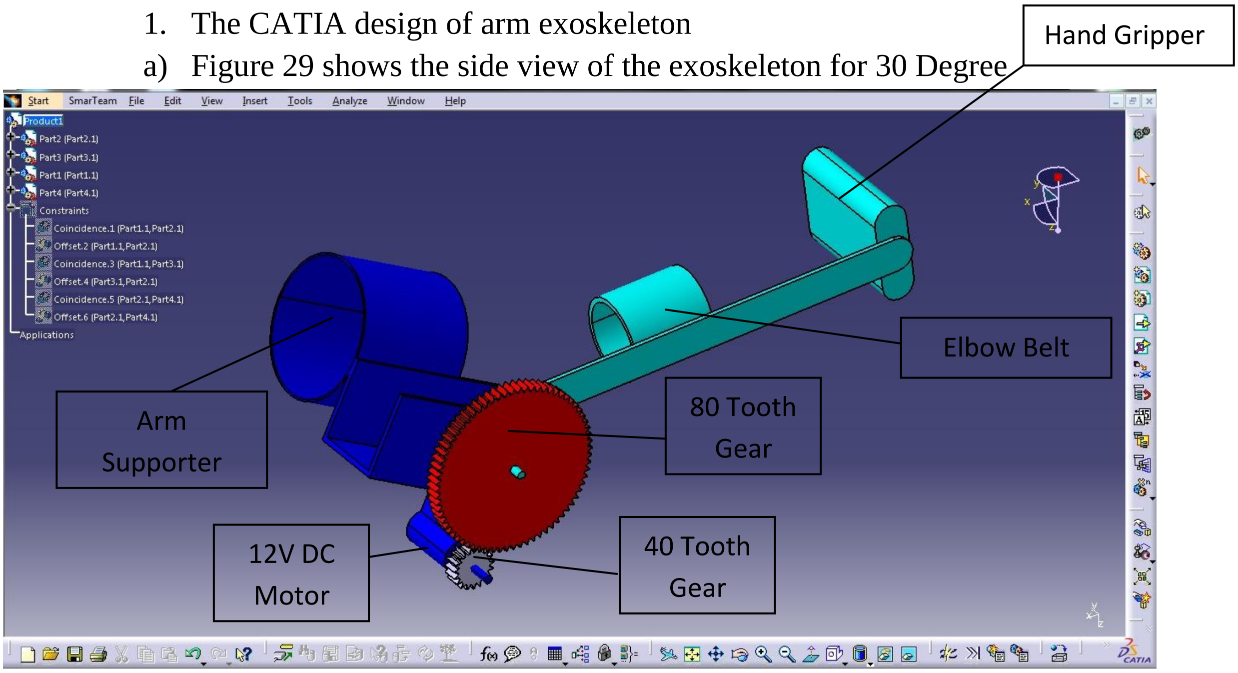


Figure 28: Side View for 30 Degree Rotation

b) Figure 30 shows the side view for 90 Degree Rotation

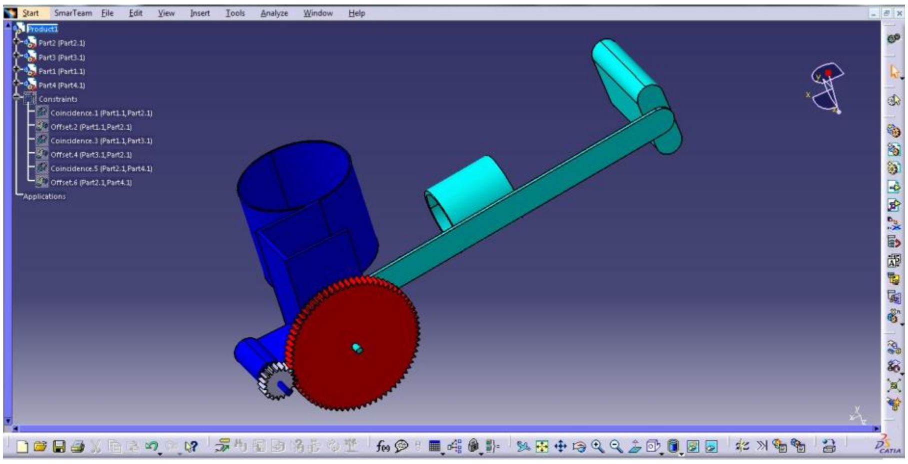


Figure 29: Side View for 90 Degree Rotation

c) Figure 31 shows the top view of exoskeleton

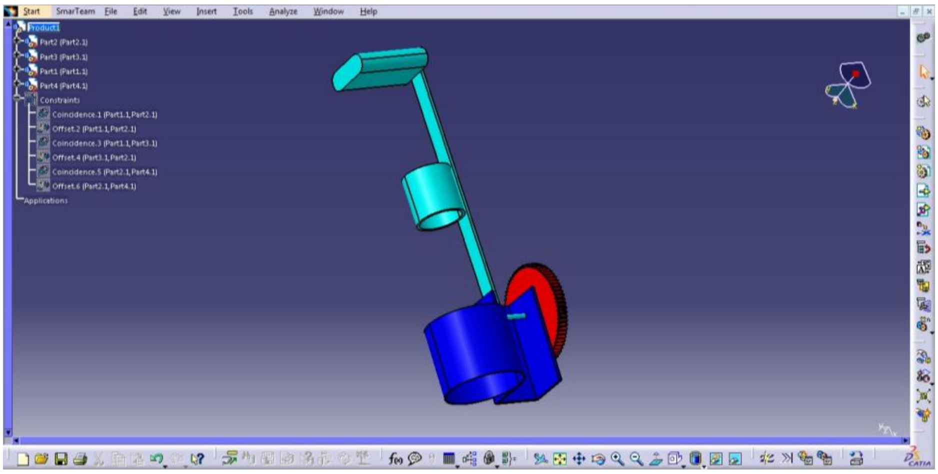


Figure 30: Top View of Exoskeleton

d) Figure 32 shows the back view of exoskeleton

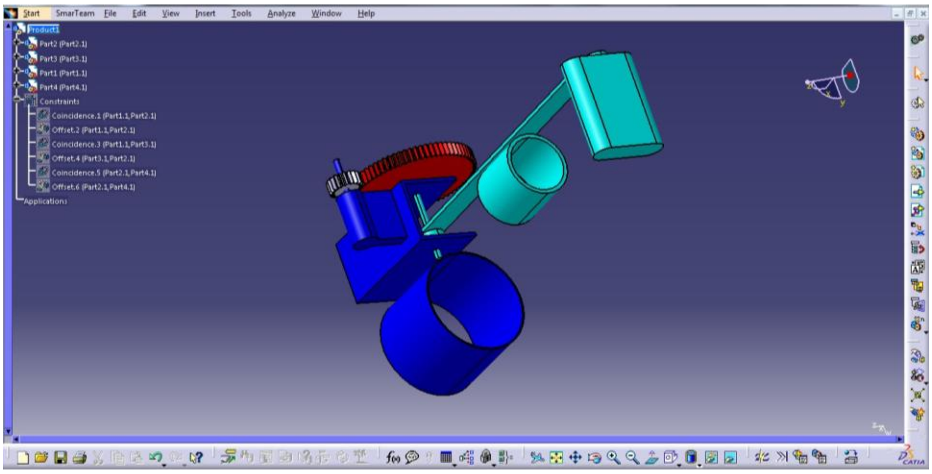


Figure 31: Back View of Exoskeleton

2. The first draft of arm exoskeleton is shown in Figure 15

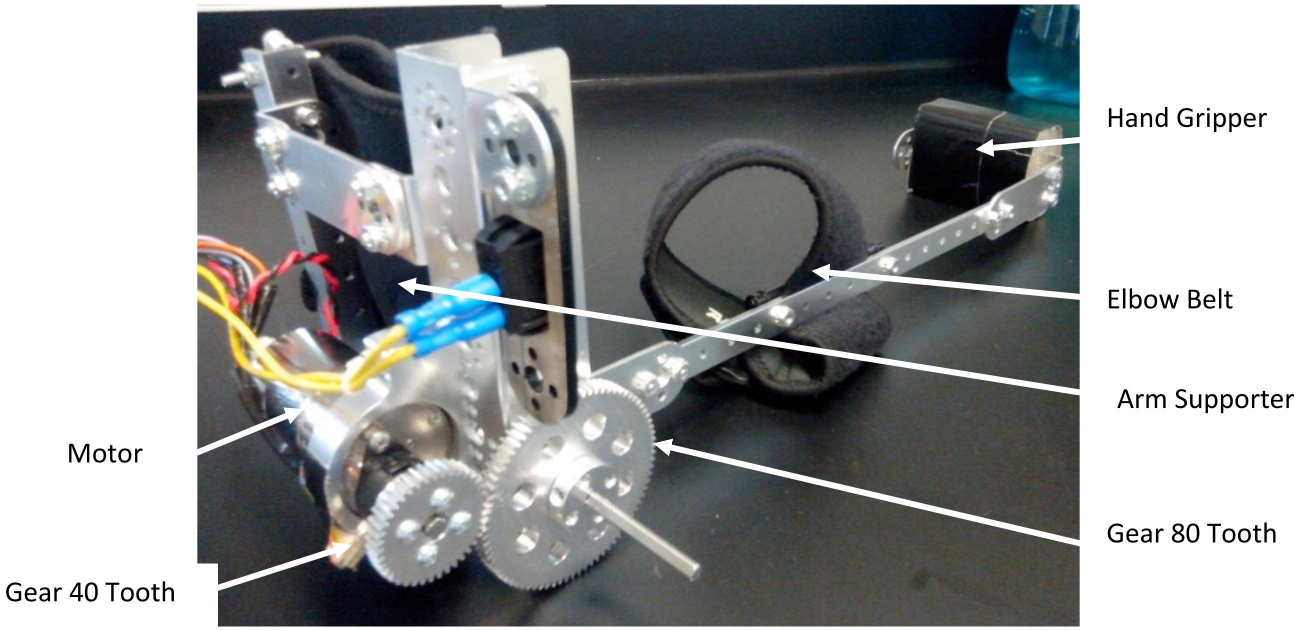


Figure 32: Model of Exoskeleton

$$\frac{\theta_1}{\theta_2} = \frac{N_1}{N_2} = \frac{40}{80} = \frac{1}{2}$$

$$\frac{T_1}{T_2} = \frac{N_2}{N_1} = \frac{80}{40} = 2$$

By using the formula mentioned above, the angle produced by using the above design is half of the angle of the small gear. This design allows experiments to be carried out safely by controlling the angle of rotation to avoid injuries on arm of subjects. By using this design, the torque is being doubled to allow the exoskeleton to support more weight on the load.

4.2 EMG Signal Acquisition

4.2.1 Subject Details

Table 5 shows the details of each subject that is being tested for the experiment. In future, height and weight of subjects maybe studied to investigate the relationship between the physical characteristics of subjects and the sEMG signals obtained.

Table 5: Details of Subjects

Identity	Gender	Height(cm)	Weight(kg)	BMI
Subject 1	M	178	72	22.72
Subject 2	M	189	60	16.80
Subject 3	M	178	69	21.78
Subject 4	M	166	60	21.77
Subject 5	F	153	46	19.65
Subject 6	F	160	62	24.22
Subject 7	F	154	49	20.66
Subject 8	F	157	57	23.12

4.2.2 EMG Signal

4.2.2.1 EMG Signal Visual Display

Figure 33 shows the raw EMG signal obtained from the EMG sensors placed on one of the subjects.

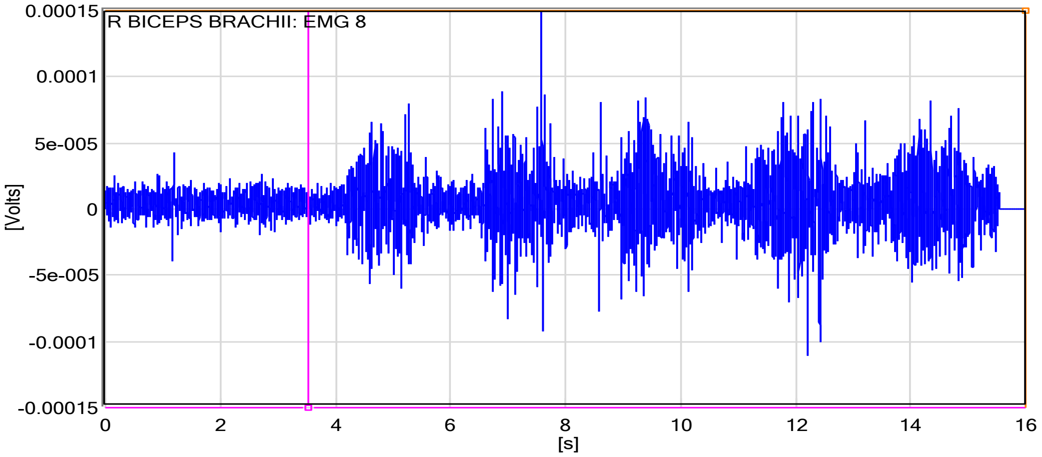


Figure 33: Raw EMG Signal

Figure 34 shows the signal after Butterworth filter is being applied to the raw EMG signal.

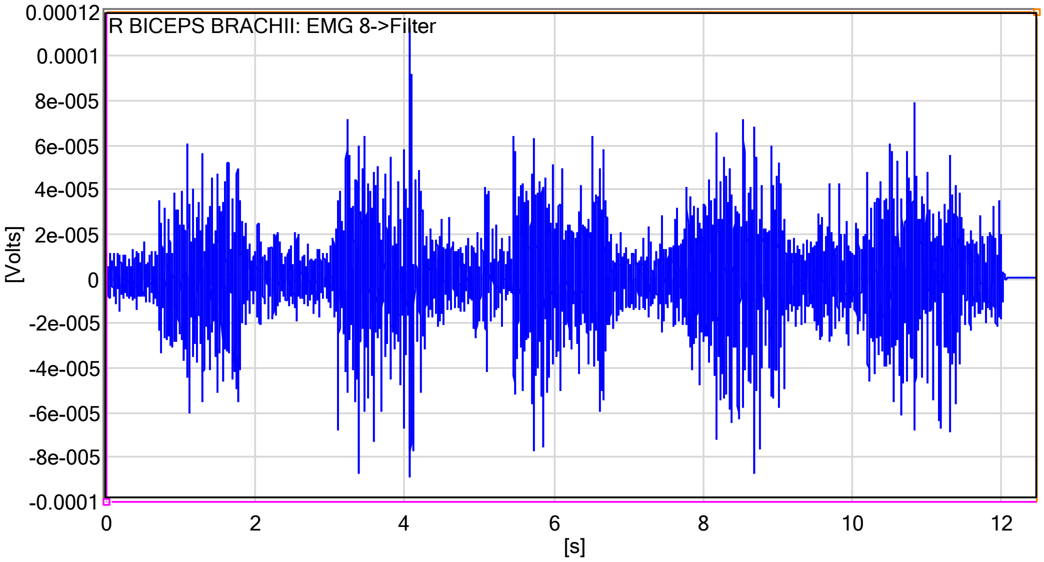


Figure 34: Butterworth Filter Signal

Figure 35 shows the signal after Chebyshev filter is being applied to the raw EMG signal.

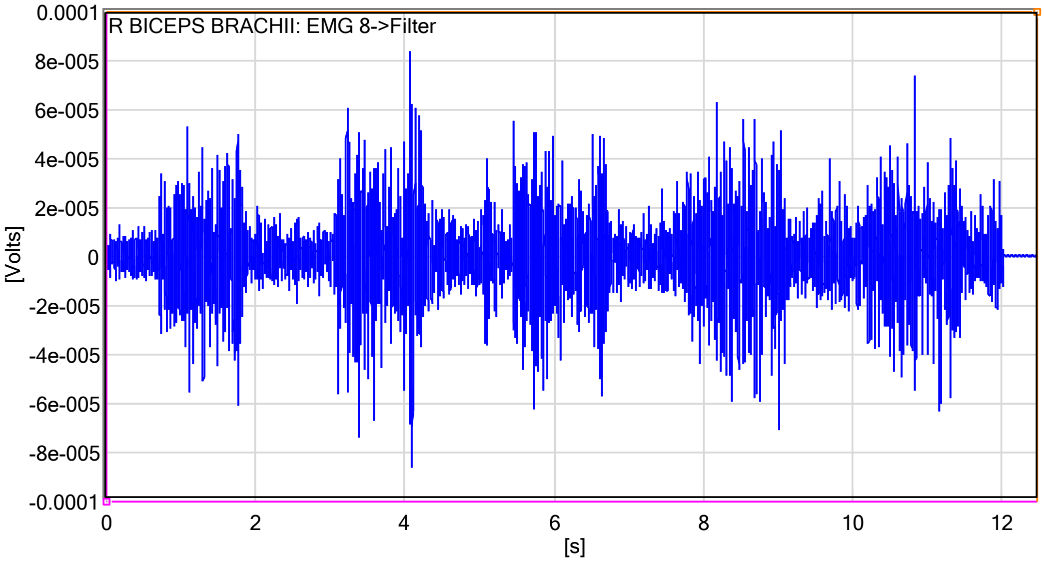


Figure 35: Chebyshev Filter Signal

Figure 36 shows the RMS of Butterworth Filter Signal

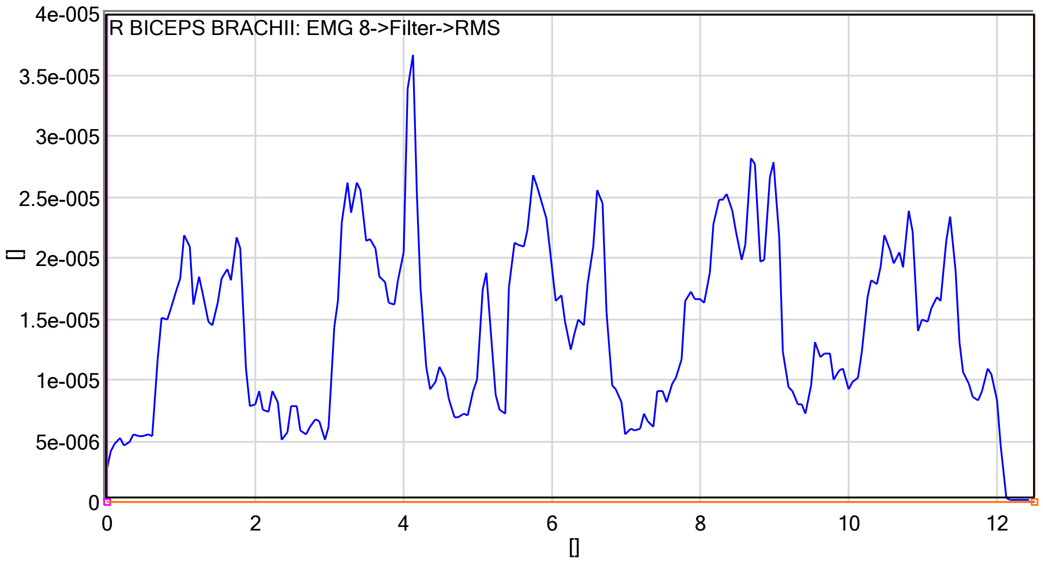


Figure 36: RMS of Butterworth Filter Signal

Figure 37 shows the RMS of Chebyshev Filter Signal

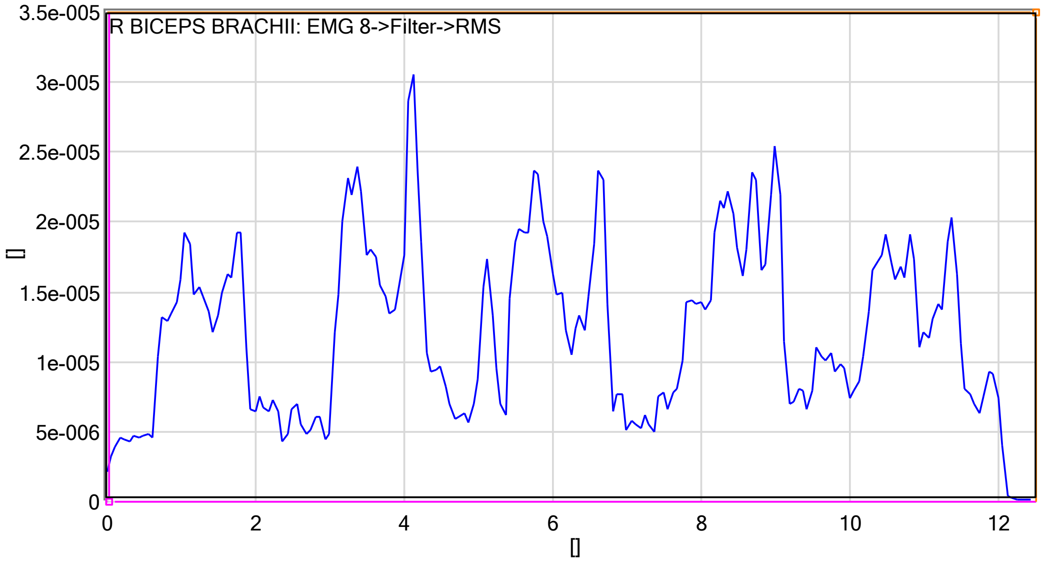


Figure 37: RMS of Chebyshev Filter Signal

4.2.2.2 Excel RMS Graph

Figure 38 shows the graph for Butterworth Filter 5x30 degree

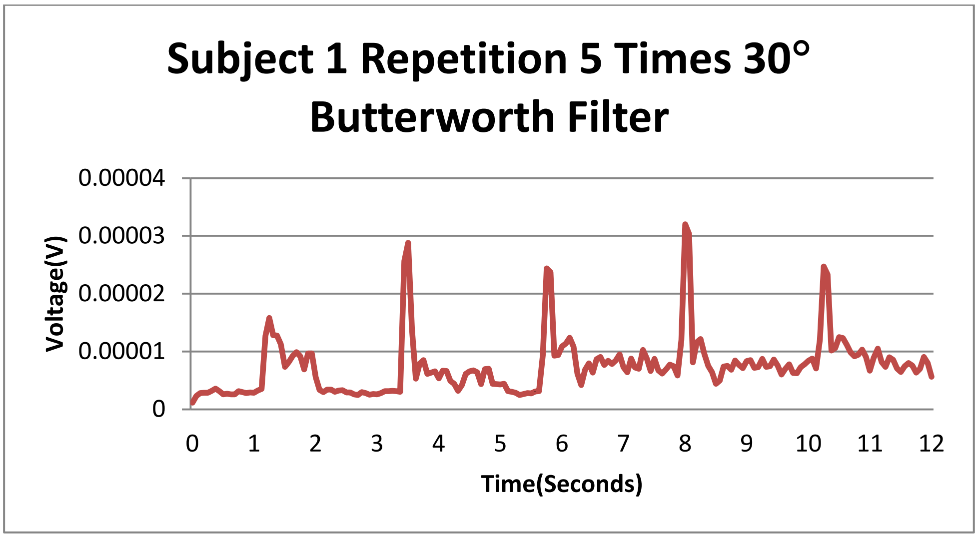


Figure 38: Excel Graph (Butterworth Filter 5x30 degree)

Figure 39 shows the graph for Chebyshev Filter 5x30 degree

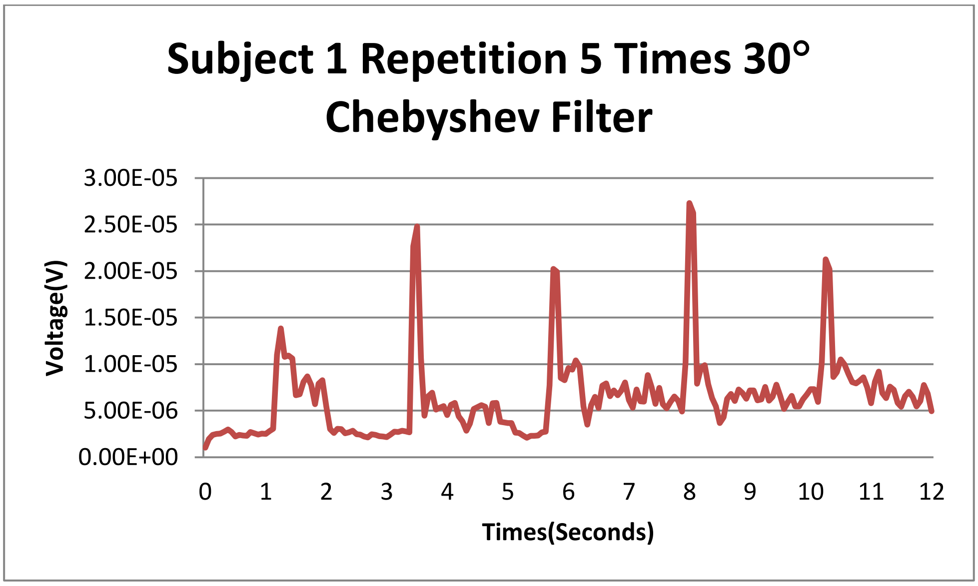


Figure 39: Excel Graph (Chebyshev Filter 5x30 degree)

Figure 40 shows the excel graph for Butterworth Filter 15x30 degree

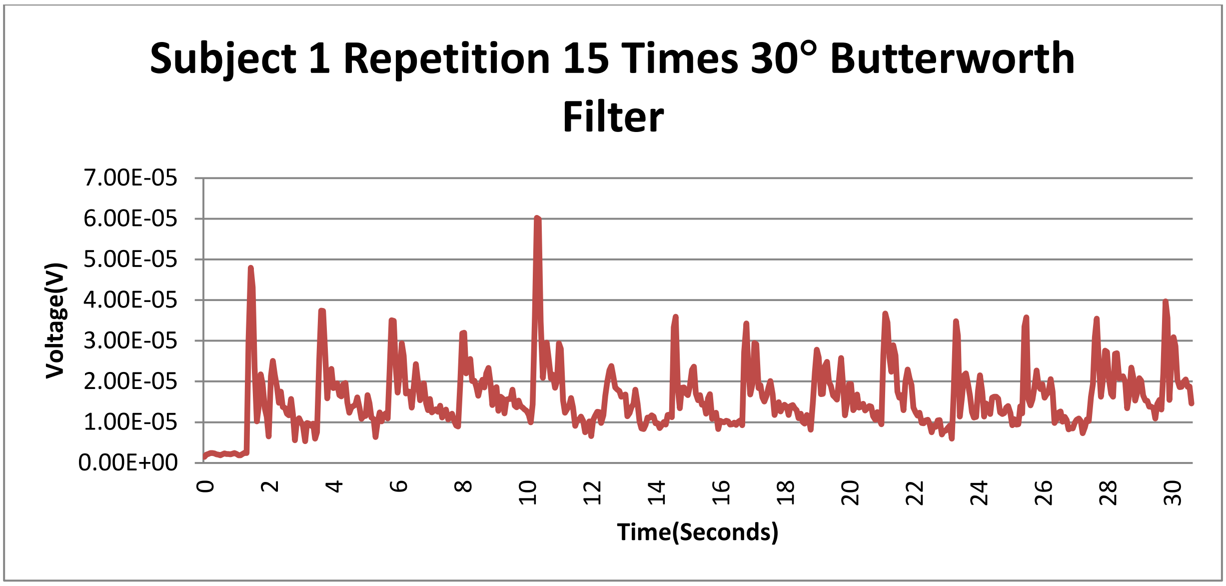


Figure 40: Excel Graph (Butterworth Filter 15x30 degree)

Figure 41 shows the graph for Chebyshev Filter 10x30 degree

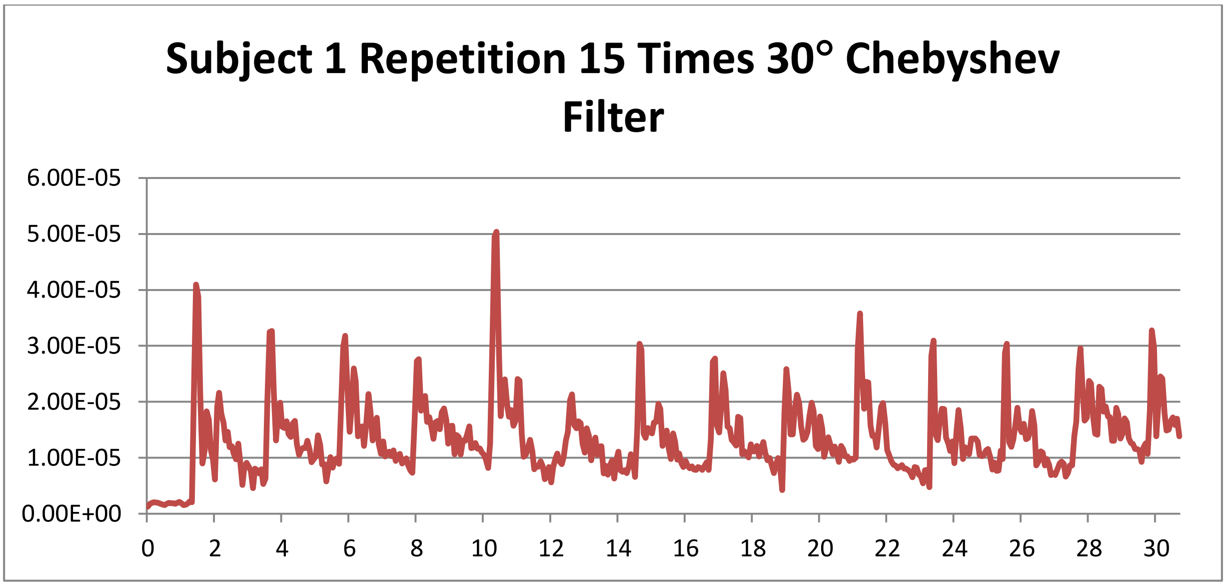


Figure 41: Excel Graph (Chebyshev Filter 10x30 degree)

Figure 42 shows the graph of Butterworth filter 5x60 Degrees

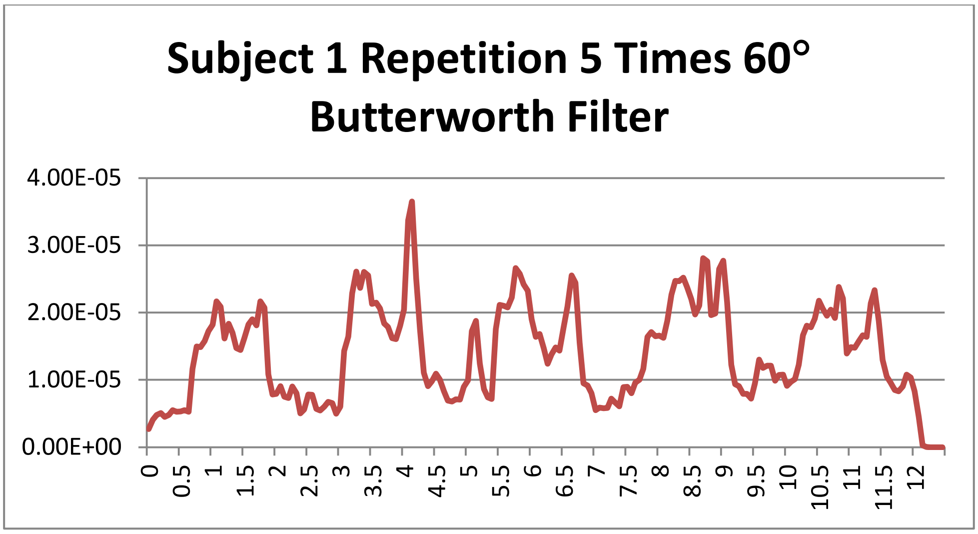


Figure 42: Excel Graph (Butterworth Filter 5x60 degree)

Figure 43 shows the graph of Chebyshev Filter 5x50 degree

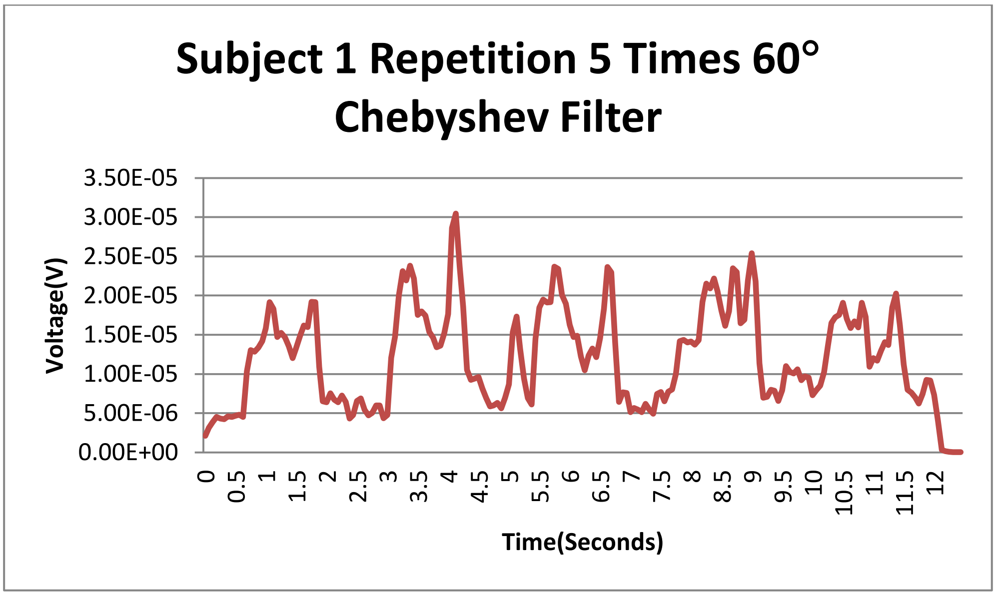


Figure 43: Excel Graph (Chebyshev Filter 5x30 degree)

Figure 44 shows the graph of Butterworth filter 15x60 degree

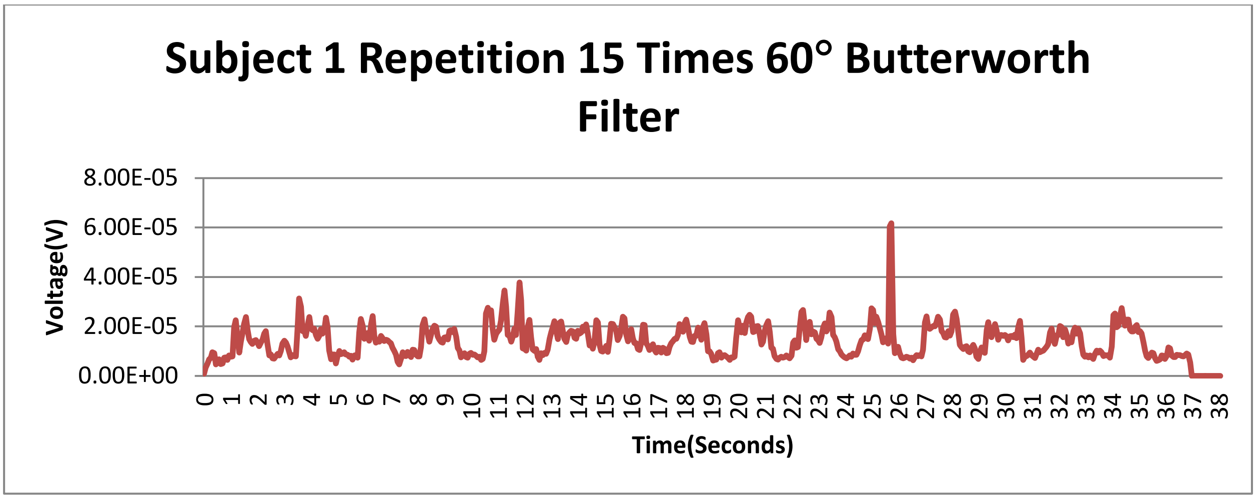


Figure 44: Excel Graph (Butterworth Filter 15x60 degree)

Figure 45 shows the graph of Chebyshev filter 15x60 degree

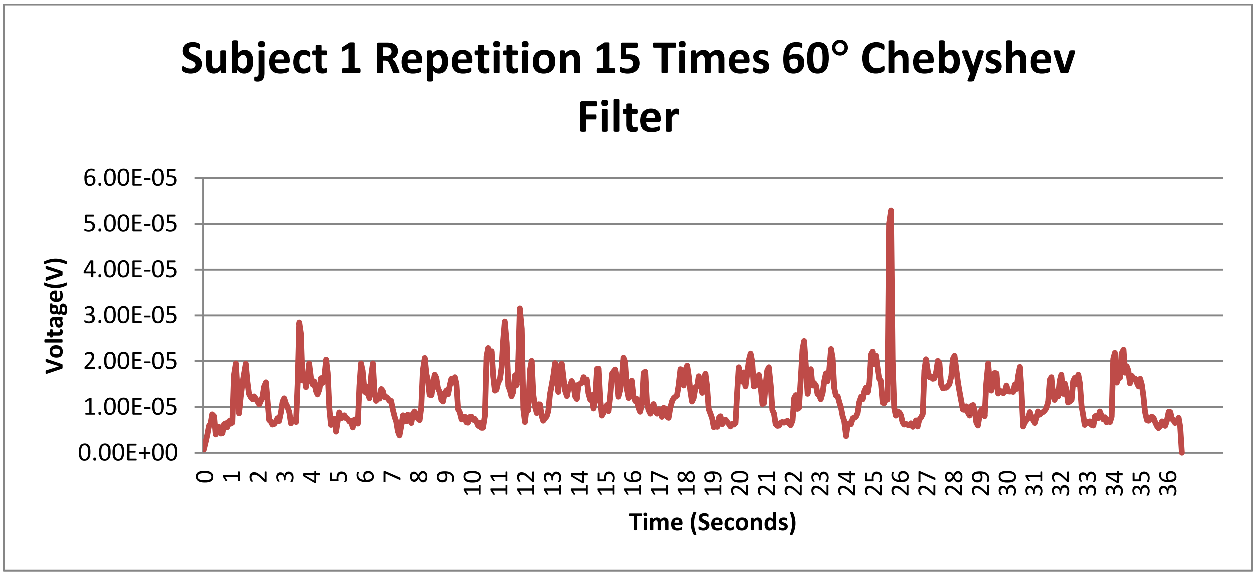


Figure 45: Excel Graph (Chebyshev Filter 15x60 degree)

Figure 46 shows the graph of Butterworth Filter 5x90 degree

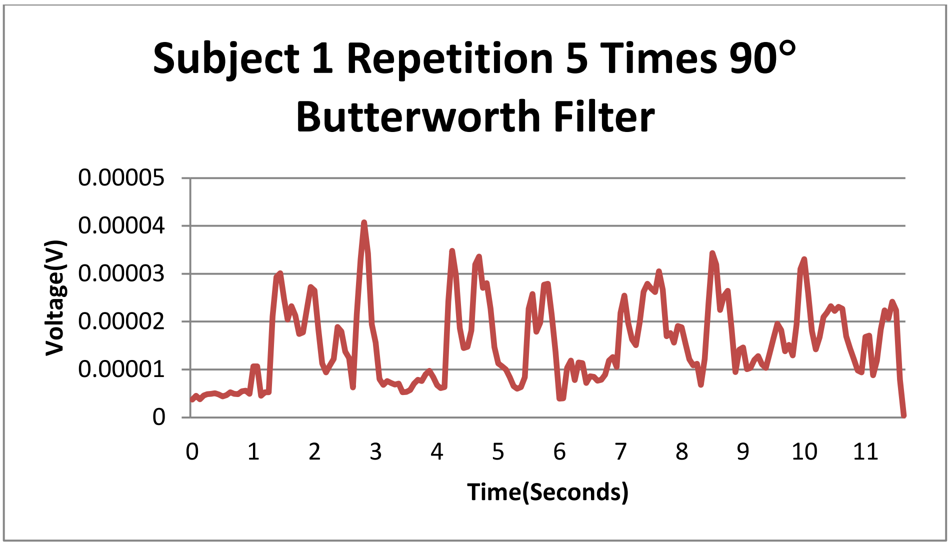


Figure 46: Excel Graph (Butterworth Filter 5x90 degree)

Figure 47 shows the graph of Chebyshev Filter 5x90 degree

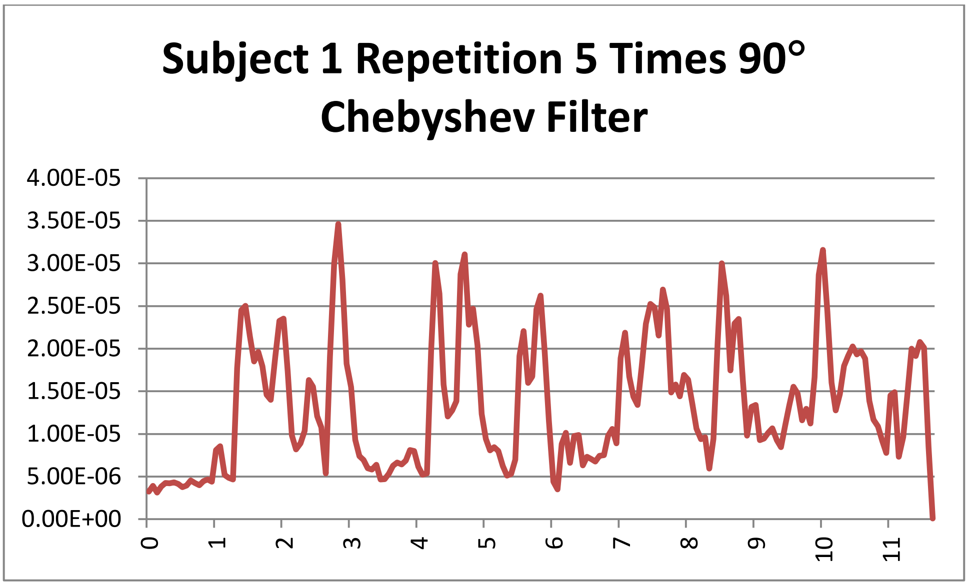


Figure 47: Excel Graph (Chebyshev Filter 5x90 degree)

Figure 48 shows the graph of Butterworth filter 15x90 degree

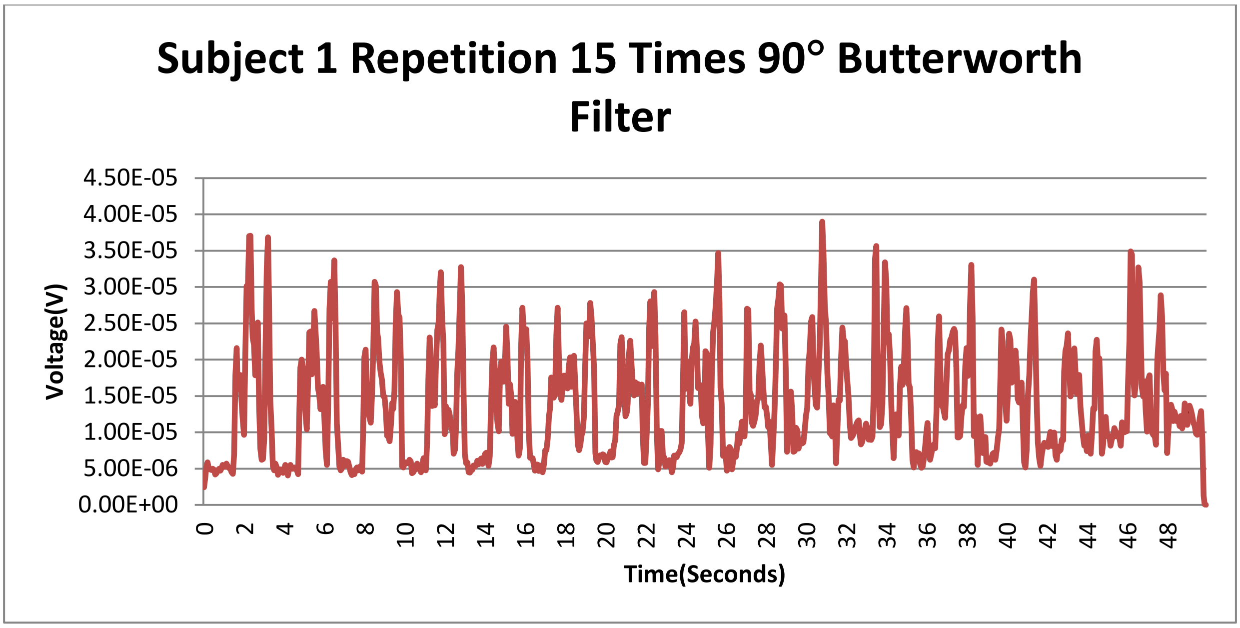


Figure 48: Excel Graph (Butterworth Filter 15x90 degree)

Figure 49 shows the graph of Chebbyshev Filter 15x90 degree

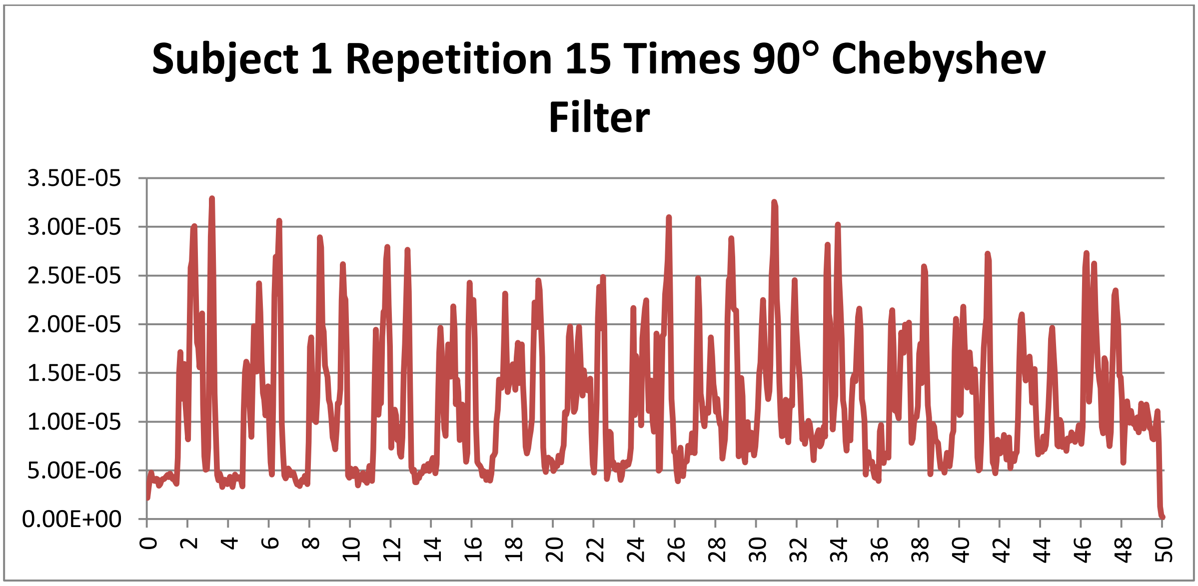


Figure 49: Excel Graph (Chebyshev Filter 15x90 degree)

4.2.2.3 Data Analysis of Excel Graph

Table 6: RMS of Subject 1

Filter	Repetition/Degree	Average
Butterworth	5/30	7.45928E-06
Chebyshev	5/30	6.37836E-06
Butterworth	15/30	1.59437E-05
Chebyshev	15/30	1.34679E-05
Butterworth	5/60	1.39936E-05
Chebyshev	5/60	1.20991E-05
Butterworth	15/60	1.38E-05
Chebyshev	15/60	1.21807E-05
Butterworth	5/90	1.54192E-05
Chebyshev	5/90	1.34299E-05
Butterworth	15/90	1.36796E-05
Chebyshev	15/90	1.179E-05

Table 7: RMS of Subject 2

Filter	Repetition/Degree	Average
Butterworth	5/30	1.36E-05
Chebyshev	5/30	1.16138E-05
Butterworth	15/30	6.77788E-06
Chebyshev	15/30	5.9985E-06
Butterworth	5/60	1.2672E-05
Chebyshev	5/60	1.07939E-05
Butterworth	15/60	1.79979E-05
Chebyshev	15/60	1.61283E-05
Butterworth	5/90	3.16764E-05
Chebyshev	5/90	2.72564E-05
Butterworth	15/90	1.09679E-05
Chebyshev	15/90	9.67036E-06

Table 8: RMS of Subject 3

Filter	Repetition/Degree	Average
Butterworth	5/30	6.10203E-05
Chebyshev	5/30	5.0297E-05
Butterworth	15/30	5.83172E-05
Chebyshev	15/30	5.57467E-05
Butterworth	5/60	5.82394E-05
Chebyshev	5/60	5.39709E-05
Butterworth	15/60	6.19841E-05
Chebyshev	15/60	5.82743E-05
Butterworth	5/90	5.73902E-05
Chebyshev	5/90	5.30927E-05
Butterworth	15/90	6.32091E-05
Chebyshev	15/90	5.91024E-05

Table 9: RMS of Subject 4

Filter	Repetition/Degree	Average
Butterworth	5/30	4.25478E-05
Chebyshev	5/30	3.81562E-05
Butterworth	15/30	3.38744E-05
Chebyshev	15/30	2.82949E-05
Butterworth	5/60	3.12088E-05
Chebyshev	5/60	2.62679E-05
Butterworth	15/60	3.06448E-05
Chebyshev	15/60	2.61662E-05
Butterworth	5/90	1.85352E-05
Chebyshev	5/90	1.63127E-05
Butterworth	15/90	3.47266E-05
Chebyshev	15/90	2.93019E-05

Table 10: RMS of Subject 5

Filter	Repetition/Degree	Average
Butterworth	5/30	3.19923E-05
Chebyshev	5/30	2.69064E-05
Butterworth	15/30	1.05338E-05
Chebyshev	15/30	8.97656E-06
Butterworth	5/60	1.7025E-05
Chebyshev	5/60	1.45253E-05
Butterworth	15/60	1.59832E-05
Chebyshev	15/60	1.29847E-05
Butterworth	5/90	1.43089E-05
Chebyshev	5/90	9.82304E-06
Butterworth	15/90	1.59202E-05
Chebyshev	15/90	1.14903E-05

Table 11: RMS of Subject 6

Filter	Repetition/Degree	Average
Butterworth	5/30	3.11012E-05
Chebyshev	5/30	2.70433E-05
Butterworth	15/30	2.30118E-05
Chebyshev	15/30	1.98693E-05
Butterworth	5/60	2.36492E-05
Chebyshev	5/60	2.04554E-05
Butterworth	15/60	1.66196E-05
Chebyshev	15/60	1.4444E-05
Butterworth	5/90	2.35447E-05
Chebyshev	5/90	2.02252E-05
Butterworth	15/90	1.78478E-05
Chebyshev	15/90	1.52889E-05

Table 12: RMS of Subject 7

Filter	Repetition/Degree	Average
Butterworth	5/30	1.69279E-05
Chebyshev	5/30	1.48583E-05
Butterworth	15/30	1.48768E-05
Chebyshev	15/30	1.35067E-05
Butterworth	5/60	1.86144E-05
Chebyshev	5/60	1.6022E-05
Butterworth	15/60	1.51305E-05
Chebyshev	15/60	1.30464E-05
Butterworth	5/90	1.7501E-05
Chebyshev	5/90	1.50154E-05
Butterworth	15/90	1.49147E-05
Chebyshev	15/90	1.27867E-05

Table 13: RMS of Subject 8

Filter	Repetition/Degree	Average
Butterworth	5/30	8.17079E-06
Chebyshev	5/30	6.9287E-06
Butterworth	15/30	5.06938E-06
Chebyshev	15/30	1.95457E-06
Butterworth	5/60	8.05896E-06
Chebyshev	5/60	7.64468E-06
Butterworth	15/60	7.61948E-06
Chebyshev	15/60	6.62462E-06
Butterworth	5/90	9.31967E-06
Chebyshev	5/90	8.08658E-06
Butterworth	15/90	1.3203E-05
Chebyshev	15/90	1.1304E-05

Tables above shows the RMS value of EMG signals for Subject 1 to Subject 8 for different repetition and different angles of rotation by using the prototype. The signals are filtered using Butterworth and Chebyshev filter to observe the performance of both filters. As shown in the tables, Butterworth filter has a flatter pass band compare to Chebyshev filter. Further analysis will be discussed in the next session.

4.2.2.4 Analysis of Graphs

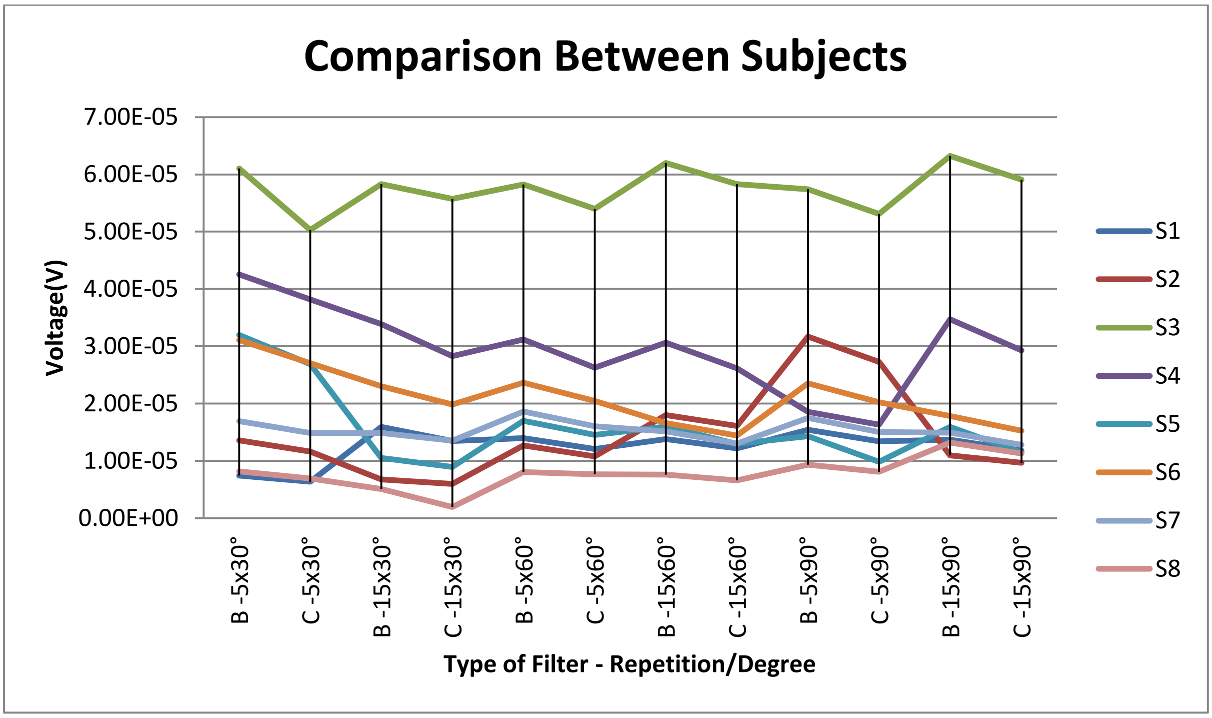


Figure 50: Comparison of RMS between 8 Subjects

Figure 50 above shows the RMS values for 8 subjects that are being tested. The muscle strength for subject 3 is the highest while the muscle strength for subject 8 is the lowest. This phenomenon is possible caused by the factor of different gender. From figure 50, the performance of filters can be analyzed. Butterworth filter perform better than Chebyshev filter. The results of this project are not as predicted which is the muscle strength will increase after few repetitions and different degree of rotation of training. There are few possible factors that may contribute to this result which is tiredness of muscle after continuous training and only one time experiment. The following suggestions can be considered in the future in this research which are long term training for healthy subjects and experimental on stroke patients under supervision of biomedical expertise to observe the difference of muscle signals between healthy subjects and stroke patients.

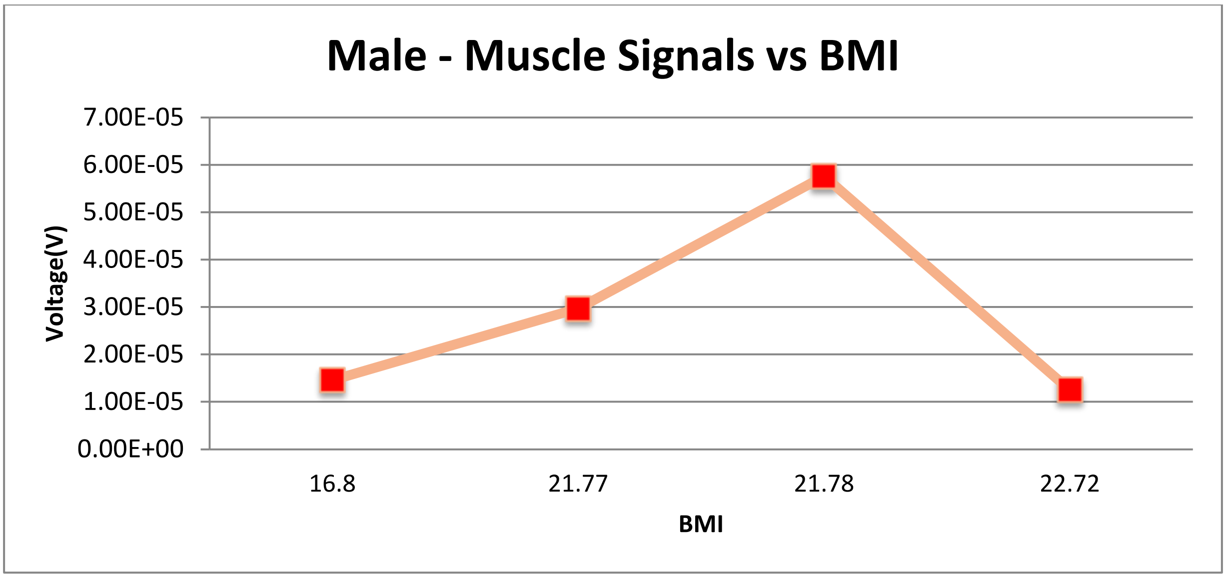


Figure 51: Muscle Signals vs BMI – Male

Figure 51 shows the relationship between muscle signals and BMI of male subjects being tested. As shown in the figure, as the BMI increases, the muscle signals increase. As for the last subject, he is only being found as a left handed person after finishing on experimental work but the experiment is carried out on his right hand. This may be one of the causes of the exception case in this analysis.

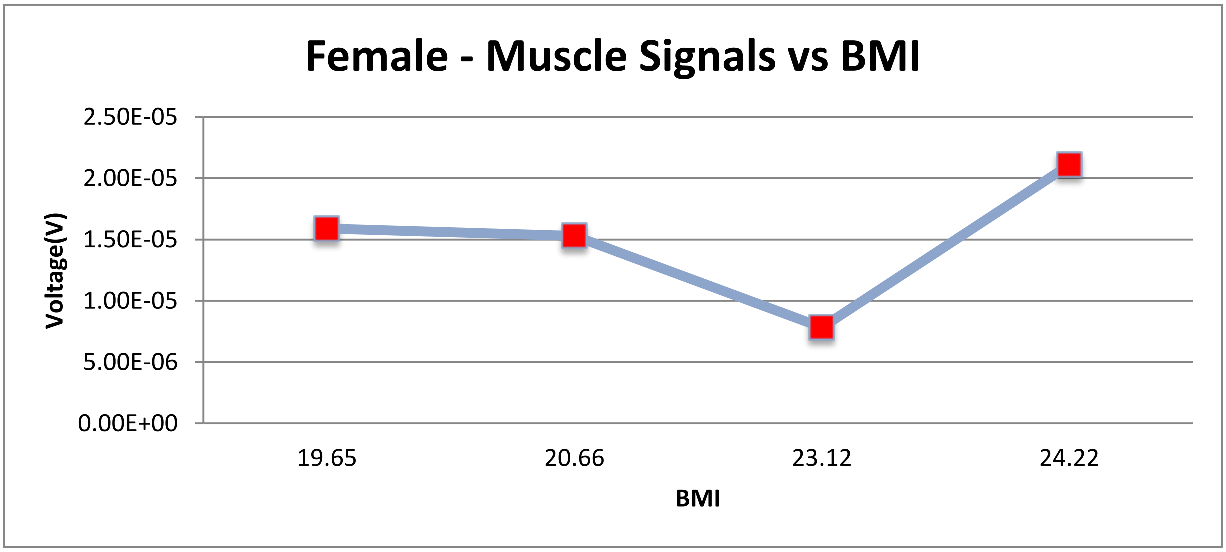


Figure 52: Muscle Signals vs BMI

In Figure 52, the muscle signals increase due to the increase in BMI. However, for the third subject, she is not a sport woman. Hence, there is a slight difference in her analysis compared to the conclusion of the whole analysis.

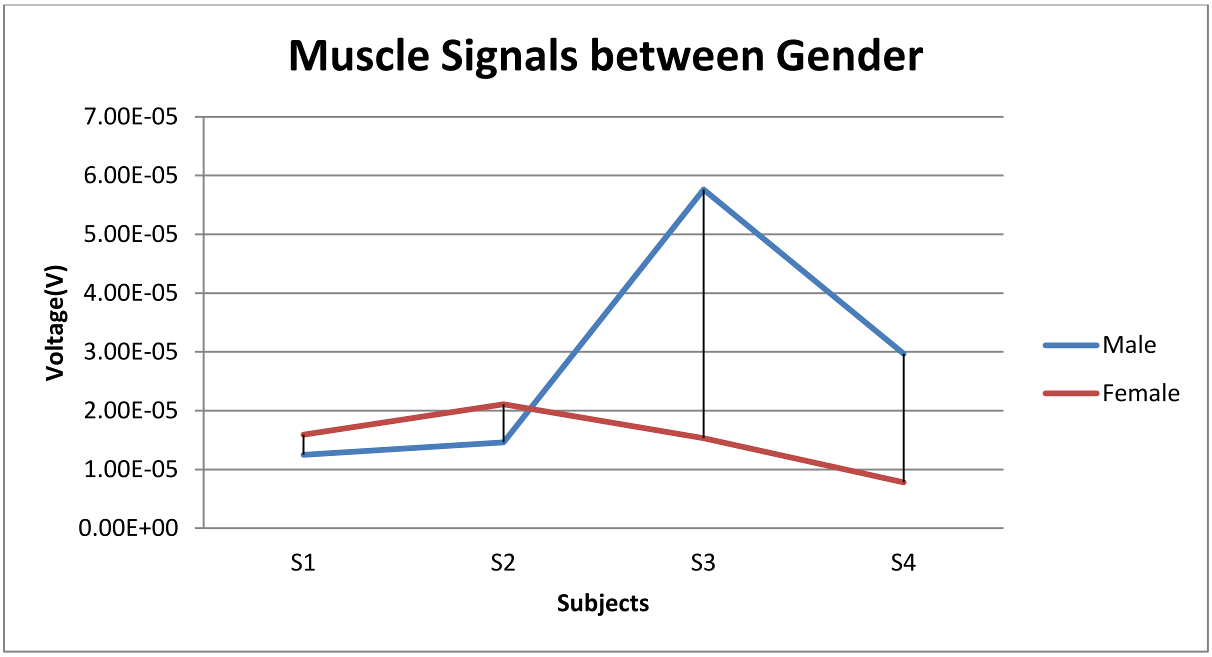


Figure 53: Muscle Signals between Gender

Through Figure 53, overall the muscle signals of male subjects are higher than the female except for the first and second subjects of the male because they are left handed but experiment is carried out on their right hand. While only the last female subject is non-athlete, her muscle signals are lower than the muscle signals of the other three female subjects.

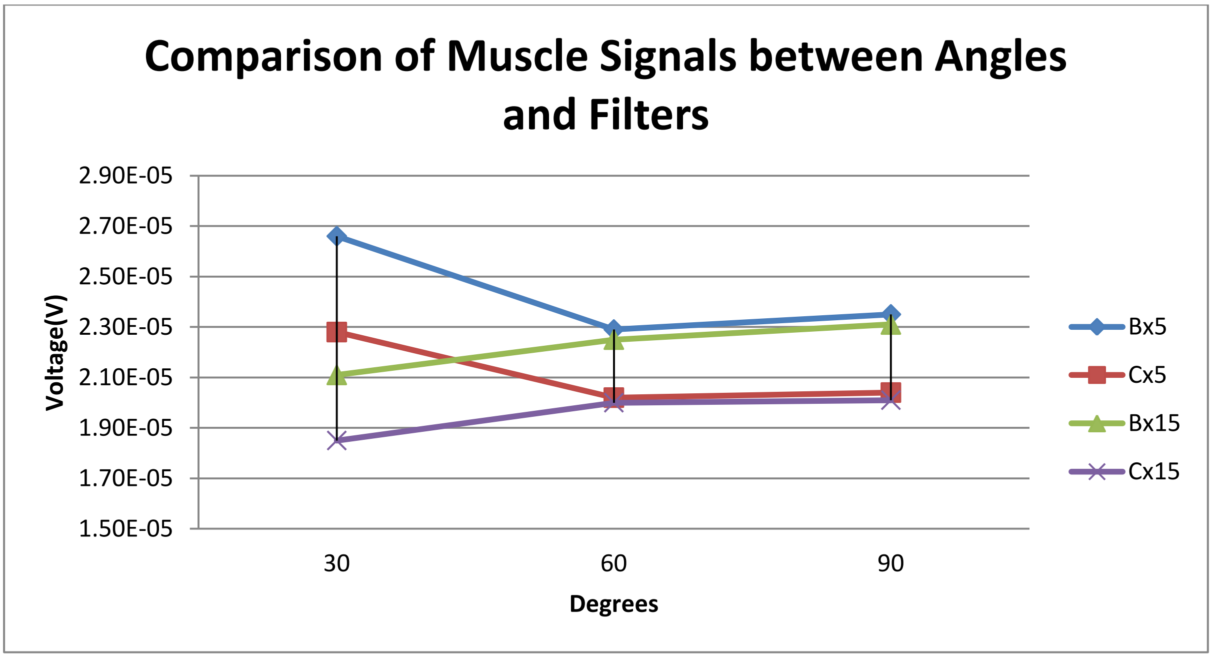


Figure 54: Comparison of Muscle Signals between Angles and Filters

Figure 54 shows the comparison of muscle signals between angles and filters. As shown in the figure, 5 times of 30 degree repetition yields the best average muscle signals. Values of Chebyshev filter are lesser than Butterworth filter because of its characteristic. The slope of

Chebyshev filter is higher hence it is able to filter better than Butterworth filter but in term of pass band, Chebyshev filter do contains ripples while Butterworth filter is able to produce a clean data. Hence, Butterworth is a better filter for filtering the noise during signals acquisition process.

CHAPTER 5

CONCLUSION

5.1 Conclusion

In this Final Year Project, arm-exoskeleton prototype is build based on Tetrix Kit and Lego Mindstorm. The 12V DC motor is used to support the joint of the exoskeleton. Literature review on the mechanical part which is the exoskeleton takes longer time because exoskeleton is a new technology that is being introduced to the engineering field recent years. The specification of each building parts for the exoskeleton is noted to make sure that an efficient arm exoskeleton will be produced and suitable to be wear by different individuals. The Literature Review on EMG signal is studied and experiment is carried out for 8 different subjects to understand more about the muscle signal of healthy person. The analysis for the improvement in the muscle strength after training and rehabilitation using EMG sensor is shown in the report. This technology aims to overcome the disability of human and acts as an assistive device in biomedical field in future.

5.2 Future Work

The arm exoskeleton is aimed to use on stroke patient in future to carry out the rehabilitation process for repetitive exercises. The trouble of going thru and fro from the hospital or clinic daily such as time availability, transport problem and insufficient of rehabilitation equipment in the medical center can be solved by having arm exoskeleton at the home.

Besides, this project can be further improvised by testing on more different subjects and have collaboration with biomedical expertise to improve the training method for stroke patients. The improvement in muscle strength of the patient will be measured by using EMG and the EMG signals will be compared as the rehabilitation process goes on so that research can be further developed to provide a better and more efficient rehabilitation method for different stroke individuals.

Next, the mechanical structure for the exoskeleton can be improved in future to a more design that is able to support more weight. Currently, the exoskeleton only uses existing material to build a prototype. Consultation on mechanical part collaboration with biomedical expertise can be included to improve the existing exoskeleton to a more reliable, light weight and safety concern exoskeleton.

REFERENCES

[1] The Internet Stroke Center [Online]. Available: http://www.strokecenter.org/patients/about-stroke/stroke-statistics/

[2] *Stroke Statistics*. Available: http://www.stroke.org.uk/

[3] M. Bortole, "Design and Control of A Robotic Exoskeleton for Gait Rehabilitation," Systems and Automation Engineering Department.

[4] Bharat. (2013). *Battery-powered upper body exoskeleton Titan Arm wins James Dyson award*. Available: http://www.damngeeky.com/2013/11/07/15354/battery-powered-upper-body-exoskeleton-titan-arm-wins-james-dyson-award.html

[5] Aurelien. *World-Changing Dreamer: Ismael Cendejas*. Available: http://perspectives.3ds.com/tag/exoskeleton/

[6] M. H. RAHMAN, "DEVELOPMENT OF AN EXOSKELETON ROBOT FOR UPPER-LIMB REHABILITATION," THE DEGREE OF DOCTOR OF PHILOSOPHY Ph. D., 2012.

[7] R. A. R. C. Gopura1 and K. Kiguchi, "Application of Surface Electromyographic Signals to Control Exoskeleton Robots," in *Applications of EMG in Clinical and Sports Medicine*, ed: InTech, 2012, pp. 69-94.

[8] K. Kiguchi, "A Study on EMG-Based Human Motion Prediction for Power Assist Exoskeletons," presented at the Proceedings of the 2007 IEEE International Symposium on Computational Intelligence in Robotics and Automation, Jacksonville, FL, USA, 2007.

[9] D. Kalika. *Surface Electromyography (SEMG)*. Available: http://www.nydnrehab.com/new-york-city/physical-therapy-therapist/treatment-methods/surface-electromyography-semg/

[10] N. E. Inc. *Ergonomics Suite Version 2.0*. Available: http://www.nexgenergo.com/ergonomics/thoughtergo.html

[11] E. Criswell, "Cram's Introduction to Surface Electromyography," E. d. D. ELEANOR CRISWELL Ed., ed, 2011, pp. 5-7.

[12] P. A. P. Roberto Merletti, *Electromyography*, 2004.

[13] Brian, "Title," unpublished|.

[14] Z. G. X. Zeeshan O Khokhar, Carlo Menon, "Surface EMG pattern recognition for real time control of a wrist exoskeleton," ed: BioMedical Engineering OnLine, 2010.

[15] M. A. Mikulski, "Electromyogram Control Algorithms for the Upper Limb Single-DOF Powered Exoskeleton," presented at the Proc. IEEE Int. Conf. on Human System Interactions (HSI), 2011.

[16] H. H. a. K.Kiguchi, "A Study on EMG-Based Control of Exoskeleton Robots for Human Lower-limb Motion Assist," presented at the Proc. IEEE Int. Conf. on Information Technology Applications in Biomedicine, 2007.

[17] W. Z. Zhang Zhen, Yao Songli, Zhang Yanan, Qian Jinwu, "Research on Control of an Exoskeletal Ankle with Surface Electromyography Signals," presented at the Proc. IEEE Int. Conf. on Bioinformatics and Biomedical Engineering, 2008.

[18] M. L. Jose M. Ochoa, Derek G. Kamper, and Sang Wook Lee, "Use of an Electromyographically Driven Hand Orthosis for Training after Stroke," presented at the Proc. IEEE Int. Conf. on Rehabilitation Robotics (ICORR), 2011.

[19] M. B. Jacob Rosen, Moshe B. Fuchs, and Mircea Arcan, "A Myosignal-Based Powered Exoskeleton System," presented at the IEEE Transactions on Systems, Man and Cybernetics, 2001.

[20] T. T. Kazuo Kiguchi, Toshio Fukuda, "Neuro-Fuzzy Control of a Robotic Exoskeleton With EMG Signals," *IEEE TRANSACTIONS ON FUZZY SYSTEMS,* vol. 12, 2004.

[21] S. K. A. D. S. Andreasen, and D.A.Backus,, "Exoskeleton with EMG Based Active Assistance for Rehabilitation," presented at the Proc. IEEE Int. Conf. on Rehabilitation Robotics, 2005.

[22] C. R. Christian Fleischer, Gunter Hommel, "Predicting the Intended Motion with EMG Signals for an Exoskeleton Orthosis Controller," presented at the Proc. IEEE Int. Conf. on Intelligent Robots and System, 2005.

[23] R. A. R. C. G. a. K. Kiguchi, "A Human Forearm and Wrist Motion Assist Exoskeleton Robot with EMG-Based Fuzzy-Neuro Control," presented at the Proc. IEEE Int. Conf. on Biomedical Robotics and Biomechatronics, 2008.

[24] N. G. T. A. D. G. CALDWELL, "Development and Control of a 'Soft-Actuated' Exoskeleton for Use in Physiotherapy and Training," 2003.

[25] S. K. M. a. S.Bhaumik, "A Bioinspired 10 DOF Wearable Powered Arm Exoskeleton for Rehabilitation," 2013.

[26] M. Moro. Appendix 1: LegoMindstorm NXT (hardware and software) [Online]. Available: http://www.terecop.eu/downloads/Appendix_1.pdf

APPENDICES

APPENDIX A Gantt Chart & Key Milestones

Table 14 Gantt Chart FYP1

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Activities														
Literature Review on sEMG signal	▨	▨	▨	▨	▨	▨	▨	▨ ●						
Literature Review on Exoskeleton								▨	▨	▨	▨	▨	▨	▨ ●
Building of Exoskeleton												▨	▨	▨ ●

Table 15 Gantt Chart of FYP2

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Activities														
Development of Exoskeleton	▨	▨	▨	▨	▨ ●									
Experimental on Subject				▨	▨	▨	▨	▨	▨	▨	▨ ●			
Data analysis of experiment								▨	▨	▨	▨	▨	▨	▨ ●

● Milestones