Assessment of Upper Extremities Using an Interactive Robotics Rehabilitation Training System

by

Sharon Ho Siew Wan

17892

Dissertation submitted in partial fulfillment of

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CERTIFICATION OF APPROVAL

Robotics Rehabilitation for Training and Assessment of Upper Extremities

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A project dissertation submitted to the Electrical & Electronics Engineering Programme

Universiti Teknologi PETRONAS in partial fulfillment of the requirement for the

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Approved by,

(Assoc. Prof. Dr. Irraivan Elamvazuthi)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2017

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 acknowledgments, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(SHARON HO SIEW WAN)

ABSTRACT

'Subject-Oriented' approach expands the cooperation and desire of the patients bit by bit but they need to remind the patient of their capacity to make progress in their attempts of muscle activation. Hence, preparing and appraisal situations for the execution of ADLs are essential for the usage robotics rehabilitation system. This study intends to research on the legitimacy of 'subject-oriented' approach in helping the patient's movement and attempt as shown by one's capacity. On that record, it is assumed that 'subject-oriented' approach will amplify the result. This robot intervened treatment ought to be as successful and proficient as that of an affirmed human therapist in enhancing versatility and scope of movement and will just help the development of the patient just as much as fundamental in a shorter timeframe while persistent giving quantitative information for better change through the rehabilitation procedure. An experiment was conducted on 4 healthy subjects which are made up 2 males(Right handed) and 2 females (Left Handed) where they are request to contract a muscle such as Extensor Carpi Radial and Palmaris Longus by doing movement such as Wrist Flexion and Hand Open & Hand Close to investigate on the ability of the individuals when doing an upper extremities reaching task. Then the EMG is acquired and analyzed.

ACKNOWLEDGEMENT

First of all, I would like to express my warm thanks to all that have aided and helped me along the way. This project has been an incredible accomplishment and milestone for me and my supervisor, Assoc. Prof. Dr. Irraivan Elamvazuthi. I have learned many valuable lessons and experiences that will be beneficial for me in the future.

In addition, I would like to express my gratitude to Universiti Teknologi PETRONAS for including Final Year Project subject which is spread throughout two semesters in an eight months period. This long exposure definitely improved my project management, time management, and presentation skills. This curriculum includes comprehensive tasks, presentations with deadlines that are well prepared.

Besides that, I would like to thank my mentor and my teacher, Assoc. Prof. Dr. Irraivan Elamvazuthi for his teaching, guidance and support in completing this project. He prepared me well for this project and supported me tremendously throughout this project.

Furthermore, I would like to dedicate my appreciation towards all the volunteers that participated in my research despite their tight schedule.

Last but not least, I would like to thank my family and friends for always supported me throughout the entire project, both by keeping me harmonious and helping me putting pieces together. I hope that the results from this project will be able to impact some decisions in the industry

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CHAPTER 1

INTRODUCTION

1.1 Background Study

Figure 1 shows the prevalence on stroke patients around the world.

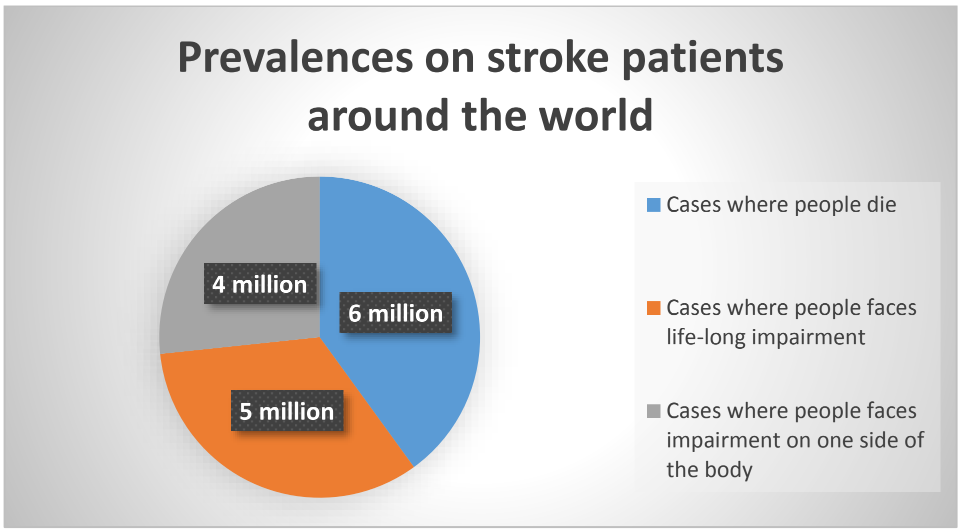


Figure 2: Prevalence on stroke patients around the world

Stroke is a serious general physical condition that affects roughly around 15 million people around the world [1], where an amount of 6 million people die and the other five million people faces life-long physical impairment. [3] The adult outbreak of disability around the world is mainly caused by stroke and in yearly 5 million people is experiencing long period of time of restriction of an individual to carry out daily activities and tend to depend on other people. [1,2,4]

The rate of stroke happening in developed countries are decreasing in develop countries, whereas a totally different progression is happening in the Asia Pacific, where patients suffering acute stroke is increasing. The outcome of the current study on the rate acute stroke condition in Malaysia will definitely affects the worldwide rate of stroke condition. [5] In most of the ASEAN countries, stroke condition is labelled as one of the top four major reasons of death. [6] Malaysian National Burden of Disease Study has classified stroke as the top two prime reasons that resulted to death. From the total of certified deaths, death due to stroke is make up of 8.9% in males and 12.1% in females. [7].

One of the method to treat stroke condition is where the patients undergo physiotherapy, by medication and also sometimes in more serious case, surgery. However, sometimes there will be lack of time, expenses and also finding transportation to the hospital maybe a problem for the patient. Therefore this type of unpredictable situation will defer the process of the rehabilitation of the stroke patient. [8]

A few research has been conducted on the effectiveness of the stroke rehabilitation process.[9,10] Application of the robotics system in the stroke rehabilitation is applied with the hope that it can help to deal with the primary restrictions on the traditional manual training such as lack in the number of certified specialized physiotherapist and patients did not repeat the movement training sufficiently. Combining Virtual Reality and robotic devices could enable the therapy to be conducted in an inspiring way to the patients in which could be promptly recorded and classified.[11]

1.2 Problem Statement

The most common rehabilitation training system involves long treatment period where the mechanism for the physiotherapy is hard physical work with 300/400 contracting and tensing arm per day and requires certified physiotherapists specified for each patient. From the view of the present state of the rehabilitation system, it means that robotic techniques are required to improve the situation of the physiotherapist.

The fundamental approach of this research would mostly depend on 'subject-focused' techniques that will perceive the patient's motion development expectations and endeavors based on the patient's ability. This vital intercession will definitely enable the involvement and hope of the patients to grow progressively nevertheless this process need some time by consistent reminding the patient they are able to make progress in their attempts of muscle functioning. It is widely believed that energetic participation of the patient is triggered by this 'subject-focused' techniques. This robot rehabilitation device ought to be as productive as the affirmed physiotherapist. The reason is that robots will be only helping the motion of the patient only when it is needed. Therefore, the changes in human muscle will be display in the movement pattern over time related to the upper extremities would be learned by the patients.

1.3 Objectives

The objectives are:

1. To enhance the ability to move and range of mobility.
2. To obtain the EMG signal using features extraction method.
3. To correlate the EMG data and hand movement assessment from the Armeo Sring

1.4 Scope of Study

In this project, a feasibility study on enhancing the ability to move and range of mobility will be carried out on ArmeoSpring by conducting an experiment. A study on upper limb exercise, involving students from Universiti Teknologi PETRONAS which is the controlled health subjects. The healthy subjects will be required to performed some computer based exercise in a virtual environment in a computer. On the other hand, the muscle activation for both muscles (Extensor Carpi Radialis and Palmaris Longus) is obtained simultaneously using Delsys surface electromyography (sEMG) system when the subjects were performing the computer based exercise. The validated outcome data is used to determine the condition of the arm and hand movements. The data from the experiment will be carefully analyzed and its association with daily life experience.

1.5 Dissertation Outline

The rest of the dissertation is written as the following:

Chapter 2 provides discussion on the introduction of stroke. Furthermore, the foundation of robotics technology innovation in rehabilitation field with their diverse methods of control. The type of rehabilitation devices is also being discussed.The diverse kind of robotics rehabilitation and their advantages and disadvantages alongside the related works will likewise be evaluated and compressed in the critical analysis segment.

Chapter 3 provides discussion on the type of robotic rehabilitation being used in this experiment. Next, the experimental design is also being shown in detailed.

Chapter 4 provides the discussion on the result of the experiment that was performed and a detailed discussion was provided based on the result.

And, finally, Chapter 5 gives a conclusion for this study and future proposals are recommended in this segment.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Literature Review

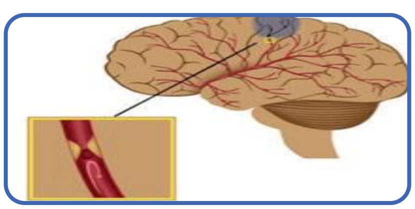
2.1.1 What is Stroke?

A stroke happens when the brain cannot receive blood with oxygen because of a blood vessel in the brain is blocked or burst. The brain do not have the capability to keep oxygen, and thus it need a system of blood vessel to supply blood that is full with oxygen. When the brain do not have sufficient supply of oxygen level, it will cause the cell around the brain loss of oxygen and nutrients and this could lead to death or life-long impairment.

TIA(Transient Ischemic Attack) refers to impermanent disturbance in the supply of blood to certain part of the brain area. This situation only last just a couple of minutes. The indications of TIAs are at times alluded to as " pre-stroke" as they might be an signal implying that a a full stroke is about to happen.

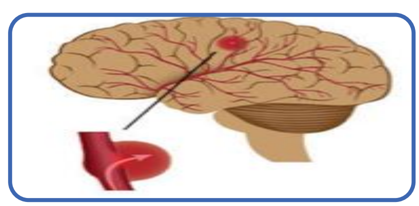
2.1.2 Types of Strokes

There are generally two types of strokes namely, ischemic stroke and hemorrhagic stroke. Ischemic stroke is mainly responsible for 80% of all strokes. Hemorrhagic stroke can be divided into two main types. Firstly, intracerebral hemorrhage occurs when burst



Ischemic Stroke

- Blood vessels is blocked and results in low supply of oxygen to the brain.
- Due to blood clumps in an artery in the brain or known as "carotid stenosis" (narrowing of the arteries)



Hemorrhagic Stroke

- Blood vessels burst, causing leakage of blood into the brain.

blood vessels drip the blood into the brain. A subarachnoid hemorrhage occurs where there is blood dripping under the external and internal layers of the brain. This kind of hemorrhage can bring harm to the brain and is most deadly kind of all types of strokes.

2.1.3 Prevalence of Stroke

Annually, 15 million individuals around the world suffer from stroke. About six million died and another 5 million are left with life-long impairment. Stroke is the second driving reason for impairment, after dementia. Stroke could cause impairment in loss of motion and vision, and disarray. Internationally, stroke is categorized as the second driving reason for death for age of 60 years, and the fifth driving reason for death in individuals age between 15 to 59 years old.

However, stroke is unlikely to happen to individuals under the age of 40, in spite of the fact that is happens too. The most widely recognized causes are hypertension or "sickle cell disease" in the youngsters.

In numerous developed nations, the occurrence of stroke is decreasing. However, in Asian countries the rate of stroke happening is increasing. Malaysian National Burden of Disease Study has classified stroke as the top two prime reasons that resulted to death. From the total of certified deaths, death due to stroke is make up of 8.9% in males and 12.1% in females.

2.2 Rehabilitation

2.2.1 Conventional Methods of Rehabilitation

Physiotherapy

- Physiotherapists help people by performing theraphy and also giving advices on patients affected by injury.

Psychotherapy

- it provides a supportive environment that allows you to talk openly with someone who's objective, neutral and nonjudgmental.

Acupunture

- is an old practise in which needles are directly inserted into the skin to stimulate a certain muslce in the body.

Chiropractor

-involves manual therapy especially spinal manipulation therapy (SMT), other joints, and soft tissues, but may also include exercises and health and lifestyle counseling.

Osteopathy

-is a type of alternative medicine that emphasizes massage and other physical manipulation of muscle tissue and bones.

2.2.2 Robotics Rehabilitation

Rehabilitation process is typically a dreary and complicated process which include repetition motion of doing task [12] in which robots are normally the best choice for task that need lots of repetition and precision and that put them as one of the best choice for rehabilitation tools

2.2.2.1 General aims of rehabilitation robotics are [13]:

1) To increase in terms of productivity and precision of the treatment ways.

2) To minimize cost involving with the therapy and could create a new workable therapeutic process

3) To accomplish physical development and mental recuperation

Distinctive methods are characterized in outlining the robotics rehabilitation which incorporates active practice and passive practice. Passive practice is demonstrated when the patient's development are being moved either by the physiotherapist to keep the muscle from decaying when the patients did not perform any intentional control. Active or dynamic practice is demonstrated by patients who tried to use their own force to finish a movement. [15] Most of the rehabilitation system, their frameworks consists of the three essential classes of rehabilitative control systems. These control systems include help-as-required, test based and submissive help. [14]

There are some restrictions on the conventional machines which is the Continuous passive motion (CPM) machine can decrease the level of edema in the hand of flabby hemiparetic patients. [16]

2.2.2.2 Upper Extremities

Figure 2 show the type of rehabilitation devices used for the upper extremities.

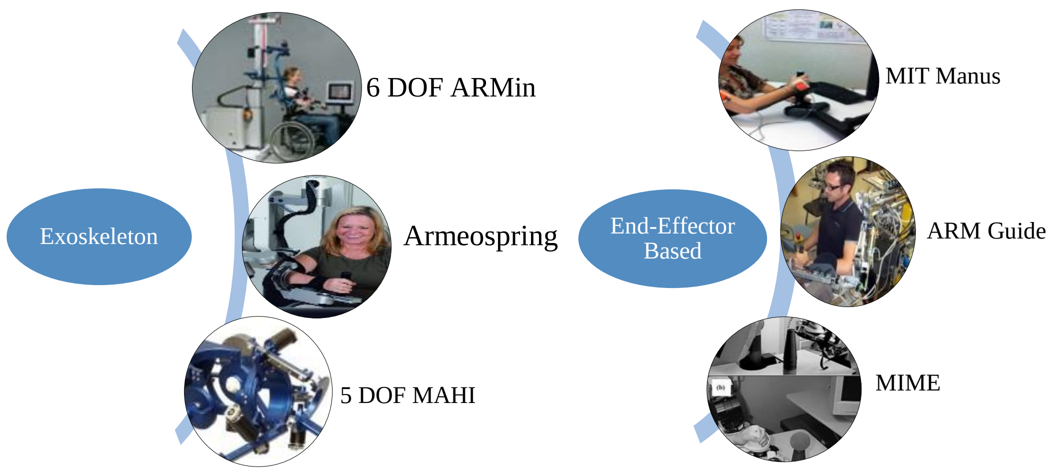


Figure 3: Type of robotics rehabilitation system

As shown in figure 2, rehabilitation sytems for the upper extremities can be divided to exoskeleton and and end-effector based. EEB robots connects only at its distal segment of the patient’s limb. It may improves the design of the gadget. However, in situations with numerous conceivable degrees of freedom, it may be more difficult to control the limb position. Exoskeleton robots are robots with machine-driven structure that possessed the skeletal system of the limb to improve the human joint motion. The EEB robots are made up of MIT Manus, ARM Guide and MME. On the other hand, exoskeletons are made up of 6DOF ARMin, ArmeoSpring and 5 DOF MAHI.

There are some other disabilities such as the lower limb disabilities in which there are several good method developed to help the patients in their rehabilitation. However, for upper limb disabilities, there are still methods that are still being researched to determine which suits the patients most. One of the most significant disorder is the function loss of the arm and hand for the patients to perform daily activities such as taking care of oneself, and working.

2.3 Electromyography (EMG)

At present, EMG had transformed into an essential gadget in biomedical area too in clinical application. Thus, the acknowledgment, managing and examination of EMG flag has wound up being uncommon and a noteworthy research run in biomedical field. In electromyography, skeletal muscle filaments sanctioning is begun amidst the electrical current. The potential movement takes after electric waves that go to the fibers to vitalize muscle pressure. Potential action moves along nerve fiber and manages the skeletal muscle as appeared in Figure 3. By then, the induction will make muscle constriction which then will make improvement in human members.

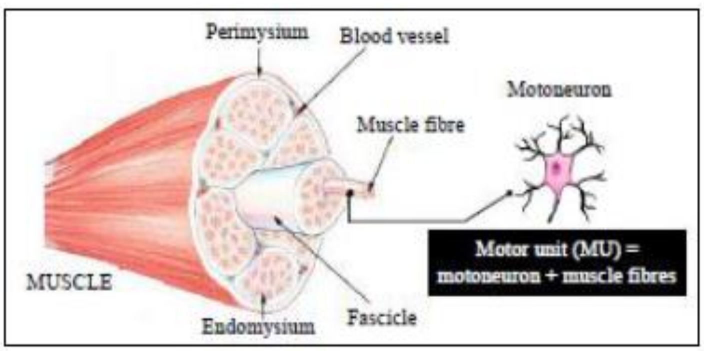


Figure 4: Muscle Structure

Electromyography is utilized to assess, record and examine the electrical action of skeletal muscle in the midst of compression Muscle includes different individual strands which are not at all like comparatively as length, shape and width. Muscles are restricted by a social event of fascicule that are bound together

2.3.1 Filters

Filtering a signal is an important step. Filtering is utilized to concentrate on a confined band of electrical imperativeness that is important to us other than all the electrical signs that the sensors will get. Generally, electromyography (EMG) filter is influenced by disturbance influence which makes by various sources.

Types of filter

Butterworth filter

This channel is best used due to the reason it has maximally-level extent or similarly called maximally level response in the transmission pass band and meanwhile limiting pass band ripple.Magnitude-squared Butterworth response:

$$|H(j\omega)|^2 = \frac{1}{1+(\omega/\omega_c)^{2N}} \quad (2.1)$$

Chebyshev filter

This channel have a more extraordinary get off where it can finish a precarious roll-offs with higher request outline. Chebyshev channel outflank Butterworth channel where for a comparable oder plan, Chebyshev channel perform superior to anything the Butterworth's weakening in the move band. The amplitude response for Chebyshev Type I with *n*th-order low-pass filter is shown below:

$$|H(j\omega)|^2 = \frac{1}{1+\varepsilon^2 C_N^2\left(\frac{\omega}{\omega_p}\right)}, \quad (2.2)$$

where

$$C_N\left(\frac{\omega}{\omega_p}\right) = \begin{cases} \cos\left[N\,cos^{-1}\,(\omega/\omega_p)\right], & |\omega| \le \omega_p \\ \cosh\left[N\,cosh^{-1}\,(\omega/\omega_p)\right], & |\omega| \ge \omega_p \end{cases}$$

Amplitude response for Chebyshev Type II with *n*th-order low-pass filter:

$$|H(j\omega)|^2 = \frac{\varepsilon^2 C_N^2\ (\omega/\omega_p)}{1+\varepsilon^2 C_N^2\ (\omega_s/\omega)}$$

where

$$C_N\left(\frac{\omega}{\omega_p}\right) = \begin{cases} \cos\ [N\ cos^{-1}\ (\omega_s/\omega)], & |\omega| \geq \omega_s \\ \cosh[N\ cosh^{-1}\ (\omega_s/\omega)], & |\omega| \leq \omega_s \end{cases}$$

Elliptic filter

Elliptic filter is more extreme however the amplitude response has ripple in both pass band and stop band. Elliptic channel keep keeping up the steepest cutoff in the most reduced number of filter order.

Definition of the magnitude-squared Elliptic response:

$$|H(j\omega)|^2 = \frac{1}{1+\ \varepsilon_p^2\, R_N^2\ (\omega,\omega_p,\omega_s,\varepsilon_p,\varepsilon_s)} \qquad (2.3)$$

where

$$R_N\left(\omega, \omega_p, \omega_s, \varepsilon_p, \varepsilon_s\right) = sn\ [K\ sn^{-1}\ (\omega/\omega_p\ , \omega/\omega_s$$

2.5 Related Work

Table 1 shows the comparison of the related robotics rehabilitation.

Table 1: Analysis of Related Works

No	Author	Year	Title	Type of Robotics Rehabilitation	Application	Merits	Demerits
1	Qizhi, Y., et al [17]	2015	Dynamic analysis of 7-DOF exoskeleton upper-limbed rehabilitation robot	Exoskeleton	6 DOF MAHI	Features a safe training environment and customized feedback	Limitation of torque output capability.
2	Sharifi et al [18]	2012	Model reference adaptive impedance control of rehabilitation robots in operational space	End-Effector Based	MIT-Manus	Low cost	Less range of movement for possible exercise scenario
3	Staubli P et al [19]	2009	Effects of intensive arm training with the rehabilitation robot ARMin II in chronic stroke patients: four single-cases	Exoskeleton	6 DOF ARMin	Highlights bona fine movement arrangements, including facilitated communicatio ns between wrist, elbow and shoulder joints	
4	Lm PS et al [20]	2006	MIME robotic device for upper-limb neurorehabilitatio n in subacute store subjects: A follow-up study	End-Effector Based	MIME	Effective as an equivalent dose of conventional rehabilitation therapy	Lack of distinct treatment for distal joints such as wrists
5	Reinkensmeyer DJ et al [21]	2000	Understanding and treating arm movement impairment after chronic brain injury : progress with the ARM guide	End-Effector Based	ARM Guide	Adjustable slide to assist forearm movements	Limited working space for linear movements

The research reported in [17] shows the results of features for a safe training environment and customized feedback .In [18], it was found that the rehabilitation using robots resulted in low cost but there was less range of movement for exercise scenario. The ARMin [19] is a 6 DOF ARMin that highlights bona fine movement arrangements, including facilitated communications between wrist, elbow and shoulder joints. On the contrary, MIME robot [20] is effective as an equivalent dose of conventional rehabilitation theraphy. The ARM Guide has an adjustable slide to assist forearm movements.

Table 2 shows the comparison of work related to EMG.

Table 2: Analysis of work related to EMG

No	Author	Year	Title	Experiment	Results	Limitations
1	Sachin Sharma [24]	2012	Techniques for Feature Extraction from EMG Signal	Testing various techniques used to extract features from EMG signal	Time domain extraction method is chosen as the feature extraction method from EMG signal	The large amount of data extracted from the myoelectric signal need to be processed.
2	Carlo J. De Luca[25]	2002	Surface Electromyography :Detection and Recording	How to analyze EMG signal	In EMG signal,need to focus on SNR or the muscle signal,bandwidth signal and muscle sample size	Do not place electrode near the tendon of the muscle to prevent crosstalk.
3	W.J.Kang et al [26]	2000	A comparative analysis of various EMG pattern recognition methods.	EMG signals of 20 repetitions of 10 motions analysed for each subject	The MMLM(modified maximum likelihood method) with S-type has the bese discrimination efficiency.	Subject were not well trained during the experiment. Need to provide more training to the subject before experiment duration
4	M. Silverstro et al [27]	1999	A hybrid approach to EMG pattern analysis for classification of arm movements using statistical and fuzzy techniques.	Six male subjects aged 22-28 were asked to perform three different planar arm pointing movements to grab and object across the table.	AR feature extraction method is found to be matching with the real time constraints.	The fuzzy inference should have a minute fraction of all computation time
5	Angkoon Phinyomarka, et al [28]	2000	EMG Feature Evaluation for Improving Myoelectric Pattern Recognition Robustness	Data are collected from a male non-amputee subject where the electrodes are placed in four positions.	The SampEn has the best classification accuracy of 93.37%	Need to have more training for the test subject to have more accurate result.

A few studies have been conducted to find out the extraction method to be use to extract features from EMG signal. Sachin Sharma [24] found out that time domain extraction method is chosen as the best feature extraction method from EMG signal according to the experiment of testing various techniques.

On the other hand, in the study of [25] Carlo J. De Luca (2002) in an experiment on how to analyze EMG signal. It is found out through they study that in EMG signal,need to focus on SNR or the muscle signal, bandwidth signal and muscle sample size. Furthermore, in [26], [27] and [28], the authors has studied on the most efficient features extraction method by conducting experiment on test subjects. W.J.Kang, C.K.Cheng and T.S.Kuo [26] (2000) has conducted an experiment on analyzing the EMG signals of 20 repetitions of 10 motions analysed for each subject and also they stated to have more training for the subject before experiment is conducted. Silverstro Micera, Angelo M.Sabatini,Paolo Dario, and Bruno Rossi[27] (1999) conducted a research by using six male subjects aged 22-28 were asked to perform three different planar arm pointing movements to grab and object across the table. Angkoon Phinyomarka, Franck Quaine, and Sylvie Charbonnier [28] (2000) experiment is about where data are collected from a male non-amputee subject where the electrodes are placed in four positions. Their research also stated to have more training for the test subject to have more accurate result.

Table 3 shows the comparison of work related to rehabilitation on hand opening/hand closing.

Table 3: Analysis of work related to rehabilitation on hand opening/hand closing

No	Author	Year	Title	Experiment	Results	Limitations
1	Angkoon Phinyomarka et al [29]	2014	Guest Editorial: Special Issue on Haptics in Rehabilitation and Neural Engineering	A two degree-of-freedom haptic device, ReHapticKnob,is used to train hand opening/closing as well as Forearm rotation during exercises which involve motor,sensory as well as cognitive aspects.	The results demonstrate that subjects are better able to control their center of pressure using closed-loop feedback.	Kinesthetic forces are responsible for the observed changes in subjects' movements, that visual distortion caused effects but no adaptation, and that cutaneous stimuli did not change the subjects' movements.
2	Yupeng Ren et al [30]	2009	Developing a wholearm exoskeleton robot with hand opening and closing mechanism for upper limb stroke rehabilitation	interface is also able to train the right or left hand, and to adapt the position of the wrist for an improved comfort	The experimental results showed part of the capabilities of the IntelliArm and demonstrated the feasibility and benefits of the developed system.	the multi-DOF hand exoskeleton system causes the patients difficulty in wearing it..

3	Ludovic Dovat et al [31]	2008	HandCARE2: A novel cable interface for hand rehabilitation	The interaction between the subject and the robotic interface is measured by means of five encoders and five force sensors located at the output of the robot (at the subject's fingertips).	can assist the subject in opening and closing movements of the hand and can be adapted to accommodate various hand shapes and finger sizes.	
4	Kevin D. Gemmell et al [32]	2016	Investigation of a passive capstan based grasp enhancement feature in a voluntary-closing prosthetic terminal device	Subjects are required to use force to disengage locks.	This device allows a range of release forces.	This device use lots of energy from the subjects.

Numerous studies have been carried out in the area of rehabilitation on hand opening/hand closing. In Table 3, Antonio ,et al [29], have carried out an experiment using a two degree-of-freedom haptic device, ReHapticKnob, used to train hand opening/closing as well as Forearm rotation during exercises which involve motor,sensory as well as cognitive aspects. The results demonstrate that subjects are better able to control their center of pressure using closed-loop feedback. On the other hand, Yupeng Ren et al [30] conducted an experiment on an interface also able to train the right or left hand, and to adapt the position of the wrist for an improved comfort. The experimental results showed part of the capabilities of the IntelliArm and demonstrated the feasibility and benefits of the developed system. Ludovic Dovat et al [31] conducted a research on the interaction between the subject and the robotic interface is measured by means of five encoders and five force sensors located at the output of the robot (at thesubject's fingertips). It is proven in this research that, this robotic interface can assist the subject in opening and closing movements of the hand and can be adapted to accommodate various hand shapes and finger sizes. Kevin D. Gemmell et al [32], conducted an experiment where subjects are required to use force to disengage locks. This device allows a range of release forces.

2.6 Critical Analysis

In this section, critical analysis in terms of Robotics Rehabilitation, Work related to EMG and Analysis of work related to rehabilitation on hand opening/hand closing would be presented.

2.6.1 Analysis of Related Robotics

6 DOF MAHI [17] has limitations in terms torque output capability. On the other hand, MIT-MANUS [18] has Less range of movement for possible exercise scenario. On top of that, the disadvantage of MIME [20] is that lack of distinct treatment for distal joints such as wrists. ARM Guide [21] has limited working space for the patients. From the investigation of the several application methods mentioned earlier, it is found out that Exoskeleton has more benefits particularly in the points of joints motion if it is compared to the EEB robotics. Subsequently, ArmeoSpring which is an exoskeleton sort is picked as as the experimentation instrument to comprehend the human movement and the attainability of robotic rehabilitation in enhancing the standard of life.

2.6.2 Analysis of work related to EMG

In [24], the limitations are the large amount of data extracted from the myoelectric signal need to be processed. On the other hand, Carlo J. De Luca[25] experiment stated, do not place electrode near the tendon of the muscle to prevent crosstalk. Furthermore, in W.J.Kang et al [26] and Angkoon Phinyomarka et al [28] experiment, subject were not well trained during the experiment. Need to provide more training to the subject before experiment duration. Silverstro Micera et al [27] states that the fuzzy inference should have a minute fraction of all computation time.

2.6.3 Analysis of work related to rehabilitation on hand opening/hand closing

Angkoon Phinyomarka et al [28] stated that kinesthetic forces are responsible for the observed changes in subjects' movements. Yupeng Ren et al [30] stated in their research that the multi-DOF hand exoskeleton system causes the patients difficulty in wearing it. Kevin D. Gemmell et al [32] concluded that the device used in their experiment use lots of energy from the subjects.

2.7 Summary

In this chapter, prevalence of stroke around the world and Malaysia have been discussed. Furthermore, the conventional methods of rehabilitation are being discussed in detail. In addition, types of rehabilitation devices used for the upper extremities which are EEB robots (MIT Manus, ARM Guide, MIME) and exoskeleton robots (ARMin, Armeo Spring, MAHI). On the other hand, the related EMG signals fundamental and filtering signal are discussed. Lastly, the related type of robotics and work related to EMG and rehabilitation on hand opening/hand closing are being discussed and analyzed.

CHAPTER 3

METHODOLOGY

3.1 General Characteristics of the system

Figure 4 shows a patient using the ArmeoSpring.

Figure 5: ArmeoSpring

The Swiss Company Hocoma AG creates a treatment idea with three diverse frameworks for upper limb rehabilitation. This treatment idea comes from the repetitive job-oriented situation in virtual domain, which encourages treatment of neurological illness of various seriousness. It provides three kind of therapeutic robots which are ArmeoPower (former ARMin), a robotic arm exoskeleton, ArmeoSpring, an exoskeleton with coordinated spring mechanism (emerging from T-WREX exoskeleton) and ArmeoBoom, an over-head sling suspension system (emerging from ROBAR project). [22] For this project, ArmeoSpring will be chosen to study the dynamic capacity on how human can control their motor. This device focuses on exercises that are self-coordinated, practical, extreme and self-commence, in this manner can increase the productiveness of rehabilitation which is an upgrade version of the T-WREX. This mechanical technology has an ergonomic arm skeleton with coordinated spring component that gives incredible gravity supportive network which can supports the whole arm. The pressure-sensitive handgrip on the device is responsible to enable the hand to practice its movement by undergoing release and grab workout. The Armeo software which consists of various games that requires movements that are alike to ADL reenacted in a virtual-reality situation that allows the patients to have quick reaction besides creating a stimulating situation.[23]

3.2 Flow of the Project

Figure 3 shows the flow of project methodology.

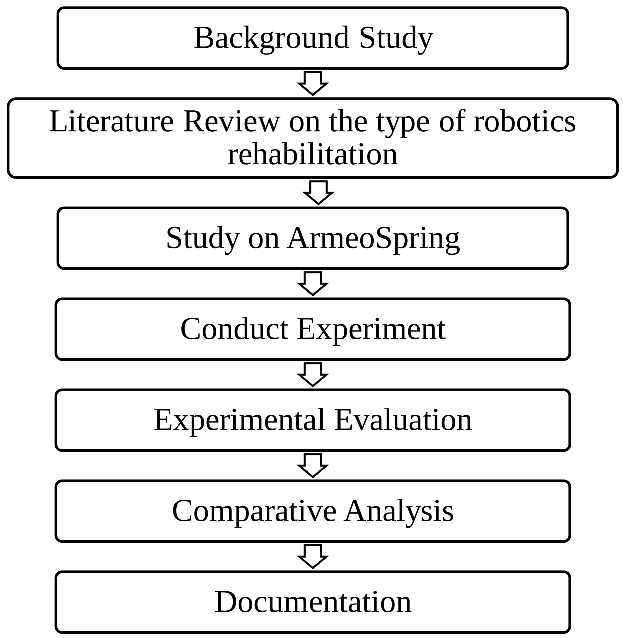
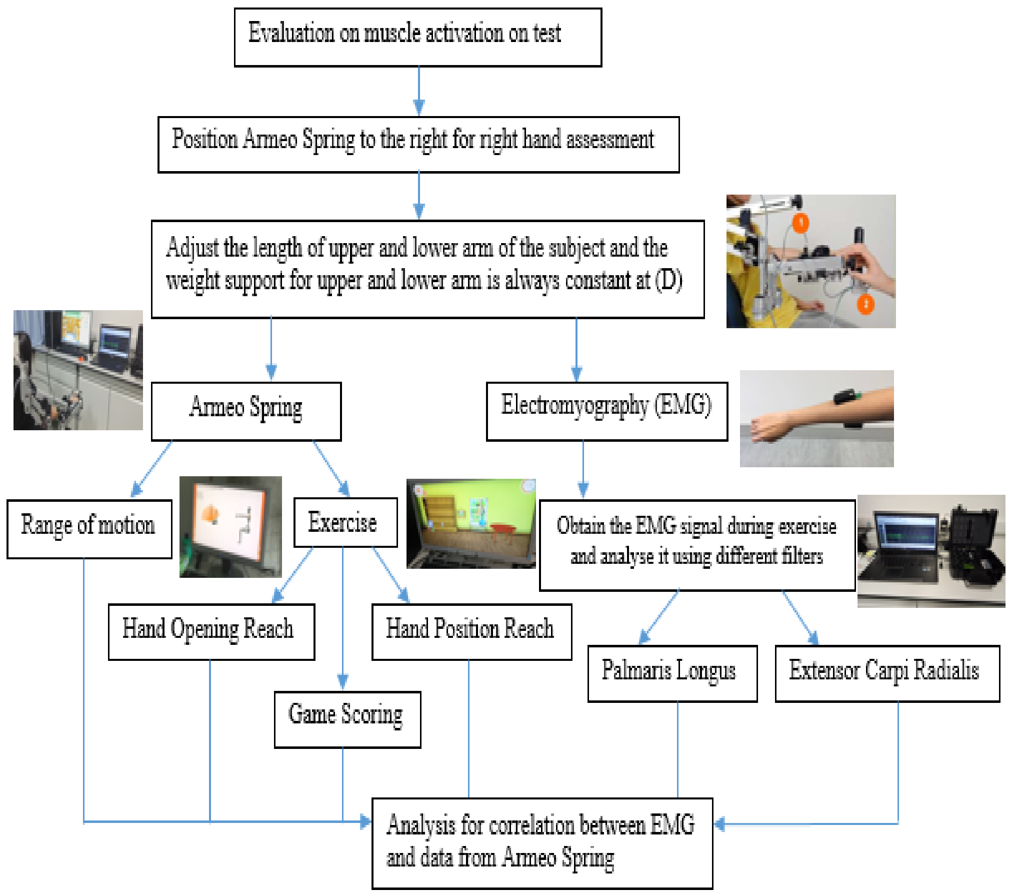


Figure 6: The flow of methodology

This project is commenced with a deep background study on this project title as it is important to fully comprehend the outline of the project to accomplish the goal that has been set. Moreover, there are different research paper sources, for example, some reading on research papers and studies is done for the collection of literature review on the sort of robotics rehabilitation. Furthermore, the control and working mechanism of the ArmeoSpring is as of now being contemplated to plan a preeminent strategy exhibiting the impact of human movement utilizing the robotics rehabilitation. Next, the analysis is being led and assessed. From the outcomes, a relative investigation can be done. At last, the whole research about this project will be recorded in document form.

3.3 Experimental Design



In this segment, the steps for the conducted experiment is being explained. The Armeo Spring is adjusted accordingly and positioned for right hand assessment. The length of the upper arm and lower arm is adjusted according to the subject requirement. On the other hand, the weight support is always constant for the all the subjects regardless of genders. The data from the Armeo Spring and EMG signal processing will be analyzed for correlation.

3.3.1 Experimental steps for EMG Acquisition

The EMG acquisition flow is shown in Figure 6

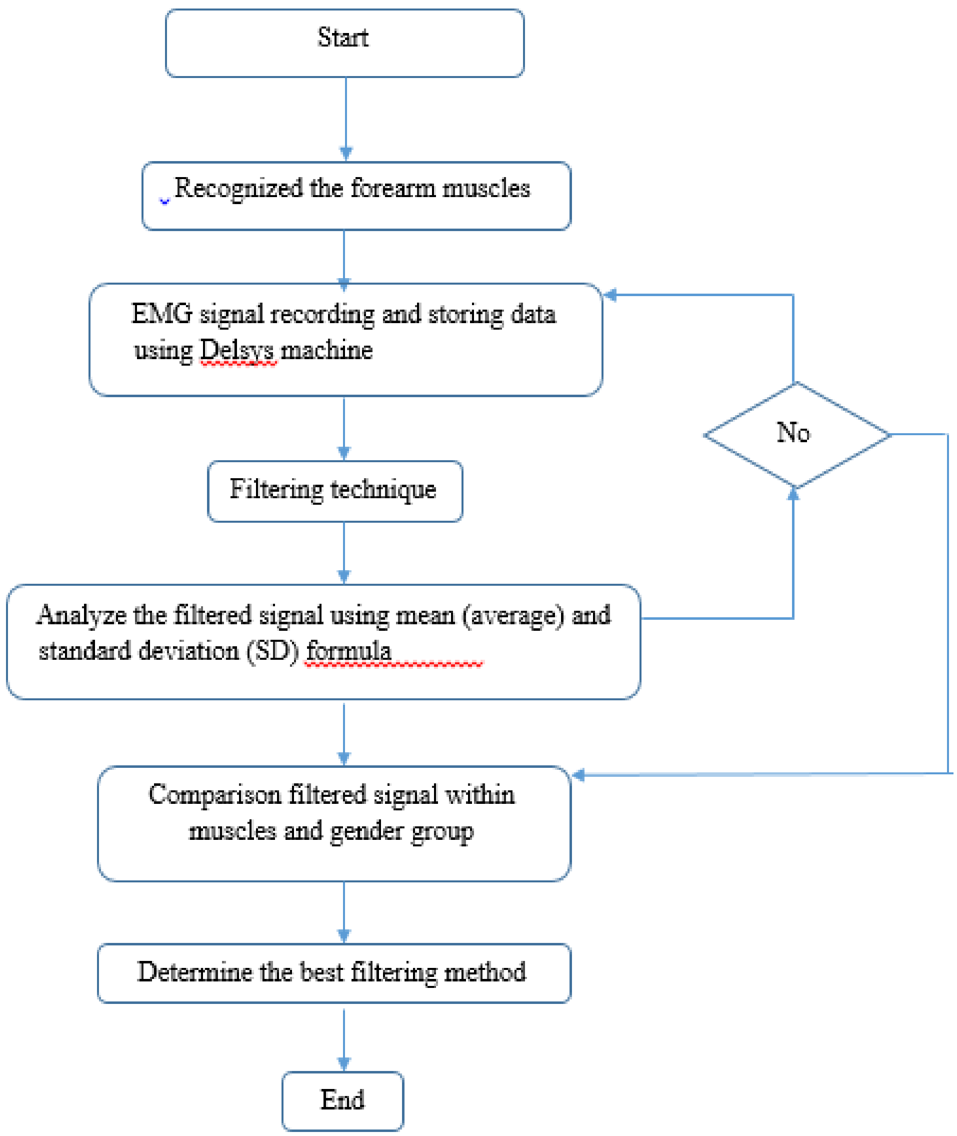


Figure 7: EMG acquisition flow

This project is begin with the writing up on the literature review on the fundamental of EMG signal where it comprises the raw signal from the healthy subjects. The basic knowledge about raw signal, studies on type of filtering method to be used. There are 4 types of filters which are made up of Butterworth filter, Bessel filter, Chebyshev filter and Elliptic filter,. Furthermore, after filtration, will tbe features extraction method which is divided to time domain, frequency domain, and time-frequency domain. In this experiment, time domain features extraction method is choosen.

The best filtering method and features extraction method will be further explained and justified. The simulation software that is being utilized for this research is EMGworks 4.0 Analysis, Delsys Inc and EMGworks 4.0 Acquisition.

For this experiment, 2 healthy male subjects (Right Handed) and 2 female healthy subjects (Left Handed), age 22 volunteered for the study. The test subjects arrangement is shown in Table 5.

Table 3: Test Subjects Arrangement

Group	Age	Test Subject	Number of test subject
1	22	UTP Students	4(2 males & 2 females)

In this experimental work, the tools required are Delsys Trigno Wireless Sensor, some alcohol swab to be applied on the skin before putting the sensors and EMG Signal Acquisition/Analysis software . Firstly, several forearm movements is required to be performed by the subjects as shown in Figure 7.

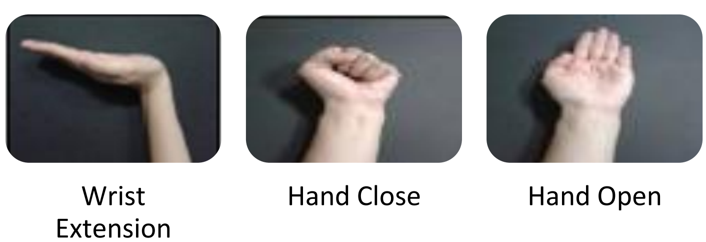


Figure 8: 3 different movements in forearm

The extensor carpi radials and palmaris longus is decided for this study because this is the two muscles that is involved in hand opening/closing. Table 6 demonstrate the type

Table 4: List of arm movements and muscles required

arm movements and the muscles involved in it.

Body part	Movement	Muscles
Wrist	Extension	Extensor carpi radials
Hand	Close	Palmaris longus
	Open	Palmaris longus

Before continuing with the test, liquor swab were utilized regarding the matter's skin to clean the skin from any soil as showed up in Figure 8. After the muscles position have been resolved, the surface sensor was put on the skin to be endeavored. The subject might be requested to contract a muscle. The subject began with wrist flexion and to hold for five seconds and to rest for five seconds. Position of the sensor regarding the matter's skin is showed up in Figure 9.

Figure 8: Packets of Alcohol swabs

Figure 10: Placement of the sensor on the subject's skin

3.3.2 Experimental Steps for Armeo Spring

The steps for this experiment is listed as below:

1. The Armeo Spring is positioned on the right for right hand assessment.

2. The Armeo Spring will be set up by reference to the length of the upper and lower arm of the subject. and the weight support for both upper and lower arm is constant which is D which is shown in Figure 10.

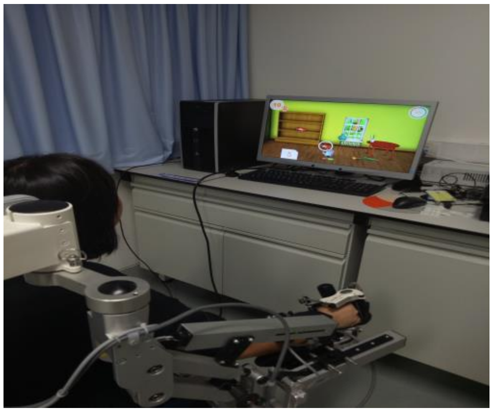


Figure 11: ArmeoSpring Set Up

3. The next step will be measuring the range of motion (ROM) as shown in Figure 11.

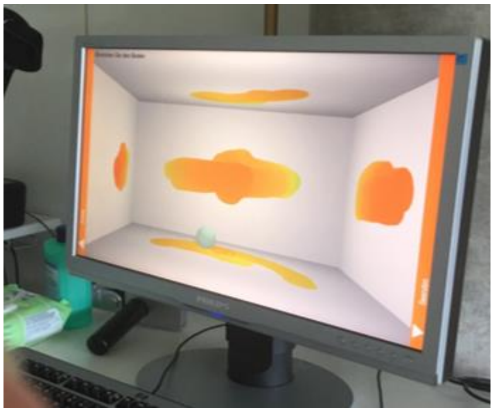


Figure 12: Measuring ROM movement

4. The range of motion of the subject is obtained by the subject painting 5 walls which include the far wall, left and right wall, and lastly upper wall and lower wall using the virtual arm on the computer screen.

5. Two electrode surface sensor is placed on top of the lower arm where the two muscles (Palmaris Longus and Extensor Carpi Radialis is located as shown in Figure 12.

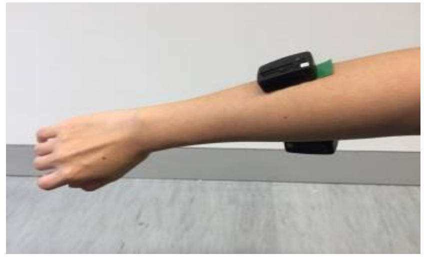


Figure 13: Placement of Electrode Sensor on the arm

6. Lastly, the subject will be required to perform the rehabilitation exercise using the virtual arm in the computer screen in a set of virtual environment. The subjects will move his/her arm to pick up fruits and placing them inside a trolley as shown in Figure 13.

Figure 14: Picking up things exercise

7. Steps 1 to 5 is repeated for left hand assessment
8. Result is obtained for further analysis.

3.3.3 Steps in obtaining EMG Signal and Processing.

1. The wireless surface EMG sensors were turned on and put on the two muscles of the subject which are (Palmaris Longus and Extensor Carpi Radialis) wirelessly from the Delsys sEMG System as shown in Figure 14.

Figure 15: Delsys sEMG System

2. The ArmeoSpring which is the rehabilitation robotic is used to obtain the EMG signal when the subject is performing the exercise in the virtual environment in the computer.

Figure 16: Obtaining the EMG signal utilizing the rehabilitation robotic.

3. Figure 16 shows the raw EMG data for muscles (Palmaris Longus and Extensor Carpi Radialis) which is obtained from the subjects performed the exercise which is about picking up things and placing at specific place which continually train the grabbing and release for the hand function.

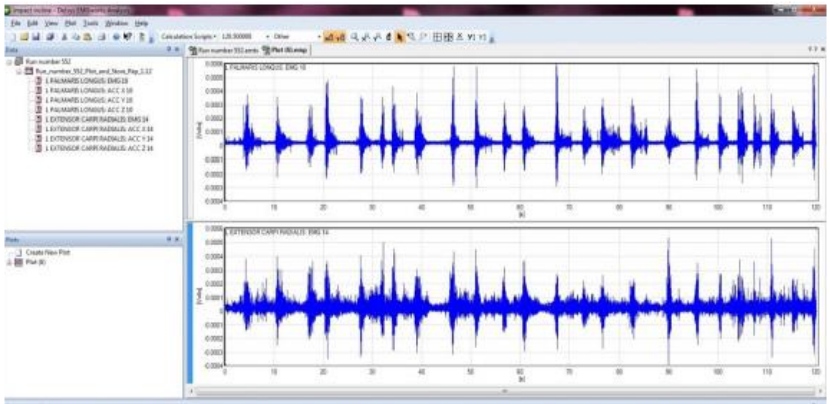


Figure 17:Raw EMG Signal

4. The raw EMG data are filtered using several specifications as shown in Figure 17:
- Bessel filter with an order of 4
- passband ripple of 3dB
- attenuation of 40dB, a band pass response
- corner frequency of 20Hz

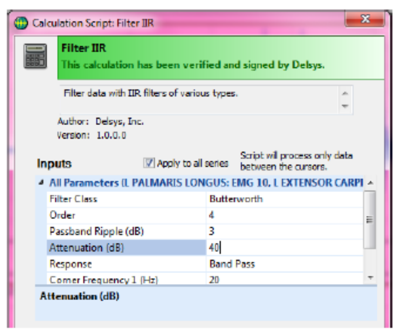


Figure 18: Specification in obtaining filtered signal

5. The figure 18 shows the filtered signal of muscles Palmaris Longus(at the top) and Extensor Carpi Radialis (at the bottom).

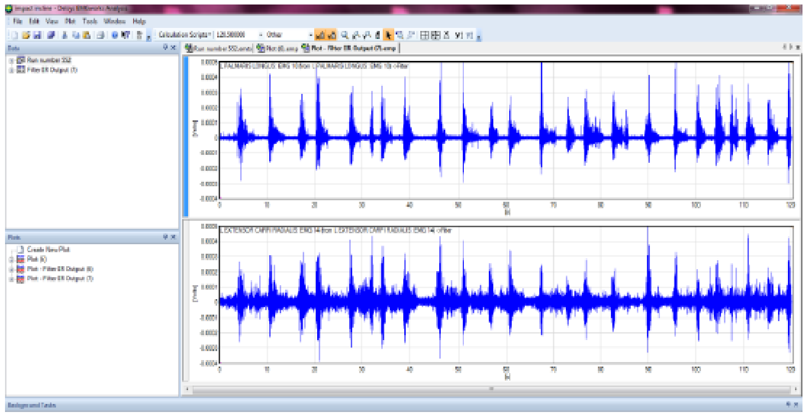


Figure 19: Filtered EMG Signal

6. Figure 19 shows the specification for obtaining the root mean square of the filtered signals.

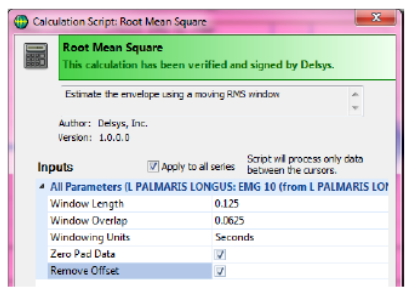


Figure 20: Specifications for obtaining RMS of the filtered

7. The RMS for the filtered signal of the Palmaris Longus and Extensor Carpi Radialis is shown in figure 20 .

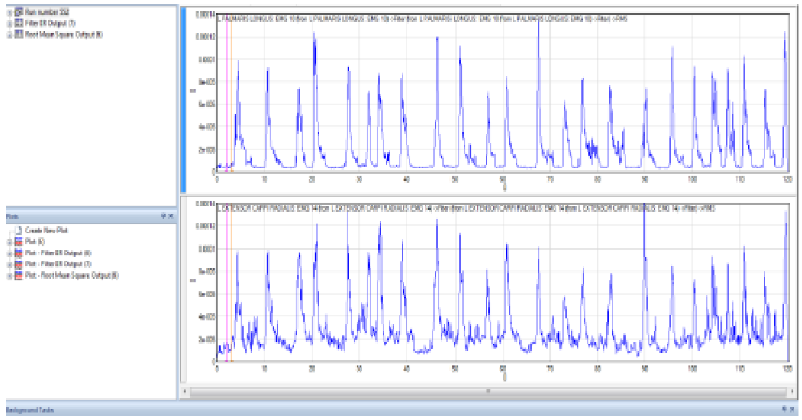


Figure 21: Filtered Signal with RMS

8. Figure 21 shows the specification to obtain the threshold from the RMS of the filtered signal for Palmaris Longus.

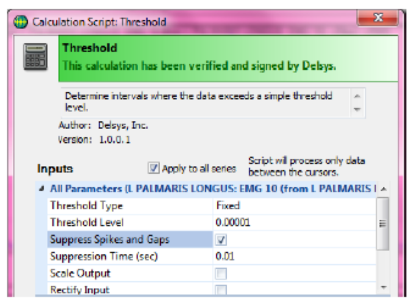


Figure 22:Specification for obtaining threshold from RMS of filtered signal

9. The threshold from the RMS of the filtered signal of Palmaris Longus is shown in Figure 22.

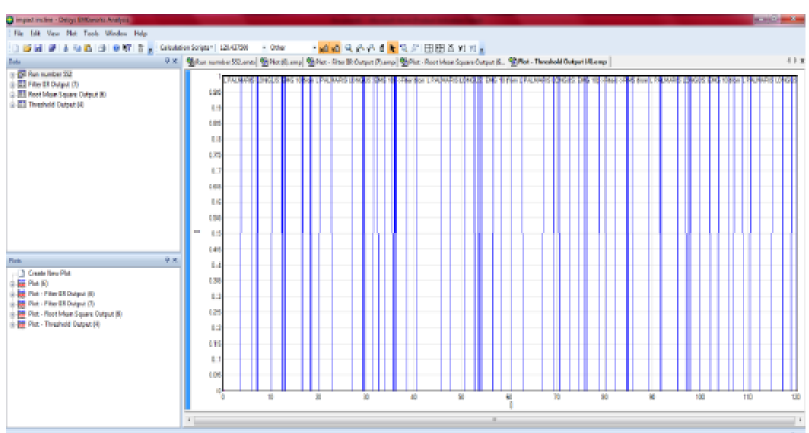


Figure 23: Threshold from RMS

10. Figure 22 shows the specification to obtain a smooth filtered with RMS signal using Simple Math. (Multiplying the RMS signal with the Threshold signal from Figure 22 for Palmaris Longus.

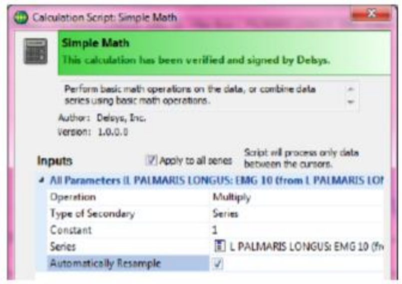


Figure 24:Using Simple Math to obtain smooth filtered RMS

11. Finally, a smooth of RMS filtered signal is obtained is shown in Figure 24. Steps 8 to 10 is repeated to obtain the smooth filtered signal for Extensor Carpi Radialis.

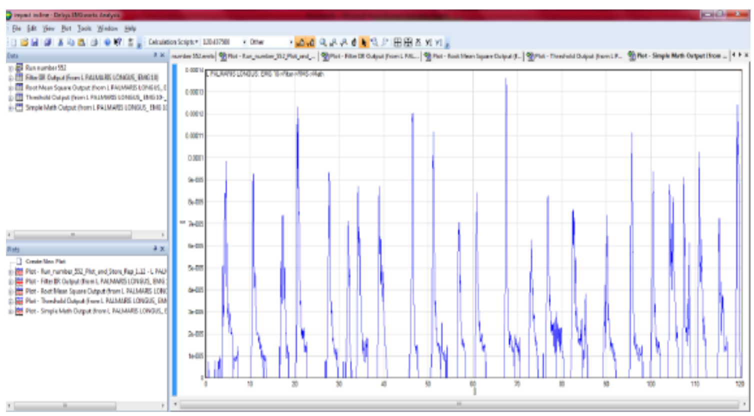


Figure 25: Smooth filtered RMS signal

For this experiment, the degree of hand opening reach, hand position reach in healthy subject will be studied using the robotic rehabilitation equipment (ArmeoSpring from Hocoma) and EMG recording (Delsys dEMG System). This analysis will measure the range of motion, measuring the score from a computer based-game (picking up things and positioning them in a specified place) , from this computer based-game, hand position/ opening reach and EMG signal will be measured. The results will be discussed to draw a conclusion.

The measurements:

1. Range of Motion (ROM)
   The subjects are required to do a few assessment which are horizontal shoulder abduction/adduction , shoulder inner/outer rotation and shoulder flexion/extension, elbow flexion/extension, forearm pronation/ supination, wrist flexion/extension and hand opening/closing.

2. Game Scoring, Hand Position Reach and Hand Opening Reach
   The subjects are required to perform the computer-based games which is picking up things and positioning them in a specified place which is very similar to human daily activities. Hand Opening Reach is how much the fingers is able to move to able to grab something.

3. EMG signal
   EMG signal of two muscles (Extensor Carpi Radials and Palmaris Longus) are obtained simultaneously by placing the electrodes on position of the muscles on the hand when the subjects is doing the ArmeoSpring's exercise.

3.5 Summary

In this chapter, the general characteristics of Armeo Spring is being discussed. Next, the experimental steps is shown in a flowchart. In addition, the experimental steps for EMG acquisition and Armeo Spring is also being explained. Lastly, the steps in obtaining the EMG Signal and Processing are being reviewed in depth.

CHAPTER 4

RESULTS & DISCUSSION

4.1 EMG Acquisition Plan

The raw signal acquired from three particular movements, for example, (1) wrist extension and (2) hand open and hand close.

The 4 different types of filter (Butterworth, Bessel ,Chebyshev, and Elliptic filter,) is used to filter the raw signal using band pass filter with corner frequency at 20 Hz to 400 Hz. After that, Root Mean Square (RMS) and Mean Absolute Value was decided for features extraction before continuing to threshold step. In this, RMS was chosen of the fact that; positive side of raw flag was required. MAV was chosen because it can produce out the average rectified value(ARV). The experiment is proceeded with threshold process and lastly will be able to get muscle activation analysis. The details in Table 4 shows the value used for the experiment during the simulation.

Table 5: Values used in the Experiment

Sampling frequency (Hz)	
Test subject	4 healthy subjects (2 male, 2 female)
Types of filter	Butterworth, Bessel, Chebyshev and Elliptic
Basic filter types	Band pass filter
Order (N)	4
Attenuation (dB)	4
Corner frequency 1(Hz)	20 Hz
Corner frequency 2 (Hz)	400 Hz

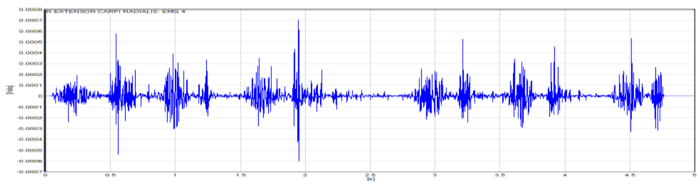
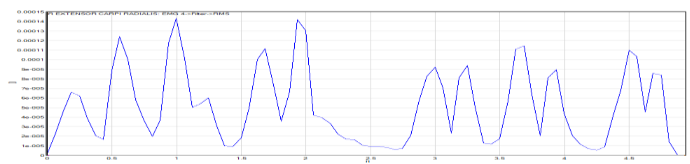
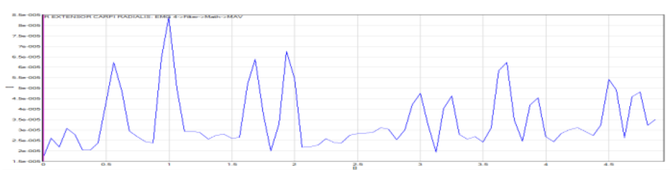
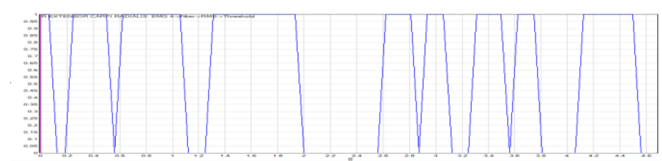
4.1.1 Results of EMG

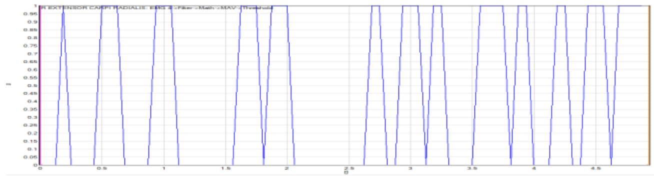
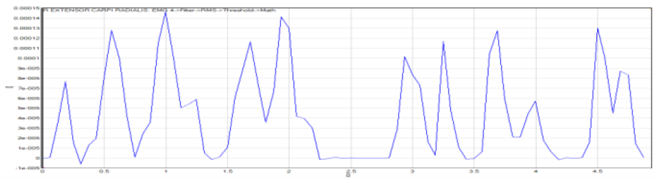
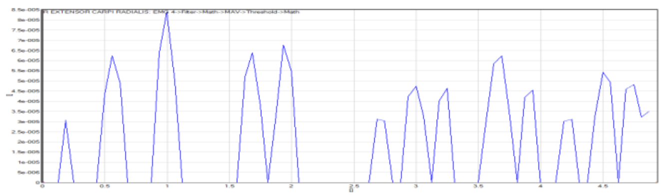
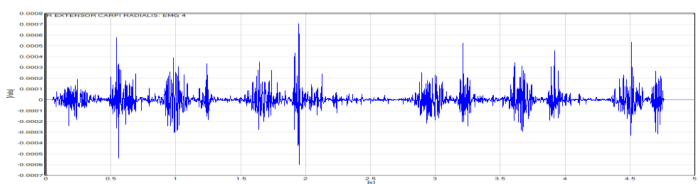
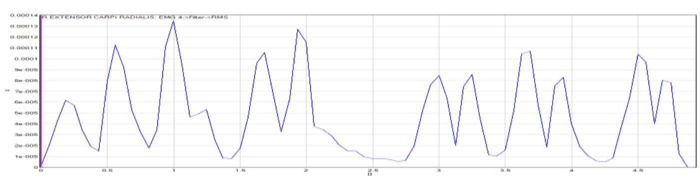
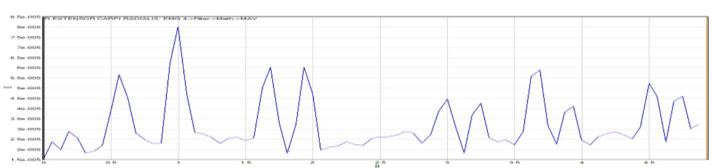
4.1.1 Test Subject 1

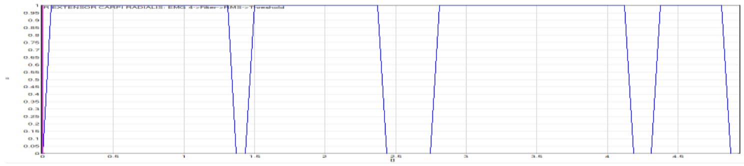
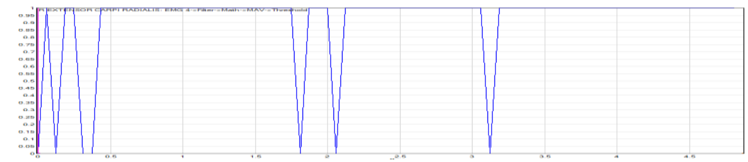
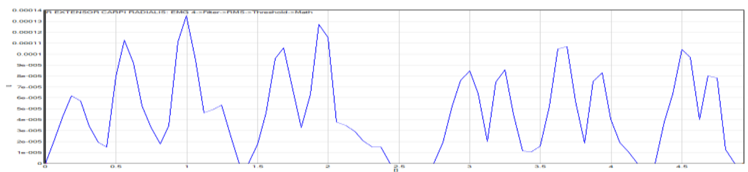
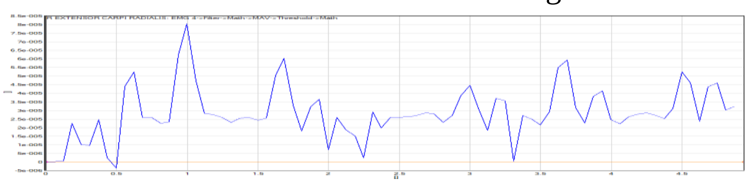
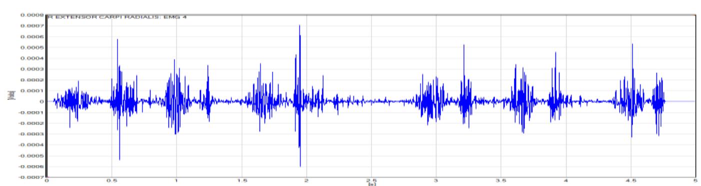
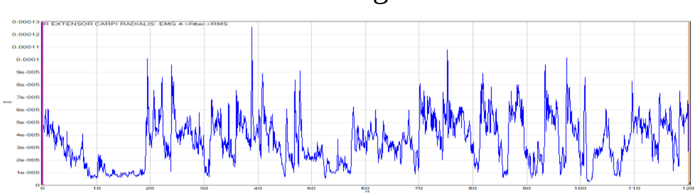
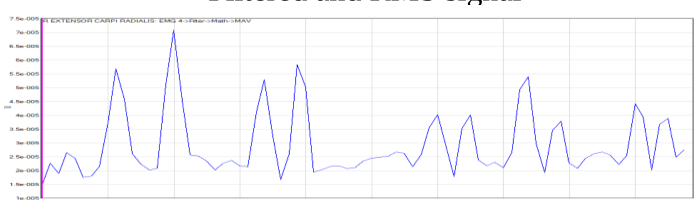
Gender	*Male*
Age	*22 years old*

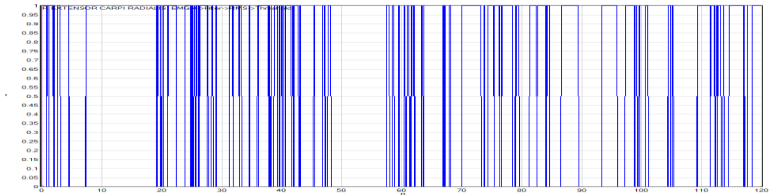
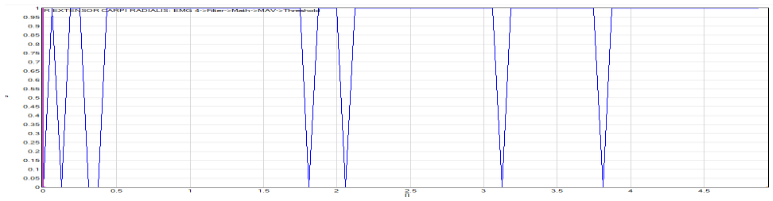
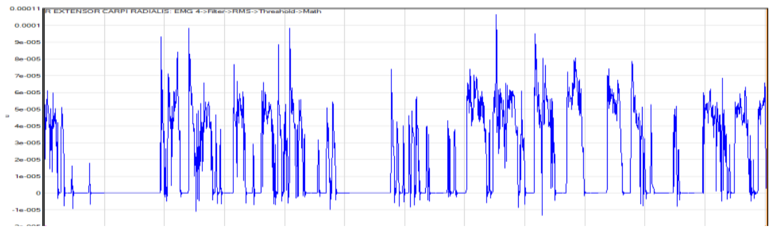
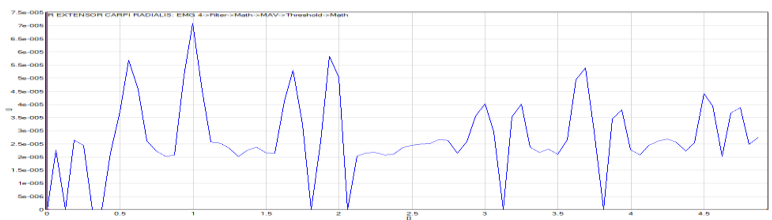
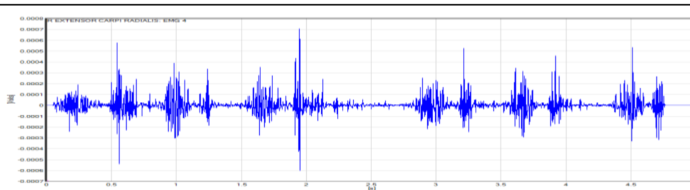
Table 6: Test Subject 1 Details

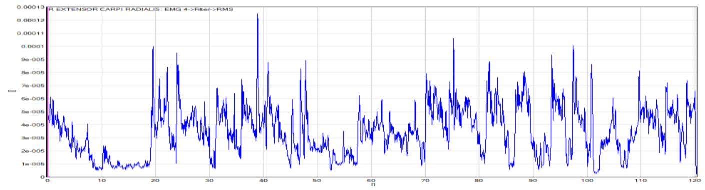
(a) Wrist extension

Types of filter	*EMG Simulations Figure*
Butterworth	 Raw signal  Filtered and RMS signal  Filtered and MAV signal  Threshold for RMS signal

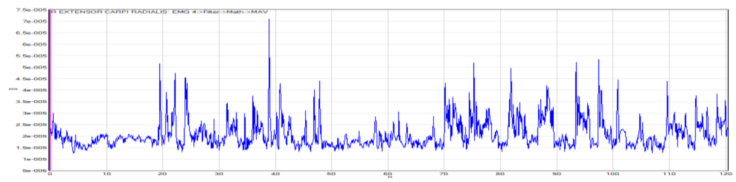
	 Threshold for MAV signal  Muscle Activation for RMS signal  Muscle Activation for MAV signal
Bessel	 Raw signal  Filtered and RMS signal  Filtered and MAV signal

	 Threshold for RMS signal  Threshold for MAV signal  Muscle Activation for RMS signal  Muscle Activation for MAV signal
Chebyshev	 Raw signal  Filtered and RMS signal  Filtered and MAV signal

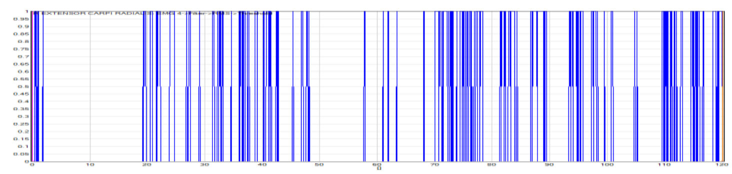
	 Threshold for RMS signal  Threshold for MAV signal  Muscle Activation for RMS signal  Muscle Activation for MAV signal
Elliptic	 Raw signal



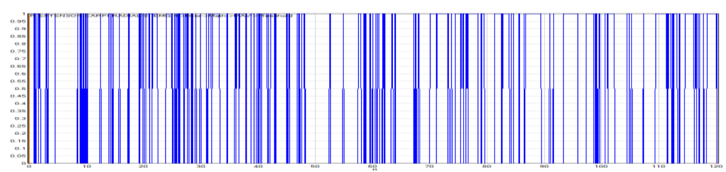
Filtered and RMS signal



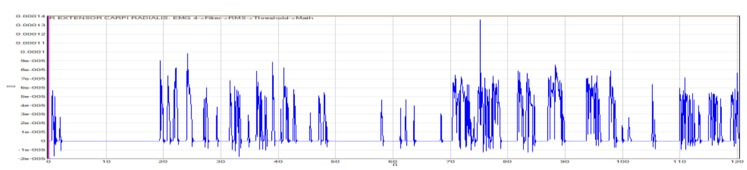
Filtered and MAV signal



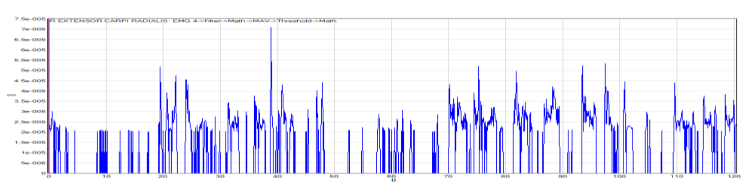
Threshold for RMS signal



Threshold for MAV signal



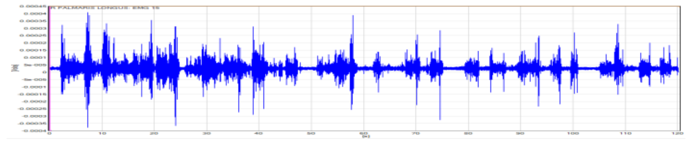
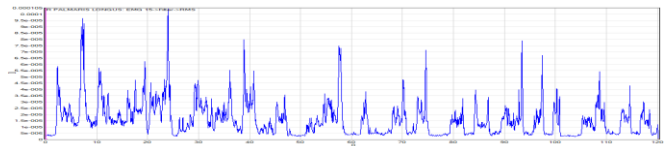
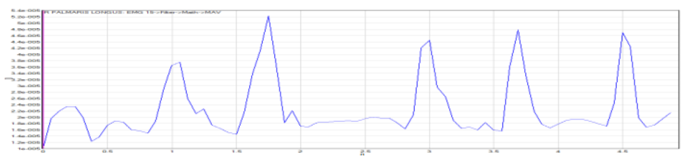
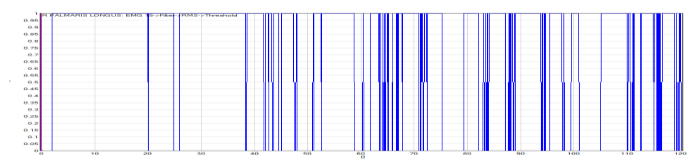
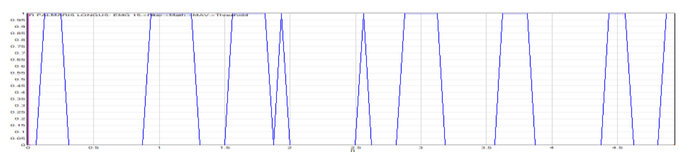
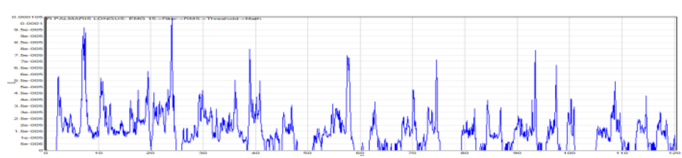
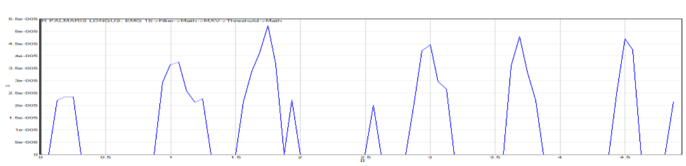
Muscle Activation for RMS signal

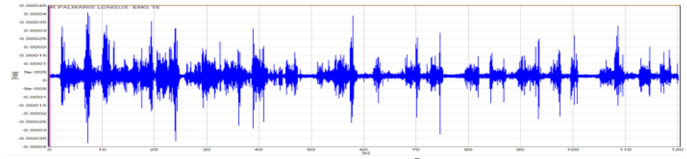
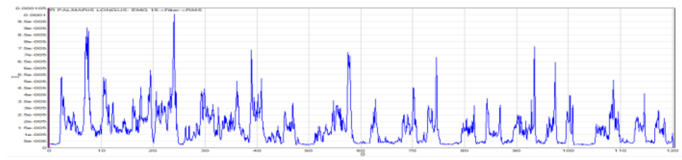
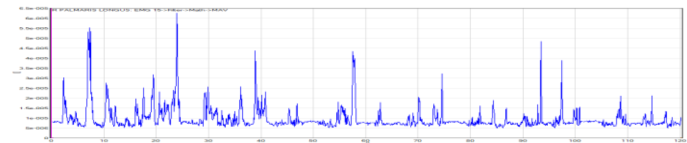
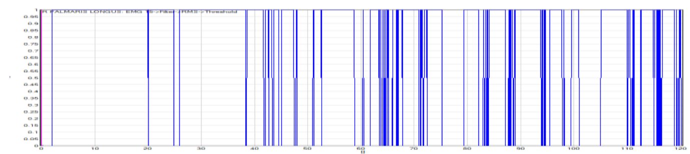
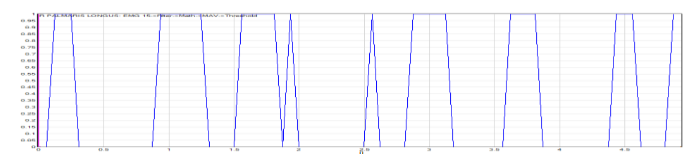
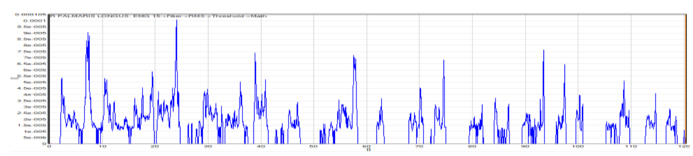
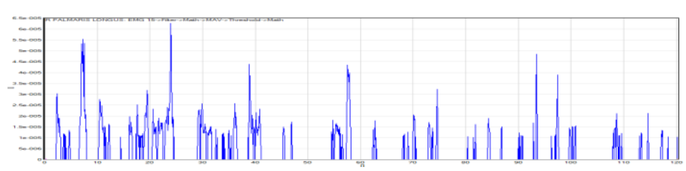


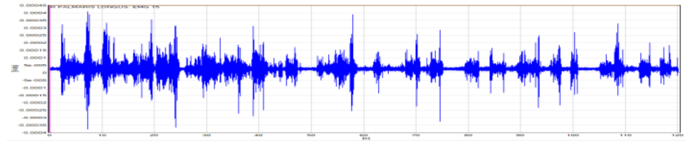
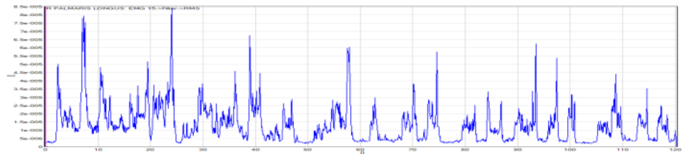
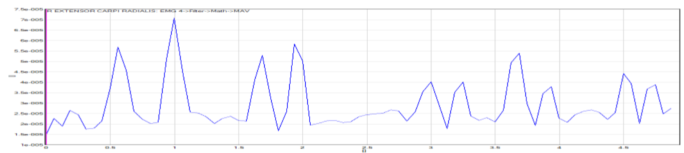
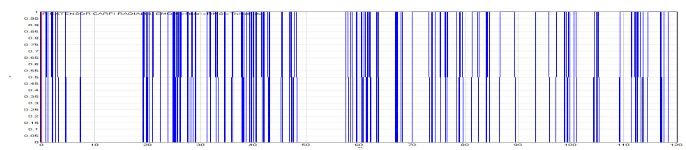
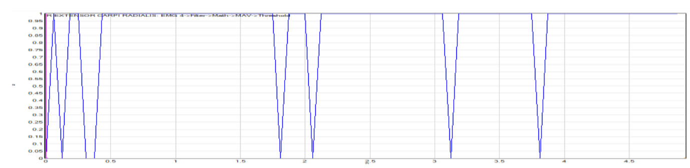
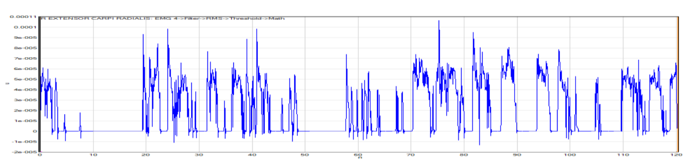
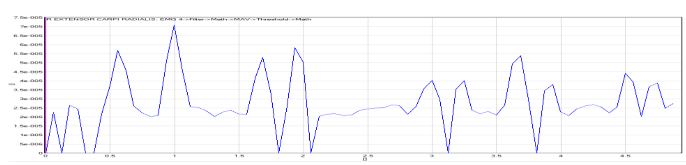
Muscle Activation for MAV signal

Table 7: Simulation figures for wrist extension (Test Subject 1)

(a) Hand Open and hand close

Types of filter	EMG Simulations Figure
Butterworth	 Raw signal  Filtered and RMS signal  Filtered and MAV signal  Threshold for RMS signal  Threshold for MAV signal  Muscle Activation for RMS signal  Muscle Activation for MAV signal

Bessel	 Raw signal  Filtered and RMS signal  Filtered and MAV signal  Threshold for RMS signal  Threshold for MAV signal  Muscle Activation for RMS signal  Muscle Activation for MAV signal

Chebyshev	 Raw signal  Filtered and RMS signal  Filtered and MAV signal  Threshold for RMS signal  Threshold for MAV signal  Muscle Activation for RMS signal  Muscle Activation for MAV signal

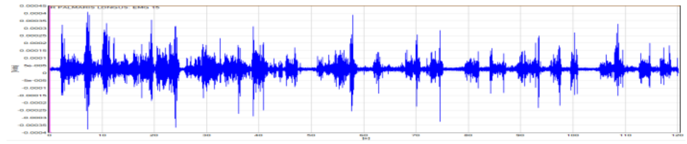
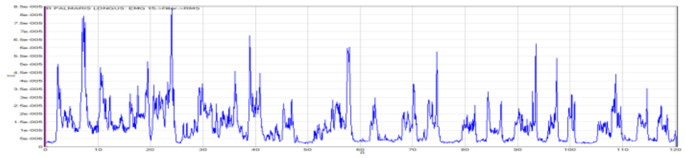
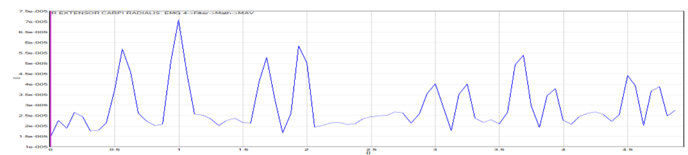
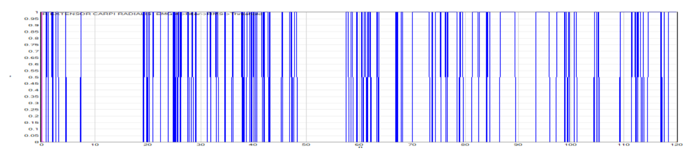
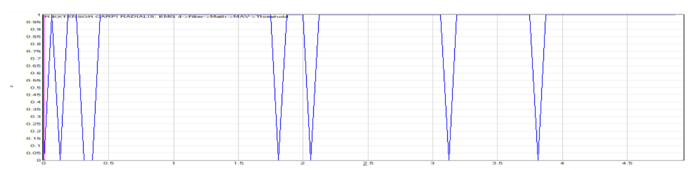
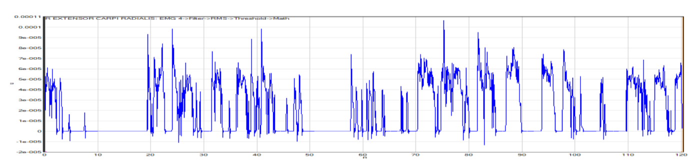
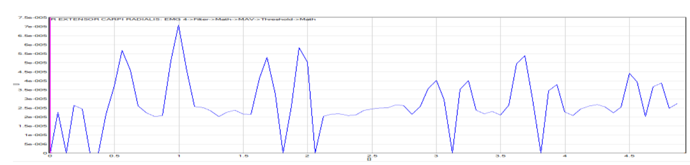
Elliptic	 Raw signal  Filtered and RMS signal  Filtered and MAV signal  Threshold for RMS signal  Threshold for MAV signal  Muscle Activation for RMS signal  Muscle Activation for MAV signal

Table 8: Simulation figures hand open & hand close (Test Subject 1)

4.1.2 Results of EMG for male subject(RMS)

4.1.2.1 ***Muscle activation using RMS features extraction method.***

Table 9 and 10 shows the muscle activation for test subject 1 and 2.

(a) *Subject 1*

<table>
<tr><th>Forearm Movement</th><th>Tabulated Data</th><th>Graphical Result</th></tr>
<tr><td>Wrist extension</td><td>
<table>
<tr><th>Filter</th><th>Mean</th><th>Standard Deviation</th></tr>
<tr><td>Butterworth</td><td>3.13E-05</td><td>1.77E-05</td></tr>
<tr><td>Chebyshev</td><td>3.87E-05</td><td>2.31E-05</td></tr>
<tr><td>Bessel</td><td>3.24E-05</td><td>1.83E-05</td></tr>
<tr><td>Elliptic</td><td>4.32E-05</td><td>2.21E-05</td></tr>
</table>
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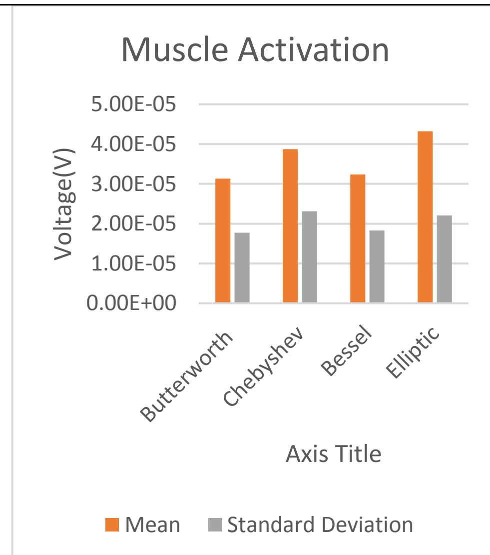

</td></tr>
<tr><td>Hand Open & Hand Close</td><td>
<table>
<tr><th>Filter</th><th>Mean</th><th>Standard Deviation</th></tr>
<tr><td>Butterworth</td><td>1.46E-05</td><td>1.46E-05</td></tr>
<tr><td>Chebyshev</td><td>1.18E-05</td><td>1.22E-05</td></tr>
<tr><td>Bessel</td><td>1.24E-05</td><td>1.46E-05</td></tr>
<tr><td>Elliptic</td><td>1.38E-05</td><td>1.15E-05</td></tr>
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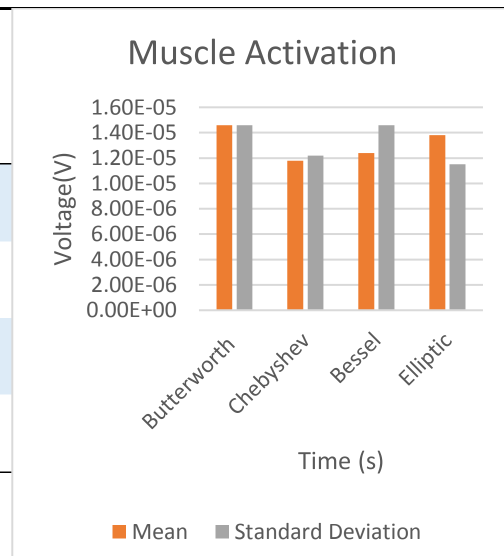

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Table 9:Muscle Activation for Test Subject 1

(b) Test Subject 2

<table>
<tr><th>Forearm Movement</th><th>Tabulated Data</th><th>Graphical Result</th></tr>
<tr>
<td>Wrist extension</td>
<td>
<table>
<tr><th>Filter</th><th>Mean</th><th>Standard Deviation</th></tr>
<tr><td>Butterworth</td><td>3.10E-05</td><td>3.16E-05</td></tr>
<tr><td>Chebyshev</td><td>1.37E-05</td><td>2.61E-05</td></tr>
<tr><td>Bessel</td><td>3.50E-05</td><td>2.42E-05</td></tr>
<tr><td>Elliptic</td><td>1.32E-05</td><td>2.57E-05</td></tr>
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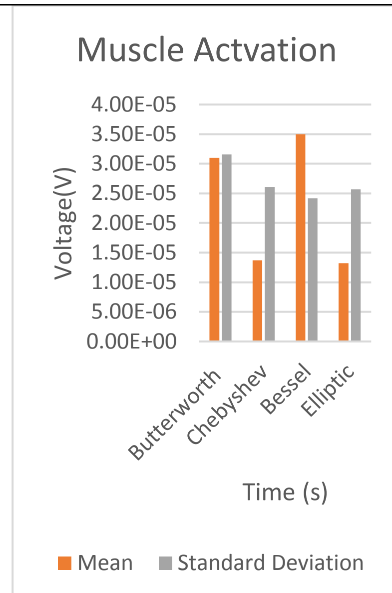

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<tr>
<td>Hand Open & Hand Close</td>
<td>
<table>
<tr><th>Filter</th><th>Mean</th><th>Standard Deviation</th></tr>
<tr><td>Butterworth</td><td>1.46E-05</td><td>1.46E-05</td></tr>
<tr><td>Chebyshev</td><td>2.91E-05</td><td>1.13E-05</td></tr>
<tr><td>Bessel</td><td>1.34E-05</td><td>1.39E-05</td></tr>
<tr><td>Elliptic</td><td>1.04E-05</td><td>1.27E-05</td></tr>
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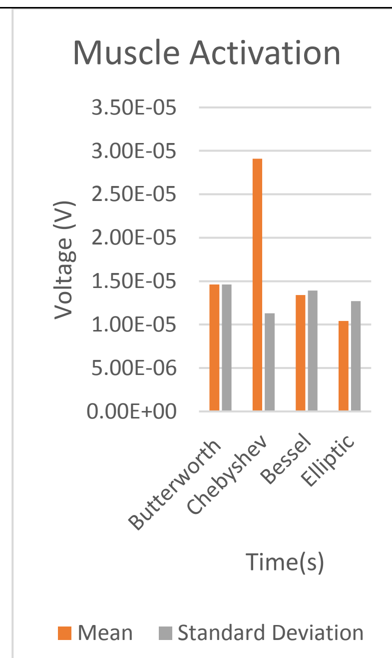

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Table 10:Muscle Activation for Test Subject 2

4.1.2.2 Muscle activation for female subjects in term of its functions

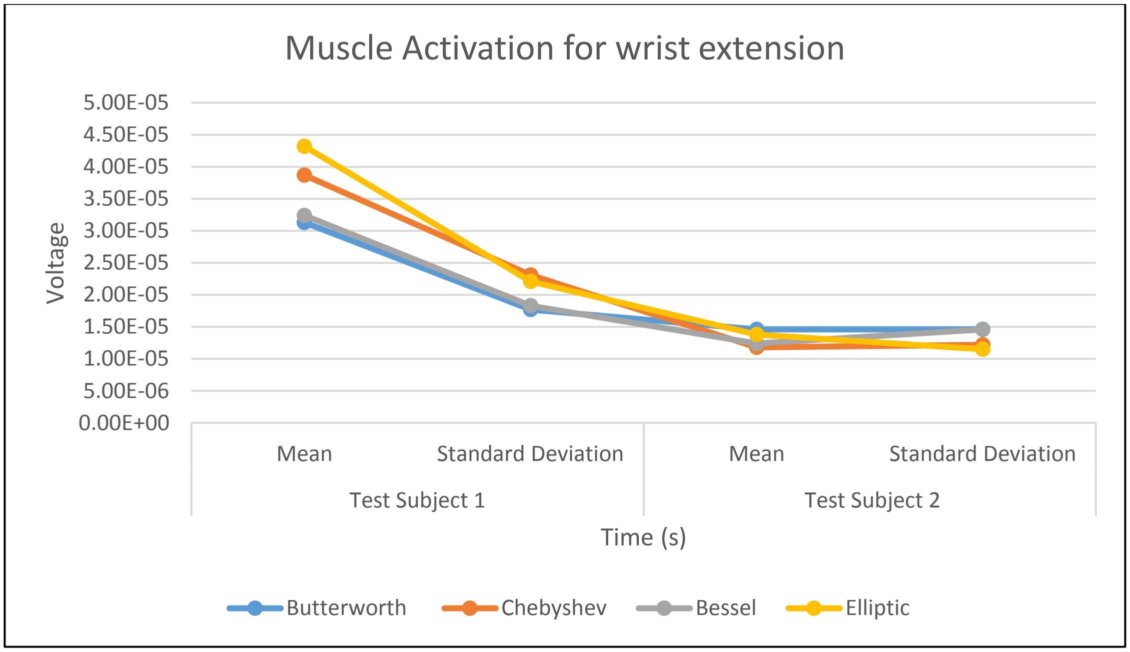

Figure 26: Muscle Activation for Wrist Extension

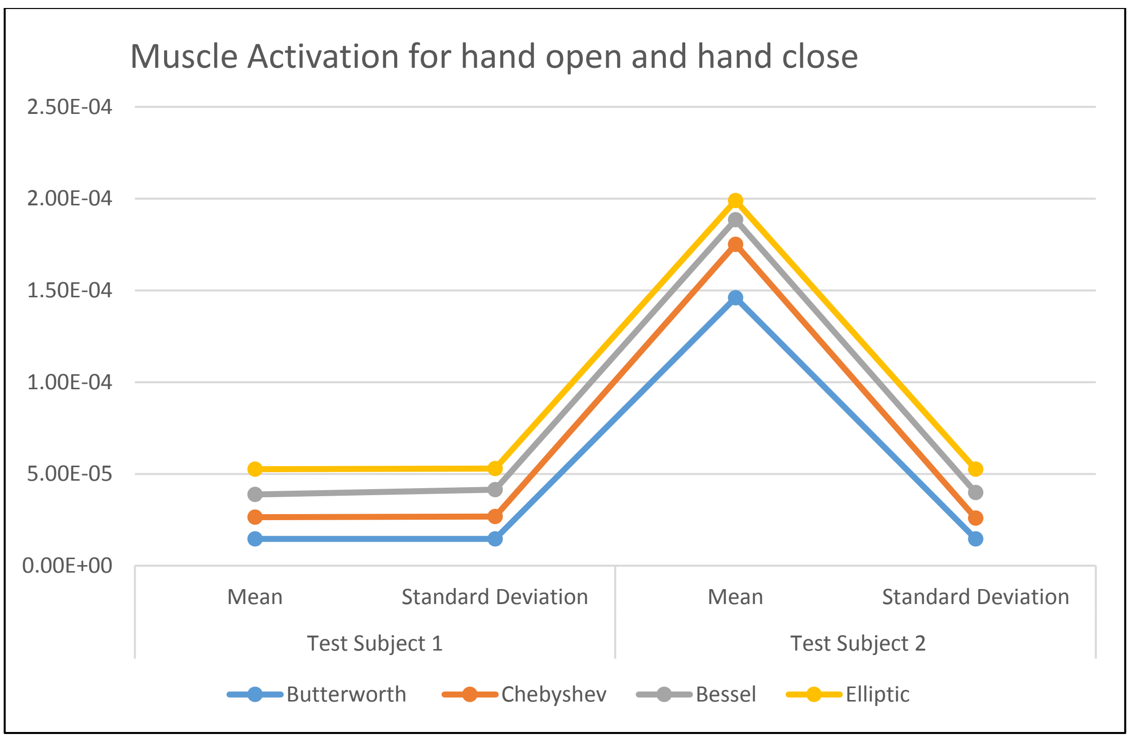

Figure 27: Muscle Activation for Hand Open & Hand Close

The statistics of male subjects (left handed) is shown in Figure 26 and Figure 27. Mean and SD is chosen as the measurement index. Generally, Bessel and Elliptic filter were found to be the best type of filter for male subject (left handed) if compared to Butterworth and Chebyshev filter. As can be seen from Table 9 and 10 Bessel filter performs the low SD with Test Subject 1(1.83E-05) and Test Subject 2 (2.42E-05). Furthermore, as shown in Table 9 and 10, the Elliptic filter was the appropriate filter with a low value of SD; TS(1) (1.15E-05) and TS(2) (1.27E-05). Figure 26 and 27 provide a quite similar trend where the graphical result show that Bessel and Elliptic was the best among the other types of filter.

4.1.3 Results of EMG for female subject (RMS)

4.1.3.1 Muscle Activation using RMS features extraction method.

Table 11 and 12 demonstrated the muscle activation for test subject 1 and 2.

(c)Test Subject 3

<table>
<tr><th>Forearm Movement</th><th>Tabulated Data</th><th>Graphical Result</th></tr>
<tr><td>Wrist extension</td><td>
<table>
<tr><th>Filter</th><th>Mean</th><th>Standard Deviation</th></tr>
<tr><td>Butterworth</td><td>2.01E-05</td><td>1.78E-05</td></tr>
<tr><td>Chebyshev</td><td>1.19E-05</td><td>1.33E-05</td></tr>
<tr><td>Bessel</td><td>1.19E-05</td><td>1.57E-05</td></tr>
<tr><td>Elliptic</td><td>1.73E-05</td><td>1.09E-05</td></tr>
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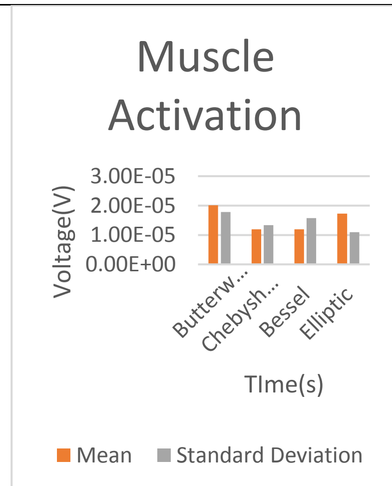

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<tr><td>Hand Open & Hand Close</td><td>
<table>
<tr><th>Filter</th><th>Mean</th><th>Standard Deviation</th></tr>
<tr><td>Butterworth</td><td>1.28E-05</td><td>1.80E-05</td></tr>
<tr><td>Chebyshev</td><td>8.82E-05</td><td>1.54E-05</td></tr>
<tr><td>Bessel</td><td>9.35E-05</td><td>1.71E-05</td></tr>
<tr><td>Elliptic</td><td>4.83E-05</td><td>9.17E-05</td></tr>
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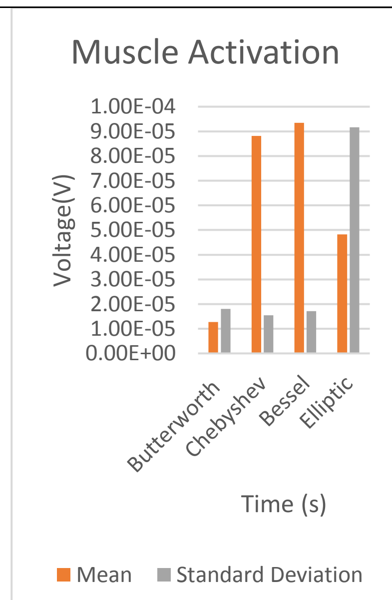

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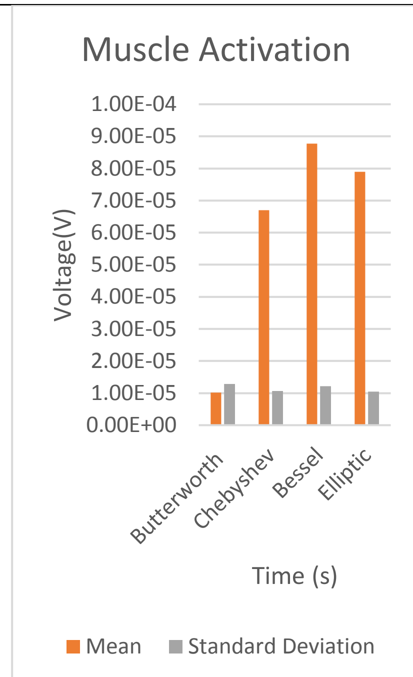
Table 11: Muscle Activation for Test Subject 3

(d)Test Subject 4

Forearm Movement	Tabulated Data	Graphical Result
Wrist extension	see table below	see chart below

Wrist extension

Filter	**Mean**	**Standard Deviation**
Butterworth	1.02E-05	1.28E-05
Chebyshev	6.70E-05	1.07E-05
Bessel	8.77E-05	1.21E-05
Elliptic	7.90E-05	1.05E-05



Hand Open & Hand Close

Filter	**Mean**	**Standard Deviation**
Butterworth	7.49E-05	7.14E-05
Chebyshev	6.78E-05	5.87E-05
Bessel	7.49E-05	3.14E-05
Elliptic	6.76E-05	5.82E-05

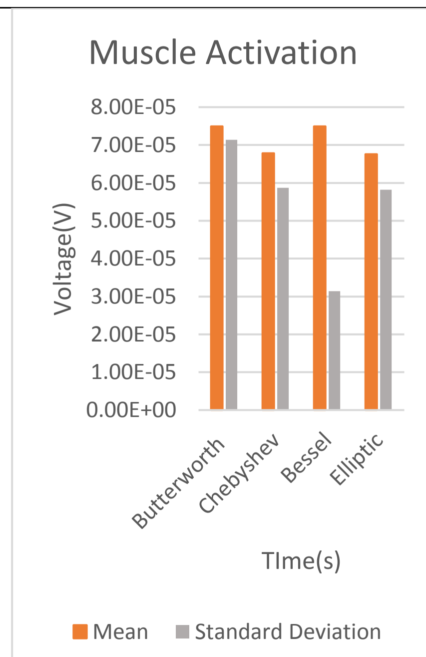


Table 12:Muscle Activation for Test Subject 4

4.1.3.2 Muscle Activation for female subjects in term of its functions

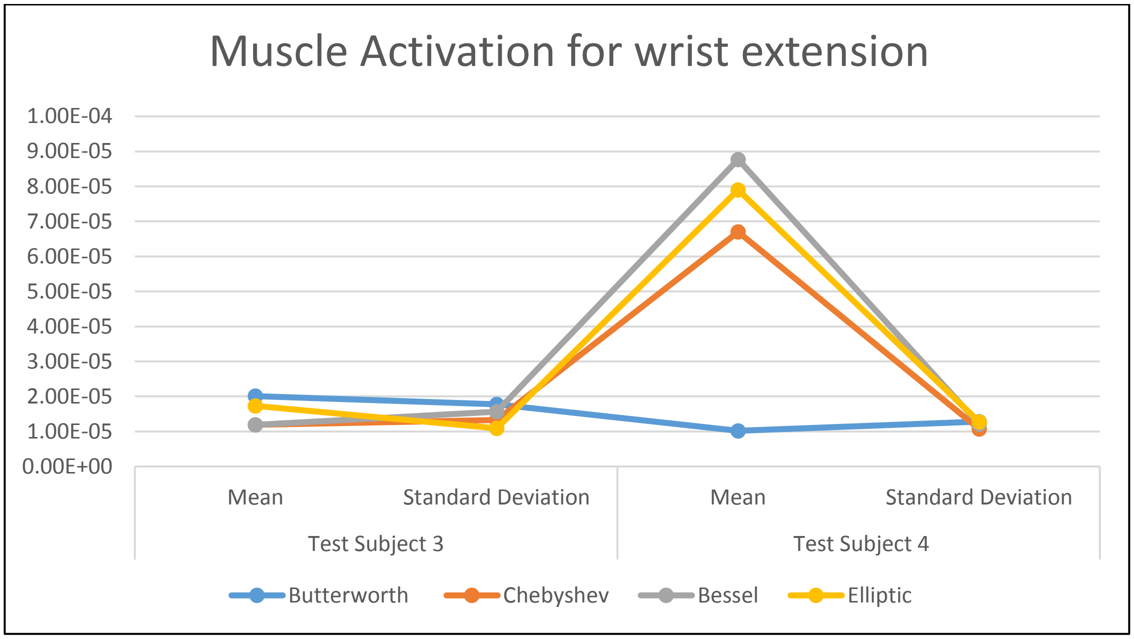


Figure 28:Muscle Activation for Wrist Extension

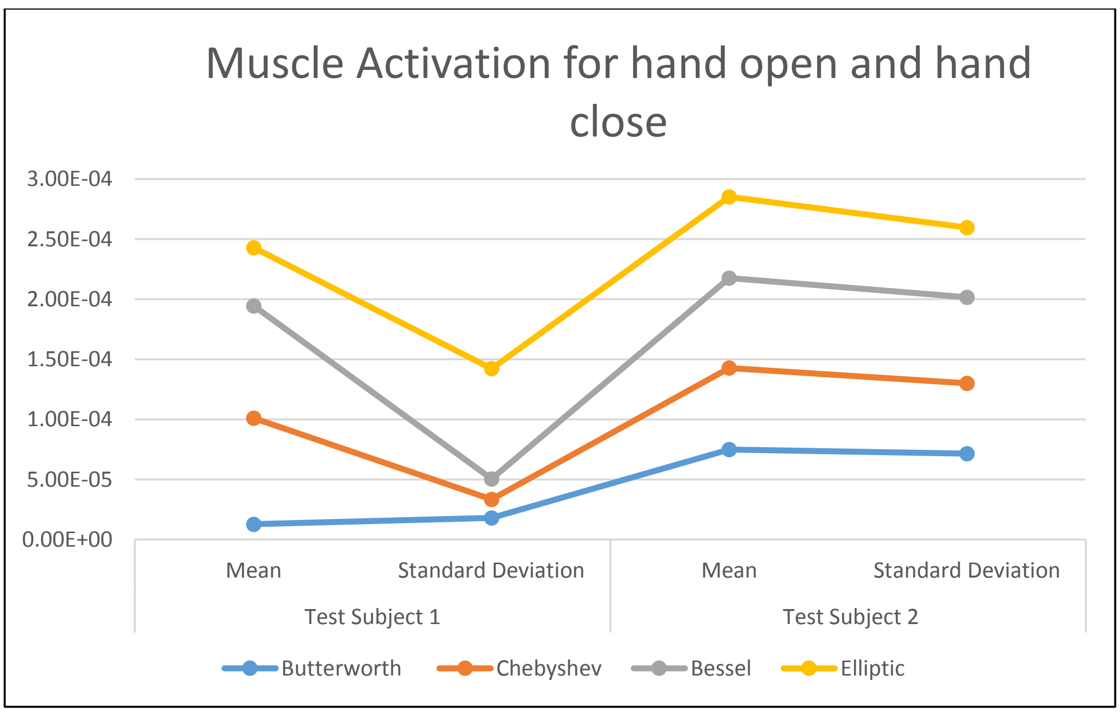


Figure 29:Muscle Activation for Hand Open & Hand Close

The statistics of female subjects (left handed) using RMS extraction method is shown in Figure 28 and Figure 29. For the female subjects, it is still the Elliptic filter was the best filtering method among the other type of filters. From table 11 and 12, it is shown that Elliptic filter showed the lower SD with Test Subject 3 (1.09E-05) and Test Subject 4 (1.05E-05). From table 11 and 12, it is shown that Bessel filter showed the lower SD with Test Subject 3 (1.71E-05) and Test Subject 4 (3.14E-05) .

In conclusion for RMS extraction method, in the form of handedness, it is still showing Bessel and Elliptic filter was the best among the other filters. This is shown from the wrist extension and hand open & hand close where the smallest SD was Bessel and Elliptic filter from Figure 12 and 13.

In form of gender, it is still showing that Bessel and Elliptic filter was the best among the other filters. This is seen in where (TS1 and TS2 which is the male subject) shows that Bessel filter performs the low SD with Test Subject 1(1.83E-05) and Test Subject 2 (2.42E-05) and Elliptic filter as TS (1) (1.15E-05) and TS (2) (1.27E-05) and Bessel filter showed the lower SD with Test Subject 3 (1.71E-05) and Test Subject 4 (3.14E-05) and Elliptic filter showed the lower SD with Test Subject 3 (1.09E-05) and Test Subject 4 (1.05E-05) . From the overall experimental result for the left handed (male subject) using RMS extraction method, Bessel and Elliptic filter was the best filtering techniques in EMG signal.

4.1.4 Results of EMG for male subject (MAV)

4.1.4.1 Muscle activation using MAV features extraction method.

(a) Test Subject 1

<table>
<tr><th>Movement</th><th>Tabulated Data</th><th>Graphical Result</th></tr>
<tr><td>Wrist extension</td><td>

Filter	Mean	Standard Deviation
Butterworth	3.67E-05	2.18E-05
Chebyshev	3.67E-05	2.14E-05
Bessel	2.91E-05	1.64E-05
Elliptic	3.57E-05	1.67E-05

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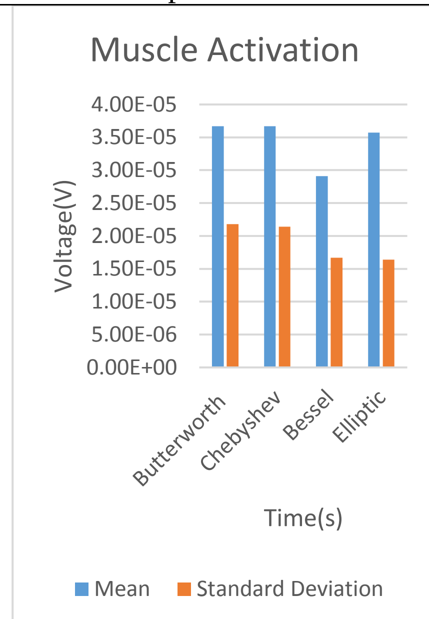

</td></tr>
<tr><td>Hand Open & Hand Close</td><td>

Filter	Mean	Standard Deviation
Butterworth	1.15E-05	1.62E-05
Chebyshev	8.33E-06	5.19E-06
Bessel	3.82E-06	1.34E-05
Elliptic	3.24E-05	1.30E-05

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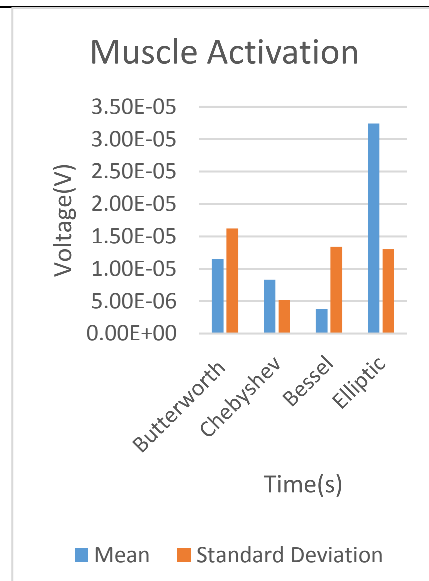

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Table 13:Tabulated Data and Graphical Result of Muscle Activation for Test Subject 1

(b) Test Subject 2

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<tr><td>Wrist extension</td><td>
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<tr><th>Filter</th><th>Mean</th><th>Standard Deviation</th></tr>
<tr><td>Butterworth</td><td>1.50E-05</td><td>3.16E-05</td></tr>
<tr><td>Chebyshev</td><td>1.37E-05</td><td>2.61E-05</td></tr>
<tr><td>Bessel</td><td>1.56E-05</td><td>2.42E-05</td></tr>
<tr><td>Elliptic</td><td>1.32E-05</td><td>2.57E-05</td></tr>
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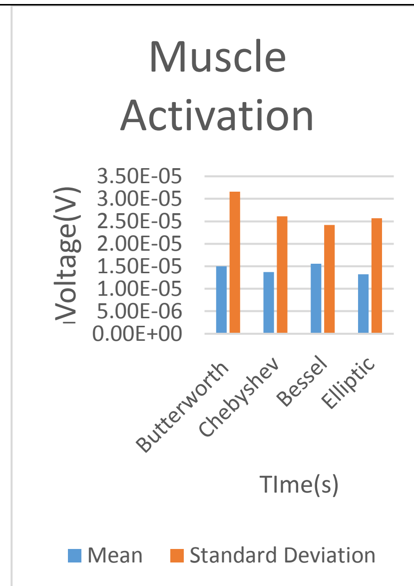

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<tr><td>Hand Open & Hand Close</td><td>
<table>
<tr><th>Filter</th><th>Mean</th><th>Standard Deviation</th></tr>
<tr><td>Butterworth</td><td>1.48E-05</td><td>2.46E-05</td></tr>
<tr><td>Chebyshev</td><td>1.01E-05</td><td>1.25E-05</td></tr>
<tr><td>Bessel</td><td>1.48E-06</td><td>1.21E-05</td></tr>
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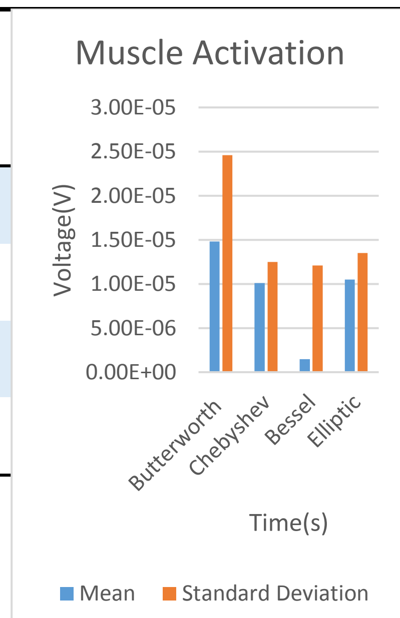

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Table 14:Tabulated Data and Graphical Result of Muscle Activation for Test Subject 2

4.1.4.2 Muscle Activation for male subjects in term of its functions (Using MAV features extraction method)

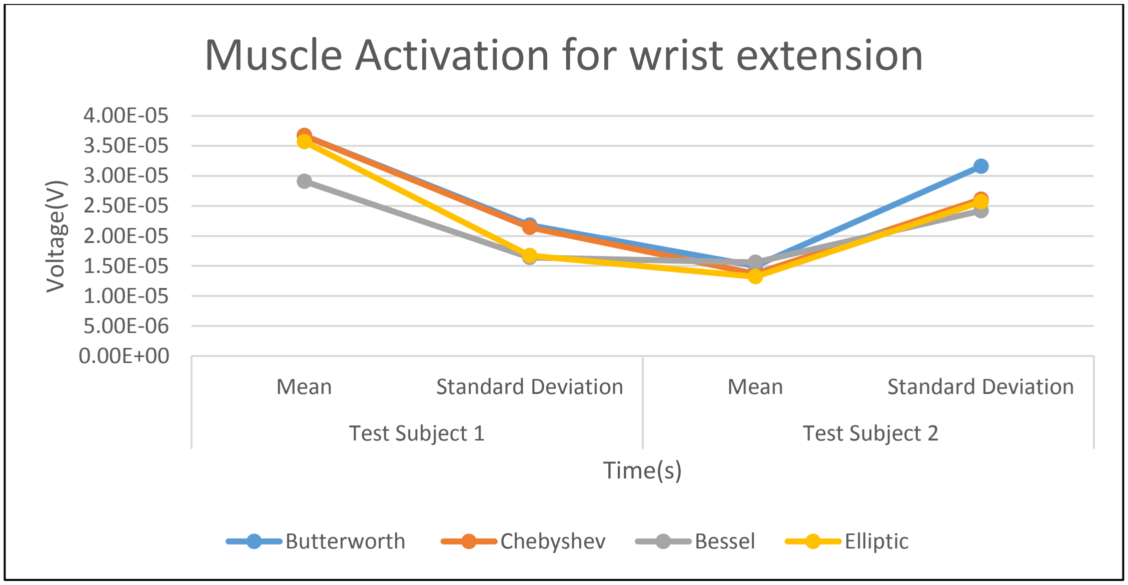


Figure 30: Muscle Activation for Wrist Extension

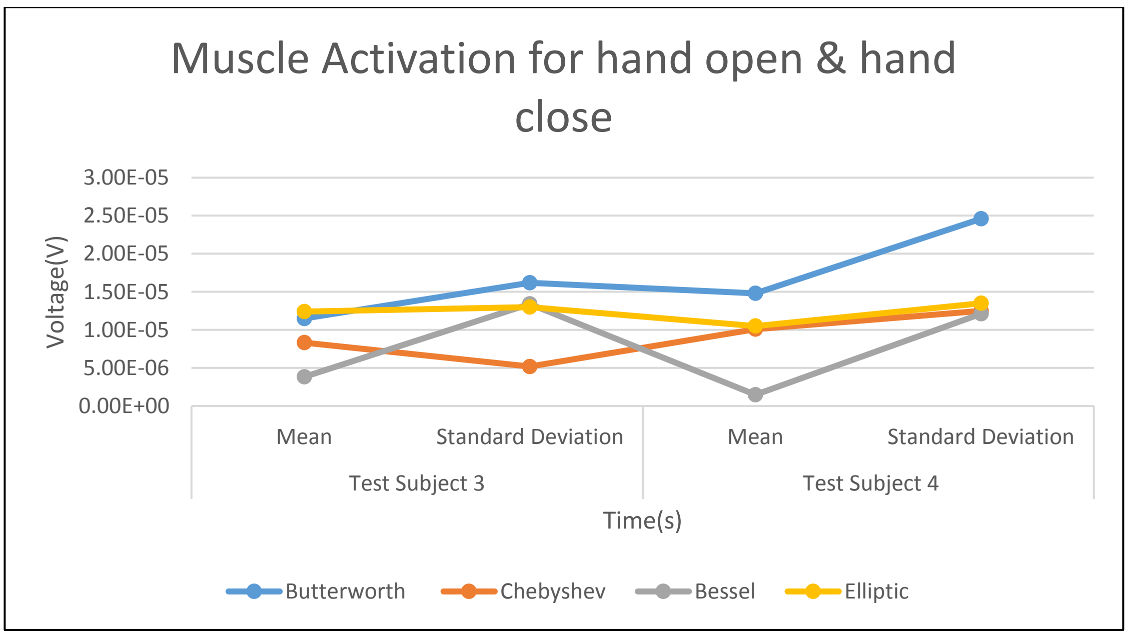


Figure 31: Muscle Activation for hand open & hand close

The statistics of male subjects (left handed) using MAV features extraction method is shown in Figure 30 and Figure 31. Mean and SD is chosen as the measurement index. Generally, Bessel and Elliptic filter were found to be the best type of filter for male subject (left handed) if compared to Butterworth and Chebyshev filter. As can be seen from table 13 and 14, Bessel filter performs the low SD with Test Subject 1(1.64E-05) and Test Subject 2 (2.42E-05). Furthermore, as shown in Table 13 and 14, the Elliptic filter was the appropriate filter with a low value of SD; TS(1) (1.30E-05) and TS(2) (1.35E-05). Figure 30 and 31 provide a quite similar trend where the graphical result show that Bessel and Elliptic was the best among the other types of filter.

4.1.5 Results of EMG for female subject (MAV)

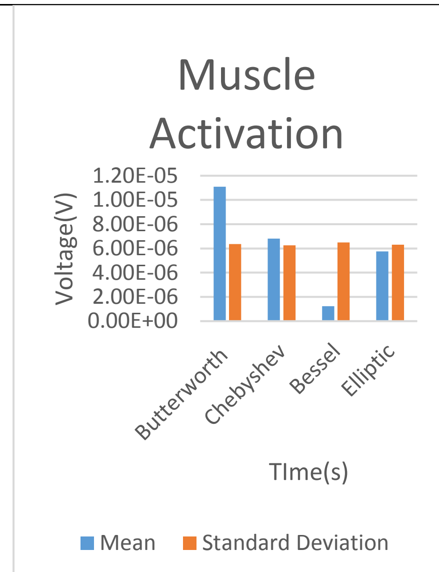
4.1.5.1 Muscle activation using MAV features extraction method.

(c) Test Subject 3

Forearm Movement	Tabulated Data	Graphical Result
Wrist extension	see table below	see chart below

Wrist extension

Filter	**Mean**	**Standard Deviation**
Butterworth	1.11E-05	6.36E-06
Chebyshev	6.81E-06	6.49E-06
Bessel	1.23E-06	6.25E-06
Elliptic	5.75E-06	6.30E-06



Hand Open & Hand Close

Filter	**Mean**	**Standard Deviation**
Butterworth	5.27E-06	1.10E-05
Chebyshev	3.13E-06	1.09E-05
Bessel	6.34E-06	1.19E-05
Elliptic	4.83E-06	1.01E-05

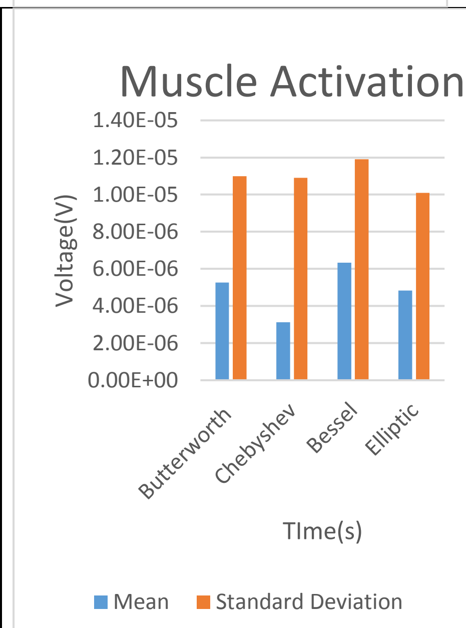


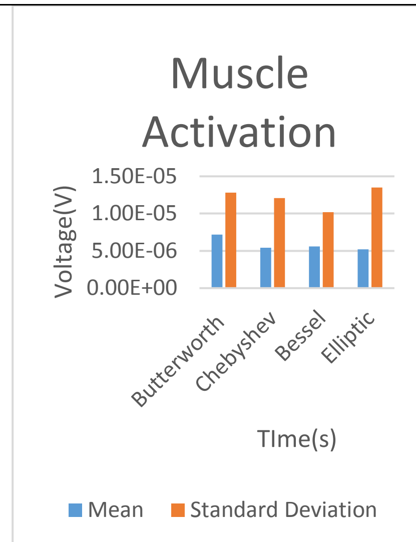
Table 15:Tabulated Data and Graphical Result of Muscle Activation for Test Subject 3

(d)Test Subject 4

Forearm movement	Tabulated Data	Graphical Result

Wrist extension

Filter	Mean	Standard Deviation
Butterworth	7.19E-06	1.28E-05
Chebyshev	5.44E-06	1.21E-05
Bessel	5.61E-06	1.02E-05
Elliptic	5.22E-06	1.35E-05



Hand Open & Hand Close

Filter	Mean	Standard Deviation
Butterworth	4.88E-06	3.48E-06
Chebyshev	3.59E-06	3.56E-06
Bessel	3.69E-06	3.63E-06
Elliptic	3.49E-06	3.38E-06

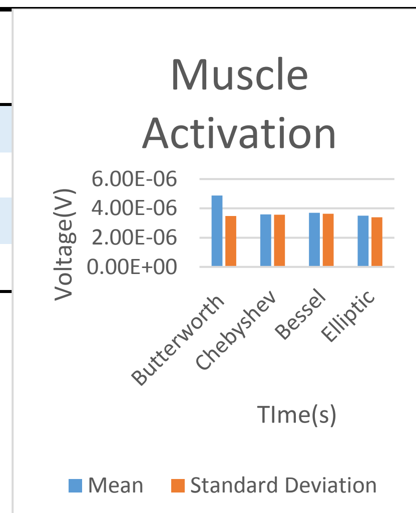


Table 16:Tabulated Data and Graphical Result of Muscle Activation for Test Subject 4

4.1.5.2 Muscle activation for female subjects (Using MAV features extraction method)

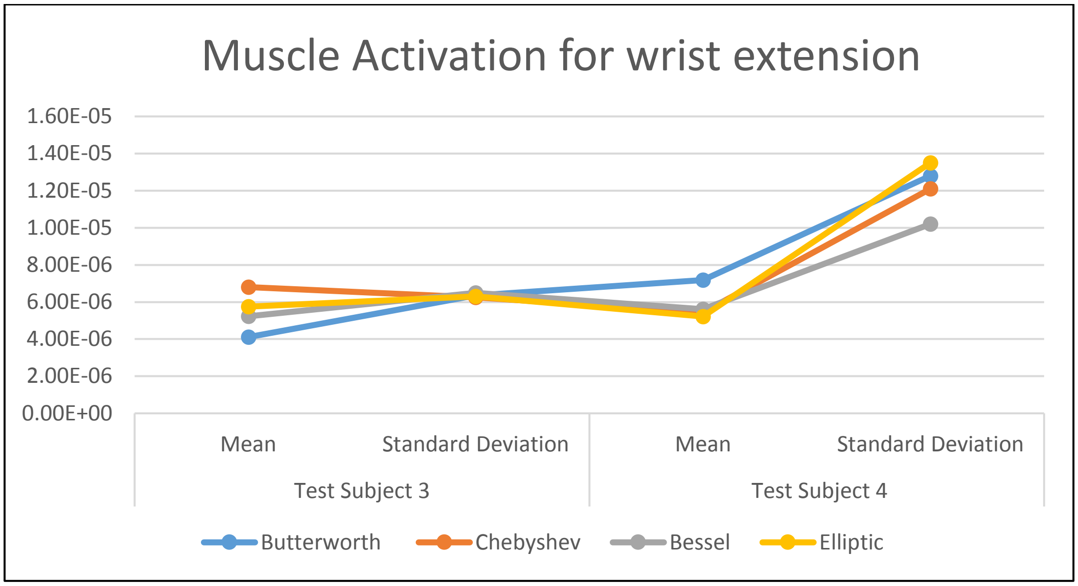


Figure 32:Muscle Activation for Wrist Extension

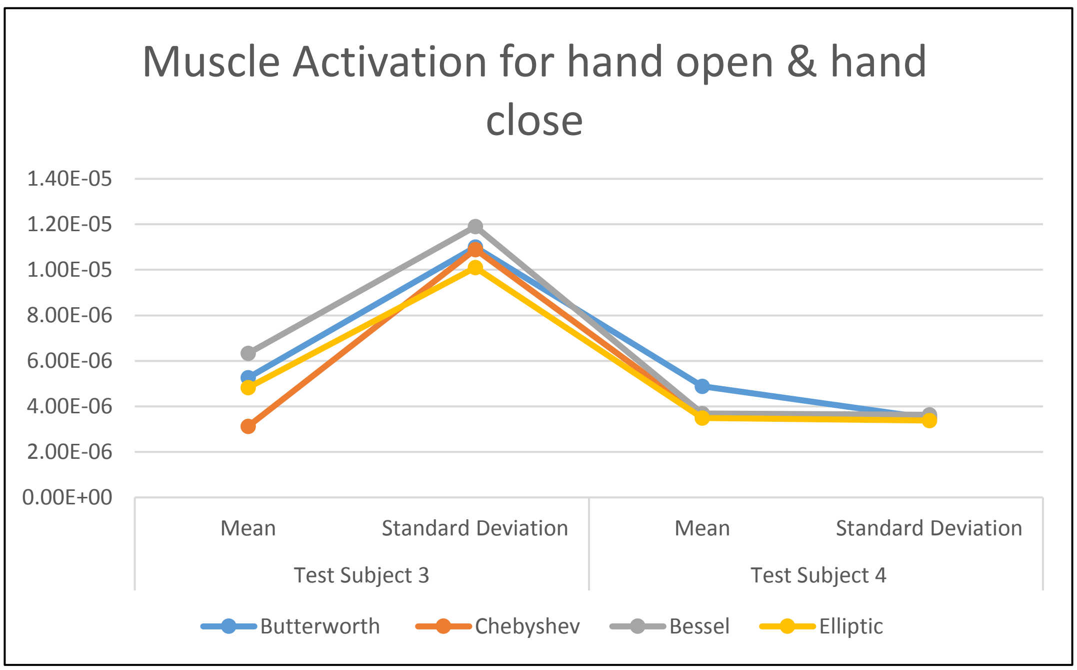


Figure 33: Muscle Activation for Hand Open& Hand Close

The statistics of female subjects (right handed) using MAV extraction method is shown in Figure 32 and Figure 33. For the female subjects, it is still the Bessel and Elliptic filter was the best filtering method among the other type of filters. From table 15 and 16, it is shown that Bessel filter showed the lower SD with Test Subject 3 (6.25E-06) and Test Subject 4 (1.02E-05). From table 15 and 16, it is shown that Elliptic filter showed the lower SD with Test Subject 3 (1.01E-05) and Test Subject 4 (3.38E-06) .

In the form of handedness, it is still showing Bessel and Elliptic filter was the best among the other filters. This is shown from the wrist extension and hand open & hand close where the smallest SD was Bessel and Elliptic filter from Figure 20 and 21.

In conclusion, in form of gender, it is still showing that Bessel and Elliptic filter was the best among the other filters. This is shown in table 13 and 14 that Bessel filter performs the low SD with Test Subject 1(1.64E-05) and Test Subject 2 (2.42E-05) and in table 15 and 16 Elliptic filter as TS (1) (1.30E-05) and TS (2) (1.35E-05). Furthermore, it is also shown in Table 16 that Bessel filter performs the lowest SD with TS3(6.25E-06). From the overall experimental result for the left handed (male subject) and right handed using MAV extraction method, Bessel and Elliptic filter was the best filtering techniques in EMG signal.

4.2 Muscle Activation between Muscles

The raw signal of the EMG is obtained during the five times repetition of exercise. Smooth RMS and MAV filtered signal is obtained to determine the mean and standard deviation for analysis as shown in Figure 34. The muscle activation for the other 4 trial of exercise are attached in appendix. Throughout the five times of repetition of exercise, the graphs for the mean and standard deviation is found out to be similar because the difference in the muscle activation for the two muscle was small. Therefore, only one graph which is for Trial 1 is shown.

Table 17: Mean and Standard Deviation for Extensor Carpi Radialis and Palmaris Longus for Trial 1

Muscle	Features Extraction Method	Mean	Standard Deviation
Extensor Carpi Radials	RMS	4.882392E-05	6.386870E-05
	MAV	1.95669E-05	3.55001E-05
Palmaris Longus	RMS	1.23557E-05	1.60971E-05
	MAV	7.17064E-06	8.09749E-06

Table 18: Mean and Standard Deviation for Extensor Carpi Radialis and Palmaris Longus for Trial 2

Muscle	Features Extraction Method	Mean	Standard Deviation
Extensor Carpi Radials	RMS	3.768070E-05	5.844670E-05
	MAV	1.55163E-05	3.62214E-05
Palmaris Longus	RMS	1.87045E-05	1.54420E-05
	MAV	1.22627E-05	1.52627E-05

Table 19: Mean and Standard Deviation for Extensor Carpi Radialis and Palmaris Longus for Trial 3

Muscle	Features Extraction Method	Mean	Standard Deviation
Extensor Carpi Radials	RMS	3.654710E-05	6.987380E-05
	MAV	3.31085E-05	4.70479E-05
Palmaris Longus	RMS	1.55667E-05	1.54420E-05
	MAV	8.24503E-06	8.74684E-06

Table 20:Mean and Standard Deviation for Extensor Carpi Radialis and Palmaris Longus for Trial 4

Muscle	Features Extraction Method	Mean	Standard Deviation
Extensor Carpi Radials	RMS	4.545750E-05	5.987640E-05
	MAV	2.16419E-05	4.49163E-05
Palmaris Longus	RMS	9.45706E-06	1.10848E-05
	MAV	6.39410E-06	8.86905E-06

Table 21: Mean and Standard Deviation for Extensor Carpi Radialis and Palmaris Longus for Trial 5

Muscle	Features Extraction Method	Mean	Standard Deviation
Extensor Carpi Radials	RMS	3.913590E-05	4.777160E-05
	MAV	7.21847E-05	4.48160E-05
Palmaris Longus	RMS	2.40236E-05	1.93097E-05
	MAV	1.30190E-05	2.87728E-05

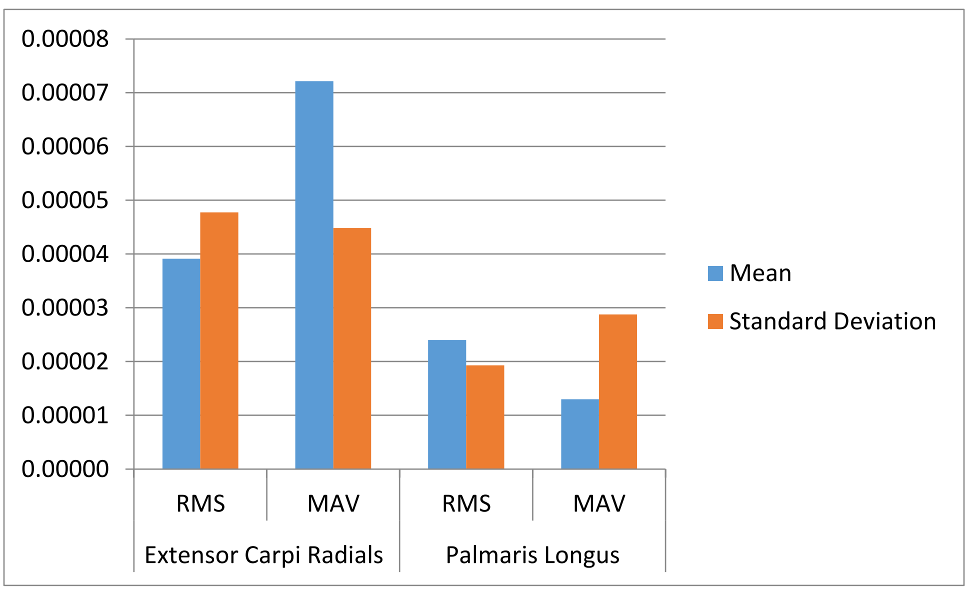


Figure 34: Muscle Activation

From Figure 34, it can be observed that the muscle extensor carpi radialis shows the higher muscle activation value regardless of using RMS or MAV filtered signal compared to Palmaris Longus. Extensor Carpi Radialis is located on the anterior body. On the contrary, Palmaris Longus is located on the posterior body. In a nutshell, it is statistically proven that while the subject is performing the exercise relating to hand opening/closing, muscle extensor carpi radialis is more affected as it has higher muscle activation value by referring to it’s mean in Figure 34.

4.3 Results from Robotics Rehalititation

4.3.1 Range of Motion

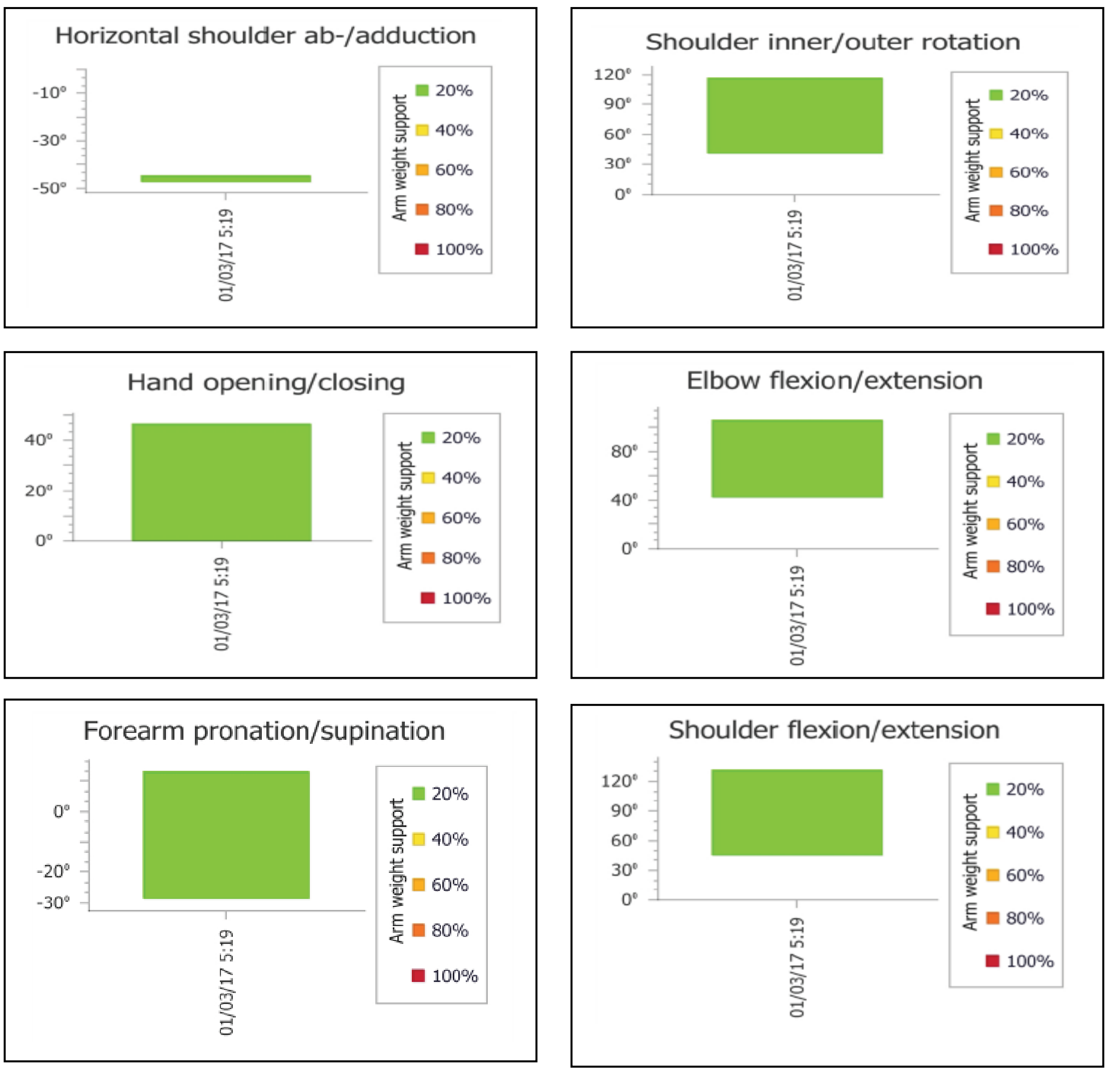


Figure 35: Score for Range of Motion (ROM)

The above figures shows the ROM for the measured data respectively. As observed from the above figures, it can be concluded that the ROM tends to be larger for shoulder flexion/ extension and shoulder inner/outer rotation which is around 120^o. Whereas, ROM tends to be smaller for horizontal abduction/ adduction and forearm pronation/supination which is around -30^o. as for hand opening/closing is around 45^o.

4.3.2 Game Scoring

Figure 36 shows the game scoring for one test subject doing a repetition of exercise for 5 times.

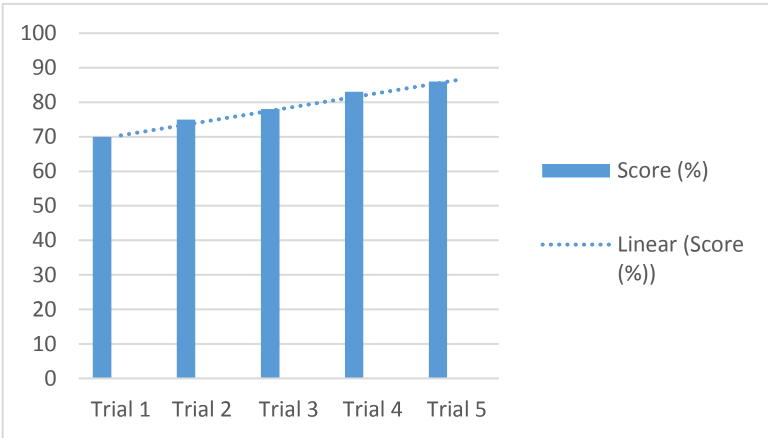


Figure 36: Game Scores

The subject was required to repeat the the exercise in the Armeo Software which is the picking up things and placing at a specific place for 5 times. The game scoring, hand position reach and hand opening reach scored were obtained simultaneously for analysis purposes. The subjects shows the tendency of getting high scores for this exercise throughout the 5 times of repetition. Moreover, this result also shows that the game score is increasing throughout the 5 times of repetition.

4.3.3 Hand Position Reach

Figure 37 shows the scores for the hand position reach for repetition of exercise of 5 times.

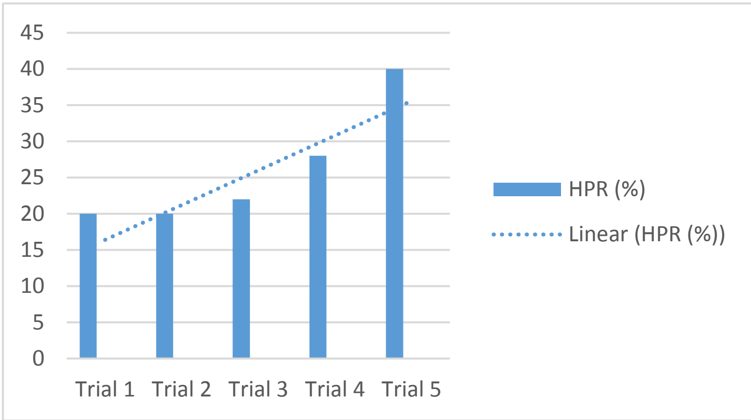


Figure 37:Hand Position Reach (3D)

From figure 37, it can be observed that the scores is increasing from trial 1 to 5. For trial 1 and 2, the hand position reach scores is the same which is 20%. This hand position reach data supported the game scoring data which also shows increase in scoring throughout the five times of repetition.

4.3.4 Hand Opening Reach

Figure 38 shows the scores for the hand opening reach for repetition of exercise of 5 times.

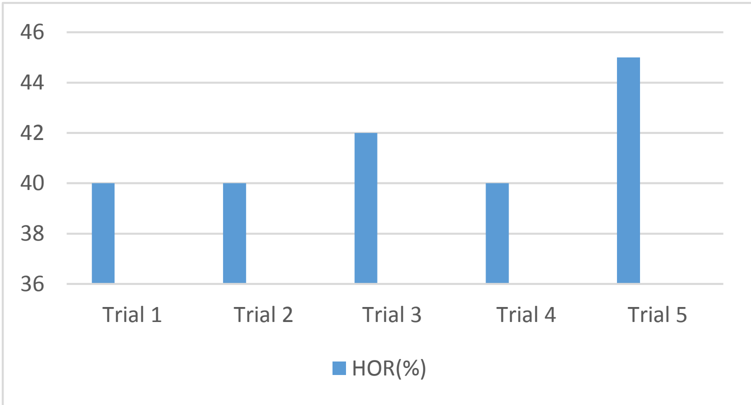


Figure 38:Hand Opening Reach

Hand opening reach measured data is shown in Figure 38. The score for the first two trial is consistent with a value of 40% during the duration of the exercise which is 2 minutes. It can be observed that during trial no 5, the score for hand opening is the highest which is 45%. In conclusion, the findings from the hand opening reach supports the finding in the game scoring.

There was no significant difference in terms of EMG for all the five trials. However, there was a slight difference in terms of ROM for the trials. There was no direct correlation between the EMG and ROM. However, it is statistically proven that while the subject is performing the exercise relating to hand opening/closing, muscle extensor carpi radialis is more affected as it has higher muscle activation value by referring to it's mean in Figure 37.

4.4 Summary

In this chapter, the results of EMG signal and processing where the signal is being filtered using different types of filter for comparison by using both features extraction method which are RMS and MAV. Next, the results of the EMG signal in terms of muscle activation is tabulated and compared in graph form for all the test subjects. On the other hand, the results from the robotics rehabilitation which includes the range of motion, game scoring, hand position reach and hand opening reach is also being discussed and analyzed.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, best filtering method was chosen by comparing the filtered signal using mean and standard deviation. Extensor carpi radialis and palmaris longus is evaluated for its muscle activation when the test subject is performing a series of repetition exercise.

By using two different features extraction method, it is proven that Bessel filter is the most suitable filter as it provides the highest standard deviation from the muscle activation for both type of muscles.

There are four kinds of data that is obtained from the rehabilitation robot, ArmeoSpring, which are range of motion (ROM), game scoring, hand position reach, and hand opening reach. Firstly, game scoring is found to be increasing after each repetition of exercise. On the contrary, hand position reach and hand opening reach scores was found to be the same for the first two repetition and subsequently increase after that..

Besides that, EMG signal of the hand movement was obtained to analyse the muscle activation in extensor carpi radialis and palmaris longus. Extensor carpi radialis which is located on the anterior posture of the body has higher muscle activation value by analyzing the mean value. Finally, quantitative information from the experiment will be study to decide the attainability of robotics rehabilitation in improving the quality of life of the population.

5.2 Future Work

These are a few proposals on future areas of research that is not included in this project because of the time limitation and different limitations.

- Stroke patients should to be invited to be subjects of study for the attainability of robotics rehabilitation
- Electroencephalography (EEG) which is for brain action and electromyography (EMG) which is for muscle movement and functional near indrared (fNIR) can be comebined to form the exoskeleton robot.

REFERENCES

1. Murray CJ, Lopez AD. *Mortality by cause for eight regions of the world: Global Burden of Disease Study*. Lancet 1997, 349(9061), pp. 1269–1276.
2. Saka O, McGuire A, Wolfe C.*Cost of stroke in the United Kingdom. Age Ageing* 2009, 38(1), pp. 27–32.
3. S Norsima Nazifah and I Khairul Azmi, National Stroke Registry,vol.67, (3), pp 302-304, June 2012.
4. World Health Organisation: The Atlas of Heart Disease and Stroke. (2014, April) Available: http://www.who.int/cardiovascular_diseases/ resources/atlas/en/.
5. Aziz ZA. (2015, August): Acute Stroke Registry Malaysia,2010-2014 : Results from the National Neurology Registry.[Online]. Available: https://www.ncbi.nlm.nih.gov/pubmed/26338106
6. N. Venketasubramanian, "The epidemiology of stroke in ASEAN countries-A review," *Neurol J Southeast Asia,* vol. 3, pp. 9-14, 1998.
7. Ministry of Health. Malaysian Burden of Disease and Injury Study. Kuala Lumpur, Malaysia. 2004 pp.42.
8. Wenkang, X., C. Bing, and E. Rogers. *Cascade based iterative learning control of robotic-assisted upper extremity stroke rehabilitation*. in *Decision and Control (CDC), 2013 IEEE 52nd Annual Conference on*. 2013.

9 E Ernst, A review of stroke rehabilitation and physiotherapy, *Stroke* **21** (7) (1990), 1081–1085.

10. S J Page, P Levine, S Sisto, Q Bond and M V Johnston, Stroke patients' and therapists' opinions of constraint-induced movement therapy, *Clinical Rehabilitation* **16** (1) (2002), 55.
11. S H Jang, S You, Y H Kwon, M Hallett, M Y Lee and SH Ahn, Reorganization Associated Lower Extremity Motor Recovery As Evidenced by Functional MRI and Diffusion Tensor Tractography in a Stroke Patient, *Restor Neurol & Neurosci*, **23** (2005), 325–329.

12. Munih, M., et al. *Biocooperation in rehabilitation robotics of upper extremities*. in *Rehabilitation Robotics, 2009. ICORR 2009. IEEE International Conference on*. 2009.
13. B. R. Brewer, S. K. McDowell, and L. C. Worthen-Chaudhari, "Poststroke upper extremity rehabilitation: a review of robotic systems and clinical results," *Topics in Stroke Rehabilitation*, vol.14, no. 6, pp. 22–44, 2007.
14. L. Marchal-Crespo and D. J. Reinkensmeyer, "Review of control strategies for robotic movement training after neurologic injury," *Journal of NeuroEngineering and Rehabilitation*, vol. 6, no. 20, 2009.
15. Melbourn, L.M., *Passive versus active exercise: An examination of affective change.* 2012.
16. Dirette, D. and J. Hinojosa (1994). "Effects of Continuous Passive Motion on the Edematous Hands of Two Persons with Flaccid Hemiplegia." *American Journal of Occupational Therapy* **48**(5): 403-409.
17. Qizhi, Y., et al. *Dynamic analysis of 7-DOF exoskeleton upper-limbed rehabilitation robot*. in *Cyber Technology in Automation, Control, and Intelligent Systems (CYBER), 2015 IEEE International Conference on*. 2015.
18. Sharifi, M., S. Behzadipour, and G.R. Vossoughi. *Model reference adaptive impedance control of rehabilitation robots in operational space*. in *Biomedical Robotics and Biomechatronics (BioRob), 2012 4th IEEE RAS & EMBS International Conference on*. 2012.
19. Staubli, P., et al., *Effects of intensive arm training with the rehabilitation robot ARMin II in chronic stroke patients: four single-cases.* Journal of NeuroEngineering and Rehabilitation, 2009. **6**(1): p. 46.
20. Lum, P.S., et al., *MIME robotic device for upper-limb neurorehabilitation in subacute stroke subjects: A follow-up study*. Journal of rehabilitation research and development, 2006. **43**(5): p. 631.
21. Reinkensmeyer, D.J., et al., *Understanding and treating arm movement impairment after chronic brain injury: progress with the ARM guide.* Journal of rehabilitation research and development, 2000. **37**(6): p. 653-662.

22. T.Nef,M.Mihelj, G. Kiefer,C. Perndl, R. M¨uller, and R. Riener, “ARMin—exoskeleton for arm therapy in stroke patients,” in *Proceedings of the IEEE 10th International Conference on Rehabilitation Robotics (ICORR ’07)*, pp. 68–74, Noordwijk, Netherlands, June 2007.
23. Rudhe, C., et al., *Reliability of movement workspace measurements in a passive arm orthosis used in spinal cord injury rehabilitation.* Journal of NeuroEngineering and Rehabilitation, 2012. **9**: p. 37-37.
24. W. J. Kang, C. K. Cheng, J. S. Lai, J. R. Shiu, and T. S. Kuo, "A comparative analysis of various EMG pattern recognition methods," *Medical Engineering & Physics,* vol. 18, pp. 390-395, 1996/07/01 1996.
25. A. R. Soylu and P. Arpinar-Avsar, "Detection of surface electromyography recording time interval without muscle fatigue effect for biceps brachii muscle during maximum voluntary contraction," *Journal of Electromyography and Kinesiology,* vol. 20, pp. 773-776, 8// 2010.
26. W. J. Kang, C. K. Cheng, J. S. Lai, J. R. Shiu, and T. S. Kuo, "A comparative analysis of various EMG pattern recognition methods," *Med Eng Phys*, vol. 18, pp. 390-5, Jul 1996.
27. S. Micera, A. M. Sabatini, P. Dario, and B. Rossi, "A hybrid approach to EMG pattern analysis for classification of arm movements using statistical and fuzzy techniques," *Medical Engineering & Physics*, vol. 21, pp. 303-311, 6// 1999.
28. A. Phinyomark, F. Quaine, S. Charbonnier, C. Serviere, F. Tarpin-Bernard, and Y. Laurillau, "EMG feature evaluation for improving myoelectric pattern recognition robustness," *Expert Systems with Applications,* vol. 40, pp. 4832-4840, 9/15/ 2013.
29. A. Frisoli, M. O’Malley, D. Campolo, and K. Sienko, "Guest Editorial: Special Issue on Haptics in Rehabilitation and Neural Engineering," *IEEE Transactions on Haptics,* vol. 7, pp. 107-109, 2014.
30. Y. Ren, H. S. Park, and L. Q. Zhang, "Developing a whole-arm exoskeleton robot with hand opening and closing mechanism for upper limb stroke rehabilitation," in *2009 IEEE International Conference on Rehabilitation Robotics*, 2009, pp. 761-765.

31. L. Dovat, O. Lambercy, R. Gassert, E. Burdet, and L. Teo Chee, "HandCARE2: A novel cable interface for hand rehabilitation," in *2008 Virtual Rehabilitation*, 2008, pp. 64-64.

APPENDIX

Table 3 shows the key milestones of activities that shall be carried out in FYP 1

Table 22: FYP 1

No.	Details/ Week		FYP 1													
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Background Study		■	■												
2	Literature Review on the types of robotics rehabilitation				■	■	■		■	■						
3	Study on ArmeoSpring								■	■		■	■	■	■	
4	Proposal Defense										○					
5	Documentation	Extended proposal						○								
		Interim Report														○

Table 3 shows the key milestones of activities that shall be carried out in FYP 2

Table 23: FYP 2

No.	Details/ Week		FYP II														
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	Conduct experiment		■	■	■												
2	Experimental Evaluation			■	■	■	■			■	■	■	■				
3	Comparative analysis						■	■	■			■	■	■			
4	Pre-sedex											○					
5	Project Viva														○		
6	Documentation	Progress Report							○								
		Draft Final Report											○				
		Dissertation (soft copy)												○			
		Technical Paper												○			
		Dissertation (hard bound)															○