ELECTROMYOGRAPHY (EMG) SIGNAL PROCESSING AND THERMOGRAPHY FOR DETERMINING MUSCLES CONDITION

By

ZULIKA BINTI ZULKIFLI

FINAL REPORT PROJECT

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Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved:

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AP Dr. Irraivan Elemvazuthi
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2012

CERTIFICATION OF ORIGINALITY

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

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Zulika Binti Zulkifli

ABSTRACT

Electromyography (EMG) is a study of the muscular activity through analysis of electrical activity produced from muscles. This electrical activity is present as a raw signal as a signal is the result of neuromuscular activation that linked with muscle contraction. The most frequent techniques of signal recording are using surface and needle or wire electrode. The needle or wire electrode usually used by clinicians in clinical electromyography. This paper will concentrate on surface electromyography (SEMG) signal or also known as kinesiological signal. During recording and storing EMG data, several problems had to be encountered such as noise, motion artifacts and signal instability. Therefore, various filtering signal processing have been implemented to improve reliable signal for analysis. The purpose of this paper is to illustrate the best filtering methods that can be used for an EMG signal analysis. Then, the correlation between thermal images and EMG devices is implemented.

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I hereby would like to grab this opportunity to express my deepest gratitude and gratefulness firstly to God; The Almighty for giving me a chance to acquire new knowledge and with His will, this project was successfully completed.

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
AgCl	Silver Chloride
BPS	Band Pass Filter
CNS	Central Nervous System
CMRR	Common Mode Rejection Ratio
ECG	Electrocardiography
EMG	Electromyography
FSFP	Forearm Supination and Pronation
HPF	High Pass Filter
HOHC	Hand Open Hand Close
LPF	Low Pass Filter
MIT	Medical Infrared Thermography
MU	Motor Unit
MUAP	Motor Unit Actual Potential
RMS	Root Mean Square
SEMG	Surface Electromyography
WFWE	Wrist Flexion and Extension

CHAPTER 1

INTRODUCTION

1.1 Background of study

Nowadays, world is filled with accidents, infectious organism, exposure to toxins, and just plain bad genetic luck, there are countless peripheral muscle injuries waiting to happen. When injuries occur, patients may present to physician immediately and the muscle injuries need to be diagnosed and treated. The best choice of test for diagnosing most of the problems is electromyography (EMG). The physiatrist (physician specializing in physical medicine and rehabilitation) or neurologist also used EMG in clinical application.

In globalization era, there are development and advance technologies in signal processing and mathematical that has made it practical. This is to enlarge the recording, detection of EMG and analysis techniques. In 2006, extensive attractions have been focused on various mathematical techniques and Artificial Intelligence (AI). [1] As described by Mobasser, the study of surface electromyography becomes more popular and wide spread due to its unique ability such as interaction between human-robot, control of prosthetic arms and human factor studies dynamics include the voluntary and non-voluntary (reflex) excitation. [2] As time goes by, developing better filtering method, researchers and extensive effort have been made in order to reduce noise and acquire accurate EMG signals. This paper relates to data storing, recording, processing and filtering of EMG signals.

1.2 Problem Statement

A raw signal occurred during a contraction where there are synchronous activities in the muscle. The electrical signal recorded from a contracting of muscle is known as electromyography (EMG) signal. Electromyography (EMG) signals are usually affected by noise. This noise came from electronics equipment, ambient noise from electromagnetic radiation and motion artifact. Signal acquisition of EMG may results in noisy raw data. So, noise must be removed to get an accurate data. Therefore, a mechanism is needed to remove the noise from raw signal. The mechanism is by using filtering method. Hence, filtering techniques is very important to achieve a relevant data.

1.3 Objective

The project is a study based on electromyography (EMG) signal which emphasized on filtering. The main objective of this project is to come out with the signature of muscle strength in development of robot exo-skeleton. Apart of that, the objective of this project is to investigate the correlation of thermal imaging and EMG devices in determining the muscle condition.

1.4 Scope of study

The scope of this project consists of research, simulation, analysis and performs a good result. The filtering techniques and thermal imaging will be presented in this paper to provide efficient and effective ways of understanding the EMG signal. A comparison study between types of filters is also given to show performance of various EMG signal analysis. The correlation of thermal images and EMG devices also will be analyzed. Furthermore, basic knowledge is applied to developed efficient application of EMG. The simulation must be done by using SmartView 3.1, EMGworks 4.0 Acquisition and EMGworks 4.0 Analysis, Delsys Inc to present the result.

CHAPTER 2

LITERATURE REVIEW

2.1 EMG Signal Fundamental

Currently, EMG had become an important tool in biomedical and clinical application. Hence, the detection, processing and analysis of EMG signal has become well known and a major research area in biomedical field. In electromyography, skeletal muscle fibers activation is activated during the action potential (or electrical currents) [3]. The action potential is similar to electric waves that pass along the fibers to stimulate muscle contraction. Action potential moves along nerve fiber and stimulates the skeletal muscle as shown in Figure 1. Then, the stimulation generates muscle contraction which then result in movement of human limbs.

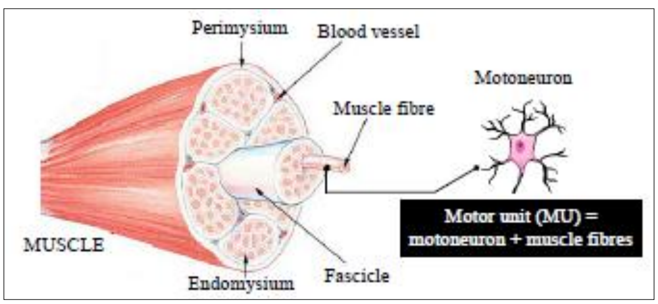


Figure 1: Structure of skeletal muscle [4].

Electromyography is used to evaluate, record and analysis the electrical activity of skeletal muscle during contraction. Muscle consists of many individual fibres which different in terms of length, shape and width. Muscles are formed by groups of fascicule that are bound together. Motor unit (MU) is the combination of a single alpha neuron and all the muscle fibres it activates. Muscle contraction is controlled by central nervous system (CNS) and the concept is shown in Figure 2.

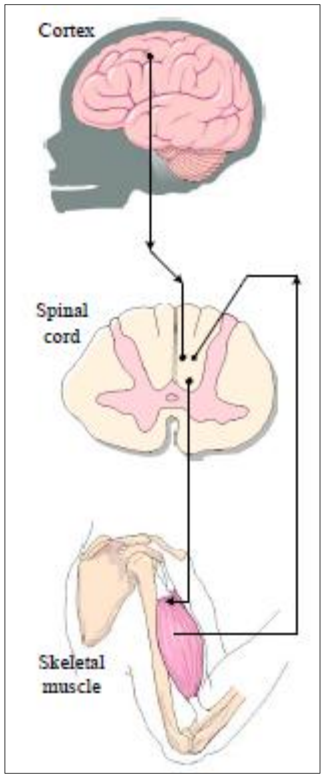


Figure 2: A schematic of basic motor mechanism, the motor unit and its components [4].

Neurons will activate the muscle fibres which located in spinal cord. Then, the nerve fibres of the neurons leave the spinal cord and distributed to the motor nerve. It will cause the muscle fibres activation. Depolarized occur when the signal propagates along its surfaces and the fibre twitches. Due to depolarization, electrical activity at the area of the muscle fibres will be generated. This process is called muscle fibre action potential. The electrical activities combination created by each motor unit is called electromyography (EMG) signal.

2.1.1 Raw signal

A raw EMG signal is an unfiltered and unprocessed signal detecting the superpose Motor Unit Actual Potential (MUAP). The most general technique to estimate muscle force is by using surface electromyography (SEMG) signal. Moreover, extensive processing of the raw SEMG signal is needed before proceed with the signal analysis. The picture of raw SEMG signal is shown in Figure 3. The processing include: i) the differential amplification of two surface electrode recordings from a muscle, ii) band pass filtering of the resultant raw signal, iii) full wave rectification, and iv) subsequent low pass filtering to determine a 'linear envelope' of the time-history [5]. EMG signal from the electrode is too small with the amplitude range up to 10mV or ±5V (peak-to-peak) or 0 to 15mV (RMS) [1]. The amplitude is too small for further processing. Most of the applications, EMG signal required to be digitized and sent to processor, microcontroller or CPU for feature extraction.

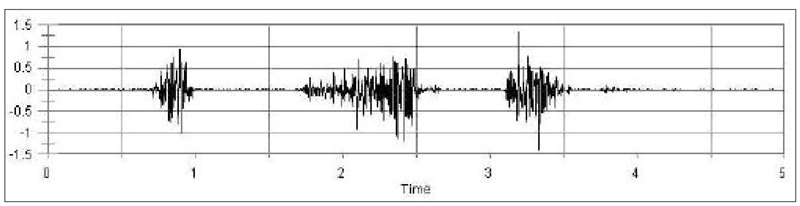


Figure 3: The figure showing a raw SEMG signal [6].

2.1.2 Electrical noise and factor affecting EMG signal

EMG signal contains inevitable noise. With the existence of noise, the data muscle contraction is no longer being genuine. Inherent noise in electronic equipment, ambient noise from electromagnetic radiation, motion artifacts and inherent instability of signal are the factors that affecting EMG signals [7]. There are three aspects that affects the EMG signal which are causative, intermediate and deterministic factors. Causative factor can be classified into two classes; intrinsic and extrinsic. The intrinsic factor is associated to physiological, anatomical, biochemical character of EMG signals while extrinsic factors are due to electrode structure and placement such as location of electrode. Moreover, the intermediate factors are physically influenced by one or more causative factor; for example are crosstalk and superposition. The deterministic are affected by intermediate factor; for instance motor unit firing rate, number of motor unit activate and MUAP shape and duration [8].

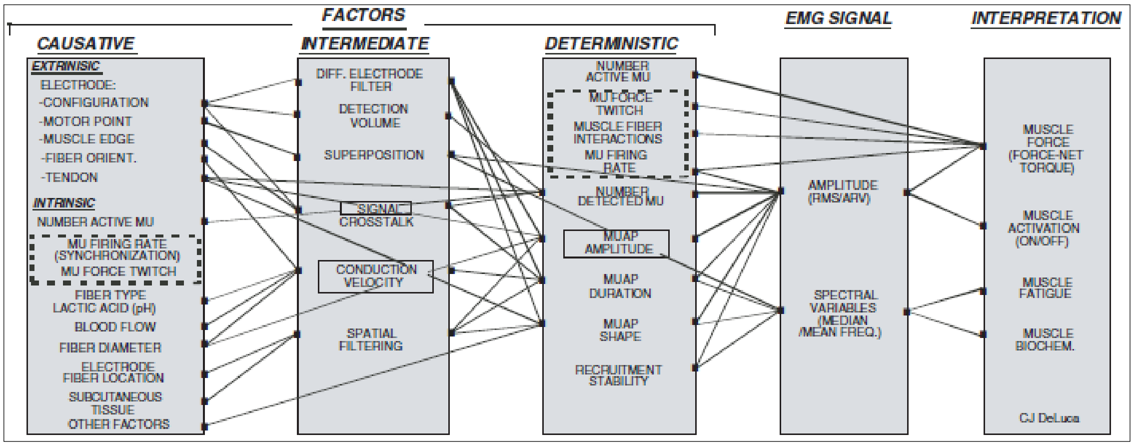


Figure 4: Relationship among the various factors that affect the EMG signal [9].

2.1.3 Electrodes

There are two main types of electrodes are used to detect the EMG signal which are surface electrode and wire or needle electrode. Typically, electrodes are used singularly or in pairs. These types of configurations are referred as monopolar and bipolar. In most cases, surface electrodes are used in kinesiological studies due to non-invasive characteristic. Kinesiological EMG is a neuromuscular activation of muscle within postural tasks, functional movement, work conditions and treatment or training [10]. The benefit of surface electrode is easy handling and the main limitation is that only surface muscles can be detected. Wire or needle electrodes are used for deeper muscle (covered by surface muscles or bones).

2.1.3.1 Surface electrode

The most often surface electrode used is silver/silver pre-gelled electrodes as shown in Figure 5. It is recommended for the general used (SENIAM). The advantage of surface electrode is easy, quick handling and hygienic aspects is not a problem when using a disposable electrode type. The silver-silver chloride electrodes is highly popular in EMG because of the light mass (0.25g), small size (<100mm diameter) and high reliability and durability.

Figure 5: Surface EMG Sensor [11].

2.1.3.2 Wire or needle electrode

Thin and flexible wire electrodes are required due to muscle movements. For deeper muscle layer, flexible wire electrodes are the preferred choice for invasive electrode application. The most common needle electrode is the 'concentric' electrode used by clinicians.

2.1.4 Recording EMG data

Regularly, some skin preparation need to be done before start with EMG measurements. Skin preparation procedures must follow step by step to prepare the electrode application. The hair on the skin need to remove and cleaned with alcohol. Alcohol can remove dead skin cells and clean the skin from dirt and sweat. In a way to get the system input, Silver Chloride (AGCl) surface electrodes are place on the correct muscles. The input signal is recorded and analyze.

EMG amplifiers are very important to record EMG signal. EMG amplifiers known as differential amplifiers and it have the ability to reject or remove artifacts. The differential amplifier is used to detect potential differences between two electrodes and cancel outside noise. The relationship between differential and common mode gain is the 'Common Mode Rejection Ratio' (CMRR). CMRR is chosen for amplification method. The acceptable value for CMRR is >95dB [12]. Next, the signal is filtered by using different type of filter such as Butterworth filter, Bessel filter, Chebyshev filter and Elliptic filter. After that, the filtered signal is converted with 16-bit resolution by using A/D convertor. The output data is analyzed to get an accurate data. The block diagram for EMG process flow is illustrates in Figure 6.

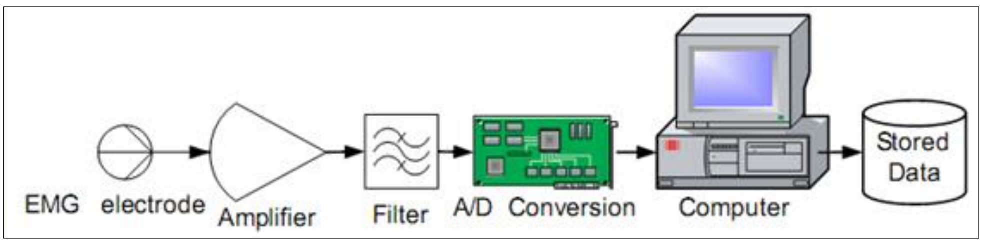


Figure 6: Blog diagram for EMG process flow from raw input signal to output stored data [13].

2.2 Filters

Filtering of the signal is very important. Filtering is used to focus on a narrow band of electrical energy that is of interest to us rather than all the electrical signals that the sensors will pick up. Usually, electromyography (EMG) signal is affected by noise which produces by different source such as movement of cables during data collection and the activity of motor units distant from the detection point. The most common filter used in EMG signal is adaptive filter. The EMG signal after filtering is demonstrates in Figure 7.

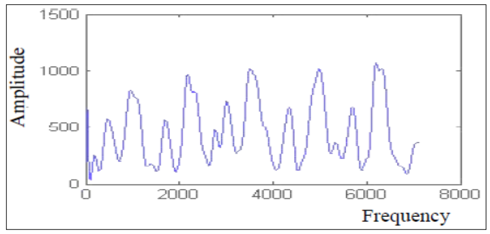


Figure 7: EMG signal after filtering [14].

2.2.1 The basic filter type

High pass filter (HPF), low pass filter (LPF), band pass filter (BPS) and notch filter are a different type of filter used to filter a raw SEMG. A raw SEMG signal contains of electrocardiography (ECG) artifacts and adaptive filter had been used as an ECG artifacts removal [15]. The processing of SEMG signal involves four steps which are amplification, band pass filtering, full wave rectification and subsequent low pass filter. Band pass filter is consists of low pass filter and high pass filter. It is applied to the signal to reduce noise and artifacts.

Regularly, LPF is used to remove unwanted amplitude modulation due to sliding of innervations zone below the electrodes and to create a linear envelope in EMG signal. On the other hand, HPF is used to get rid of movement artifacts that are often with lower frequency. Band pass filter are needed to avoid anti-aliasing effect within sampling. The typical frequency range for band pass filter is 1Hz and 500Hz. However, there is drawback with notch filter. Notch filter is not acceptable because it demolish too much EMG signal power. Power lines frequency may contain components of the desired signal SEMG. This may lead to distortion of desired signal [16]. Therefore, notch filter is not recommended to be applied in EMG signal as it is not a good practice. Example of digital notch filtering is shown in Figure 8.

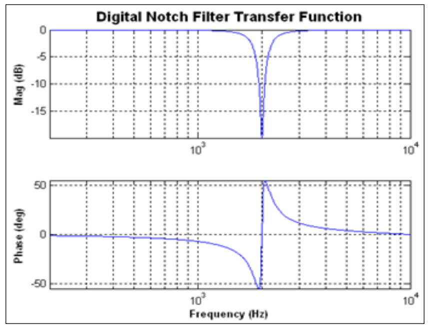


Figure 8: The illustration of digital notch filtering [17].

2.2.2 Types of filter

The basic or ideal types of filters have been presented in 2.2.1. Each type of ideal filter has specific limitation and function which can be optimized to approach ideal filter features at the expense of some other characteristic. There are four types of filter which are Butterworth, Chebyshev, Elliptic and Bessel or Thompson.

2.2.2.1 Butterworth filter

Butterworth filter is introduced in 1930 and become one of the earliest systematic analog filter design methods. This type of filter is widely used and the best used. High past filtering using Butterworth filter is the most easy, simple and straightforward idea. This filter is best used because it has maximally-flat magnitude or also called maximally flat response in the transmission pass band and at the same time minimizing pass band ripple.

The important specification of frequency-limiting filters is a corner frequency which separates the pass band and stop band regions. The corner frequency is defined as that frequency where the output voltage is approximately 0.707 of the input value. In order to satisfy Analog Filter Design Theorem, the formula of magnitude-squared Butterworth response must be fulfilled.

Definition of the magnitude-squared Butterworth response:

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

Note that N is the Butterworth filter order, ω is frequency response, ω_c is filter's cutoff frequency and the magnitude-squared Butterworth response is ½ when $\omega=\omega_c$ and independent of N. The definition above referred to as the 3dB frequency. Figure 9 demonstrates the Butterworth filter magnitude response with order 1 to 10.

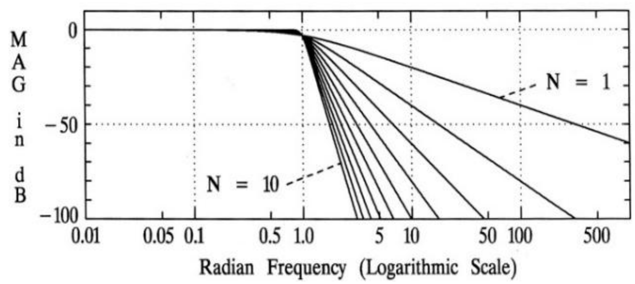


Figure 9: The Butterworth filter magnitude response with the value of ωc =1 and values of N from 1 to 10 [18].

2.2.2.2 Chebyshev filter

Another type of filter is Chebyshev filter. It is also known as equal ripple response. It has been developed in 1950. This filter having a steeper roll-off where it can achieve steep roll-offs with high order design. Chebyshev filter surpass Butterworth filter where for the same order design, Chebyshev filter outperforms the Butterworth's attenuation in the transition band. This benefits leads to noticeable ripple in the pass band [19].Chebyshev Type I filter have more ripple is pass band region and Chebyshev Type II filter have flat response in the pass band but more ripple in stop band.

The cutoff frequency for Chebyshev filter cannot be assumes as -3dB frequency like Butterworth filter. Normally, the cutoff frequency for Chebyshev filter is the frequency at which the ripple (or A_{max}) specification is exceeded [19]. The additional of pass band ripple as parameter make the filter more complicated than Butterworth filter but increase the flexibility of the filter.

Definition of the amplitude response for Chebyshev Type I with *n*th-order low-pass filter:

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

where

$$C_N\left(\frac{\omega}{\omega_p}\right) = \begin{cases} \cos\left[N\,cos^{-1}\,(\omega/\omega_p)\right], & |\omega| \le \omega_p \\ \cosh\left[N\,cosh^{-1}\,(\omega/\omega_p)\right], & |\omega| \ge \omega_p \end{cases} \tag{2.3}$$

ω_p is a frequency scaling constant and ε is a constant that adjust the influences of $C_N\,(\omega/\omega_p)$ in the denominator of $|H(j\omega)|^2$. The value of $0 \le \omega \le \omega_p$ defines the passband where $0 \le C_N^2\,(\omega/\omega_p) \le 1$, for $0 \le \omega \le \omega_p$, and $C_N^2\,(\omega/\omega_p) \ge 1$. $|H(j\omega)|^2$ monotonically falls for $\omega \ge \omega_p$. The ripple in frequency response is following the cosine function. Figure 10 illustrates the magnitude response of Chebyshev filter with order n= 1, 2, 4 and 8.

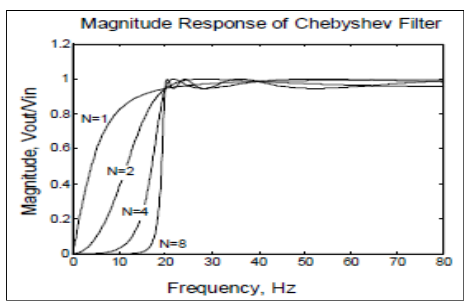


Figure 10: Magnitude response of Chebyshev filter with low pass filter with a cutoff frequency of 20Hz and varying orders (n=1, 2, 4, 8) [19].

Definition of the amplitude response for Chebyshev Type II with *n*th-order low-pass filter:

$$|H(j\omega)|^2 = \frac{\varepsilon^2\, C_N^2\ (\omega/\omega_p)}{1+\varepsilon^2\, C_N^2\ (\omega_s/\omega)} \tag{2.4}$$

where

$$C_N\left(\frac{\omega}{\omega_p}\right) = \begin{cases} \cos\ [N\, cos^{-1}\,(\omega_s/\omega)], & |\omega| \geq \omega_s \\ \cosh[N\, cosh^{-1}\,(\omega_s/\omega)], & |\omega| \leq \omega_s \end{cases} \tag{2.5}$$

ω_s is a frequency scaling constant and ε is a constant that adjust the influences of $C_N\ (\omega_s/\omega)$ in the denominator of $|H(j\omega)|^2$.

2.2.2.3 Elliptic filter

Elliptic filter is known as Cauer filter. Compared to Butterworth and Chebyshev filter, Elliptic filter is steeper but the amplitude response has ripple in both pass band and stop band. Elliptic filter keep maintaining the steepest cutoff in lowest filter order. The elliptic can maintain the sharp cut off by adding dips or 'notches' in the stop band region. These notches is important because notches introduce zero transmission is selected region. [19]

Definition of the magnitude-squared Elliptic response:

$$|H(j\omega)|^2 = \frac{1}{1+\,\varepsilon_p^2\, R_N^2\ (\omega,\omega_p,\omega_s,\varepsilon_p,\varepsilon_s)} \tag{2.6}$$

where

$$R_N\left(\omega, \omega_{p,}\omega_s, \varepsilon_p, \varepsilon_s\right) = sn\ [K\ sn^{-1}\left(\omega/\omega_p\,, \omega/\omega_s\right)] \tag{2.7}$$

$sn\ (x, \tau)$ is the Jacobian elliptic since of x with modulus τ, ω_p denotes the frequency of the pass band edge, ω_s denotes the frequency of the stop band edge, K denotes a parameter that is a function of the filter order N, ε_p is a positive real constant for pass band and ε_s is a positive real constant for stop band. In order to design elliptic filter, the following rules must be fulfilled [20]:

(1) R_N squared must be real,
(2) R_N squared must have a equipripple in the passband,
(3) R_N squared must have a equipripple in the stopband,
(4) R_N squared satisfy the Analog Filter Design Theorem

2.2.2.4 Bessel or Thompson filter

This type of filter are often used in audio crossover system. Bessel filter have monotonic and smooth magnitude response. In the stop band and trsnmission band, there is no ripple. The roll off of this filter have less steep than the Butterworth, Chebyshev and Elliptic filter. A Bessel filter may be useful. The Bessel filter characteristic is its exceptional phase linearity. [19] The higher the order, the more linear the phase response. The phase protection can minimize ‘ringing’ cause by sharp inputs (step response or impulse response).

From the basic Fourier Transform, the required filter frequency response, magnitude and phase, across the pass band is as follows:

$$H\ (j\omega) = K_p\ e^{-jt_d w} \tag{2.8}$$

The magnitude frequency response must be constant across the passband.

The application of Bessel filter is widespread and one of them is a filter in an oscilloscope amplifier. As we know, oscilloscope is used to electronically display a graph of the signal waveform. [21] Therefore, the usage of Bessel filter is very useful where it is able to assume that the displayed graph is accurate and any ‘ringing’ or distortion caused by filtering is minimal.

2.3 Thermography

Thermography is a non-radiating and non-invasive technique that measures temperature in a surface area. It measures the temperature distribution over the surface skin area. In bio-imaging application, thermography use to measures skin temperature variation. In our body, skin is the largest thermoregulatory organ. Skin contains of blood vessels in the dermis layer that play an important role to control the temperature. Hypothalamus controls vasoconstriction and vasodilatation of coetaneous blood vessels when the body is hot or cold. [22]

Thermography also referred to as medical infrared imaging or telethermography. It utilized highly resolute and sensitive infrared cameras (thermo graphic). Medical infrared thermography (MIT) provides a non-radiating analysis tool to analyze physiological functions that related to the control of skin temperature. Mostly, this developing technology is function to detect and locate thermal abnormalities at the surface skin. It characterized by an increase or decrease found on the surface skin. [23]

2.3.1 Current Thermography Applications

Typically, thermoraphy is used in medical terms. An injury is related to blood flow variation and this will affect the skin temperature. There are several applications of thermography in human medicine field such as neurological disorder, open-heart surgery, vascular disease, urology problems and mass fever screening. Currently, the most popular application of thermography is breast cancer. [24]

2.3.2 Limitations in Using Thermography

Thermography is very effective in diagnosing injuries of musculoskeletal muscle. Nevertheless, there are also disadvantages of using thermography. As we know, smoking is not good for health. Smoking has a biasing effect on the thermal images.

Cigarettes contains of tobacco that can restrict blood circulations by vasoconstriction and lowers body temperature. In order to reduce these biasing effects, subjects (participant) cannot have smoked on the day of the experiment. Body fat and menstrual cycles also affects thermography readings. [22]

2.4 Related Work

The related work for this project is shown in Table 1.

Table 1: Related work of the project

No	Author	Year	Publication	Title of module	Technique use	Applications	Advantages	Limitations
1.	C.J. De Luca	1997	Delsys Incorporated	The Use of Surface Electromyography in Biomechanics	Low pass filter	EMG signal.	-Remove crosstalk in EMG signal	- Only concentrate on low frequency.
2.	J.F. Alan, T.C. John	2002	The Society of Physiological Research, Inc	Guidelines for Human Electromyographic Research	Bandpass filter	EEG, EKG artifacts	-Increase signal-to-noise ratio. -Reduce inter-site crosstalk -Sharp filter slope	-Depends on the distance of electrodes from underlying muscle.
3.	Peter Konrad	2005	Noraxon INC. USA	The ABC of EMG	High pass filter	EMG	-Eliminate heavy movement and contact artifacts. -Stabilize baseline shifts due to instable contact between probe and skin.	-
4.	Peter Konrad	2005	Noraxon INC. USA	The ABC of EMG	High pass filter	EMG	-Remove movement artifacts in EMG.	-

5.	Oljeta Bida	2005	-	Influence of Electromyogram (EMG) Amplitude Processing in EMG-Torque Estimation, p 15.	RMS and MAV	EMG Torque Estimation	- Can compute EMG amplitude. -MAV initially used than RMS because of the lesser amount of time necessary for computation -No need relinearization.	- RMS need more amount of time necessary during computation.
6.	-	2008	Thought Technology Ltd.	Basics of SURFACE ELECTROMYOGRAPHY Applied to Psychophysiology	HPF	Movement Artifacts	-Remove the residual artifacts.	-Very sensitive to electrode movement
7.	-	2008	Thought Technology Ltd.	Basics of SURFACE ELECTROMYOGRAPHY Applied to Psychophysiology	Notch filter	Line interference (50/60Hz)	- Remove the 60/50Hz component of the signal.	-Electronic devices frequency will not be removed.
8.	A.N. Norali, M. H Mat Som	2009	UNIMAP	Surface Electromyography Signal Processing and Application: A Review	Butterworth filter	Electrocardiography (ECG) artifact	- Have ability to rejects all components correlated to QRS complex	- Signal amplitude exceeds threshold value

9.	A.N. Norali, M. H Mat Som	2009	UNIMAP	Surface Electromyography Signal Processing and Application: A Review	Root Mean Square (RMS) & Mean Absolute Value (MAV)	EMG amplitude analysis.	-Can estimate the amplitude of dynamic EMG. -RMS involves a measure of the power of the EMG signal.	- The signal has to be rectified before implementing MAV.
10.	Fang Dai	2009	© Copyright Fang Dai	Onset Detection for Surface Electromyography Signals	High pass filter	EMG	-Provide a superior estimate of force. -Better correlation.	-Cannot remove artifact at high frequency, limited to ≤200Hz
11.	Siti Anom Ahmad	2009	University of Southampton	Moving Approximation Entropy and its Application to the Electromyographic Control of an Artificial Hand , pg 51	ZC, SD and MAV	Artificial hand	- Can support the performance of the moving ApEn.	-
12.	Francois Hug	2011	Elesevier Ltd.	Journal of Electromyography and Kinesiology	Low pass filter	EMG	- Perform different EMG patterns	-Care must be taken to adapt the LPF to each velocity condition.

13.	M. Hidalgo, G. Tene & A. Sanchez	-	Dept. of Automation Control Industrial, Ecuador	Fuzzy Control of a Robotic Arm using EMG Signals	Butterworth filter	Robotic Arm	- Easy to implement	-
14.	M. Hidalgo, G. Tene & A. Sanchez	-	Dept. of Automation Control Industrial, Ecuador	Fuzzy Control of a Robotic Arm using EMG Signals	RMS	Robotic Arm	- Perform linear relationship with analyzed muscle contraction.	-
15.	B. Gerdle, K. Stefan, S.Day and D. Mats	-	-	Acquisition, Processing and Analysis of the Surface Electromyogram	RMS	Surface EMG (SEMG)	-Can amplified signal to appropriate level to optimize the resolution of recording	-
16.	B. Gerdle, K. Stefan, S.Day and D. Mats	-	-	Acquisition, Processing and Analysis of the Surface Electromyogram	Bandpass filter	SEMG	-Remove movement artifacts -Remove high frequency noise -Anti aliasing	-
17.	C.B. Ian	2006	-	Using Thermography to Evaluate the Effects of Arm	Borg Slope	- Anterior detroid surface temperature	- Vital tools for ergonomics analysis, biomechanics and	- Outside of physycological temperature effect therml

				Flexion and Loading on the Anterior Deltoid during a Simulated Overhead Task			blood flow impairment	reading - Subcutaneous fat effect thermal images - Superficial abnormalities
18.	H. Carolin, R. Christia n, A.Kurt	2010	-	Overview of Recent Application of Mediacal Infrared Thermography in Sports Medicine in Austria	Medical Infrared Thermography (MIT)	- Sport medicine -Traumatic knee injuries	- Non-invasive, non-radiating, low cost detection tool	-Cutaneous temperature changes during exercise can effect thermal imaging

The use of surface electromyography has been introduced since 1997 where the filtering techniques used was low pass filter. Low pass filter can remove crosstalk in EMG signal. Mostly, low pass filter was used in EMG signal. This filter only focuses on low frequency and attenuates high frequency. Due to the limitation, band pass filter technique was established in 2002. It has a lot of advantages such as increase signal-to-noise ratio; reduce inter-site crosstalk and sharp filter slope. Band pass filter was use in electroencephalography (EEG) and electrocardiography (EKG) artifacts. High pass filter also one of the common techniques for filtering. Peter Konrad found that high filter techniques was good and used in many application such as anal and vaginal probes and fine wire application [7]. High pass filter has less limitation where it cannot remove artifact in high frequency. The frequency limit was less than 200Hz.

Other than that, the most popular type of filter was Butterworth filter. Butterworth filter was used in Robotic Arm application and electrocardiography (ECG) artifact. This type of filter was most frequently used because it was easy to implement and straight forward. In term of ECG application, Butterworth filter have the ability to reject all components correlated to QRS complex but sometimes signal amplitude exceed threshold value become the limitation. According to Table 1, A.N. Norali, M. H Mat has using high pass filter with Butterworth filter and found this filter was good and easy to use. So, the author wants to explore more about filtering techniques and improve further.

In addition, thermography was an advance technology used to detect and locate thermal abnormalities at the skin surface. Thermography was widely being used in many applications especially in sport medicine, traumatic knees injuries and clinical used. One of the rapidly developing technology was used to detect the thermal imaging on skin surface was by using Medical Infrared Thermography (MIT). From Table 1, C. B. Ian, H. Carolin, R. Christian and A.Kurt found that thermography have a lot of benefits such as thermography was a vital tools for ergonomic and biomechanics analysis, non-invasive, non-radiating and low cost detection tool. The limitations of using thermography were subcutaneous fat and outside of physiological temperature can affect the thermal reading and images.

CHAPTER 3

METHODOLOGY

3.1 EMG Acquisition

The EMG acquisition process flow was shown in Figure 11.

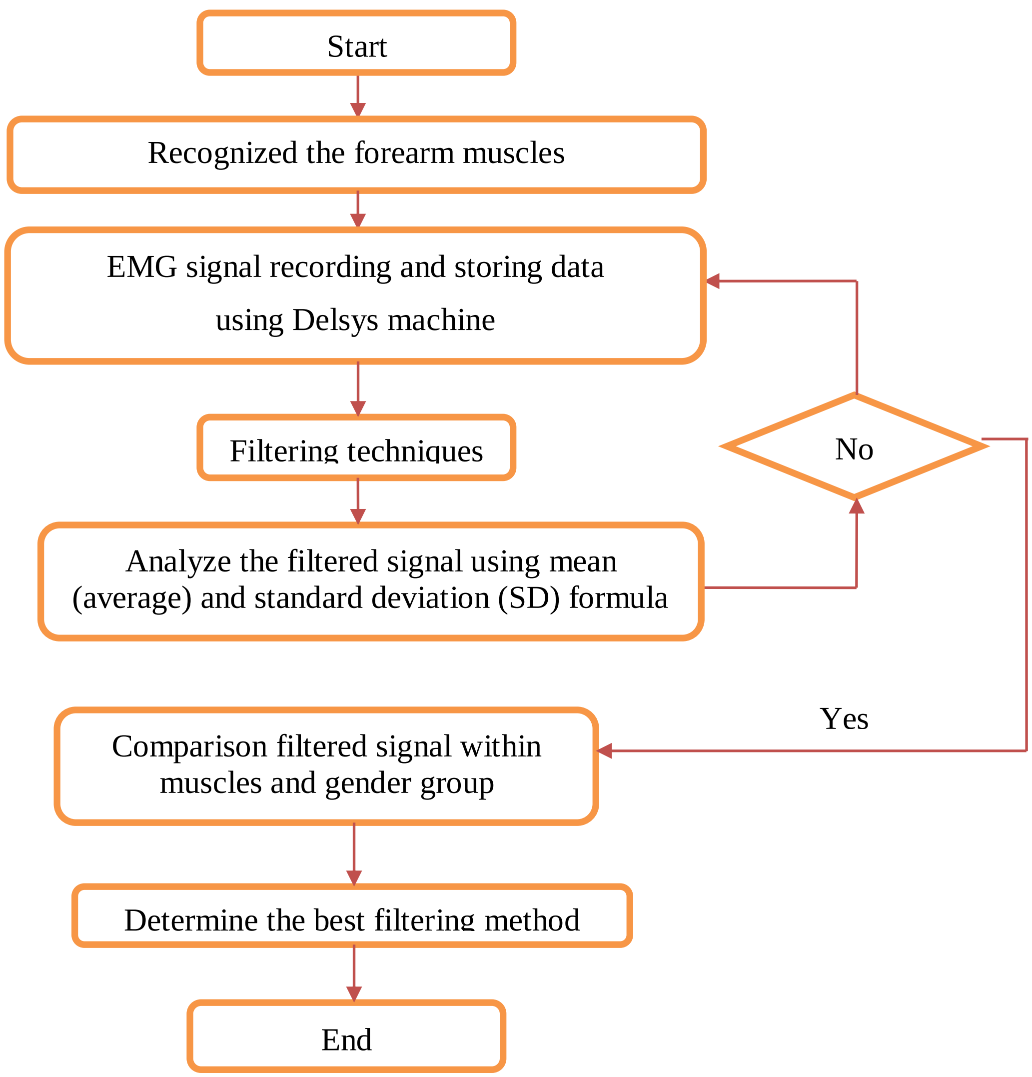


Figure 11: The EMG acquisition process flow

3.2 Thermal Imaging

The thermal imaging process flow was illustrated in Figure 12.

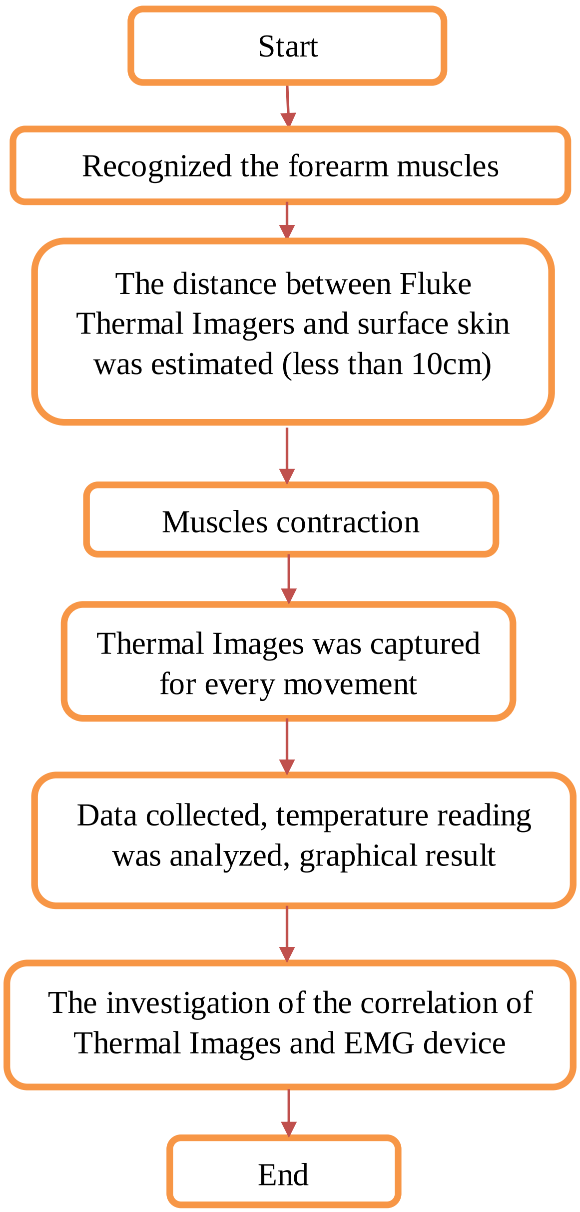


Figure 12: The thermal imaging process flow

The project was begun with writing the literature review on fundamental of EMG signal studies where it consists of a raw signal from subjects. Firstly, literature review was done by studying and collecting articles from the internet. All the information will be evaluated and highlighted carefully to get the exact data. The author will discussed a basic knowledge about raw signal, factor affecting EMG signal, type of electrodes used in EMG signal, recording EMG data and thermography.

After completing the literature review, the further studies will move on the filtering studies. Discussion about the best type of filter was the main focused. There were four types of filter classification which were Butterworth filter, Chebyshev filter, Elliptic filter and Bessel filter. Then, the process proceeded with capturing the thermal images by using Fluke Thermal Imagers to get the image of the temperature. The investigation was done to find the correlation of thermal imaging and EMG devices.

Lastly, all the studies and discussion will be compiled in the final report. Apart from that, the best type of filter used and the correlation of thermal imaging and EMG devices will further explained and justified. The simulation software in this research was SmartView 3.1, EMGworks 4.0 Acquisition and EMGworks 4.0 Analysis, Delsys Inc.

3.3 Experimental procedure

Initially, test subject ware provided with written description of the project, objectives of the research and procedure of the experimental work. Five healthy male subjects and three healthy female subjects (range: 20-25 years) volunteered for the study after providing institutionally approved written informed consent. The test subjects grouping was demonstrated in Table 2.

Table 2: Test Subjects grouping

Group	Age Range	Test Subject	Number of people
1	20-25	UTP Students	8 (3 females & 5 Males)

The tools required for the experimental work were Delsys Trigno Wireless Sensor, alcohol swab and Delsys EMG Signal Acquisition software. The procedure started with recording each test subject weight and height. The subject will be asked to perform six different forearm movements as shown in Figure 13.

(a) Wrist flexion

(b) Wrist extension

(c) Hand close

(d) Hand open

(e) Forearm supination

(f) Forearm pronation

Figure 13: Six different movements in forearm

The different muscles extensor and flexor carpi radialis, palmaris longus and pronator teres were chosen for this study because of their different body part and skin thickness. Table 3 showed the list of arm movements and the muscles required.

Table 3: List of arm movements and muscles required

Body part	Movement	Muscles
Wrist	Extension	Extensor carpi radialis
	Flexion	Flexor carpi radialis
Hand	Close	Palmaris longus
	Open	Palmaris longus
Forearm	Supination	Pronator teres
	Pronation	Pronator teres

Before proceeding with the experiment, alcohol swab were used on the subject's skin to clean the skin from dust or sweat as shown in Figure 14. After the muscles have been recognized, the surface electrode/sensor was put on the skin to be tested. The subject may ask to contract a muscle. The subject started with wrist flexion and hold for five seconds and rest for five seconds. Placement of the sensor on the subject's skin was shown in Figure 15.

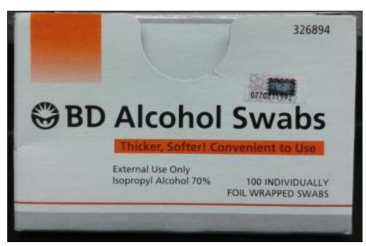


Figure 14: Alcohol swabs

Figure 15: Placement of the sensor on the subject's skin

Then, the process was repeated for other gestures as shown in Table 2. After that, thermal images (without sensors) were taken for every movement to get the image of the temperature. Thermal imagers were captured using Fluke Thermal Imagers. Figure 16 below was the figure of Fluke Thermal Imagers.

Figure 16: Fluke Thermal Imagers

The raw signal for six subjects was collected. The subjects need to do six movements as discussed in the experimental procedure. Thermal image was captured for every movement and the images were analyzed using SmartView 3.1 software. Thermal images results were analyzed by means observing the surface skin temperature, and displayed it in the graphs. Performance of temperature was analyzed and the correlation of thermal imaging and EMG devices was discussed in determining the muscle condition.

CHAPTER 4

RESULT & DISCUSSION

4.1 EMG Acquisition

As discussed in the previous chapter, the experimental procedure must be done to the subjects to collect the raw signal. The subject must follow the rules and procedure in order to obtain a good raw signal. The raw signals acquired from three different types of movement such as (1) wrist extension and wrist flexion, (2) hand open and hand close and (3) forearm supination and forearm pronation.

The raw signal was filtered at the different representative filter (Chebyshev, Elliptic, Butterworth and Bessel filter) with band pass filter corner frequency at 1 Hz to 500 Hz. The filtered signal obtained from EMGWorks database. The signal taken limited to 20 second with 320 samples (in Voltage). After that, Root Mean Square (RMS) was chosen for feature extraction before proceed to threshold process. In this experiment, RMS was selected because; only positive side of raw signal was needed. Then, the experiment was carried on with threshold process in order to get the muscle activation. The database in Table 4 shows the experimental details during the simulation.

Table 4: Experimental Details

Sampling frequency (Hz)	2000 Hz
Test subject	8 healthy subjects (3 female, 5 male)
Types of filter	Butterworth, Bessel, Chebyshev and Elliptic
Basic filter types	Band pass filter
Order (N)	4

Attenuation (dB)	4 dB
Corner frequency 1(Hz)	1 Hz
Corner frequency 2 (Hz)	500Hz

4.1.1 EMG Simulations

4.1.1.1 Test Subject 1

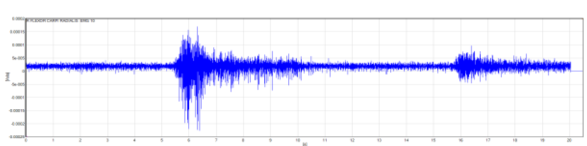
Table 5 below was the details of test subject 1. Table 6, 7 and 8 was shown the EMG simulation for test subject 1.

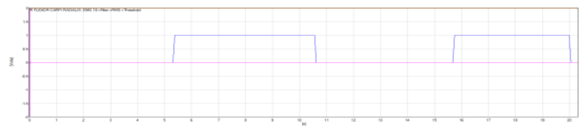
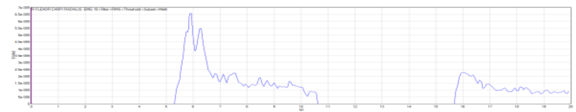
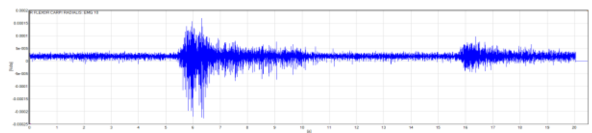
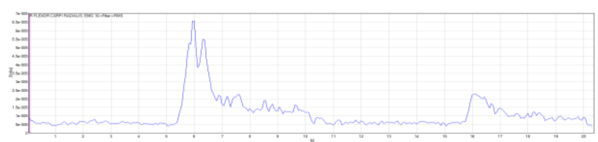
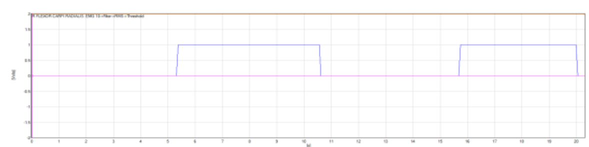
Table 5: Test Subject 1 Details

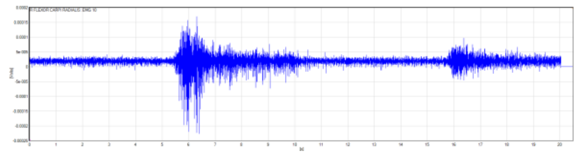
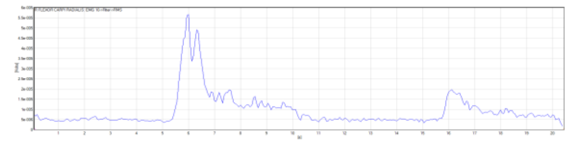
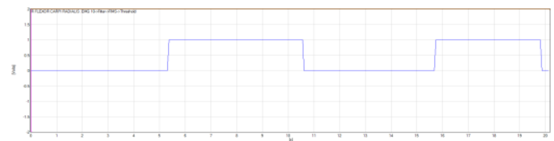
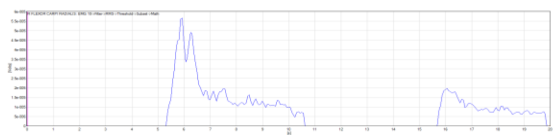
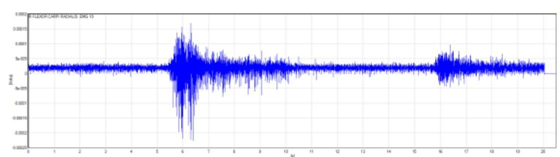
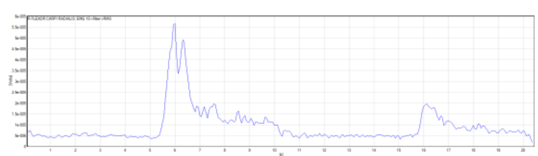
Gender	Female
Age	23 years old

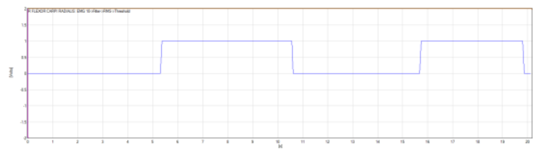
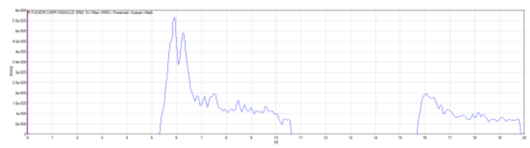
(a) Wrist extension and wrist flexion

Table 6: Test Subject 1 simulation figures for wrist extension and wrist flexion

Types of filter	EMG Simulations Figure
Butterworth	 Raw signal  Filtered and RMS signal

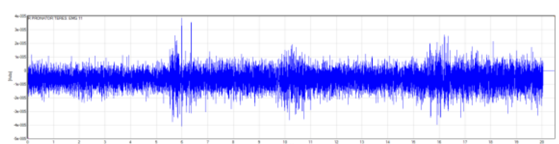
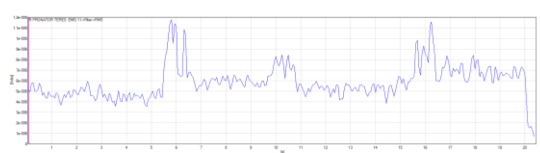
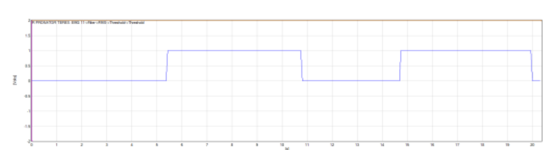
	 Threshold signal  Muscle activation
Bessel	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation

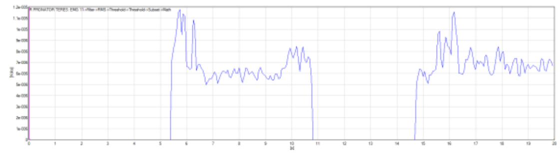
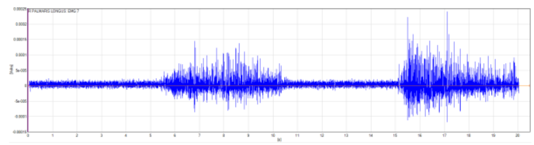
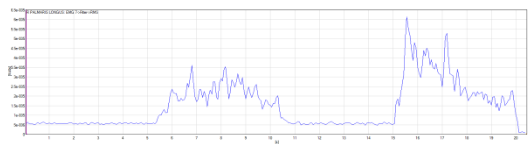
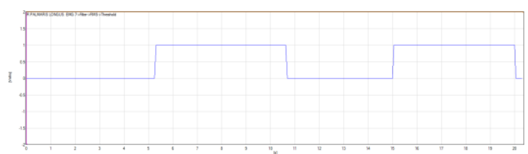
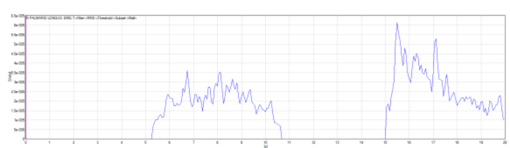
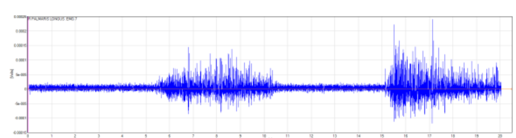
Chebyshev	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Elliptic	 Raw signal  Filtered and RMS signal

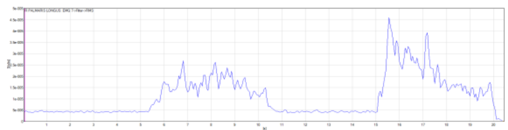
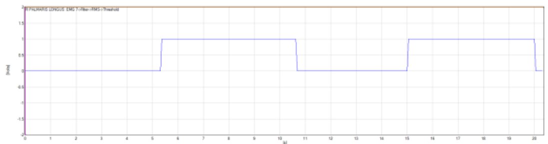
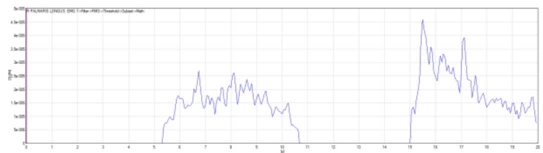
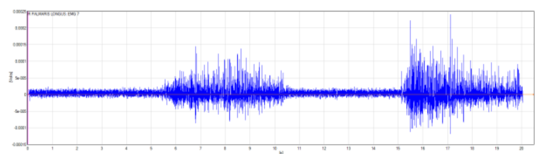
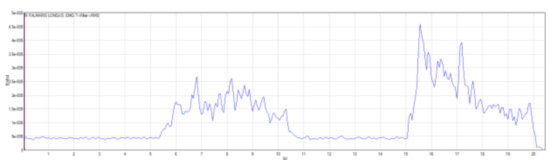
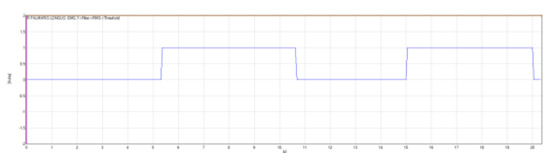
	 Threshold signal  Muscle activation

(b) Hand open and hand close

Table 7: Test Subject 1 simulation figures for hand open and hand close

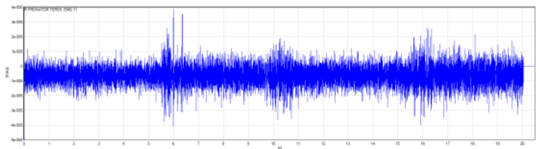
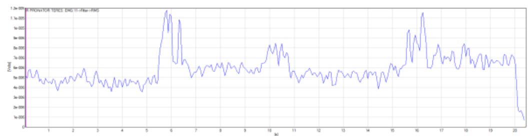
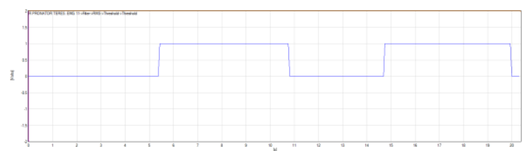
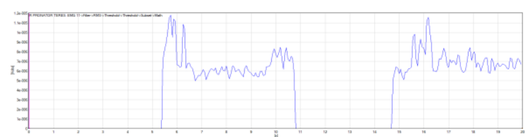
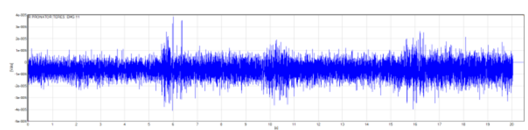
Types of filter	EMG Simulations Figure
Butterworth	 Raw signal  Filtered and RMS signal  Threshold signal

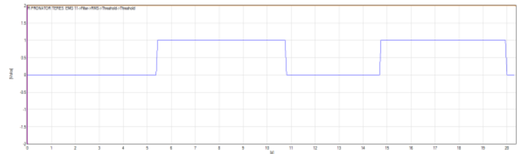
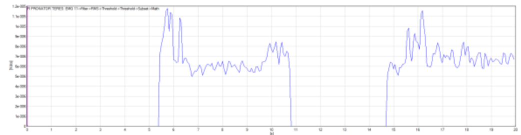
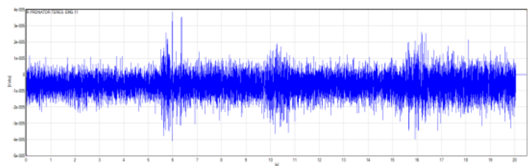
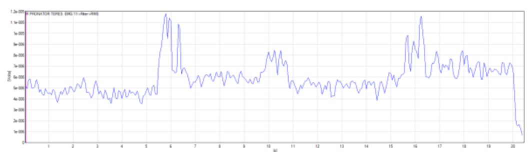
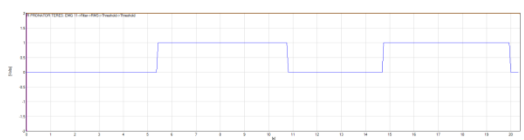
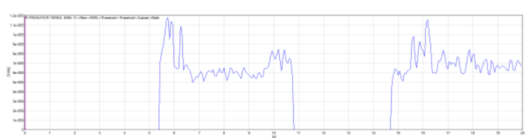
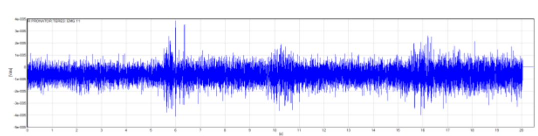
	 Muscle activation
Bessel	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Chebyshev	 Raw signal

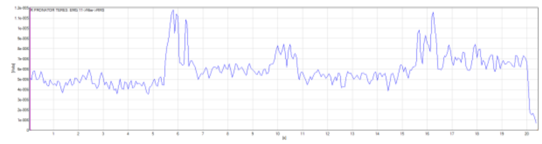
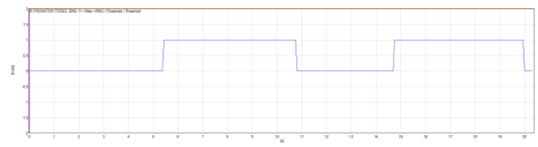
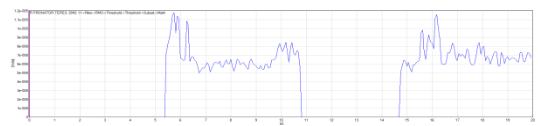
	 Filtered and RMS signal  Threshold signal  Muscle activation
Elliptic	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation

(c) Forearm supination and forearm pronation

Table 8: Test Subject 1 simulation figures for forearm supination and forearm pronation

Types of filter	EMG Simulations Figure
Butterworth	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Bessel	 Raw signal  Filtered and RMS signal

	 Threshold signal  Muscle activation
Chebyshev	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Elliptic	 Raw signal

	 Filtered and RMS signal  Threshold signal  Muscle activation

4.1.1.2 Test Subject 2

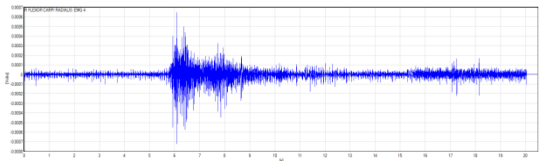
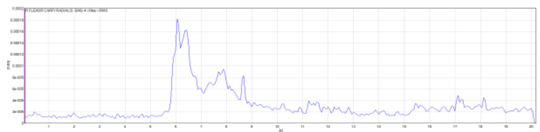
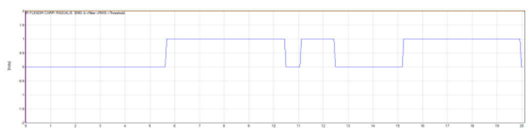
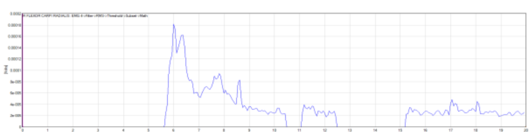
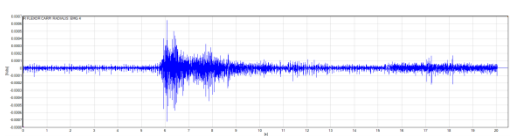
Table 9 below was the details of test subject 2. Table 10, 11 and 12 was shown the EMG simulation for test subject 2.

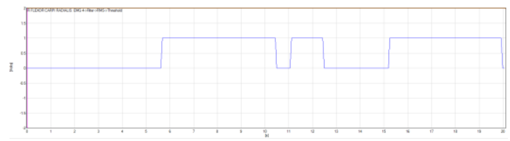
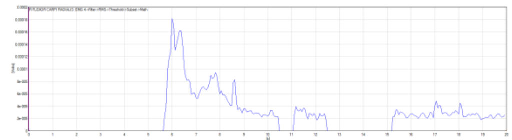
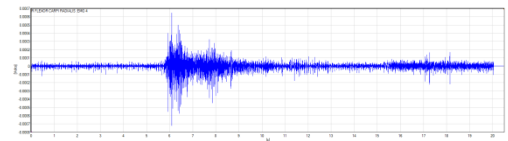
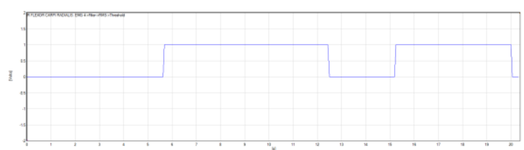
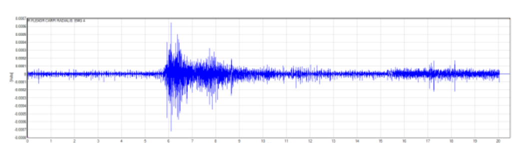
Table 9: Test Subject 2 Details

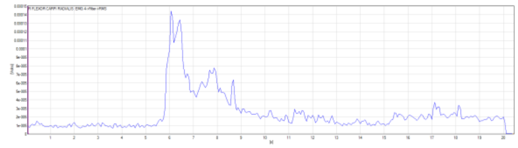
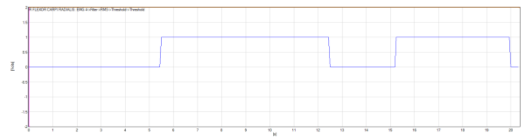
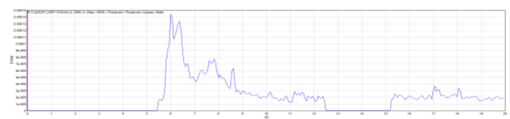
Gender	Female
Age	23 years old

(a) Wrist extension and wrist flexion

Table 10: Test Subject 2 simulation figures for wrist extension and wrist flexion

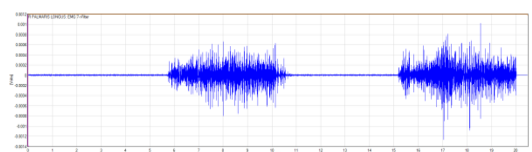
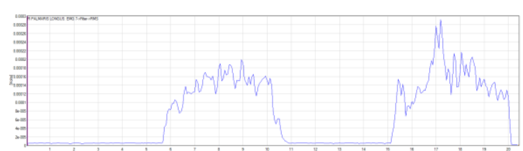
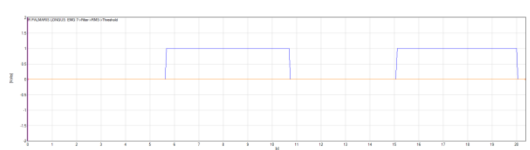
Types of filter	EMG Simulations Figure
Butterworth	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Bessel	 Raw signal  Filtered and RMS signal

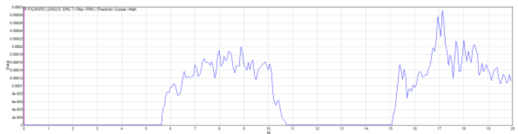
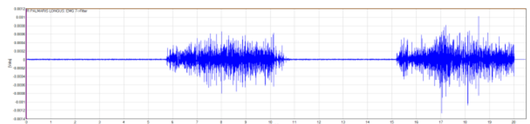
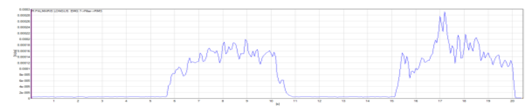
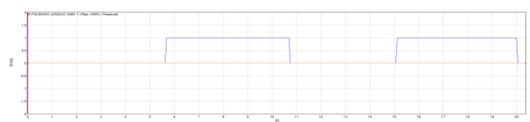
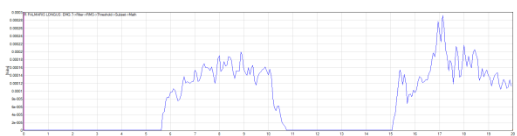
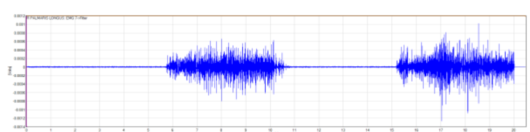
	 Threshold signal  Muscle activation
Chebyshev	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Elliptic	 Raw signal

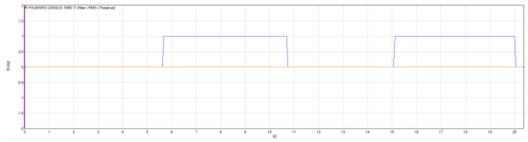
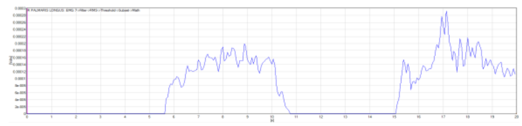
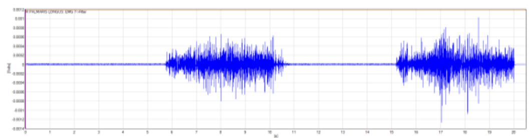
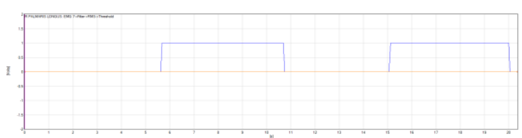
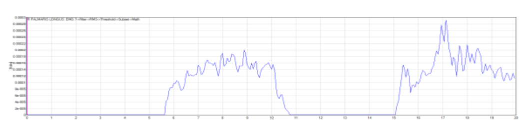
	 Filtered and RMS signal  Threshold signal  Muscle activation

(b) Hand open and hand close

Table 11: Test Subject 2 simulation figures for hand open and hand close

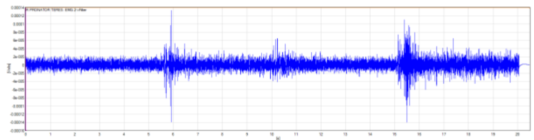
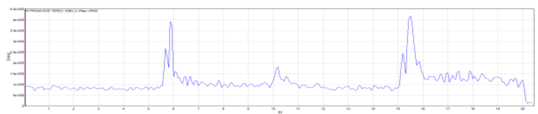
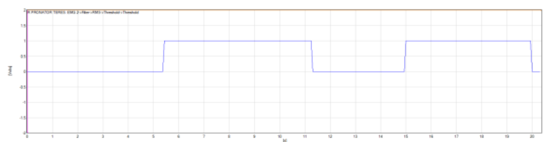
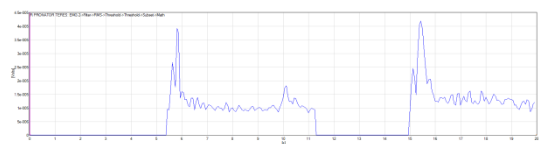
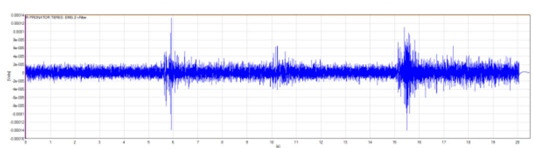
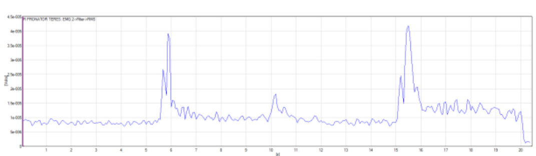
Types of filter	EMG Simulations Figure
Butterworth	 Raw signal  Filtered and RMS signal  Threshold signal

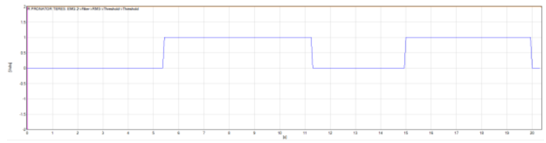
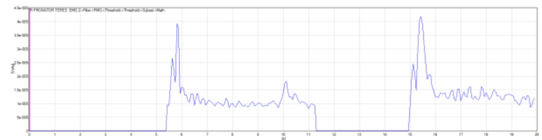
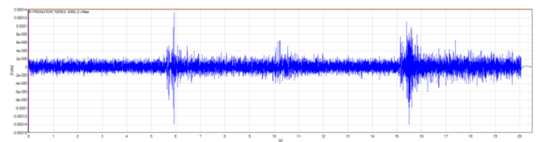
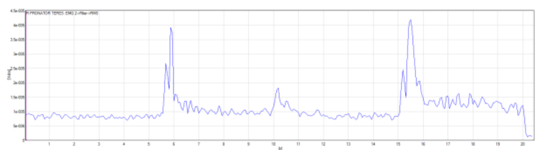
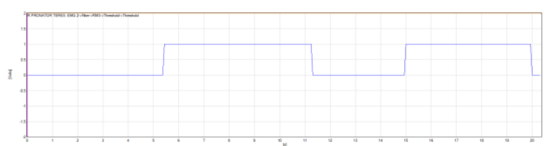
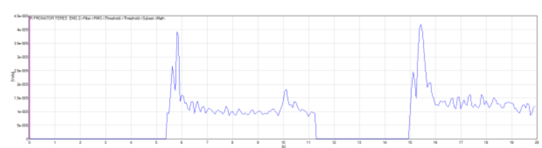
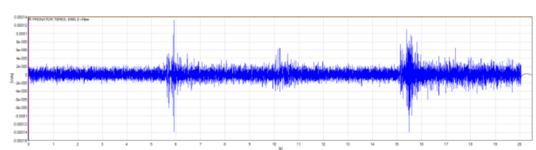
	 Muscle activation
Bessel	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Chebyshev	 Raw signal  Filtered and RMS signal

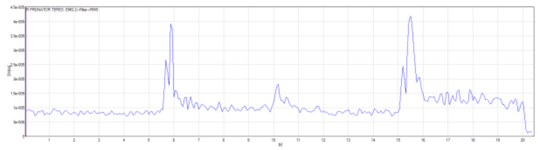
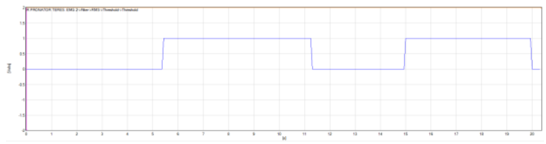
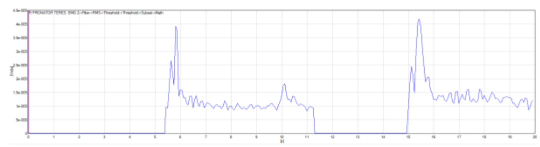
	 Threshold signal  Muscle activation
Elliptic	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation

(c) Forearm supination and forearm pronation

Table 12: Test Subject 2 simulation figures for forearm supination and forearm pronation

Types of filter	EMG Simulations Figure
Butterworth	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Bessel	 Raw signal  Filtered and RMS signal

	 Threshold signal  Muscle activation
Chebyshev	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Elliptic	 Raw signal

	 Filtered and RMS signal  Threshold signal  Muscle activation

4.1.1.3 Test Subject 3

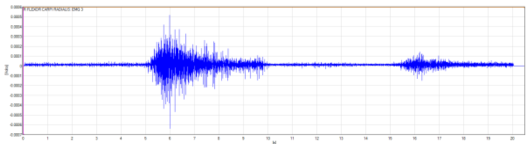
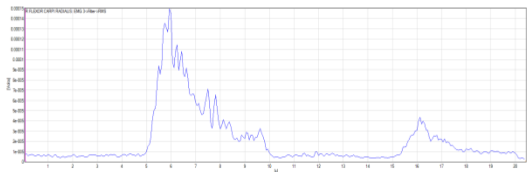
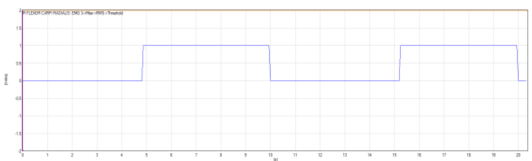
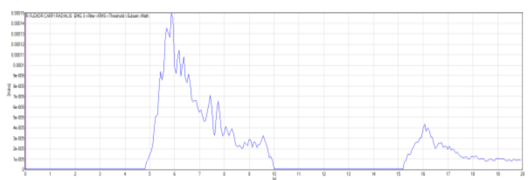
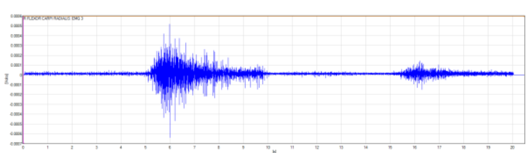
Table 13 below was the details of test subject 3. Table 14, 15 and 16 was shown the EMG simulation for test subject 2.

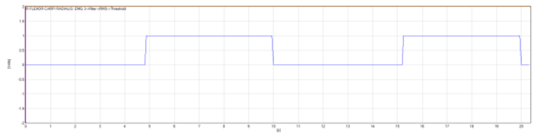
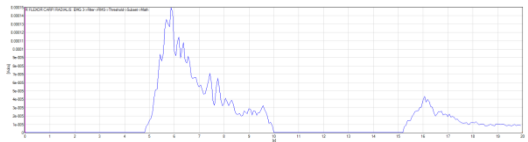
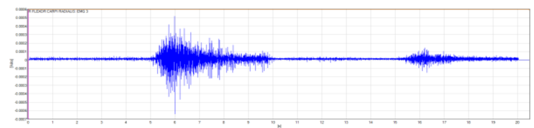
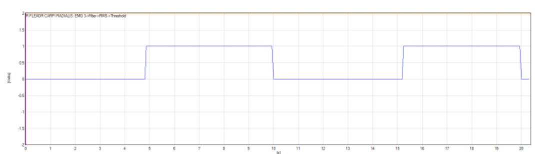
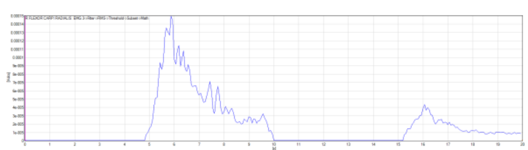
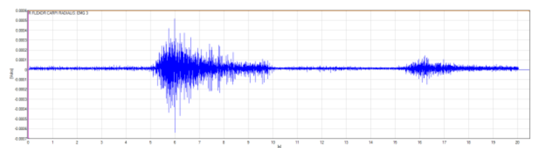
Table 13: Test Subject 3 Details

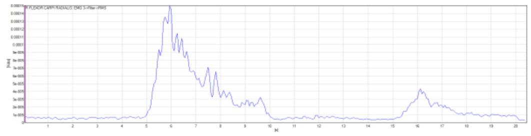
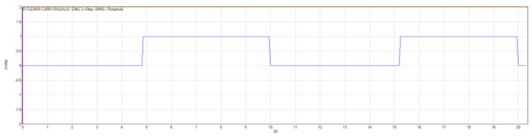
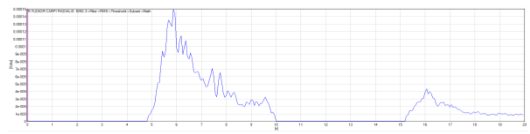
Gender	Female
Age	24 years old

(a) Wrist extension and wrist flexion

Table 14: Test Subject 3 simulation figures for wrist extension and wrist flexion

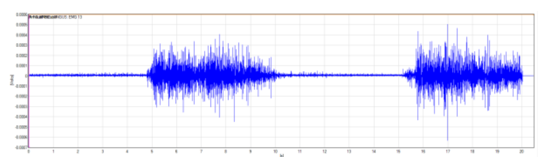
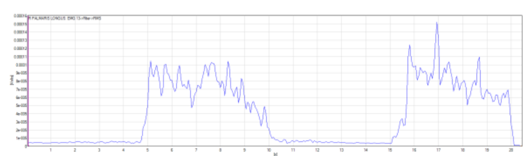
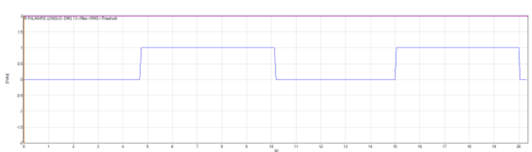
Types of filter	EMG Simulations Figure
Butterworth	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Bessel	 Raw signal  Filtered and RMS signal

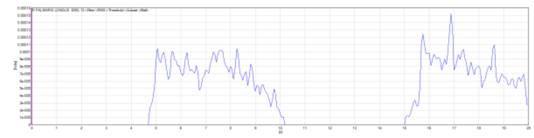
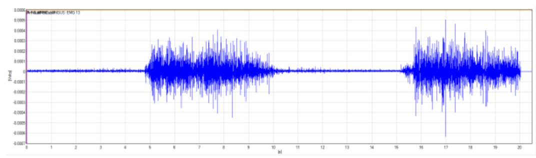
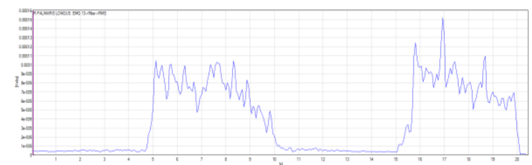
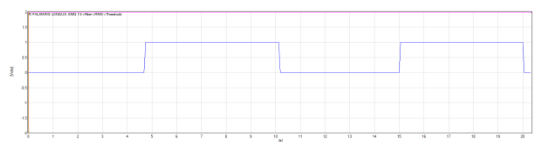
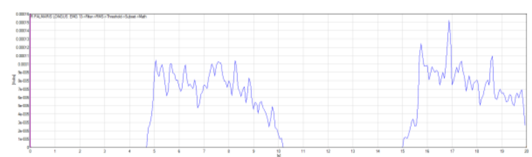
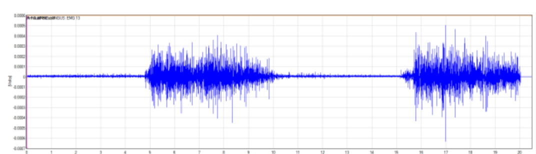
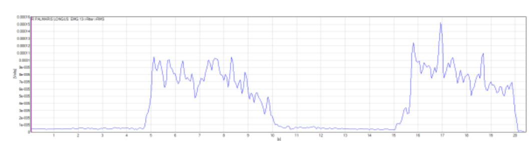
	 Threshold signal  Muscle activation
Chebyshev	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Elliptic	 Raw signal

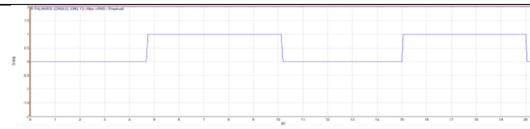
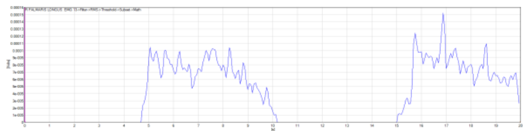
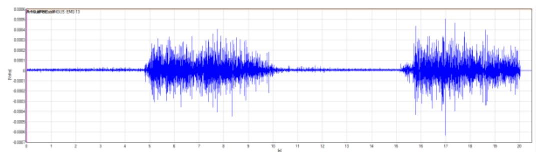
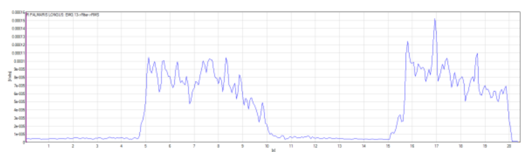
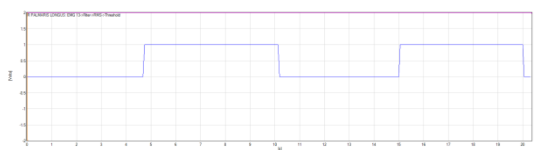
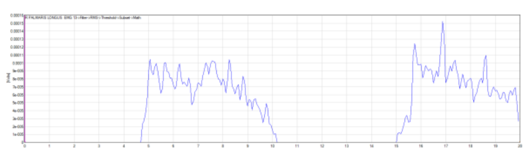
	 Filtered and RMS signal  Threshold signal  Muscle activation

(b) Hand open and hand close

Table 15: Test Subject 3 simulation figures for hand open and hand close

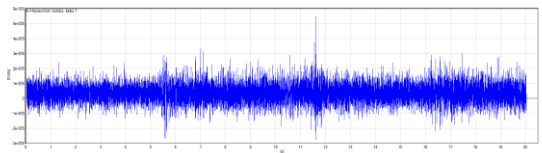
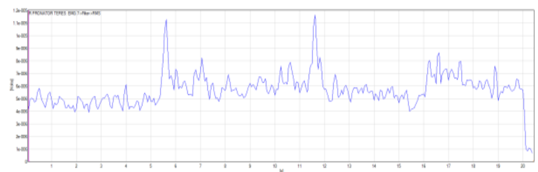
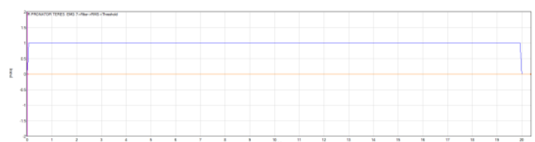
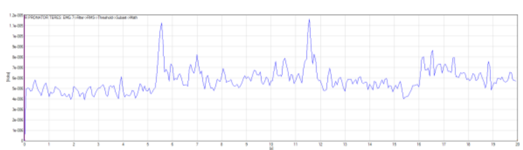
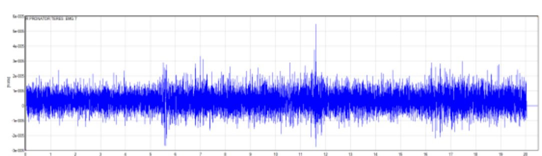
Types of filter	EMG Simulations Figure
Butterworth	 Raw signal  Filtered and RMS signal  Threshold signal

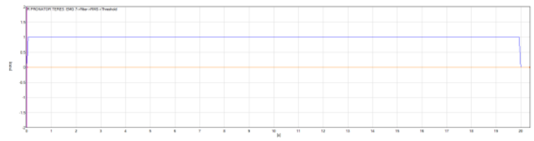
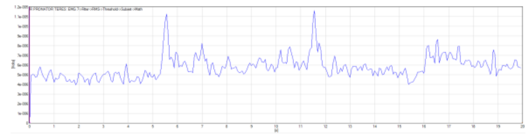
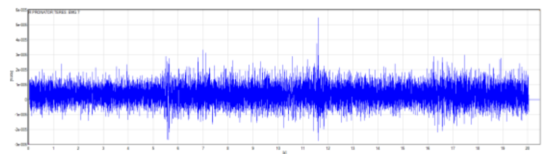
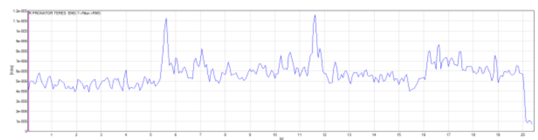
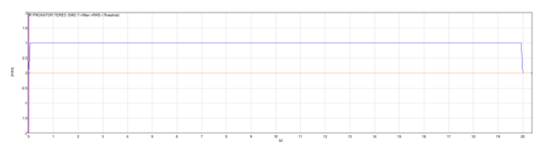
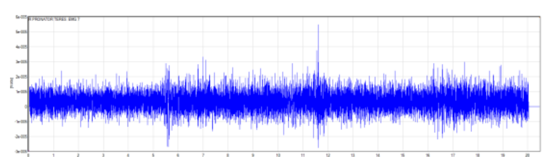
	 Muscle activation
Bessel	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Chebyshev	 Raw signal  Filtered and RMS signal

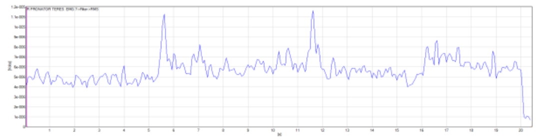
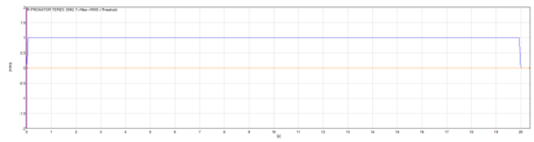
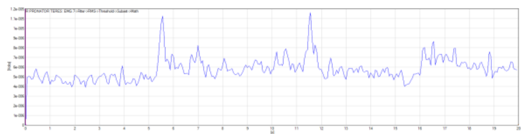
	 Threshold signal  Muscle activation
Elliptic	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation

(c) Forearm supination and forearm pronation

Table 16: Test Subject 3 simulation figures for forearm supination and forearm pronation

Types of filter	EMG Simulations Figure
Butterworth	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Bessel	 Raw signal  Filtered and RMS signal

	 Threshold signal  Muscle activation
Chebyshev	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Elliptic	 Raw signal

	 Filtered and RMS signal  Threshold signal  Muscle activation

4.1.1.4 Test Subject 4

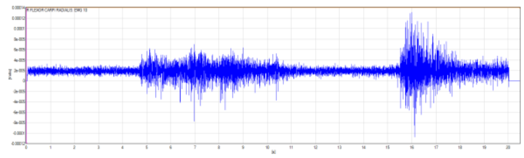
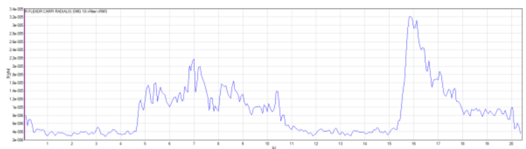
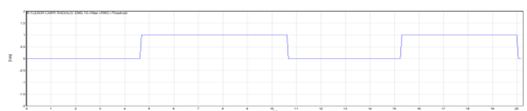
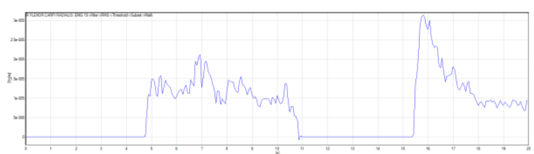
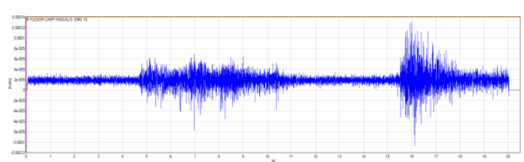
Table 17 below was the details of test subject 4. Table 18, 19 and 20 was shown the EMG simulation for test subject 4.

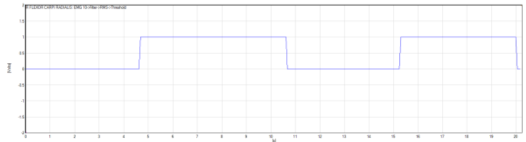
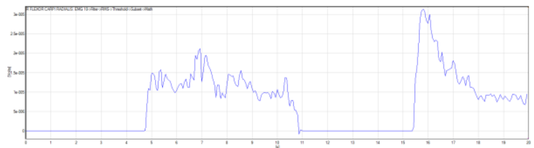
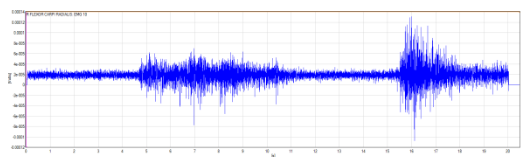
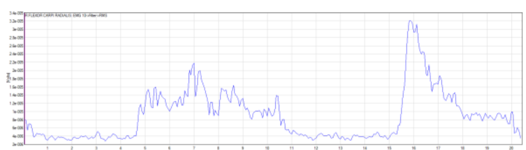
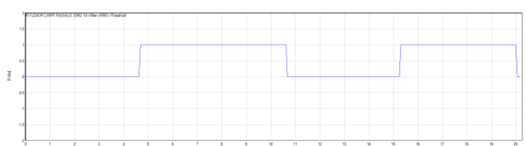
Table 17: Test Subject 4 Details

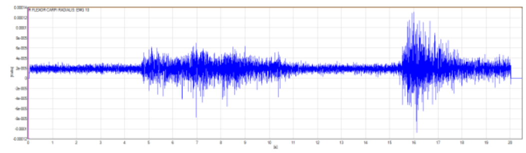
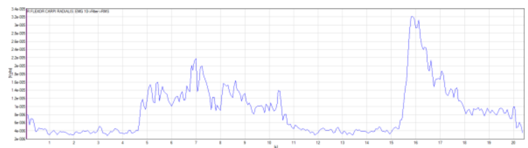
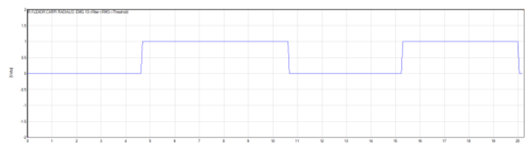
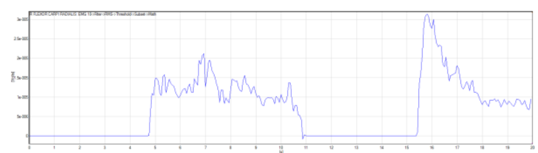
Gender	Male
Age	23 years old

(a) Wrist extension and wrist flexion

Table 18: Test Subject 4 simulation figures for wrist extension and wrist flexion

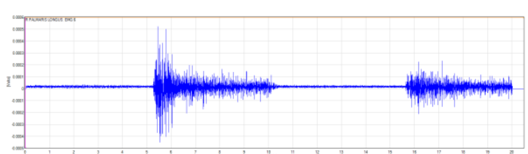
Types of filter	EMG Simulations Figure
Butterworth	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Bessel	 Raw signal  Filtered and RMS signal

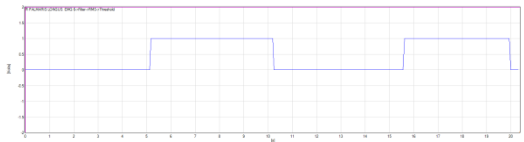
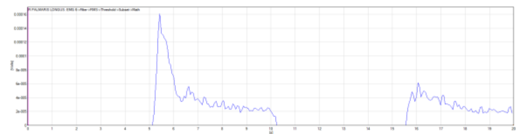
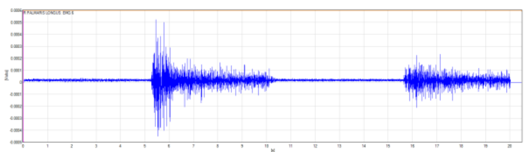
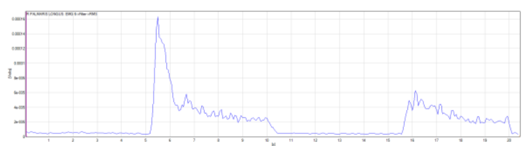
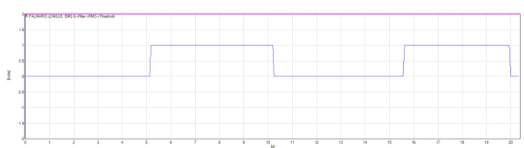
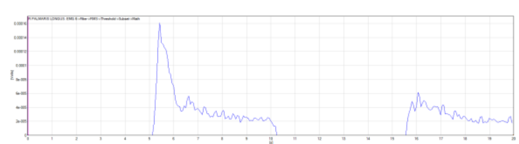
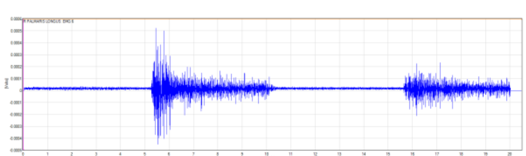
	 Threshold signal  Muscle activation
Chebyshev	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation

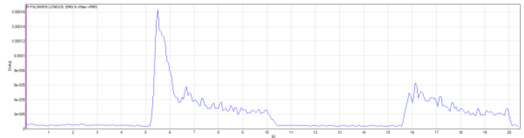
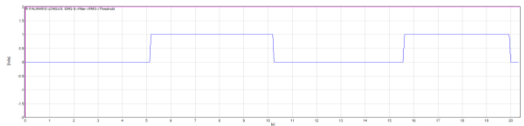
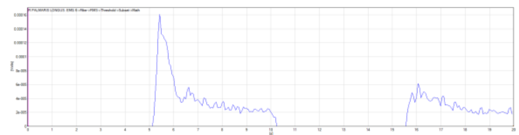
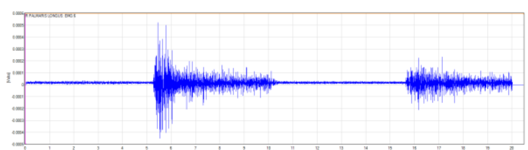
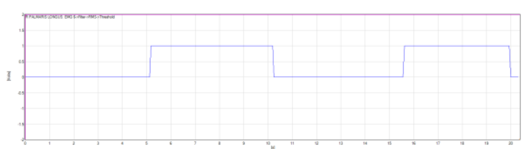
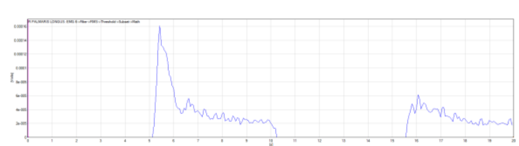
Elliptic	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation

(b) Hand open and hand close

Table 19: Test Subject 4 simulation figures for hand open and hand close

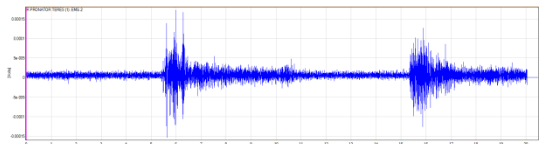
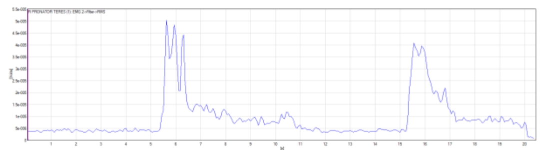
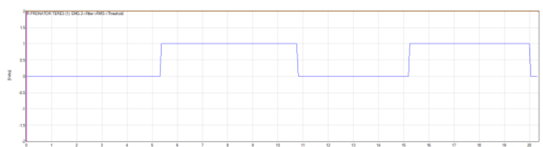
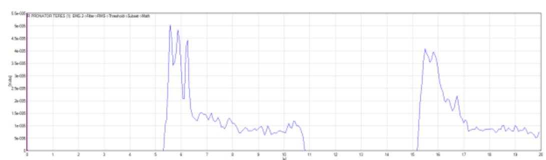
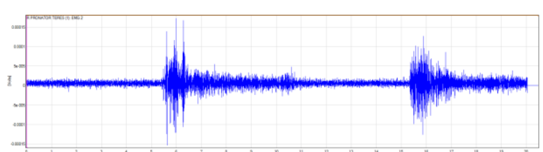
Types of filter	EMG Simulations Figure
Butterworth	 Raw signal  Filtered and RMS signal

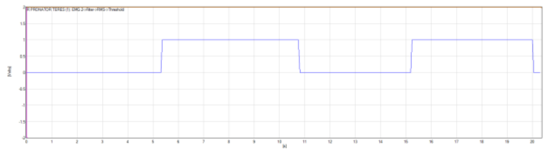
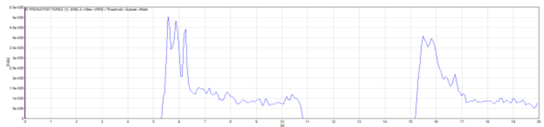
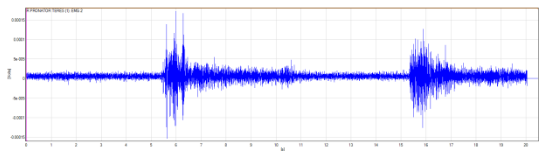
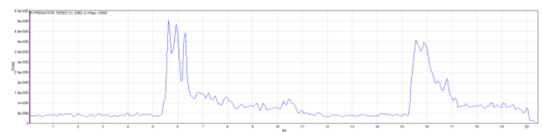
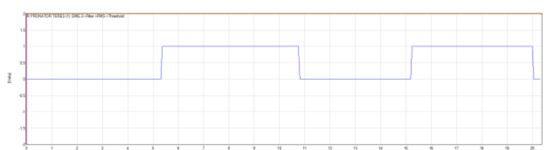
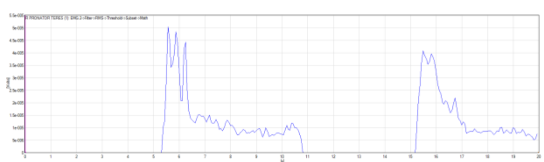
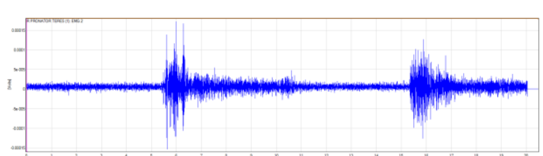
	 Threshold signal  Muscle activation
Bessel	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Chebyshev	 Raw signal

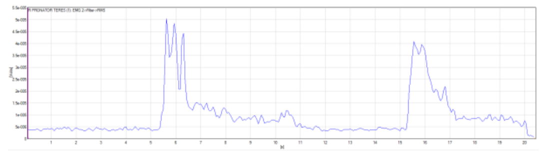
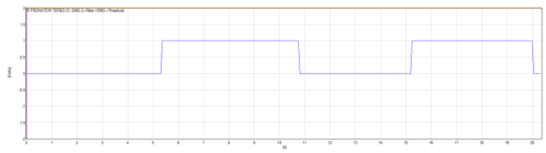
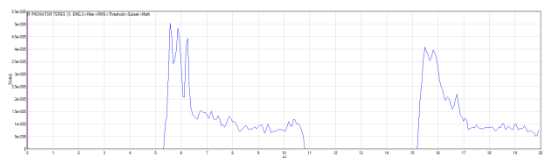
	 Filtered and RMS signal  Threshold signal  Muscle activation
Elliptic	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation

(c) Forearm supination and forearm pronation

Table 20: Test Subject 4 simulation figures for forearm supination and forearm pronation

Types of filter	EMG Simulations Figure
Butterworth	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Bessel	 Raw signal  Filtered and RMS signal

	 Threshold signal  Muscle activation
Chebyshev	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Elliptic	 Raw signal

	 Filtered and RMS signal  Threshold signal  Muscle activation

4.1.1.5 Test Subject 5

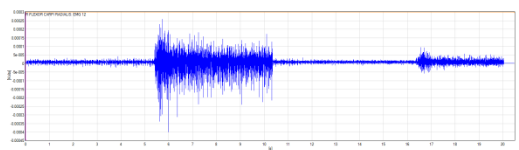
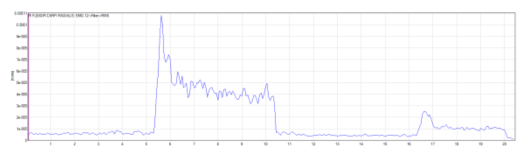
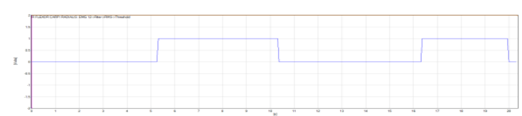
Table 21 below was the details of test subject 5. Table 22, 23 and 24 was shown the EMG simulation for test subject 5.

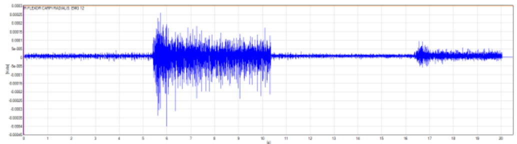
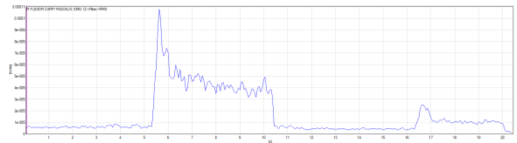
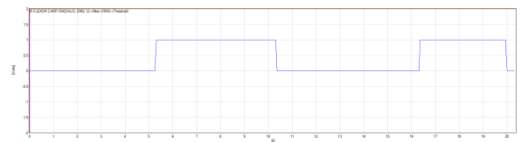
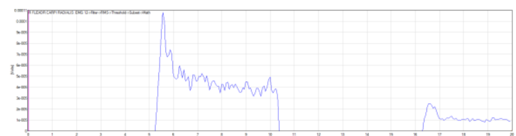
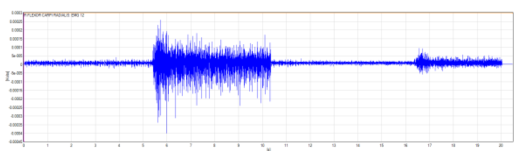
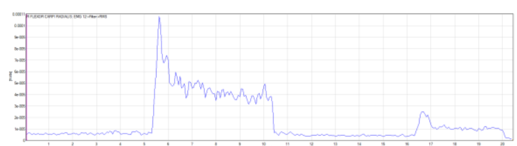
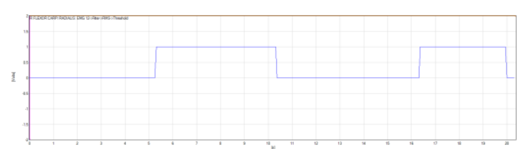
Table 21: Test Subject 5 Details

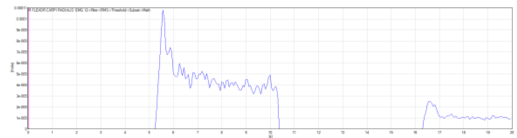
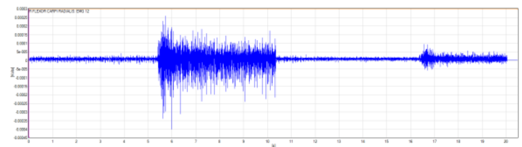
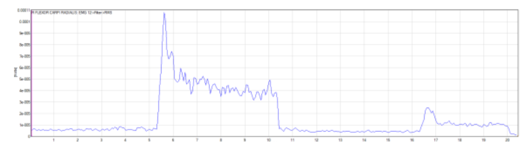
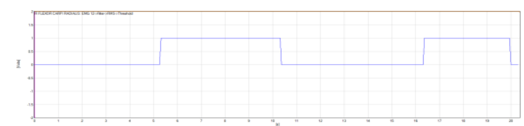
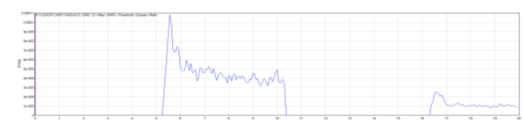
Gender	Male
Age	23 years old

(a) Wrist extension and wrist flexion

Table 22: Test Subject 5 simulation figures for wrist extension and wrist flexion

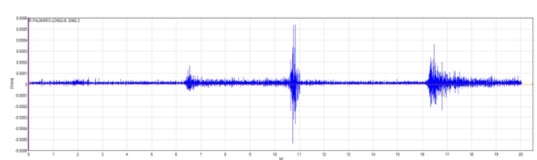
Types of filter	EMG Simulations Figure
Butterworth	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation

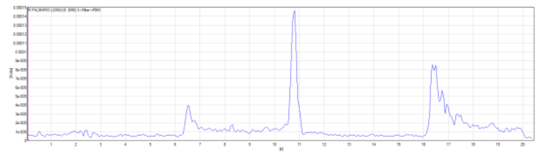
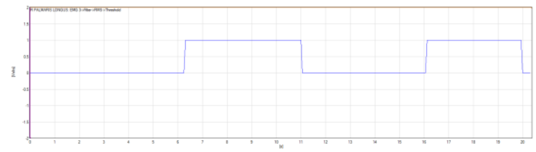
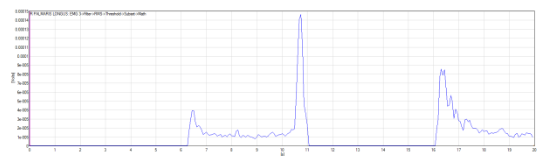
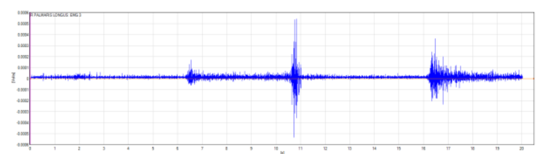
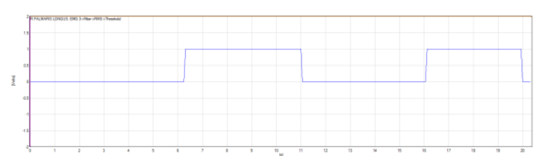
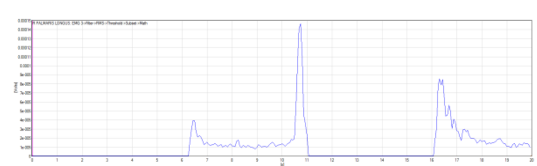
Bessel	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Chebyshev	 Raw signal  Filtered and RMS signal  Threshold signal

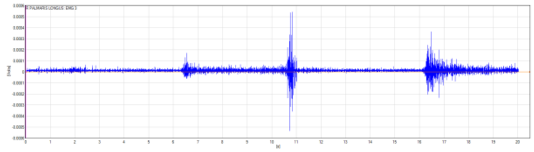
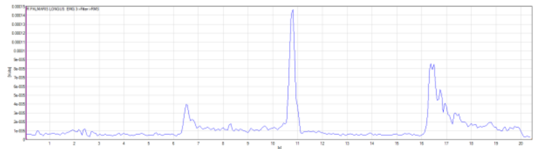
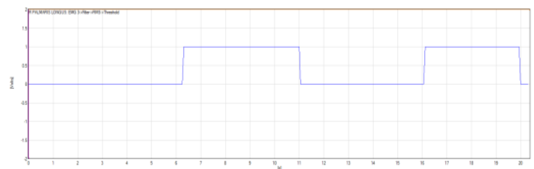
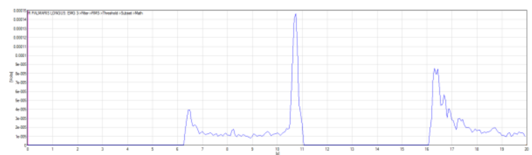
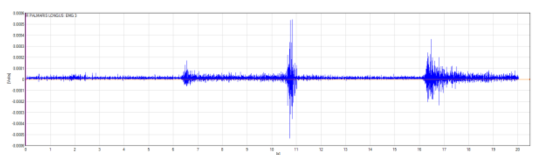
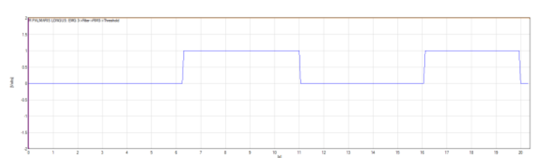
	 Muscle activation
Elliptic	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation

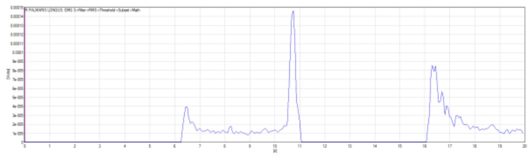
(b) Hand open and hand close

Table 23: Test Subject 5 simulation figures for hand open and hand close

Types of filter	EMG Simulations Figure
Butterworth	 Raw signal

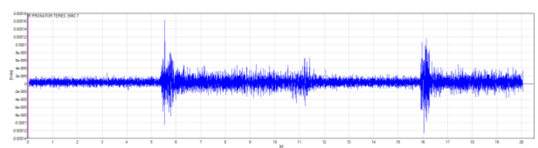
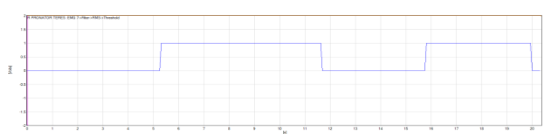
	 Filtered and RMS signal  Threshold signal  Muscle activation
Bessel	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation

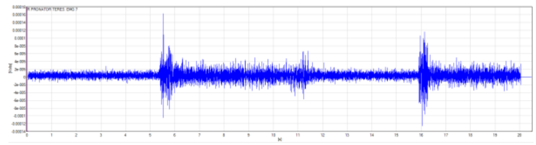
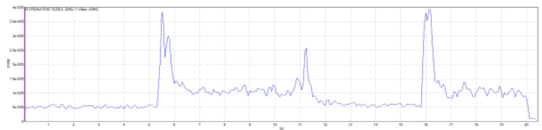
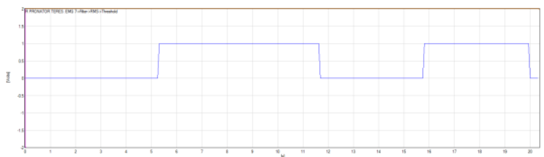
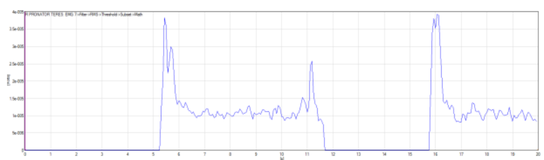
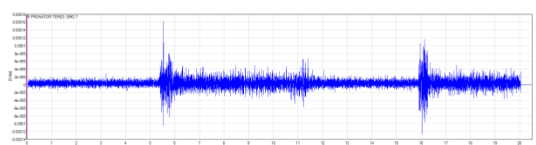
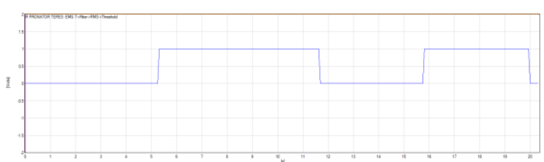
Chebyshev	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Elliptic	 Raw signal  Filtered and RMS signal  Threshold signal

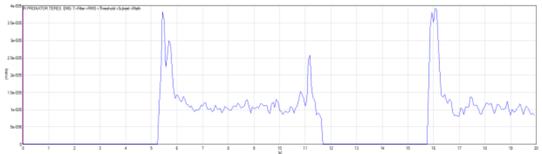
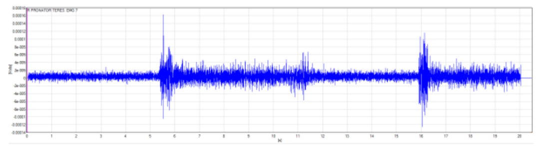
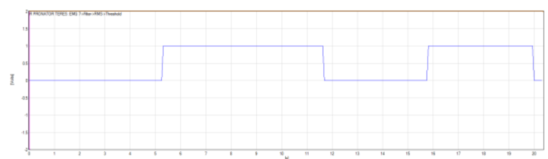
	 Muscle activation

(c) Forearm supination and forearm pronation

Table 24: Test Subject 5 simulation figures for forearm supination and forearm pronation

Types of filter	EMG Simulations Figure
Butterworth	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation

Bessel	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Chebyshev	 Raw signal  Filtered and RMS signal  Threshold signal

	 Muscle activation
Elliptic	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation

4.1.1.6 Test Subject 6

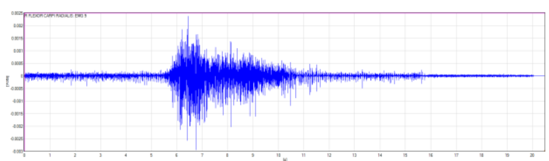
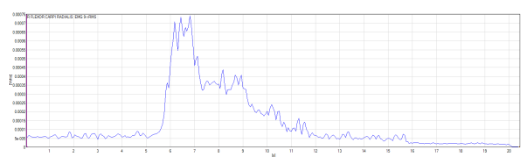
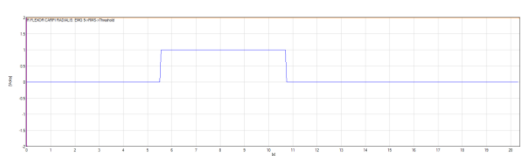
Table 25 below was the details of test subject 6. Table 26, 27 and 28 was shown the EMG simulation for test subject 6.

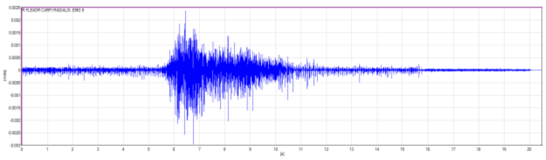
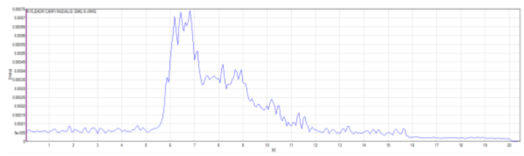
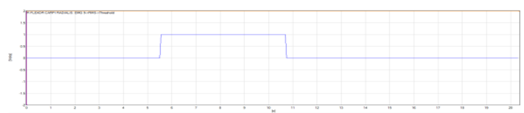
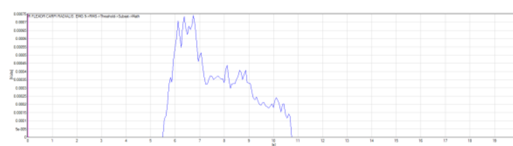
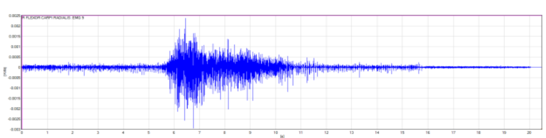
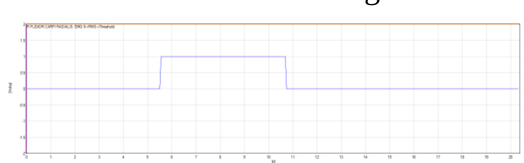
Table 25: Test Subject 6 Details

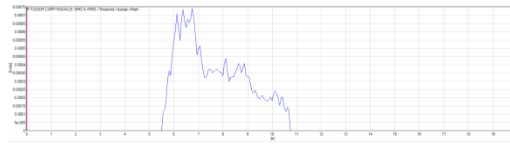
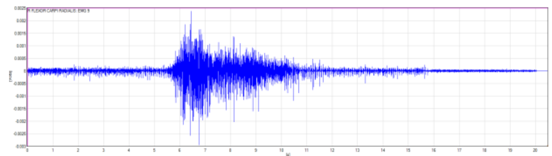
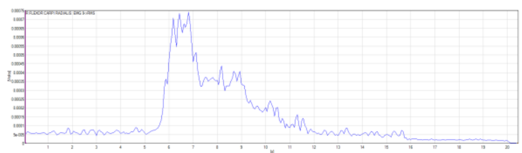
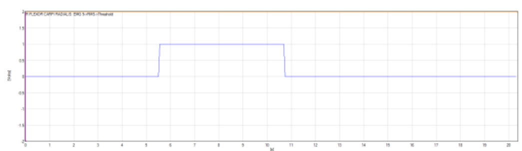
Gender	Male
Age	23 years old

(a) Wrist extension and wrist flexion

Table 26: Test Subject 6 simulation figures for wrist extension and wrist flexion

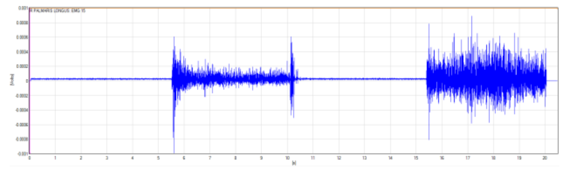
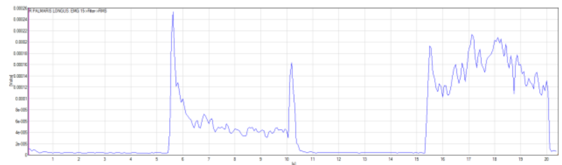
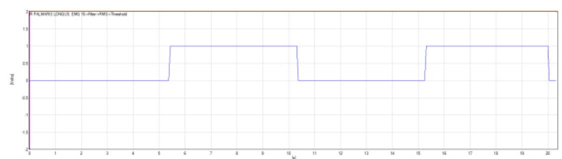
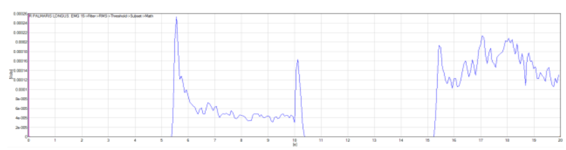
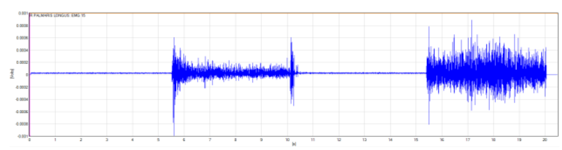
Types of filter	EMG Simulations Figure
Butterworth	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation

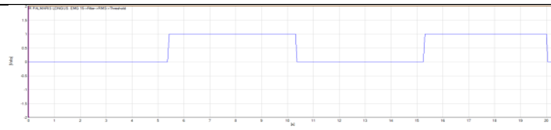
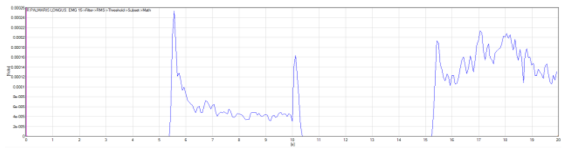
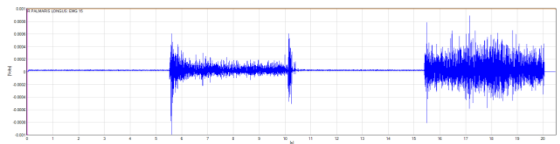
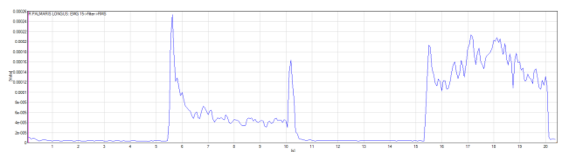
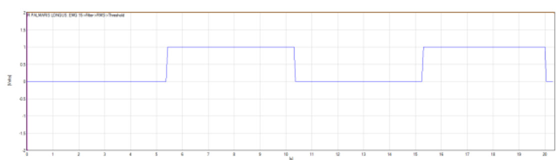
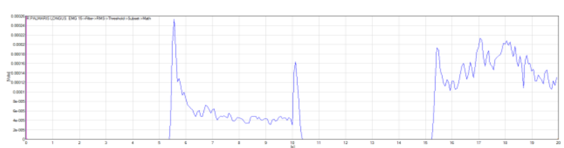
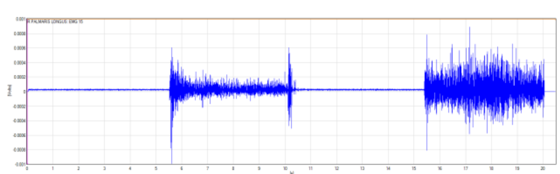
Bessel	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Chebyshev	 Raw signal  Filtered and RMS signal  Threshold signal

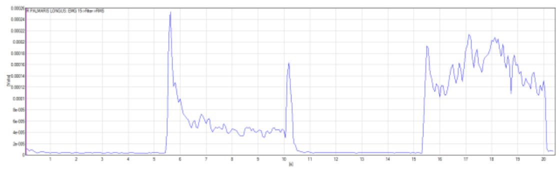
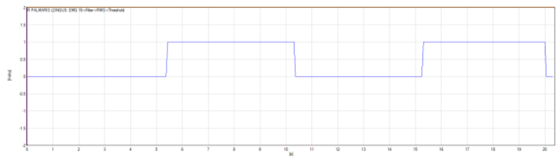
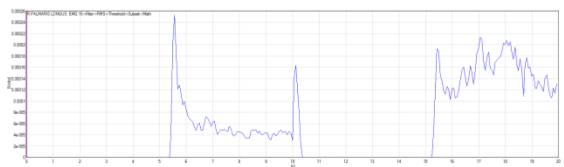
	 Muscle activation
Elliptic	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation

(b) Hand open and hand close

Table 27: Test Subject 6 simulation figures for hand open and hand close

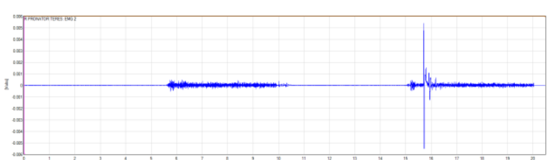
Types of filter	EMG Simulations Figure
Butterworth	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Bessel	 Raw signal  Filtered and RMS signal

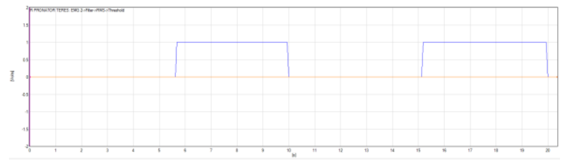
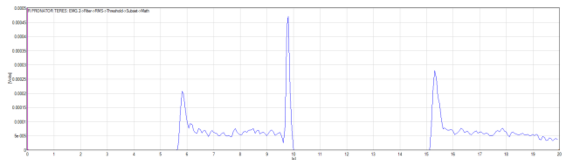
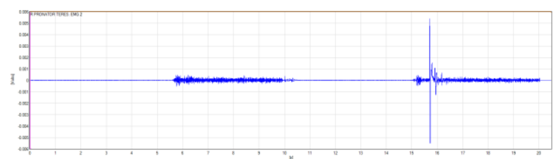
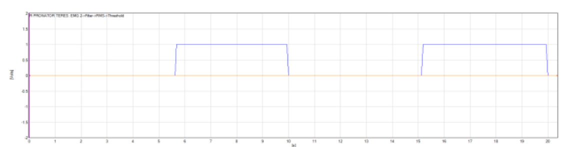
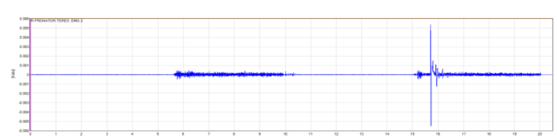
	 Threshold signal  Muscle activation
Chebyshev	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Elliptic	 Raw signal

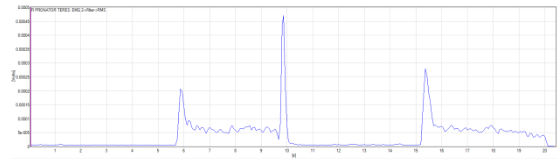
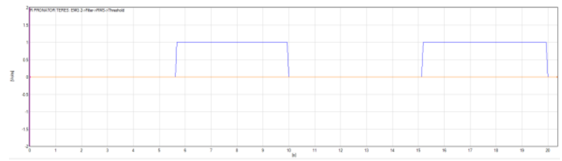
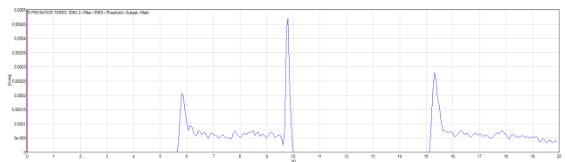
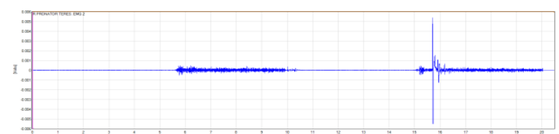
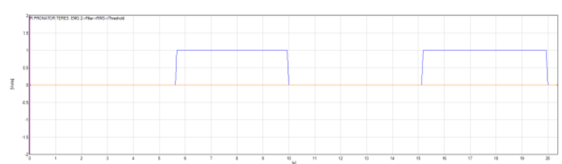
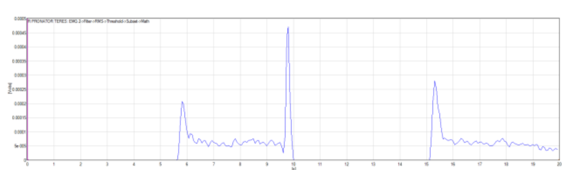
	 Filtered and RMS signal  Threshold signal  Muscle activation

(c) Forearm supination and forearm pronation

Table 28: Test Subject 6 simulation figures for forearm supination and forearm pronation

Types of filter	EMG Simulations Figure
Butterworth	 Raw signal  Filtered and RMS signal

	 Threshold signal  Muscle activation
Bessel	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Chebyshev	 Raw signal

	 Filtered and RMS signal  Threshold signal  Muscle activation
Elliptic	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation

4.1.1.7 Test Subject 7

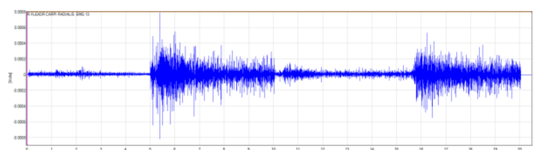
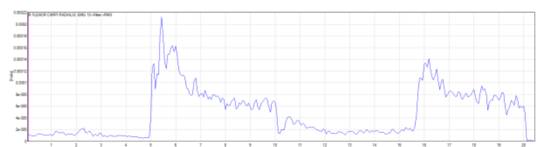
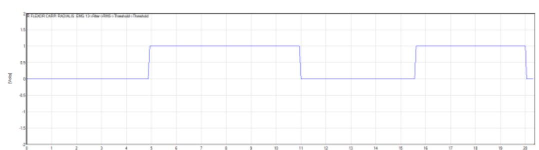
Table 29 below was the details of test subject 7. Table 30, 31 and 32 was shown the EMG simulation for test subject 7.

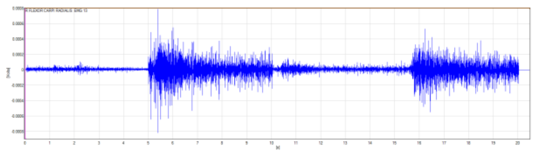
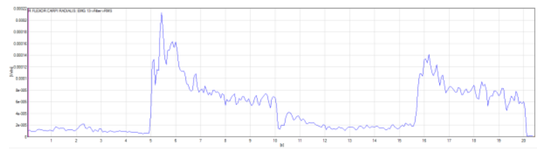
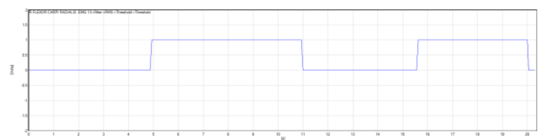
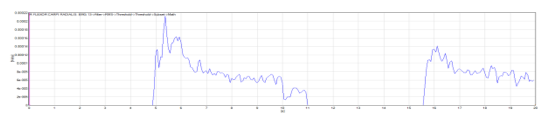
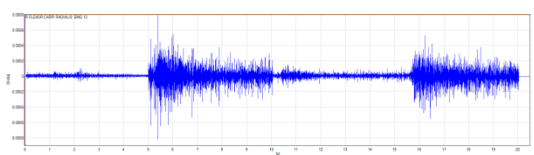
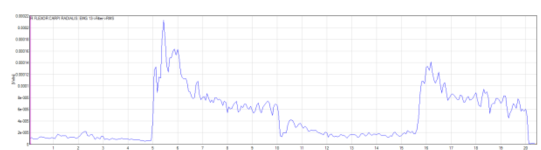
Table 29: Test Subject 7 Details

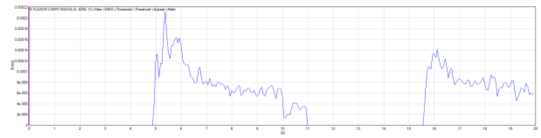
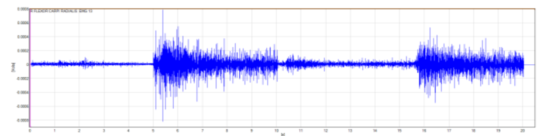
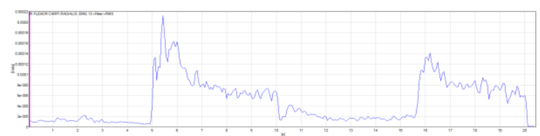
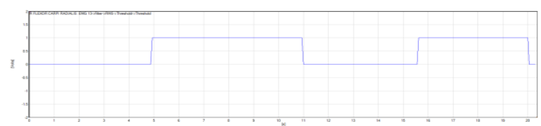
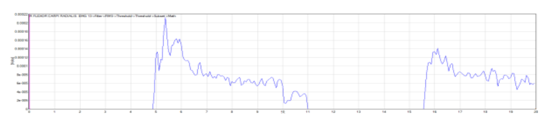
Gender	Male
Age	24 years old

(a) Wrist extension and wrist flexion

Table 30: Test Subject 7 simulation figures for wrist extension and wrist flexion

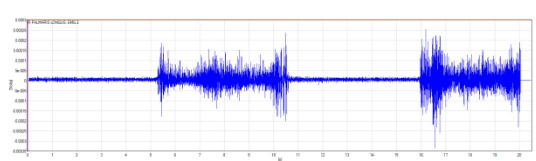
Types of filter	EMG Simulations Figure
Butterworth	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation

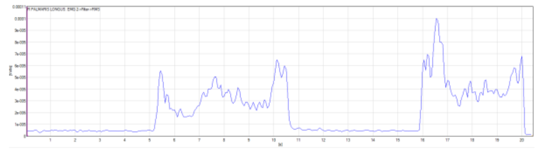
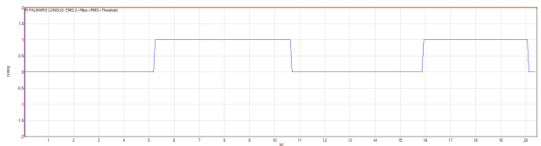
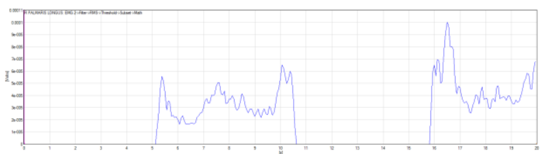
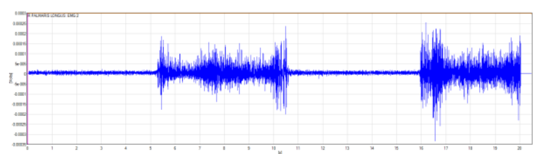
Bessel	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Chebyshev	 Raw signal  Filtered and RMS signal  Threshold signal

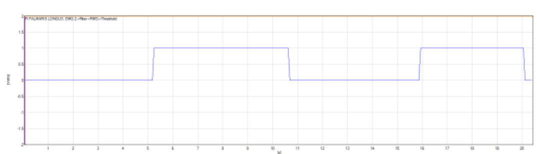
	 Muscle activation
Elliptic	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation

(b) Hand open and hand close

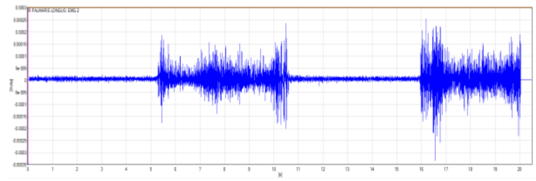
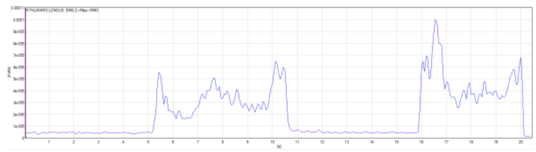
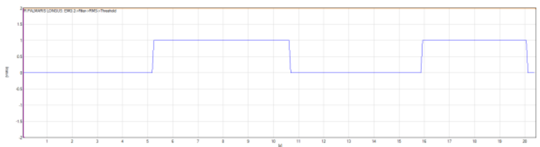
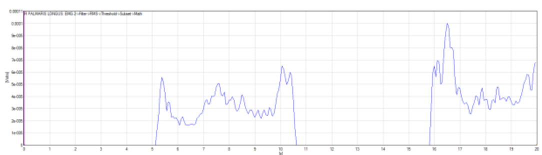
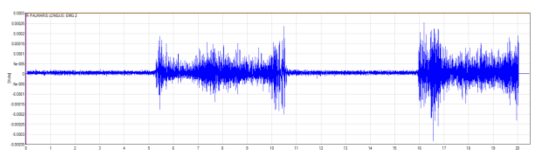
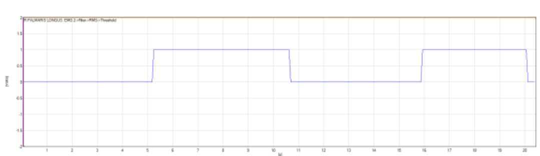
Table 31: Test Subject 7 simulation figures for hand open and hand close

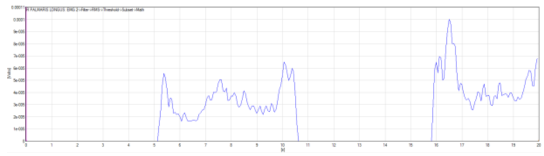
Types of filter	EMG Simulations Figure
Butterworth	 Raw signal

<table>
<tr><td></td><td>
Filtered and RMS signal

Threshold signal

Muscle activation</td></tr>
<tr><td>Bessel</td><td>
Raw signal

Filtered and RMS signal

Threshold signal

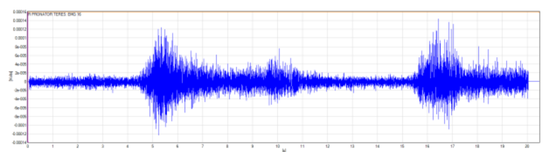
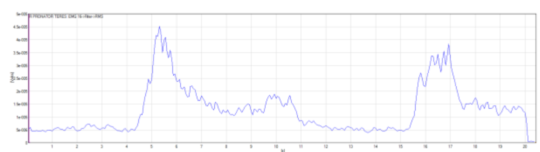
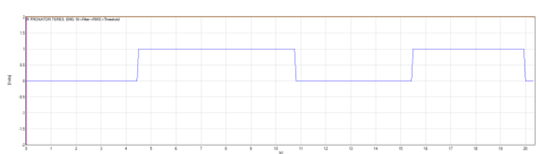
Muscle activation</td></tr>
</table>

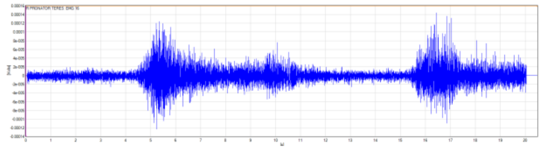
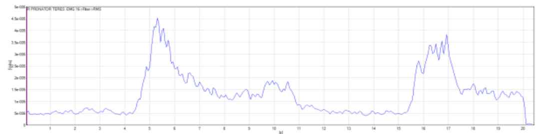
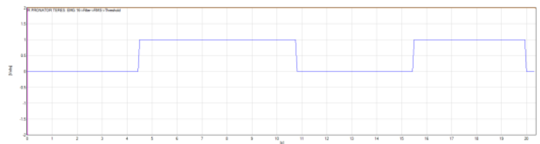
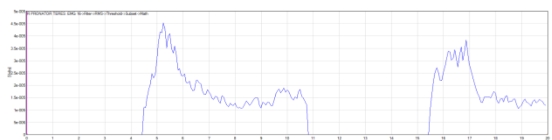
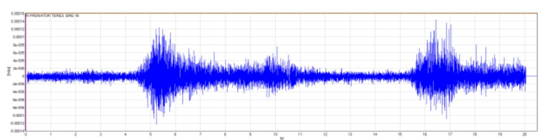
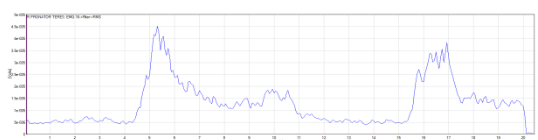
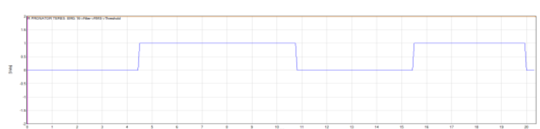
Chebyshev	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Elliptic	 Raw signal  Filtered and RMS signal  Threshold signal

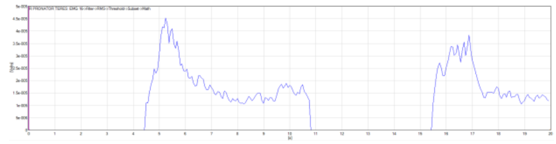
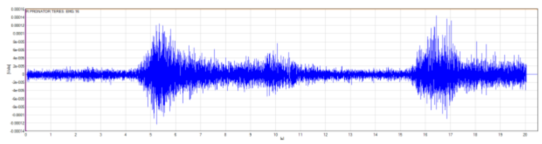
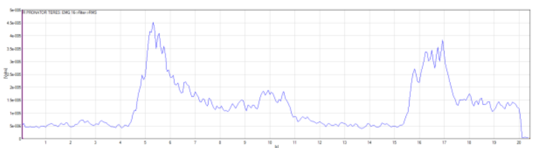
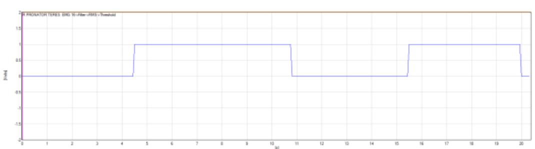
	 Muscle activation

(c) Forearm supination and forearm pronation

Table 32: Test Subject 7 simulation figures for forearm supination and forearm pronation

Types of filter	EMG Simulations Figure
Butterworth	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation

Bessel	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Chebyshev	 Raw signal  Filtered and RMS signal  Threshold signal

	 Muscle activation
Elliptic	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation

4.1.1.8 Test Subject 8

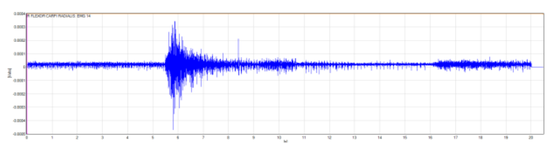
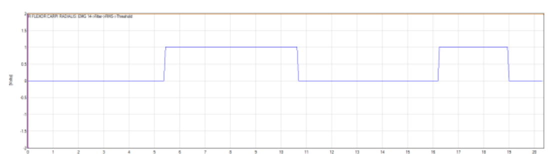
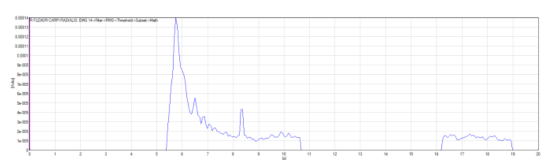
Table 33 below was the details of test subject 8. Table 34, 35 and 36 was shown the EMG simulation for test subject 8.

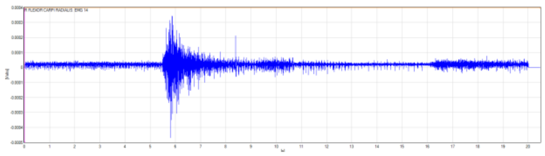
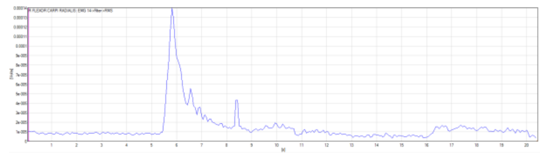
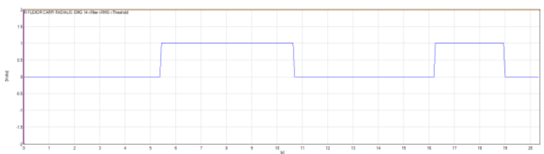
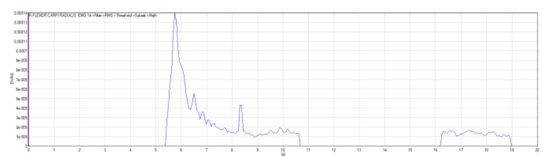
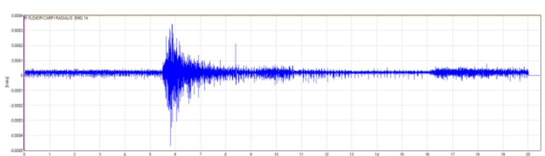
Table 33: Test Subject 8 Details

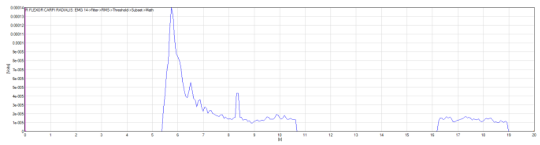
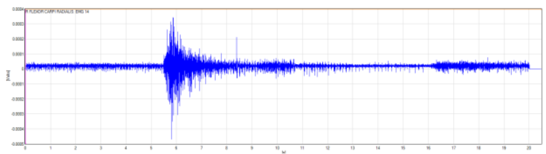
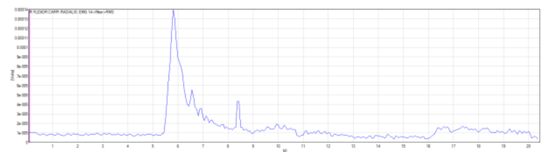
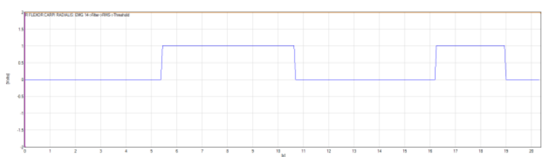
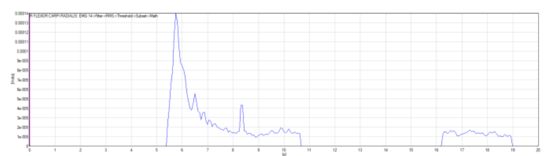
Gender	Male
Age	23 years old

(a) Wrist extension and wrist flexion

Table 34: Test Subject 8 simulation figures for wrist extension and wrist flexion

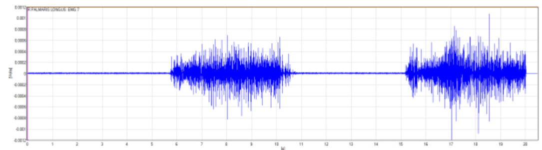
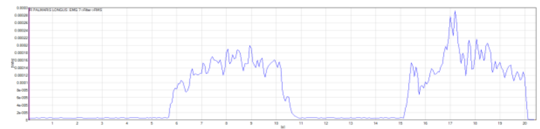
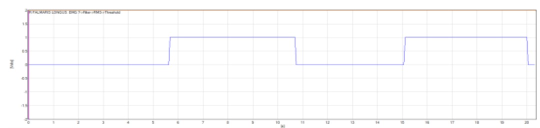
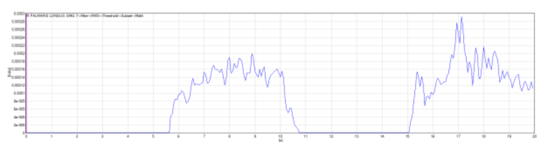
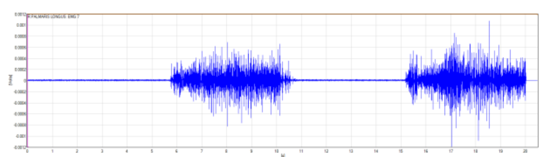
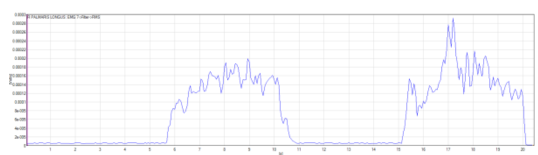
Types of filter	EMG Simulations Figure
Butterworth	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation

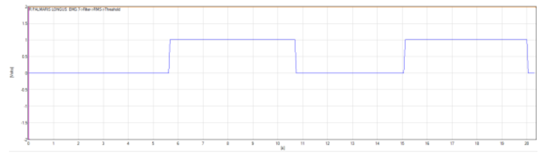
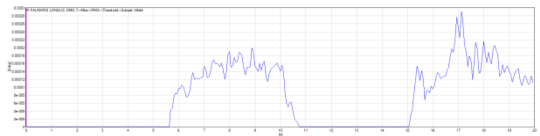
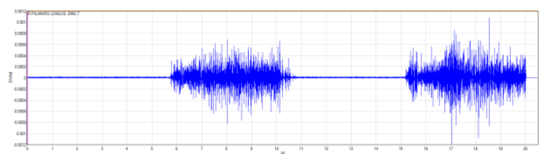
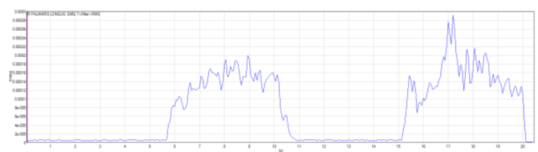
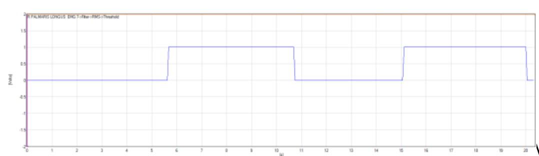
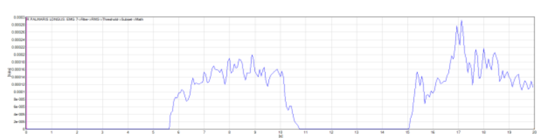
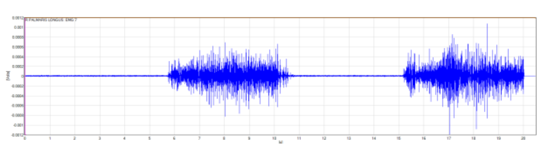
Bessel	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Chebyshev	 Raw signal  Filtered and RMS signal  Threshold signal

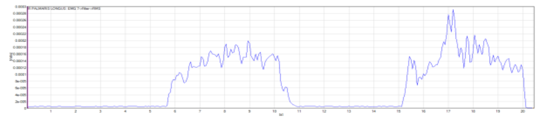
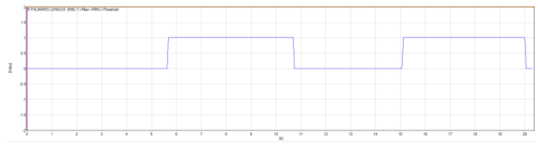
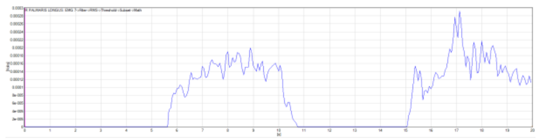
	 Muscle activation
Elliptic	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation

(b) Hand open and hand close

Table 35: Test Subject 8 simulation figures for hand open and hand close

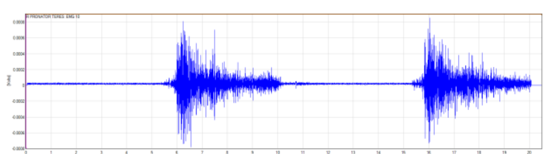
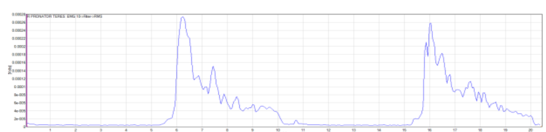
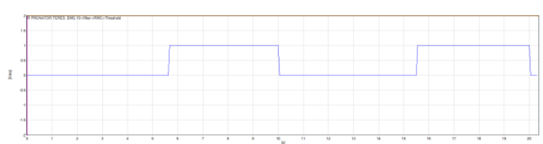
Types of filter	EMG Simulations Figure
Butterworth	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Bessel	 Raw signal  Filtered and RMS signal

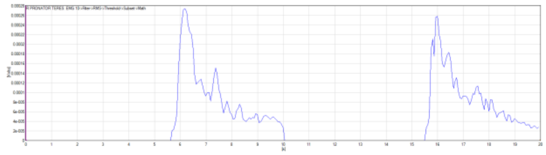
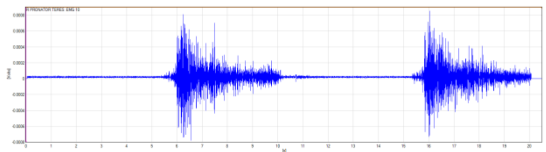
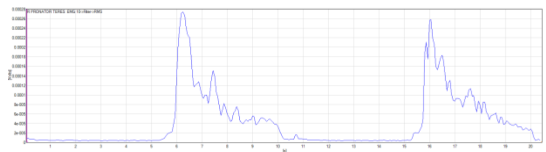
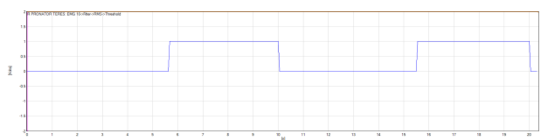
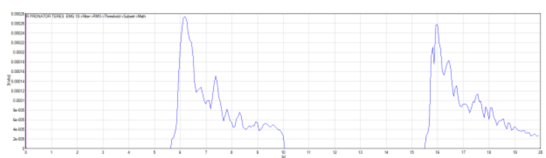
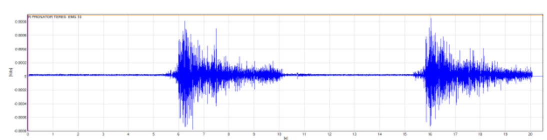
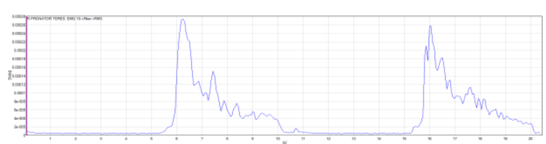
	 Threshold signal  Muscle activation
Chebyshev	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Elliptic	 Raw signal

	 Filtered and RMS signal  Threshold signal  Muscle activation

(c) Forearm supination and forearm pronation

Table 36: Test Subject 8 simulation figures for forearm supination and forearm pronation

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

	 Muscle activation
Bessel	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation
Chebyshev	 Raw signal  Filtered and RMS signal

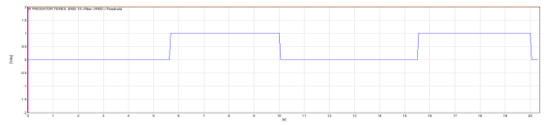
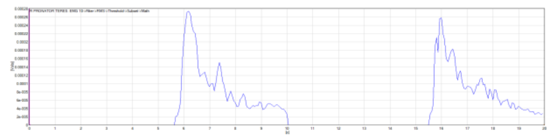
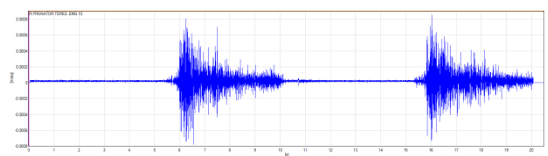
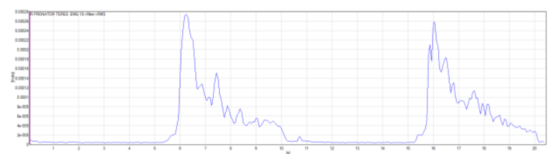
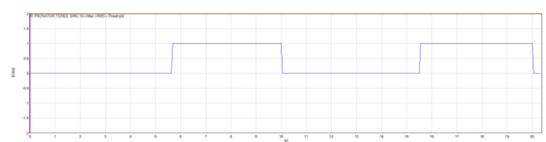
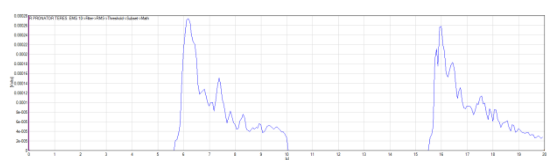
	 Threshold signal  Muscle activation
Elliptic	 Raw signal  Filtered and RMS signal  Threshold signal  Muscle activation

Table 6 until 36 showed the tabulated data and graphical result for test subject 1 until 8. The tabulated data and graphical result represent samples of muscle raw signal detected by the Delsys sensor for wrist flexion and extension (WFWE), hand open hand close (HOHC) and forearm supination and pronation (FSFP). The data were from eight healthy test subject with age range from 20 until 25 years old. The signal were recorded for 20 seconds and it is filtered using four different filters with a band pass filter at 1Hz to 500 Hz to allow higher and lower frequency. The recorded data were set at the same order (N) to facilitate comparison across samples. The resultant for function was variable for every test subject due to the skin thickness, noise artifacts and muscle strength. The comparison between female subject and male subject had been made for each functions to achieve the main objective of this experiment. The comparison was using mean and standard deviation (SD) as the measurement index.

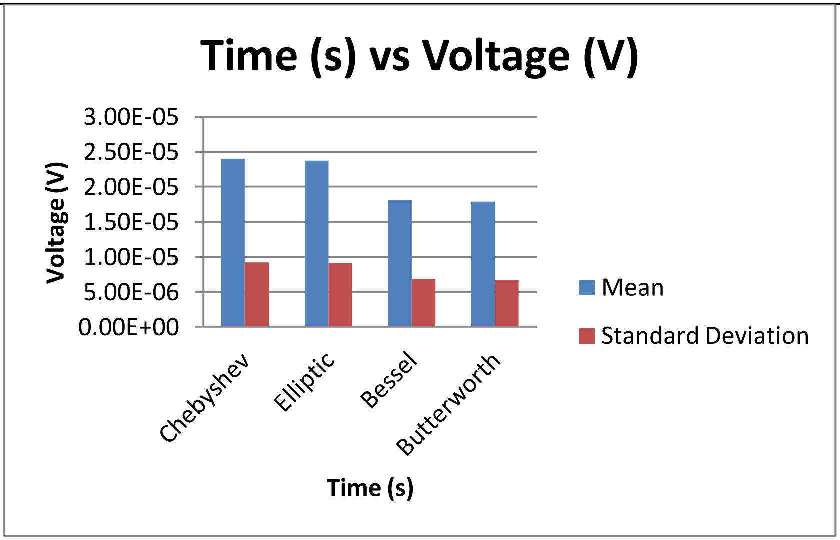
4.1.2 Analysis of EMG simulations for female subject

4.1.2.1 Tabulated data and graphical result

Table 37, 38 and 39 demonstrated the tabulated data and graphical result for test subject 1 until test subject 3.

(a) Test Subject 1

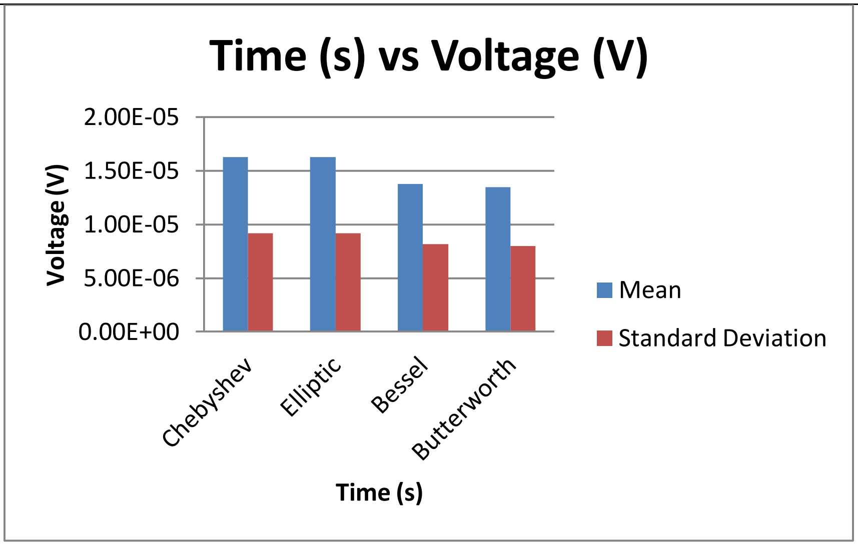
Table 37: Tabulated Data and Graphical Result for test subject 1

<table>
<tr><th>Movement</th><th>Tabulated Data</th><th>Graphical Result</th></tr>
<tr><td>Wrist flexion & Wrist extension</td><td>
<table>
<tr><th>Filter</th><th>Mean</th><th>Standard Deviation</th></tr>
<tr><td>Chebyshev</td><td>2.40E-05</td><td>9.24E-06</td></tr>
<tr><td>Elliptic</td><td>2.37E-05</td><td>9.15E-06</td></tr>
<tr><td>Bessel</td><td>1.81E-05</td><td>6.84E-06</td></tr>
<tr><td>Butterworth</td><td>1.79E-05</td><td>6.69E-06</td></tr>
</table>
</td><td>


</td></tr>
</table>

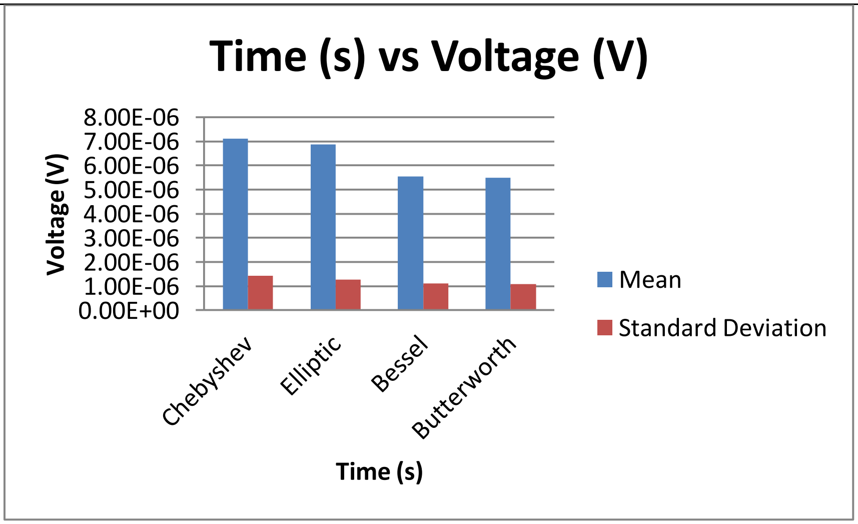
Hand open & Hand close

Filter	Mean	Standard Deviation
Chebyshev	1.63E-05	9.15E-06
Elliptic	1.63E-05	9.15E-06
Bessel	1.37E-05	8.17E-06
Butterworth	1.35E-05	7.98E-06



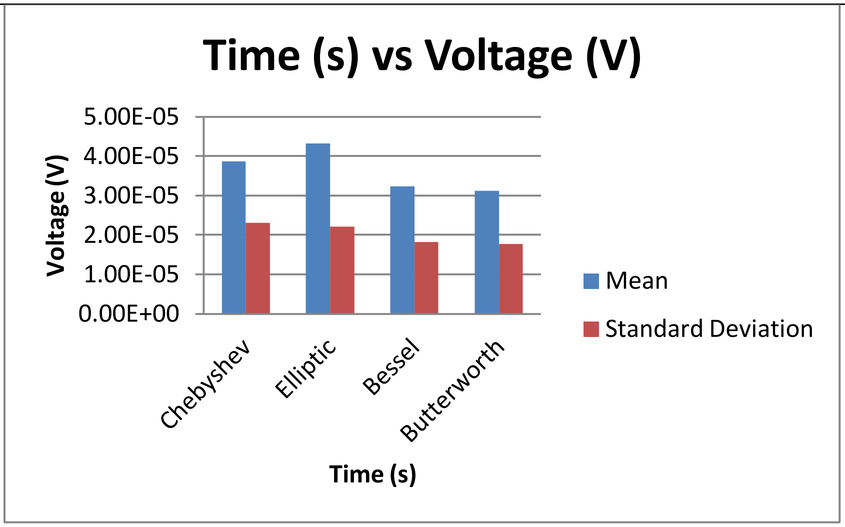
Forearm supination & forearm pronation

Filter	Mean	Standard Deviation
Chebyshev	7.11E-06	1.42E-06
Elliptic	6.88E-06	1.28E-06
Bessel	5.55E-06	1.10E-06
Butterworth	5.49E-06	1.08E-06



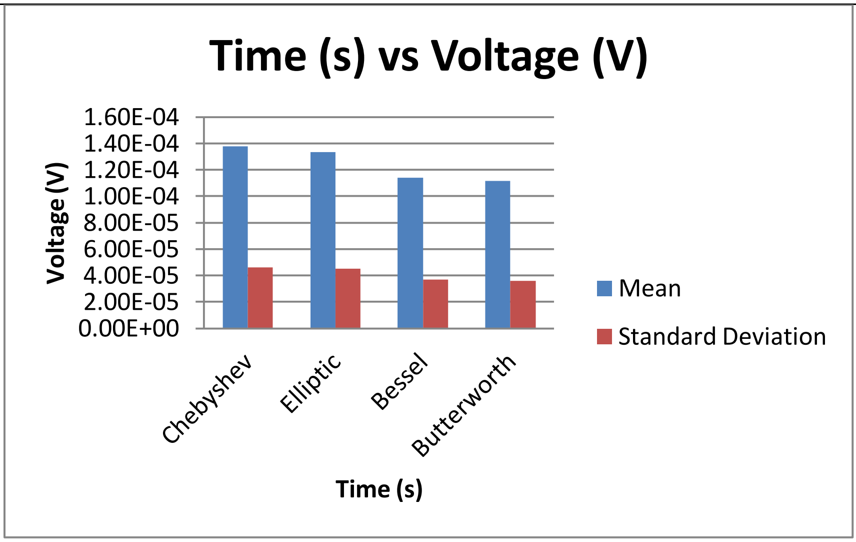
(b) Test Subject 2

Table 38: Tabulated Data and Graphical Result for test subject 2

Movement	Tabulated Data			Graphical Result
	Filter	Mean	Standard Deviation	
Wrist flexion & Wrist extension	Chebyshev	3.87E-05	2.31E-05	
	Elliptic	4.32E-05	2.21E-05	
	Bessel	3.24E-05	1.83E-05	
	Butterworth	3.13E-05	1.77E-05	

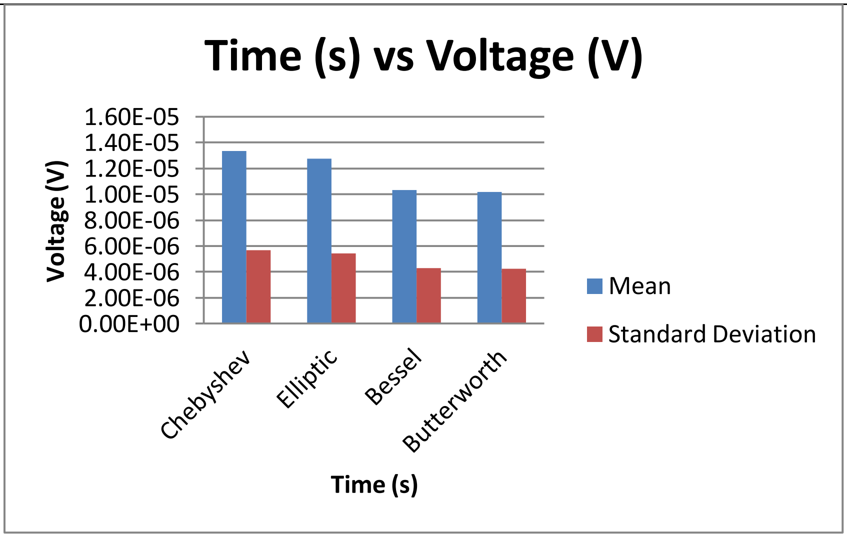
Hand open & Hand close

Filter	Mean	Standard Deviation
Chebyshev	1.38E-04	4.62E-05
Elliptic	1.33E-04	4.50E-05
Bessel	1.14E-04	3.68E-05
Butterworth	1.11E-04	3.59E-05



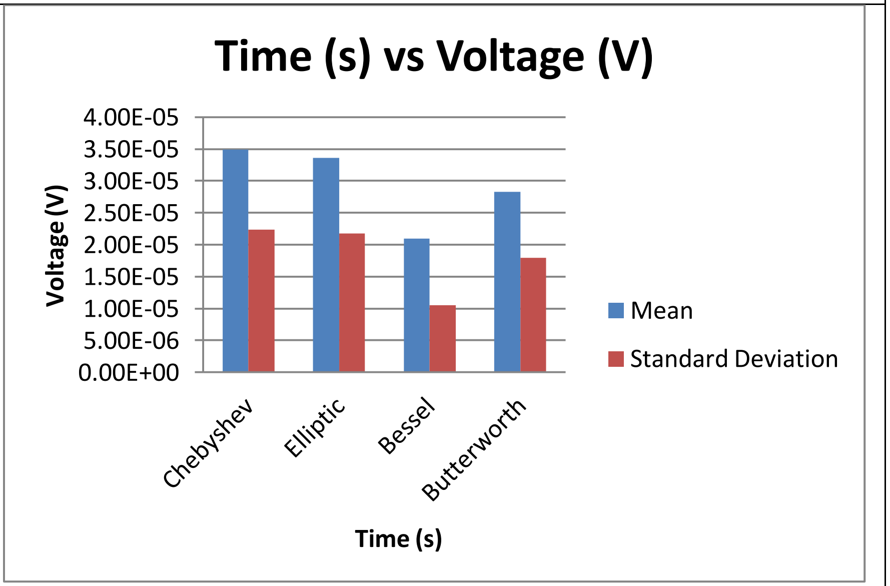
Forearm supination & forearm pronation

Filter	Mean	Standard Deviation
Chebyshev	1.33E-05	5.66E-06
Elliptic	1.28E-05	5.45E-06
Bessel	1.03E-05	4.30E-06
Butterworth	1.02E-05	4.23E-06



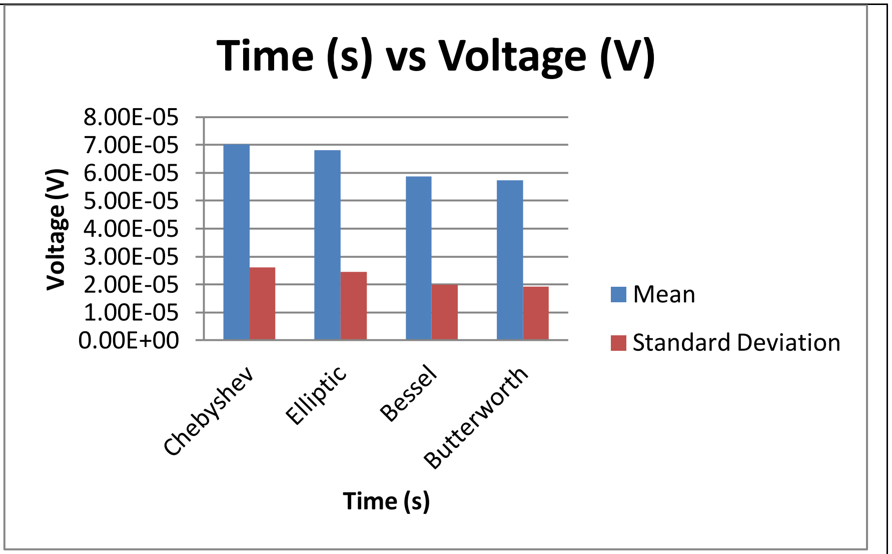
(c) Test Subject 3

Table 39: Tabulated Data and Graphical Result for test subject 3

<table>
<tr><th>Movement</th><th>Tabulated Data</th><th>Graphical Result</th></tr>
<tr><td>Wrist flexion & Wrist extension</td><td>
<table>
<tr><th>Filter</th><th>Mean</th><th>Standard Deviation</th></tr>
<tr><td>Chebyshev</td><td>3.49E-05</td><td>2.24E-05</td></tr>
<tr><td>Elliptic</td><td>3.36E-05</td><td>2.18E-05</td></tr>
<tr><td>Bessel</td><td>2.09E-05</td><td>1.06E-05</td></tr>
<tr><td>Butterworth</td><td>2.83E-05</td><td>1.80E-05</td></tr>
</table>
</td><td>
</td></tr>
</table>

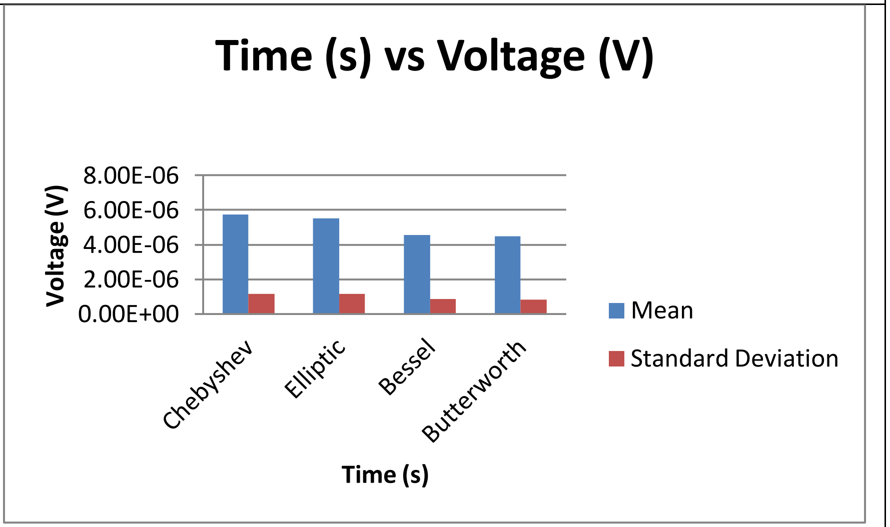
Hand open & Hand close

Filter	Mean	Standard Deviation
Chebyshev	7.03E-05	2.62E-05
Elliptic	6.82E-05	2.45E-05
Bessel	5.88E-05	1.99E-05
Butterworth	5.72E-05	1.93E-05



Forearm supination & forearm pronation

Filter	Mean	Standard Deviation
Chebyshev	5.75E-06	1.14E-06
Elliptic	5.51E-06	1.14E-06
Bessel	4.54E-06	8.40E-07
Butterworth	4.49E-06	8.27E-07



4.1.2.2 Comparison of muscle movement between female subjects

The comparison between female subjects was illustrated in Table 40, 41 and 42.

(a) Wrist extension and wrist flexion

Table 40: Comparison between TS1, TS2 and TS3 for wrist extension and wrist flexion movement

Filter	Test Subject 1 (TS1)		Test Subject 2 (TS2)		Test Subject 3 (TS3)	
	Mean	SD	Mean	SD	Mean	SD
Chebyshev	2.40E-05	9.24E-06	1.33E-05	5.18E-06	3.49E-05	2.24E-05
Elliptic	2.37E-05	9.15E-06	1.27E-05	5.33E-06	3.36E-05	2.18E-05
Bessel	1.81E-05	6.84E-06	1.05E-05	4.39E-06	2.89E-05	1.86E-05
Butterworth	1.79E-05	6.69E-06	1.04E-05	4.08E-06	2.83E-05	1.80E-05

(b) Hand open and hand close

Table 41: Comparison between TS1, TS2 and TS3 for hand open and hand close movement

Filter	Test Subject 1 (TS1)		Test Subject 2 (TS2)		Test Subject 3 (TS3)	
	Mean	SD	Mean	SD	Mean	SD
Chebyshev	1.63E-05	9.15E-06	3.67E-05	2.18E-05	7.03E-05	2.62E-05
Elliptic	1.63E-05	9.15E-06	3.57E-05	2.14E-05	6.82E-05	2.45E-05
Bessel	1.37E-05	8.17E-06	2.91E-05	1.67E-05	5.88E-05	1.99E-05
Butterworth	1.35E-05	7.98E-06	2.86E-05	1.64E-05	5.72E-05	1.93E-05

(c) Forearm supination and forearm pronation

Table 42: Comparison between TS1, TS2 and TS3 for forearm supination and forearm pronation

Filter	Test Subject 1 (TS1)		Test Subject 2 (TS2)		Test Subject 3 (TS3)	
	Mean	SD	Mean	SD	Mean	SD
Chebyshev	7.11E-06	1.42E-06	1.45E-05	1.05E-05	5.75E-06	1.14E-06
Elliptic	6.88E-06	1.28E-06	1.45E-05	1.05E-05	5.51E-06	1.14E-06
Bessel	5.55E-06	1.10E-06	1.21E-05	8.48E-06	4.54E-06	8.40E-07
Butterworth	5.49E-06	1.08E-06	1.17E-05	8.17E-06	4.49E-06	8.27E-07

4.1.2.3 Graphical result for female subjects in term of its functions

Figure 17, 18 and 19 showed the graphical result for female subjects in tern of its functions.

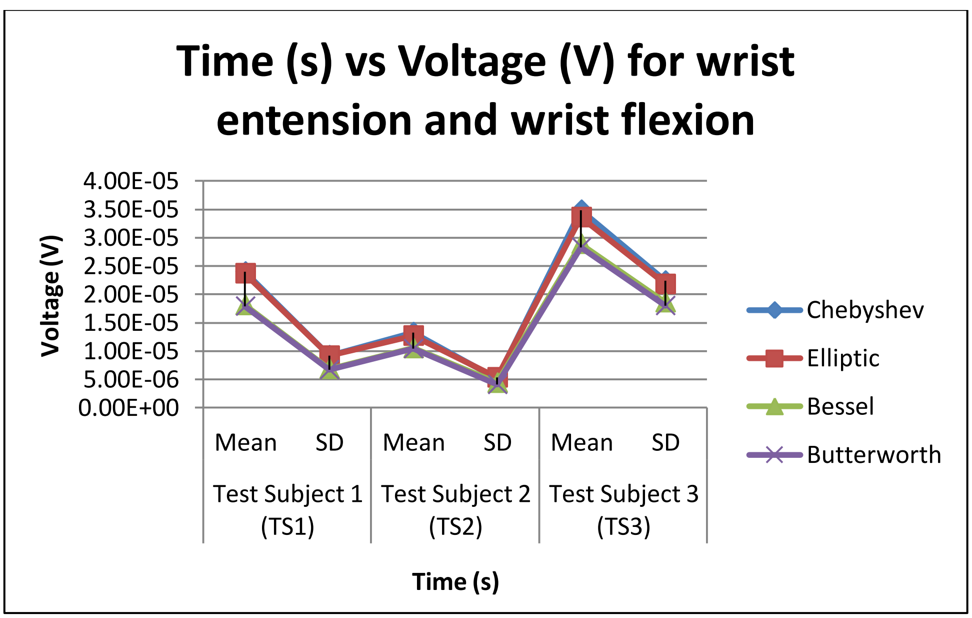


Figure 17: Graphical result for wrist extension and flexion

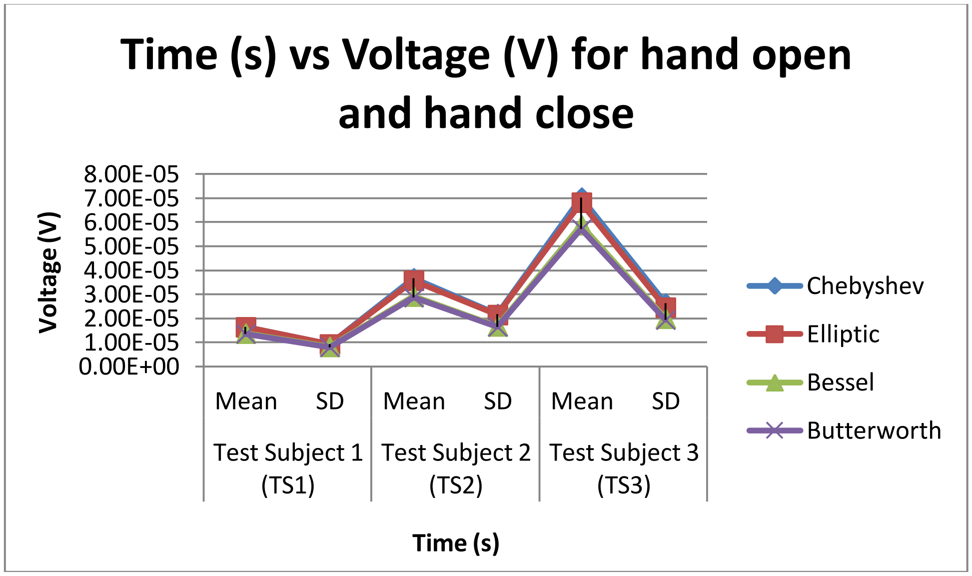


Figure 18: Graphical result for hand open and hand close

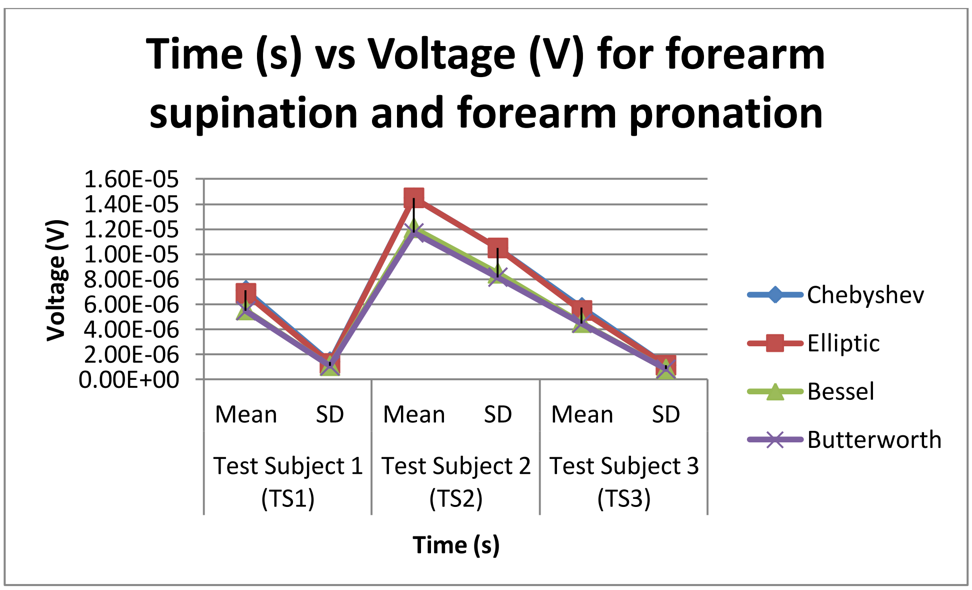


Figure 19: Graphical result for forearm supination and pronation

Descriptive statistic of female subjects in term of functions was displayed in Figure 17, 18 and 19. The statistic was showed in mean and SD as the measurement index. In general, Butterwoth and Bessel filter were found to be the best type of filter for female subject compared to Chebyshev and Elliptic filter. As can be seen from Figure 17, Butterworth filter performs the lowest SD with Test Subject 1 (6.69μV), Test Subject 2 (4.08μV) and Test Subject 3 (0.18μV). From Figure 18, the result obtained was similar as Figure 17 where Butterworth filter performed the best filter followed by Bessel, Elliptic and Chebyshev filter. Figure 19 shows that Butterworth filter and Bessel filter was the most appropriate filter with the lowest value of SD; TS1 (1.08μV), TS2 (8.17μV) and TS3 (8.27μV). Figure 17, 18 and 19 provide a similar trend where the grahical result illustrated that Butterworth and Bessel filter was the best among the other type of filter.

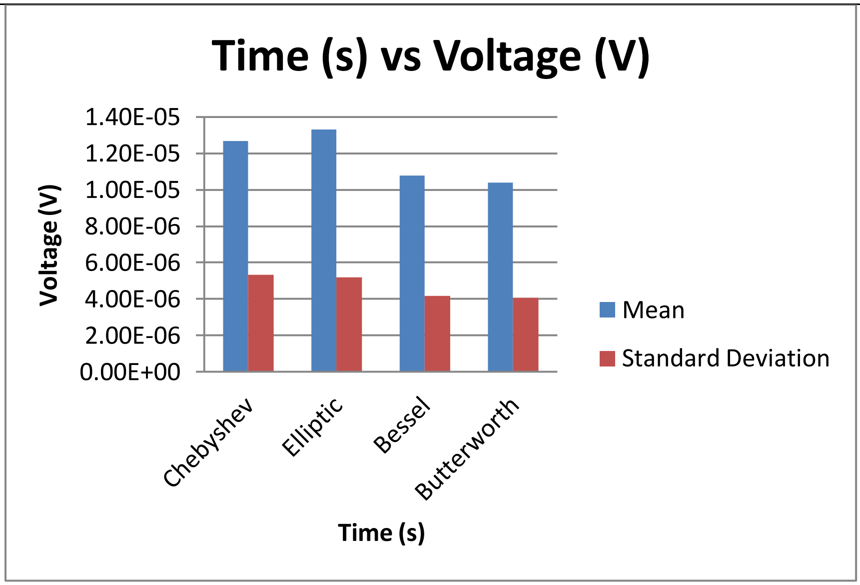
4.1.3 Analysis of EMG simulations for male subject

4.1.3.1 Tabulated data and graphical result

Table 43, 44 and 45 demonstrated the tabulated data and graphical result for test subject 4 until test subject 8.

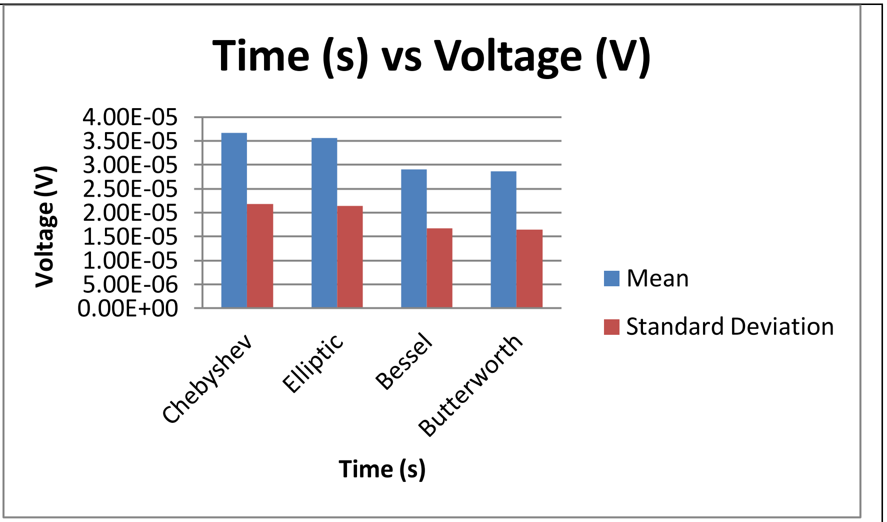
(a) Test Subject 4

Table 43: Tabulated Data and Graphical Result for test subject 4

Movement	Tabulated Data			Graphical Result
	Filter	Mean	Standard Deviation	
Wrist flexion & Wrist extension	Chebyshev	1.27E-05	5.33E-06	
	Elliptic	1.33E-05	5.18E-06	
	Bessel	1.08E-05	4.18E-06	
	Butterworth	1.04E-05	4.08E-06	

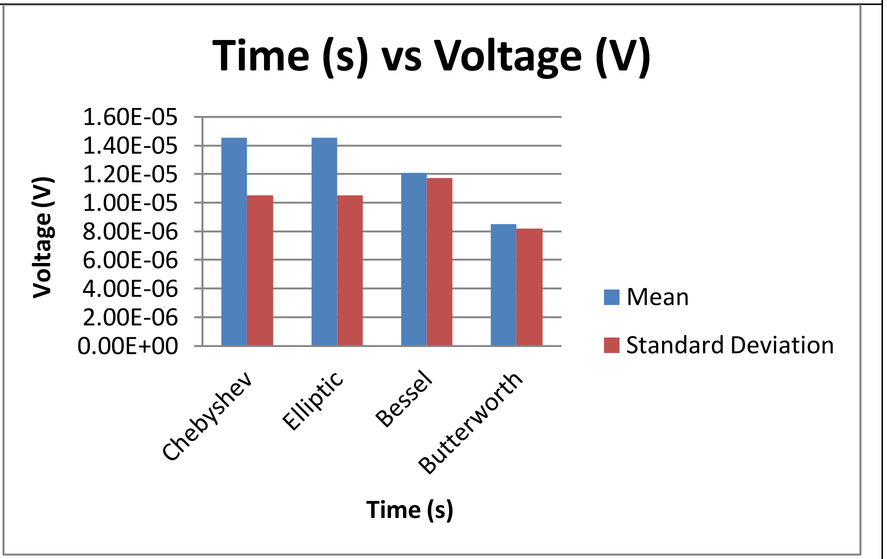
Hand open & Hand close

Filter	Mean	Standard Deviation
Chebyshev	3.67E-05	2.18E-05
Elliptic	3.57E-05	2.14E-05
Bessel	2.91E-05	1.67E-05
Butterworth	2.86E-05	1.64E-05



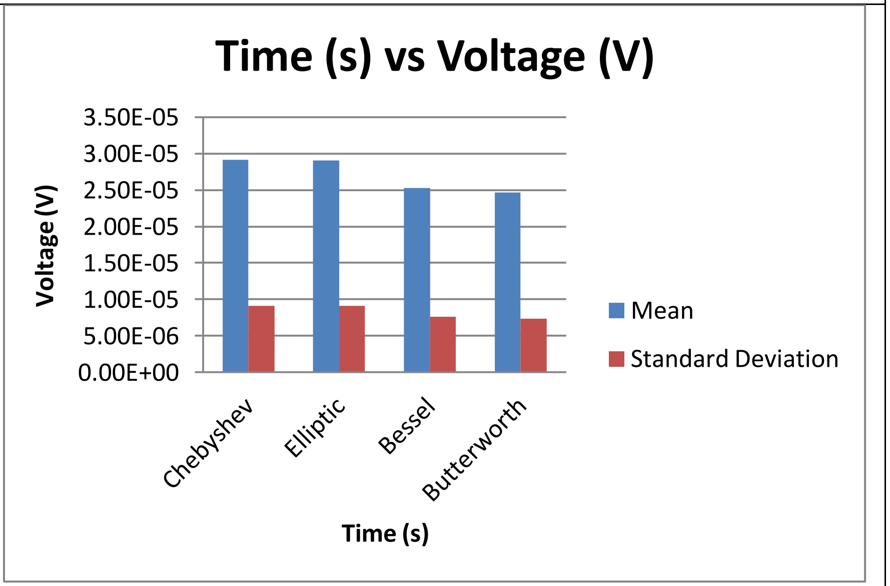
Forearm supination & forearm pronation

Filter	Mean	Standard Deviation
Chebyshev	1.45E-05	1.05E-05
Elliptic	1.45E-05	1.05E-05
Bessel	1.21E-05	1.17E-05
Butterworth	8.48E-06	8.17E-06



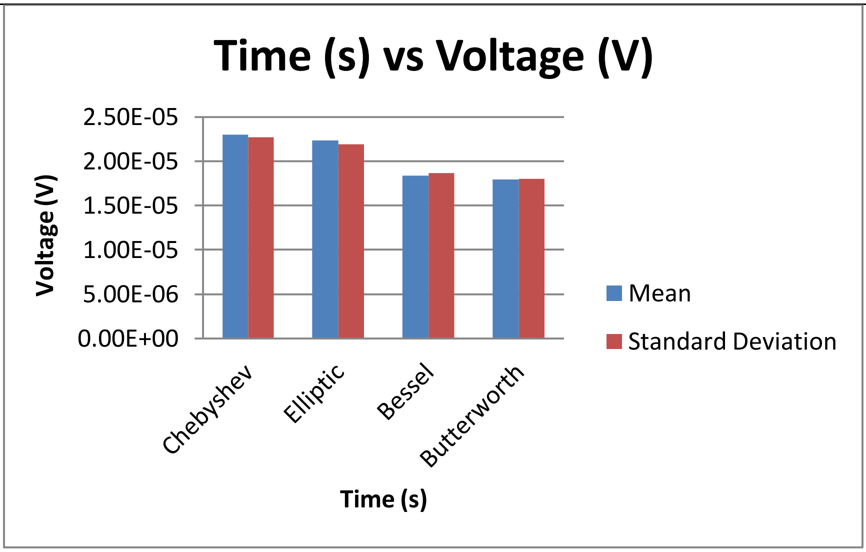
(b) Test Subject 5

Table 44: Tabulated Data and Graphical Result for test subject 5

<table>
<tr><th>Movement</th><th>Tabulated Data</th><th>Graphical Result</th></tr>
<tr><td>Wrist flexion & Wrist extension</td><td>
<table>
<tr><th>Filter</th><th>Mean</th><th>Standard Deviation</th></tr>
<tr><td>Chebyshev</td><td>2.91E-05</td><td>9.10E-06</td></tr>
<tr><td>Elliptic</td><td>2.91E-05</td><td>9.09E-06</td></tr>
<tr><td>Bessel</td><td>2.53E-05</td><td>7.58E-06</td></tr>
<tr><td>Butterworth</td><td>2.47E-05</td><td>7.35E-06</td></tr>
</table>
</td><td>
</td></tr>
</table>

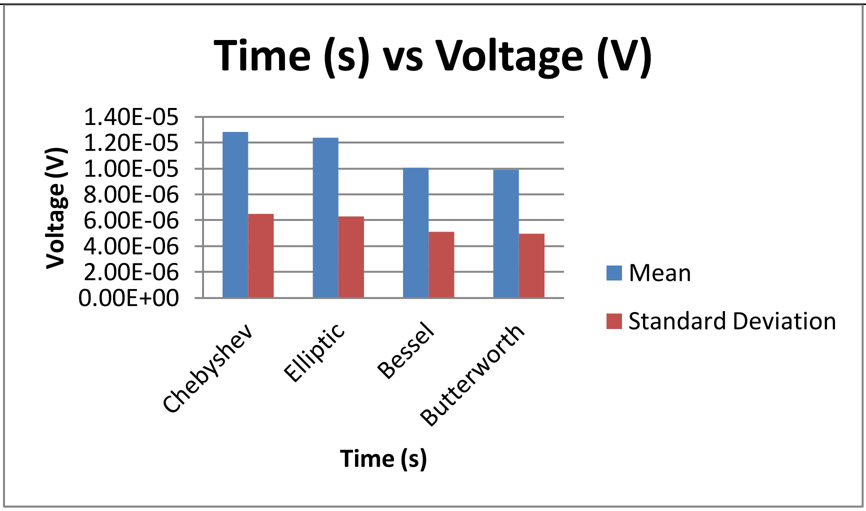
Hand open & Hand close

Filter	Mean	Standard Deviation
Chebyshev	2.30E-05	2.27E-05
Elliptic	2.24E-05	2.19E-05
Bessel	1.83E-05	1.87E-05
Butterworth	1.79E-05	1.80E-05



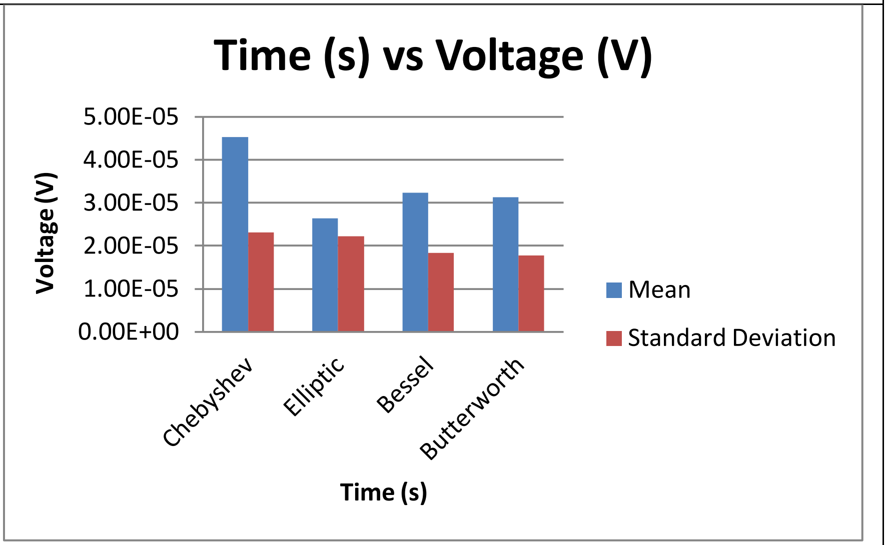
Forearm supination & forearm pronation

Filter	Mean	Standard Deviation
Chebyshev	1.28E-05	6.47E-06
Elliptic	1.24E-05	6.31E-06
Bessel	1.01E-05	5.08E-06
Butterworth	9.91E-06	4.98E-06



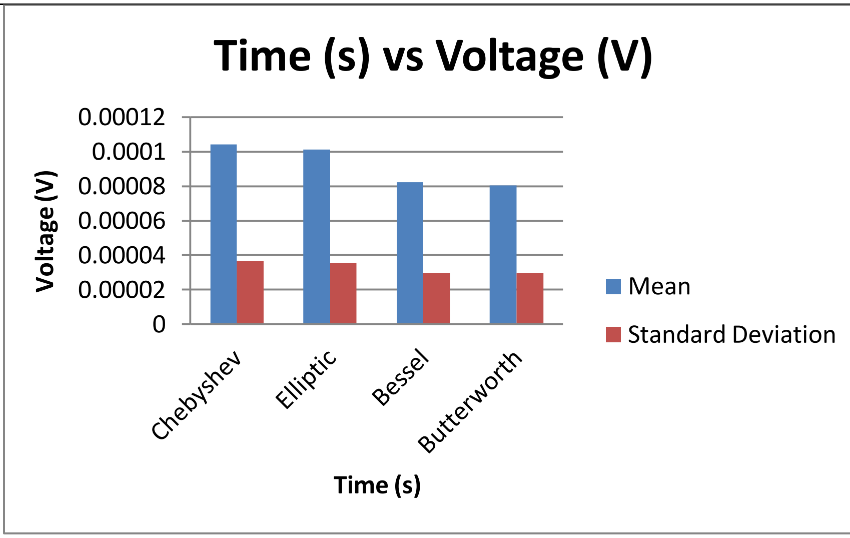
(c) Test Subject 6

Table 45: Tabulated Data and Graphical Result for test subject 6

<table>
<tr><th>Movement</th><th>Tabulated Data</th><th>Graphical Result</th></tr>
<tr><td>Wrist flexion & Wrist extension</td><td>
<table>
<tr><th>Filter</th><th>Mean</th><th>Standard Deviation</th></tr>
<tr><td>Chebyshev</td><td>4.53E-05</td><td>2.31E-05</td></tr>
<tr><td>Elliptic</td><td>2.65E-05</td><td>2.22E-05</td></tr>
<tr><td>Bessel</td><td>3.24E-05</td><td>1.83E-05</td></tr>
<tr><td>Butterworth</td><td>3.13E-05</td><td>1.77E-05</td></tr>
</table>
</td><td>
</td></tr>
</table>

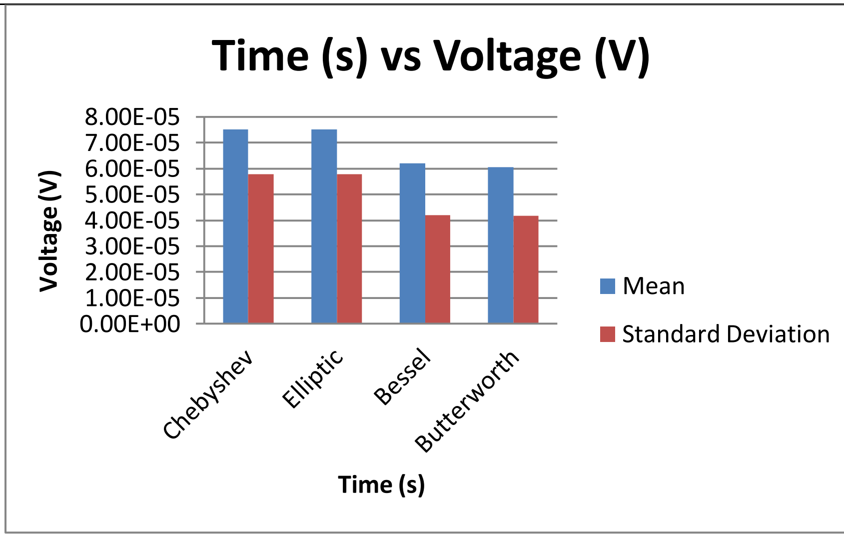
Hand open & Hand close

Filter	Mean	Standard Deviation
Chebyshev	0.000104	3.68E-05
Elliptic	0.000101	3.55E-05
Bessel	8.22E-05	2.95E-05
Butterworth	8.04E-05	2.95E-05



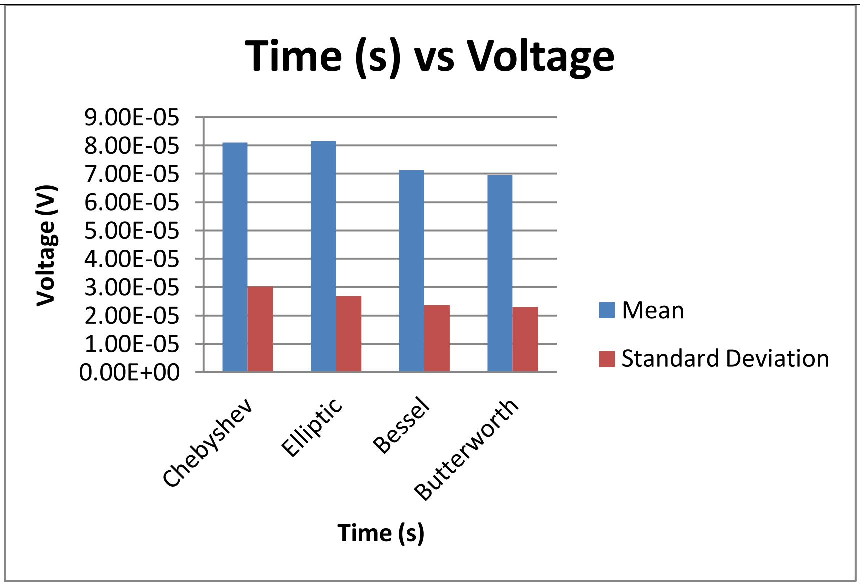
Forearm supination & forearm pronation

Filter	Mean	Standard Deviation
Chebyshev	7.51E-05	5.79E-05
Elliptic	7.51E-05	5.79E-05
Bessel	6.21E-05	4.19E-05
Butterworth	6.07E-05	4.17E-05



(d) Test Subject 7

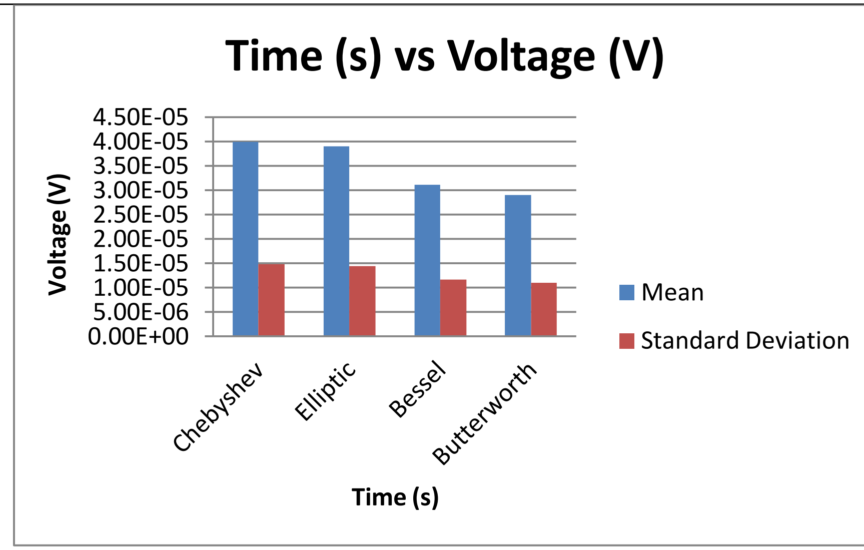
Table 46: Tabulated Data and Graphical Result for test subject 7

Movement	Tabulated Data	Graphical Result
Wrist flexion & Wrist extension	(see table below)	

Filter	Mean	Standard Deviation
Chebyshev	8.10E-05	3.01E-05
Elliptic	8.14E-05	2.68E-05
Bessel	7.14E-05	2.36E-05
Butterworth	6.96E-05	2.30E-05

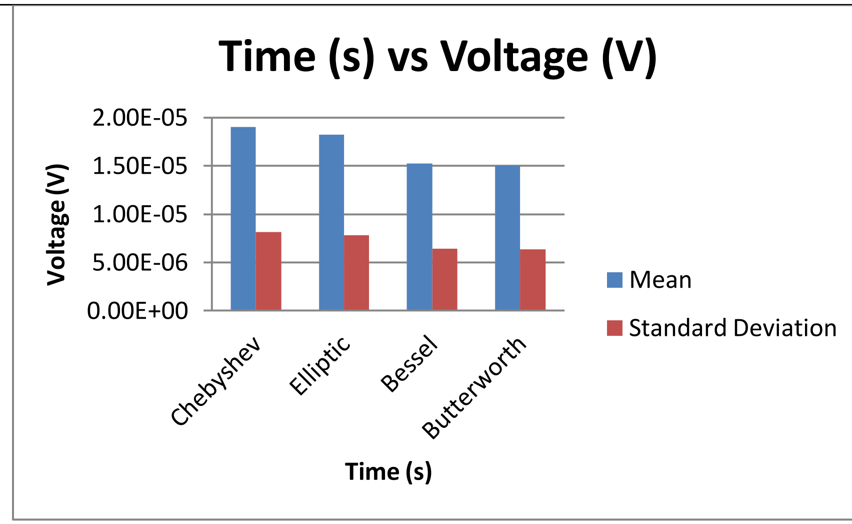
Hand open & Hand close

Filter	Mean	Standard Deviation
Chebyshev	3.99E-05	1.48E-05
Elliptic	3.90E-05	1.44E-05
Bessel	3.11E-05	1.17E-05
Butterworth	2.90E-05	1.10E-05



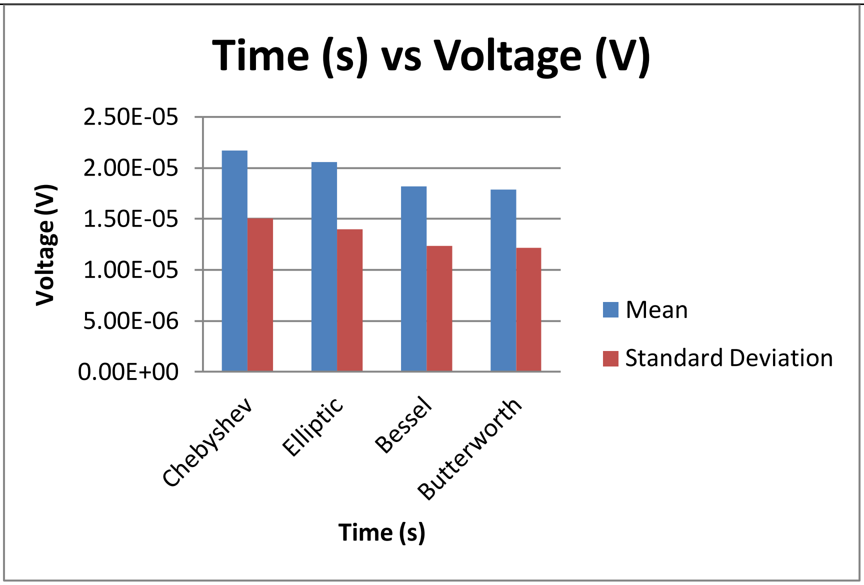
Forearm supination & forearm pronation

Filter	Mean	Standard Deviation
Chebyshev	1.90E-05	8.13E-06
Elliptic	1.82E-05	7.83E-06
Bessel	1.53E-05	6.43E-06
Butterworth	1.50E-05	6.33E-06



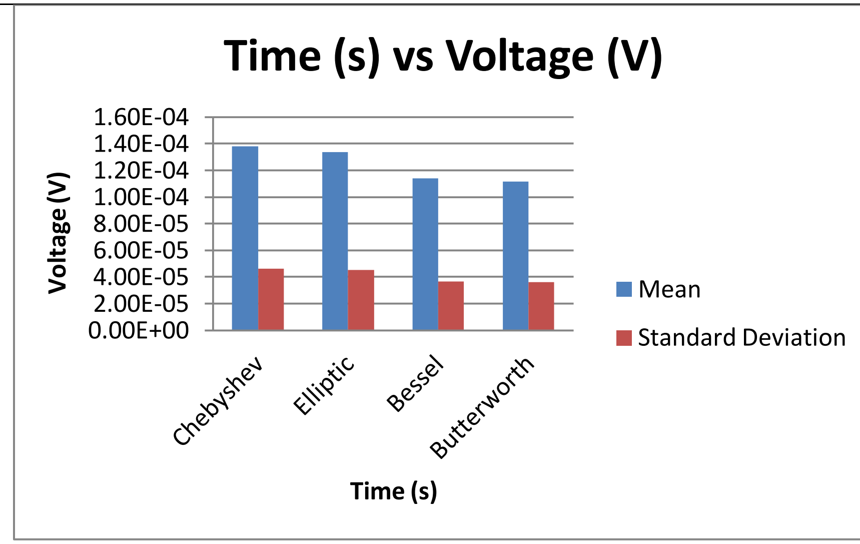
(e) Test Subject 8

Table 47: Tabulated Data and Graphical Result for test subject 8

<table>
<tr><th>Movement</th><th>Tabulated Data</th><th>Graphical Result</th></tr>
<tr><td>Wrist flexion & Wrist extension</td><td>
<table>
<tr><th>Filter</th><th>Mean</th><th>Standard Deviation</th></tr>
<tr><td>Chebyshev</td><td>2.17E-05</td><td>1.51E-05</td></tr>
<tr><td>Elliptic</td><td>2.06E-05</td><td>1.40E-05</td></tr>
<tr><td>Bessel</td><td>1.82E-05</td><td>1.24E-05</td></tr>
<tr><td>Butterworth</td><td>1.79E-05</td><td>1.22E-05</td></tr>
</table>
</td><td>
</td></tr>
</table>

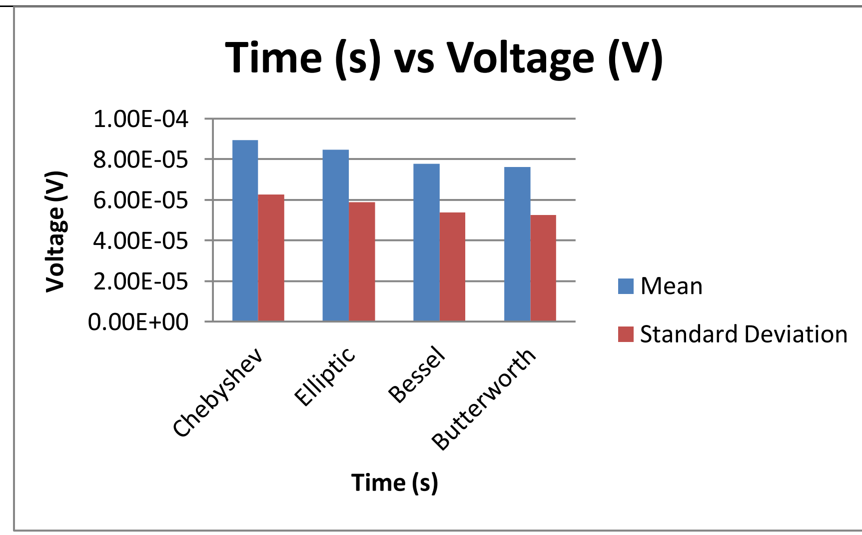
Hand open & Hand close

Filter	Mean	Standard Deviation
Chebyshev	1.38E-04	4.63E-05
Elliptic	1.33E-04	4.50E-05
Bessel	1.14E-04	3.68E-05
Butterworth	1.11E-04	3.58E-05



Forearm supination & forearm pronation

Filter	Mean	Standard Deviation
Chebyshev	8.93E-05	6.26E-05
Elliptic	8.45E-05	5.87E-05
Bessel	7.76E-05	5.87E-05
Butterworth	7.63E-05	5.25E-05



4.1.3.2 Comparison of muscle movement between male subjects

The comparison between male subjects was illustrated in Table 48 until 50.

(a) Wrist extension and wrist flexion

Table 48: Comparison between TS4, TS5, TS6, TS7 and TS8 for wrist extension and wrist flexion movement

Filter	Test Subject 4 (TS4)		Test Subject 5 (TS5)		Test Subject 6 (TS6)		Test Subject 7 (TS7)		Test Subject 8 (TS8)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Chebyshev	1.27E-05	5.33E-06	2.91E-05	9.10E-06	4.53E-05	2.31E-05	8.10E-05	3.01E-05	2.17E-05	1.51E-05
Elliptic	1.33E-05	5.18E-06	2.91E-05	9.09E-06	2.65E-05	2.22E-05	8.14E-05	2.68E-05	2.06E-05	1.40E-05
Bessel	1.08E-05	4.18E-06	2.53E-05	7.58E-06	3.24E-05	1.83E-05	7.14E-05	2.36E-05	1.82E-05	1.24E-05
Butterworth	1.04E-05	4.08E-06	2.47E-05	7.35E-06	3.13E-05	1.77E-05	6.96E-05	2.30E-05	1.79E-05	1.22E-05

(b) Hand open and hand close

Table 49: Comparison between TS4, TS5, TS6, TS7 and TS8 for hand open and hand close movement

Filter	Test Subject 4 (TS4)		Test Subject 5 (TS5)		Test Subject 6 (TS6)		Test Subject 7 (TS7)		Test Subject 8 (TS8)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Chebyshev	3.67E-05	2.18E-05	2.30E-05	2.27E-05	1.04E-04	3.68E-05	3.99E-05	1.48E-05	1.38E-04	4.63E-05
Elliptic	3.57E-05	2.14E-05	2.24E-05	2.19E-05	1.01E-04	3.55E-05	3.90E-05	1.44E-05	1.33E-04	4.50E-05
Bessel	2.91E-05	1.67E-05	1.83E-05	1.87E-05	8.22E-05	2.95E-05	3.11E-05	1.17E-05	1.14E-04	3.68E-05
Butterworth	2.86E-05	1.64E-05	1.79E-05	1.80E-05	8.04E-05	2.95E-05	2.90E-05	1.10E-05	1.11E-04	3.58E-05

(c) Forearm supination and forearm pronation

Table 50: Comparison between TS4, TS5, TS6, TS7 and TS8 for forearm supination and forearm pronation

Filter	Test Subject 4 (TS4)		Test Subject 5 (TS5)		Test Subject 6 (TS6)		Test Subject 7 (TS7)		Test Subject 8 (TS8)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Chebyshev	1.45E-05	1.05E-05	1.28E-05	6.47E-06	7.51E-05	5.79E-05	1.90E-05	8.13E-06	8.93E-05	6.26E-05
Elliptic	1.45E-05	1.05E-05	1.24E-05	6.31E-06	7.51E-05	5.79E-05	1.82E-05	7.83E-06	8.45E-05	5.87E-05
Bessel	1.21E-05	1.17E-05	1.01E-05	5.08E-06	6.21E-05	4.19E-05	1.53E-05	6.43E-06	7.76E-05	5.87E-05
Butterworth	8.48E-06	8.17E-06	9.91E-06	4.98E-06	6.07E-05	4.17E-05	1.50E-05	6.33E-06	7.63E-05	5.25E-05

4.1.3.3 Graphical result for male subjects in term of its functions

Figure 20, 21 and 22 showed the graphical result for male subjects in tern of its functions.

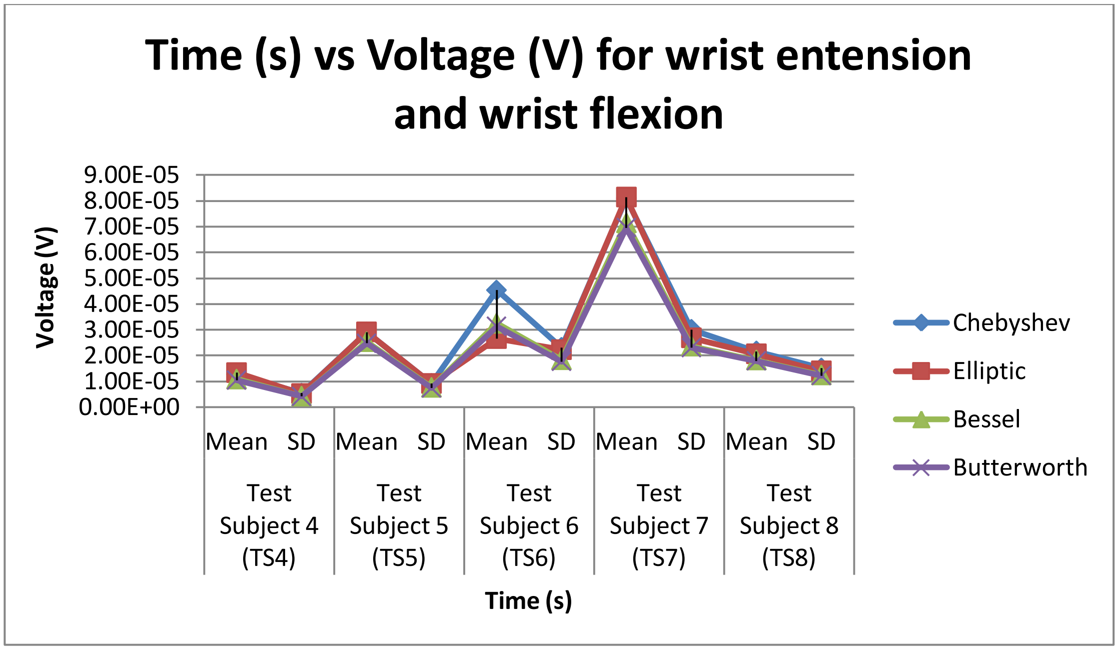


Figure 20: Graphical result for wrist extension and flexion

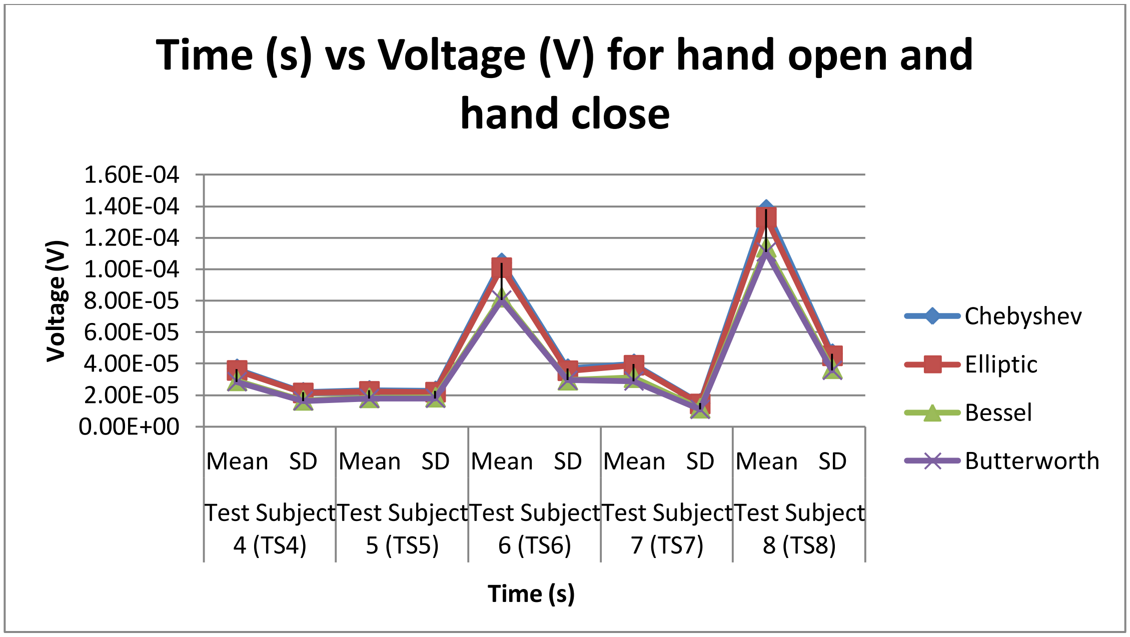


Figure 21: Graphical result for hand open and hand close

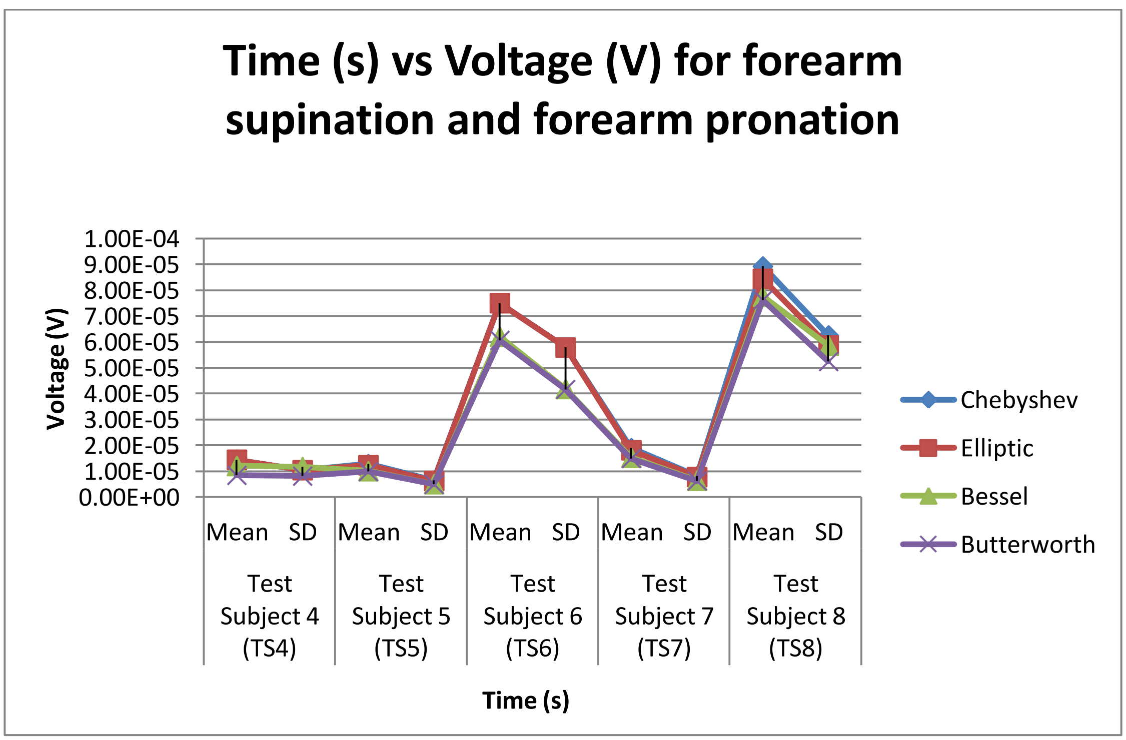


Figure 22: Graphical result for forearm supination and pronation

Analysis of five male subjects was revealed in Figure 20, 21 and 22. The figure revealed that Butterworth and Bessel filter was the best filtering among the other type of filters. In term of functions, the trend was similar to female subject where it showed that Butterworth filter was the best type of filter followed by Bessel, Chebyshev and Elliptic. From Figure 20, Butterworth and Bessel filter showed the lowest SD with Test Subject 4 (4.08 µV), Test Subject 5 (7.35µV), Test Subject 6 (1.77µV), Test Subject 7 (2.30µV) and Test Subject 8(1.22µV). In Figure 21, Butterworth filter gave the best filtering techniques and followed by Bessel, Elliptic and Chebyshev. Similarly, from Figure 22, there were two filters gave the best filtering method which were Butterworth and Bessel filter.

In term of gender, it still showing that Butterworth filter was the best among other filters. This can be proved from wrist extension and wrist flexion gesture where the smallest SD was Butterworth filter and Bessel filter. From Figure 17 and Figure 20, Butterworth filter (purple line on the graphical result) showed the lowest rate of SD where the smallest value was 0.122µV. The filtering techniques was clearly seen in hand open and hand close gesture (Figure 18 and Figure 21) where Butterworth filter performs the most appropriate filter followed by Bessel, Elliptic and Chebyshev. From the experimental result, Butterworth and Bessel filter was the best filtering with the other filters in forearm supination and forearm pronation gesture as we can observed from Figure 19 and Figure 22. Butterworth filter obtained the lowest SD as TS1 (1.08µV), TS2 (8.17µV), TS3 (8.27µV), TS4 (8.17µV), TS5 (4.98µV), TS6 (0.417µV), TS7 (6.33µV) and TS8 (0.525µV). Followed by Bessel filter; TS1 (1.10µV), TS2 (8.48µV), TS3 (8.40µV), TS4 (0.17µV), TS5 (5.08µV), TS6 (0.419µV), TS7 (6.43µV) and TS8 (0.587µV).

Therefore, Butterworth and Bessel was the best filtering techniques in EMG signal. Thus, it can be conclude that there are no change in gender and it is applicable across the gender. On the other hand, in term of function, Butterworth filter still the most suitable filter for EMG signal followed by Bessel, Elliptic and Chebyshev filter. The finding in this research was consistent with findings of other researcher using other modalty, ECG [6].

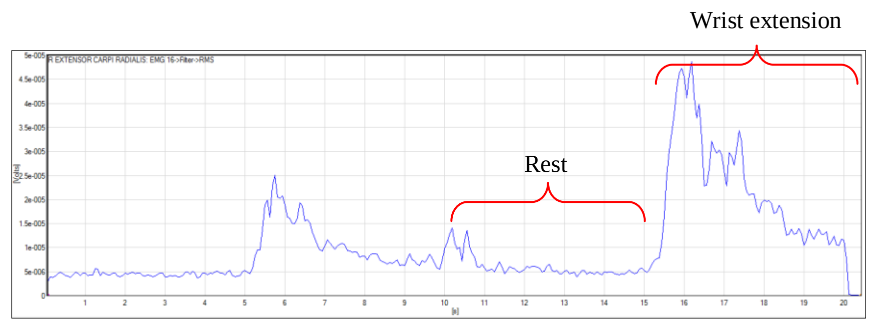
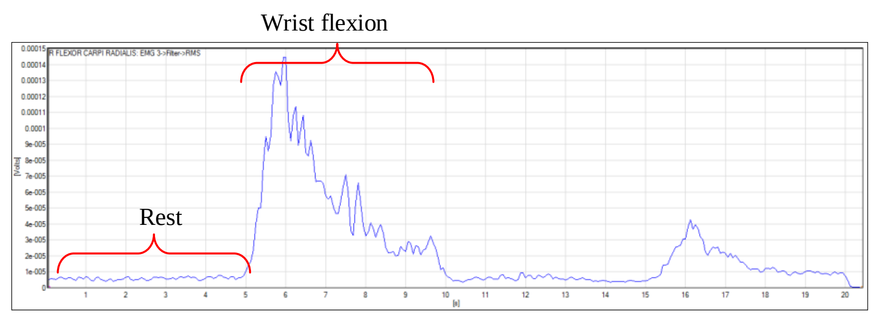
4.2 Thermal Imaging

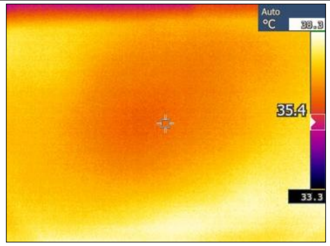
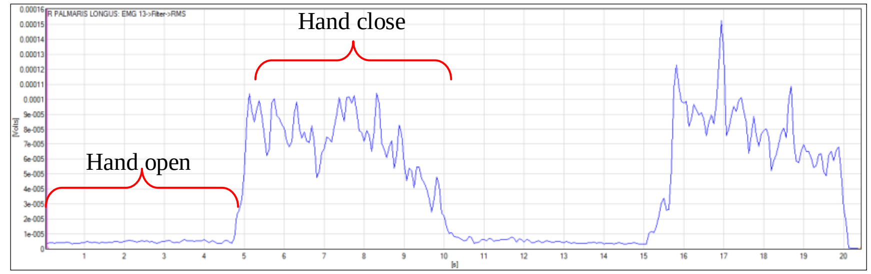
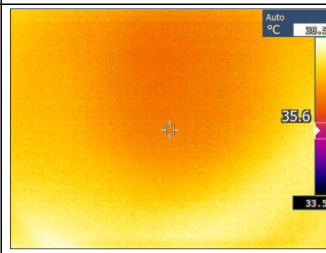
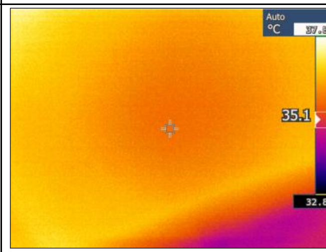
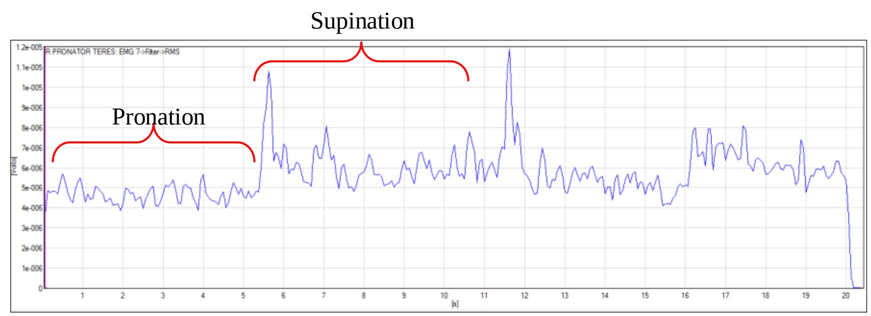
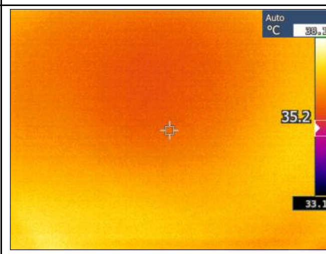
The graphs represented the temperature in celcius (°C) for two test subjects and six different movements which were wrist extension, wrist flexion, forearm supination, forearm pronation, hand open and hand close. The thermal images and EMG signal of the experiment on two of the subjects were shown in Table 51 and Table 52 respectively.

4.2.1 Test Subject 1 (female subject)

The thermal images and EMG signal for test subject 1 was shown in Table 1.

Table 51: Test Subject 1 result

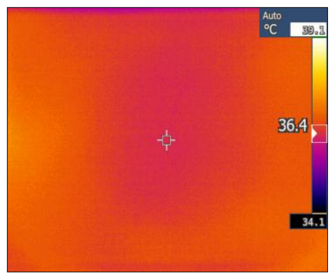
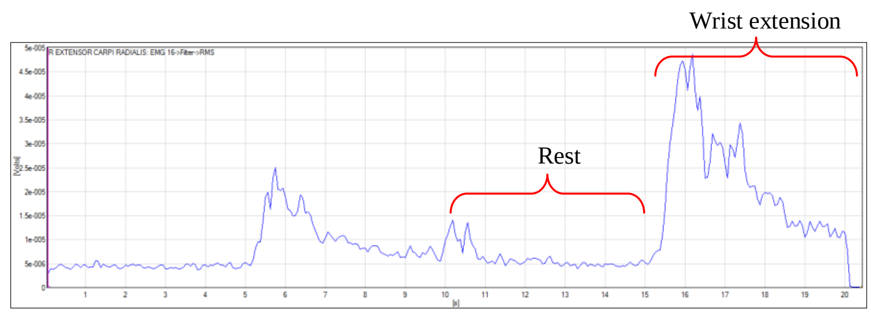
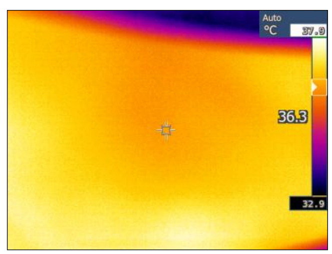
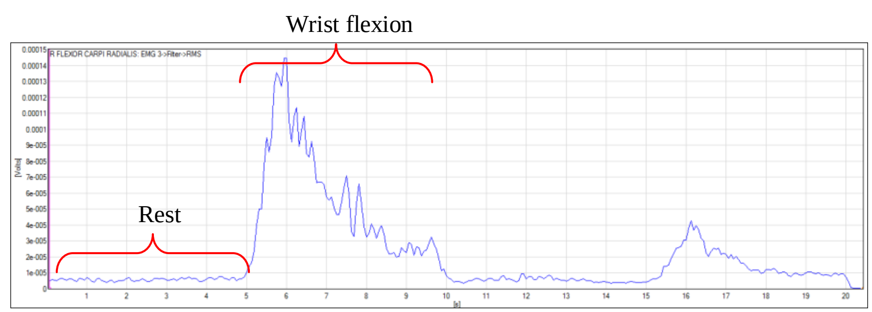
No	Body part	Movement	Temperature (°C)	Thermal Image	EMG Signal
1	Wrist	Extension	36.7 °C		
		Flexion	36.7 °C		

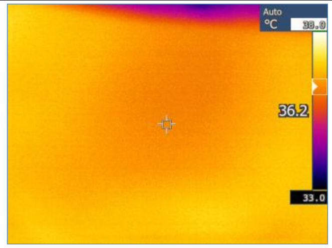
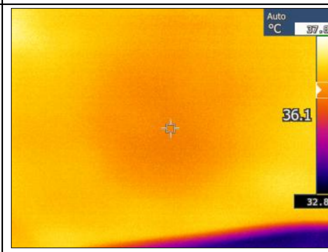
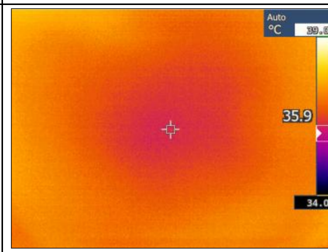
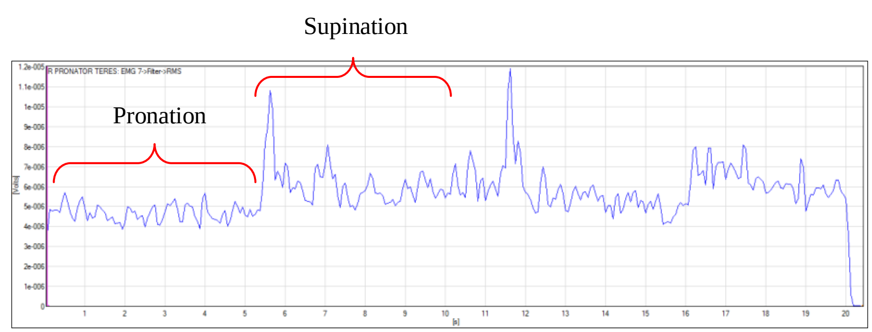
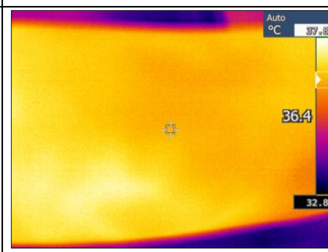
2	Hand	Close	35.4 °C		
		Open	35.6 °C		
3	Forearm	Supination	35.1 °C		
		Pronation	35.2°C		

4.2.2 Test Subject 5 (male subject)

The thermal images and EMG signal for test subject 5 was shown in Table 52.

Table 52: Test Subject 5 result

No	Body part	Movement	Temperature (°C)	Thermal Image	EMG Signal
1	Wrist	Extension	36.4 °C		
		Flexion	36.3 °C		

2	Hand	Close	36.2 °C		
		Open	36.1 °C		
3	Forearm	Supination	35.9 °C		
		Pronation	36.4 °C		

4.2.3 Discussion on thermal imaging

Table 51 and Table 52 above demonstrated the thermal images and EMG signal for test subject 1 (female) and test subject 5 (male). The thermal images were taken on the surface skin by using Fluke Thermal Images as discussed in the experimental procedure (part 3.3). The images were taken without sensor in order to get an accurate temperature reading. The skin thickness and muscle condition also played an important role in this research. Every test subject had different muscle strength and skin thickness. The best type of filter for EMG signal was recognized. Then, the correlation of EMG signal and thermal images can be discussed. Table 53 below illustrated the temperature reading for test subject 1 and 5 for wrist flexion-extension gesture, hand close-open and forearm supination-pronation.

Table 53: The temperature reading of test subject 1 and test subject 5 for wrist flexion-extension, hand close-open and forearm supination-pronation gestures.

Body part	Movement	Temperature (°C)			
		Test Subject 1	Voltage (µV)	Test Subject 5	Voltage (µ V)
Wrist	Extension	36.7	6.69µV	36.4	7.35µV
	Flexion	36.7	6.69µV	36.3	7.35µV
Hand	Close	35.4	7.98 µV	36.2	1.80 µV
	Open	35.6	7.98 µV	36.1	1.80 µV
Forearm	Supination	35.1	1.08 µV	35.9	4.98 µV
	Pronation	35.2	4.98 µV	36.4	4.98 µV

The test subject 1 temperature that were exhibit in Table 53 were 36.7 °C for wrist extension and flexion, 35.4 °C and 35.6 °C for hand close and open and 35.1 °C and 35.2 °C for forearm supination and pronation. As can be seen from Table 53, there was no different in temperature when wrist extension-flexion movement for test subject 1 with 36.7 °C. Different for test subject 5, there was slightly different when wrist extension-flexion movement with extension (36.4 °C) and flexion (36.3 °C). This can be correlated to thermal images in Table 51 and 52 where there was a slight variation in term of temperature compare to wrist extension-flexion movement. The same trend also can be observed for all test subjects (the thermal images were not shown in this research).

Similar trend was observed for hand close-open gestures where there did vary in term of temperature compared to gesture. From Table 53, test subject 1 and 5 performed random temperature reading. The temperature also illustrated a minor changing in hand open-close gesture with the temperature 36.2 °C and 36.1 °C. The EMG signal also had a different voltage for test subject 1 (7.98µV) and 5 (1.80 µV) during hand open-close gesture. There are minor changing during contraction period and rest period with mean 1°C. The correlation can be found that there was a small variation between thermal images and EMG signal.

From Table 53, during forearm supination-pronation, the temperature performance for test subject 1 and 5 can be obtained. Both subjects perform non-linear reading. This can be correlated to the EMG signal where it can be observed that there was a slight variation in term of temperature compared to the wrist flexion-extension movement. In this research, it shows there were small changing during muscle contraction period and rest period. The maximum difference between mean forearm temperatures for a patient was close to 4 °C.

Therefore, it was found that the trend temperature of the temperature for subject 1 and 5 for wrist extension-flexion, hand close-open, and forearm supination-pronation were random and non-linear. Thus, it can be assumed that temperature differences are within 4 °C. Hence, there exist a correlation of muscle contractions and heat that being generated during the activities as displayed by the EMG recording and Thermal images. The finding shows that thermal imaging in term of EMG signal did vary. There was a slight variation in term of temperature compared to EMG signal.

CHAPTER 5

CONCLUSION

The best filtering techniques was successfully identified for surface EMG. Furthermore, four different types of filter such as Butterworth, Bessel, Chebyshev and Elliptic were used in order to analyze the performance of this system. The recording of EMG signal, filtering technique and storing data using Delsys machine had been done. For experimental computation, standard deviation was used as the measurement index. For all three functions (wrist extension-flexion, hand close-open, and forearm supination-pronation) between male and female group, Butterworth and Bessel filter was able to give the best filteration compared to Elliptic and Chebyshev filter. Consequently, in the future the signature can be based on the Butterworth and Bessel filter.

This paper also carried out to study the correlation of EMG signals and Thermal Images in determining the muscle condition. Particularly, in this research it was found that there were strong correlation exists for EMG signals and Thermal Imagers for the group of muscles that were studies which are Extensor Carpi Radialis, Flexor Carpi Radialis, Palmaris Longus and Pronator Teres for arm contraction such as wrist extension-flexion, hand close-open, and forearm supination-pronation. On the basis of conducted study, Thermal Imaging cannot be recommended to use as the analytical method to the establish EMG investigation. However, with further work and research, there was an opportunity that this could become true.

As a recommendation, more test subjects need to be tested for better correlation between thermal imaging and EMG signal. On the other hand, the testing to be done for other muscles such as biceps and triceps for more improvement in electromyography signal processing.

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APPENDICES

APPENDIX A

GANTT CHART FOR FINAL YEAR PROJECT 1

No	Detail/Week	1	2	3	4	5	6	Mid-Semester Break	7	8	9	10	11	12	13	14
1.	Selection of Project Topic: Analysis of Electromyography (EMG) Signal Processing	D	D													
2.	Preliminary Research Work: Research on literatures related to the topic		D	D	D	D										
3.	Submission of Extended Proposal Report						D									
4.	Proposal Defense								D							
5.	Submission of Extended Proposal Defense									D	D					
6.	Project work continues: Further investigation on the project and do modification if necessary											D	D	D		
7.	Submission of Interim Report Draft														D	
8.	Submission of Interim Report Final Draft															D

APPENDIX B

GANTT CHART FOR FINAL YEAR PROJECT 2

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Model Development and Modification Work	D	D	D	D	D	D								
2	Testing and Validation work							D	D						
3	Submission of Progress Report								D						
4	Results Analysis and Discussion								D	D	D				
5	Pre-EDX										D				
6	Submission of Draft Report											D			
7	Submission of Dissertation												D		
8	Submission of Technical Paper												D		
9	Oral Presentation														
10	Submission of Project Dissertation														