“I hereby declare that I have read through this report entitle “**Feature Extraction Of Forearm EMG Signal for Exoskeleton Hand**” and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Mechatronic Engineering”

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Date : 24 JUNE 2015

FEATURE EXTRACTION OF FOREARM EMG SIGNAL FOR EXOSKELETON HAND

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A report submitted in partial fulfillment of the requirements for the degree of

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2015

“I declare that this report entitle “**Feature Extraction Of Forearm EMG Signal for Exoskeleton Hand**” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.”

Signature :

Name : AINE ILINA BINTI TARMIZI

Date : 24 JUNE 2015

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ABSTRACT

Electromygraphy (EMG) signal is non-stationary, non-linear, and have large variation in its signal. It consists of different type of noises in the EMG signal, some of the noises can be eliminated by filtering. However, filtering cannot eliminate random noises of the EMG signals. Therefore, feature extraction has to be performed to the EMG signals to eliminate the unwanted parts of the EMG signals. The first objective of this project includes the forearm raw EMG signals extraction for exoskeleton hand. The next objective is to perform feature extraction on the raw EMG signals that are extracted in objective one. Lastly, the feature extraction performance is analyzed by using the percentage error calculation approach. The method of this research is that, the experiment on extracting the EMG signals are done by using the Muscle Sensor V3 Kit. The performance and analysis of the feature extraction are done by using the MATLAB software. Literature review covers the theory and basic principles and review of previous work on EMG signals, muscle selection, signal conditioning of DAQ, and feature extractions. The movement of hand close (HC), hand open (HO), wrist flexion (WF) and wrist extension (WE) is selected for this research. The selected muscle are FDS, FCR and ECRL muscles. The feature extraction of IEMG and MAV is performed to the EMG signals. The expected result of this research will be the raw EMG signal, feature extracted EMG signal, and also the analysis of the performance. It is expected that the better performance will have the lower percentage of error.

ABSTRAK

Signal Elektromiografi (EMG) adalah signal yang bergerak, tidak linear dan mempunyai banyak signal yang bebeza-beza. Ia terdiri daripada banyak jenis gangguan dan sesetengah gangguan ini boleh di hapuskan menggunakan tapisan signal. Jadi, pengestrakkan ciri harus di jalankan untuk menghapuskan ciri di dalam signal EMG yang tidak deiperlukan. Objektif pertama dalam penyelidikan ini adalah untuk mendapatkan signal EMG daripada tangan manusia untuk kegunaan tangan ekso-skeleton. Seterusnya, objektif kedua adalah melakukan pengestrakkan ciri pada signal EMG. Akhirnya, analisis pengestrakkan ciri pada signal EMG dilakukan dengan menggunakan kiraan peratus kesalahan. Kaedah penyelidikan ini adalah dengan menjalankan eksperimen untuk mengestrak signal EMG daripada tangan subjek dengan menggunakan Muscle Sensor V3 Kit. Prestasi dan analisa terhadap pengestrakkan ciri dijalankan menggunakan MATLAB. Kajian literature telah merangkumi teori dan prinsip asas mengenaik signal EMG, pemilihan otot, penyesuaian isyarat dan pengesektrakkan ciri. Pergerakan tangan genggam, tangan terbuka, fleksi pergelangan tangan dan extensi pergelangan tangan telah dipilih. Otot yang terpilih untuk pergerakan-pergerakan ini adalah otot FDS, FCR da ECRL. Pengesrakkan ciri kaedah IEMG dan MAV akan dilakukan pada signal EMG tersebut. Hasil yang diharapkan oleh penyelidikan ini adalah data signal EMG, pengestrakkan ciri pada signal EMG tersebut dah juga analisa pengestrakkan ciri. Dengan harapan yang tinggin, hasil penyelidikan ini akan mendapatkan kaedah pengestrakkan ciri yang lebih baik. Ini dilakukan dengan pengiraan peratus kesalahan.

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CHAPTER 1

INTRODUCTION

This chapter is introduction of the project that covers briefly about the research background. The motivation and significant of the research is also included in this chapter. By the motivation, the problem statement of this project has been concluded. The objectives of the project are also explained in detail. In this chapter, the project scopes are determined and lastly, the report outline is executed.

1.1 Introduction

In the present time, research on Electromyography (EMG) signals has been vastly developed. The technology that utilized the advantages of EMG signals generated by human muscle had tremendously studied worldwide. In this research, feature extraction of forearm EMG signals is explored for exoskeleton hand application.

EMG signals is the study based on muscle contractions. There are two main methods of extracting the EMG signals; using the skin surface electrodes and fine wire electrodes. Skin surface electrodes, silver/silver chloride pre-gelled electrodes are used frequently. This are also called as Surface Electromyography. Surface electrodes are recommended due to their non-invasive character that makes it convenient to be applied in rehabilitation devices. However, this EMG signals is non-stationary, non-linear, complex, and has large variation. Due to these properties, it is complicated to analyze EMG signals. Therefore, feature extraction of forearm EMG signals plays a significant role for exoskeleton hand movement identification.

Feature extraction is used to emphasize the relevant structure in the EMG signals and rejecting noise and unimportant EMG signals. Since the raw EMG signals from the human muscles are normally very small, EMG-amplifiers are required to act as differential amplifiers as their quality item is the ability to reject or eliminate artifacts.

The main application of EMG signals is the control of the exoskeleton or other rehabilitation and assistive device. Exoskeleton hand is widely used as the rehabilitation and assistive device. This exoskeleton hand can be controlled by the EMG signals. This research will focus on the exoskeleton hand application for rehabilitation. This rehabilitation tool is currently high in demand for training impaired hands.

1.2 Motivation and Significant of The Research

A figure shows that, the statistic data from Hospital Kuala Lumpur in 2004, 30 to 35% out of 1000 case of stroke dies. On the other hand, in three to five years" time there are 20 to 40% post-stroke patients require help from other people to do their daily routine and activities [9]. According to the percentage, the numbers of the post-stroke patients are growing each year. The post-stroke patients normally need rehabilitation session. Exoskeleton hand is a device that is currently popular for rehabilitation. Exoskeleton hand will greatly aid the injured parties for their rehabilitation and to restore the quality of life. With the exoskeleton hand, these injured parties able to use the exoskeleton hand to train their impaired hands. EMG signals are commonly used for the controlling exoskeleton hand [12][4]. The EMG signal controls the exoskeleton hand by muscle contractions of the user. This character of the EMG signal makes the exoskeleton application robust. Due to this matter, the feature extraction is important for pattern recognition of the EMG signals before it able to be applied for controlling the exoskeleton hand.

1.3 Problem Statement

In recent time, the EMG signals technique has explored extensively for exoskeleton hand application. This exoskeleton hand is widely employed for rehabilitation application. Based on the motivation and significant of this research, exoskeleton hand applications are recently popular for training impaired hands of a post-stoke patients. The exoskeleton hand can be control by using the EMG signals. This EMG signal is important because of its character that can control device using muscle contractions.

However, the major drawback of EMG signals is the poor recognition results under conditions of existing noises especially when the frequency characteristic of noise is random. This noise, artifact and interference in recorded EMG signals are electrode noise, electrode and cable motion artifact, alternating current power line interference, and other noise sources such as a broadband noise from electronic instrument [6]. Some of these noises can be easily removed using filtering methods. Despite that, the interferences of random noise that fall in EMG dominant frequency energy are difficult to be removed. Therefore, by feature extraction, the relevant structures in the EMG signals are highlighted and the noise and unimportant EMG signals are rejected.

Feature extraction methods have three categories of time domain, frequency domain and time-frequency domain. Among these categories, feature of the function of time is the most popular in exoskeleton hand application. Feature extraction in time domain is widely used due to its performances of signal classification in low noise environments and their low computational complexity [16]. Therefore, this research will perform the feature extraction method in time domain. The feature extraction methods that will be performed in this research are the Standard Deviation (STD) and Mean Absolute Value (MAV).

1.4 Objectives

1. To obtain forearm raw EMG signals based on indirect handgrip force and wrist angle for exoskeleton hand application.
2. To perform feature extraction in time domain for raw EMG signals extracted.
3. To analyze the performance of feature extraction methods in terms of percentage error calculation.

1.5 Project Scope

In this research, the feature extraction of forearm EMG Signal for exoskeleton hand is explored. The scopes of this research are as follows:

1. The feature extraction of forearm raw EMG signals will be extracted from five healthy subjects.
2. Only four hand movements are considered for the signal extraction experiment, which are hand open (HO), hand close (HC), wrist flexion (WF), and wrist extension (WE).
3. The muscles used to get the raw EMG signals are the Flexor Digitorium Superficialis (FDS), Flexor Carpi Radialis (FCR), and Extensor Carpi Radialis Longus (ECRL).
4. Muscle Sensor V3 Kit will be used to extract the raw EMG signals. The electrodes from the Muscle Sensor V3 Kit are skin surface electrodes.
5. The muscle sensor will be connected with Arduino Mega 2560 and then further process is done using the MATLAB software.
6. Two time domain features will be performed in this research, which are Standard Deviation (STD) and the Mean Absolute Value (MAV)

1.6 Report Outline

This report starts with the introduction of the research; the general view on EMG signals and exoskeleton hand application on rehabilitation is stated. Next, the motivation is build from a figure of post-stroke patients that require rehabilitation. The problem statement is then determined based on the motivation. Then, the objectives to overcome the problem are listed. Next, the research limitations are declared in the project scope.

The literature review starts with theory and basic principles of forearm anatomy, electromyography, feature extractions, and exoskeleton hand. The next section of the report is review of previous related work. This section covers on the previous research work on muscle selection, signal conditioning, feature extraction methods and their performance analysis. Then the next part of this report is the summary of literature review.

The methodology in this research is covered next. The procedures of to achieve the three objectives are stated. After that, the preliminary results of this research is shown and explained. The last part of this report includes conclusion and future works.

CHAPTER 2

LITERATURE REVIEW

This chapter covers on the theory and basic principle, review of previous related works and the summary and discussion of the review. On the theory and basic principle section, it covers briefly on the theory on the exoskeleton hands. Other than that, the theory of Electromyography (EMG), the EMG signal extractions are also included in the section. It covers briefly about the muscles of the anterior compartment of the forearm. On the review of previous related works, the configurations of exoskeleton hands are being covered. Besides that, this part of the chapter is also cover the muscle and hand motion selection of previous works. Lastly, the feature extraction methods that performed by previous works are also listed on this chapter.

2.1 Theory and Basic Principle

In this research, theory and basic principle of forearm anatomy, electromyography and exoskeleton hand are reviewed.

2.1.1 Forearm Anatomy

EMG signals are the study on muscle contractions. In this research, forearm raw EMG signals have to be extracted in order to perform feature extractions. Due to this, the theory of forearm anatomy is reviewed. There are three types of human muscle, which are skeletal, smooth and cardiac. The muscles that produce movement of the skeleton are the skeletal muscles.

This research conducts the experiment concerning the movement of the forearm. Therefore, the type of muscle that is going to be used in this research is the skeletal muscle of forearm. The forearm muscles are divided to three fascial compartments that are anterior, lateral, and posterior.

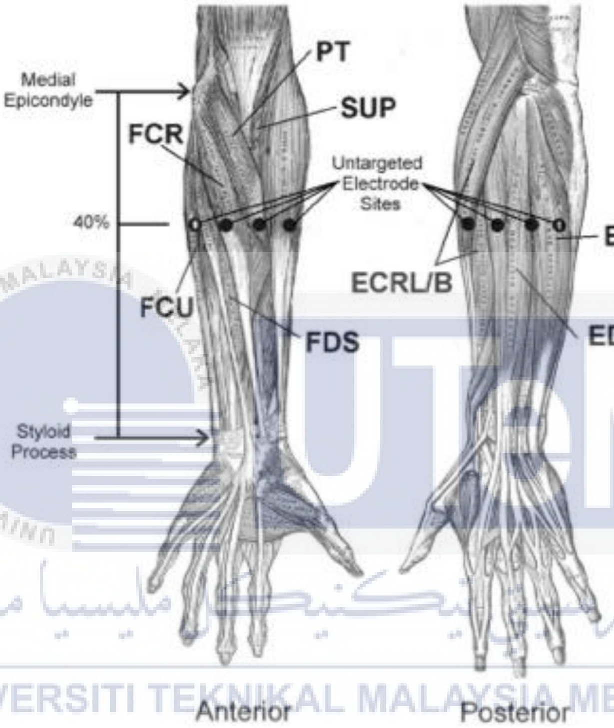


Figure 2.1: Anterior and Posterior fascial compartment of the forearm. [15]

The muscle of the anterior fascial compartment of the forearm consists of pronator teres (PT), flexor carpi radialis (FCR), palmaris longus (PL), flexor carpi ulnaris (FCU), flexor digitorum superficialis (FDS), flexor pollicis longus (FPL), and flexor digitorum profundus (FDP). These muscles have its own of actions to move the forearm. PT has the action of pronation and flexion of the forearm. FCR and FCU have the same action, which is flexes and abducts hand at wrist. PL flexes the hand, FDS flexes the hand, FPL flexes the thumb, and FDP flexes fingers, assist in flexion of middle and proximal phalanges and wrist.

Based on this information, the anterior fascial compartment muscles mostly covers on the flexion of the forearm and wrists. The suitable muscle from the anterior fascial compartment can be selected for flexion movements for the research.

The muscle of the lateral fascial compartment of the forearm consists of only one muscle that moves the hand. The extensor carpi radialis longus (ECRL) extends and abducts hand at wrist joint. The muscle of the posterior fascial compartment of the forearm consists of extensor carpi radialis (ECR), extensor digitorum (ED), extensor digiti minimi (EDM), extensor carpi ulnaris (ECU), and extensor pollicis longus (EPL). The ECR and ECU have the same action of extension and abduction hand at wrist joint, ED extends fingers and hand, EDM extends the little finger, and EPL extends the thumb. [8]. Both of lateral and posterior fascial compartments mostly cover the extension movement of the hand. This forearm anatomy is useful for determining the muscle selection for this research.

2.1.2 Electromyography

Electromyography (EMG) is an experimental technique concerned with the development, recording and analysis of myoelectric signals. Myoelectric signals are formed by physiological variations in the state of muscle fiber membranes. In other words, Electromyography, EMG is a technique to analyze the muscle activity in human body by getting the myoelectric signal from a medium [1]. EMG signals are based on the study of muscle contractions. The EMG signals are generated by the changes of ion in the muscle. Motor Unit is the smallest functional unit to describe the neural control of the muscular contraction process.

Electromyography is used in many researches and in biomedical approach. This EMG is widely used in Medical Research, Rehabilitation, Ergonomics and Sport Science, which the EMG is used as the evaluation tool. [6] This EMG signals are normally used to control the evaluation device by using the muscle contractions.

The main benefit of EMG is that, this signal allows us to look directly into the muscle. Therefore, it is possible to measure the muscular performance. Muscular performance can be analyze for different type of purpose, for example; to help in decision making before or after a surgery, to help patient „find" or train their muscle, to allow analysis on improving sport activities, or it can also detects muscle response for ergonomics studies [6]. This EMG signals are also explored in rehabilitation and assistive application of exoskeleton hand.

2.1.3 EMG signal extraction

Firstly, the skin preparation must be done before applying the medium on the skin. In addition, the identification of the correct muscle responsible for a particular motion is also has to be decided. Then, the raw EMG signal can be extracted directly by using electrodes. There are various type of electrodes that can be use to extract the EMG signal from the muscle which are, skin surface electrodes and fine wire electrodes. The skin surface electrodes are popular due to their non-invasive character. In A fine wire electrode

The EMG signal is important to be amplified due to its microvolt scaled signals. It is then undergo EMG data acquisition. Next, EMG data segmentation is applied. After that, feature extraction is done to the EMG signal before it can go into the Classifier.

2.1.4 Amplitude Normalization

Amplitude Normalization acts as the calibrator of the microvolt value of the EMG Signal. Performing the Maximum Voluntary Contraction (MVC) technique can process amplitude normalization. Only healthy and trained subjects must perform this MVC technique.

Firstly, identify exercise that allows for effective maximum innervation. Static fix at middle position within the range of motion give the best results. This method may be needed to try out by several candidates. Therefore highest EMG level can be found among the several candidates. The best candidate should perform a random order of exercise move in a period of time. This MVC exercise is done repeatedly with a pausing period. MVC require random order to avoid fatigue effects.

2.1.5 Muscle Sensor V3 Kit

In this research, the forearm raw EMG signal is required to be extracted. Muscle Sensor V3 Kit is used to extract the raw EMG data of the forearm. Muscle V3 Kit sensor is equipped with pre-gelled surface silver-silver chloride electrodes, muscle sensor board and 24” cable leads this is shown in Figure 2.2 and Figure 2.3.

This muscle sensor is designed to be used directly with a microcontroller. This sensor give the output of amplified, rectified and smoothed signal. The schematic diagram of Muscle Sensor V3 Kit is shown in Figure (). This muscle sensor is required to be connected with the power supply of two 9V batteries. The electrical specification of Muscle V3 Kit is shown in Table (). This Muscle sensor is used because it is simple and the signal is accurate.

Figure 2.2: The Muscle Sensor V3 Kit

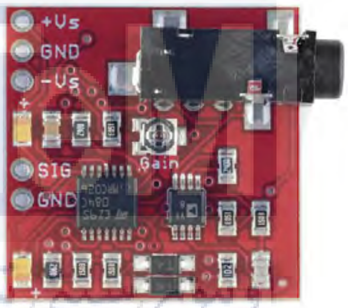


Figure 2.3: Muscle sensor board

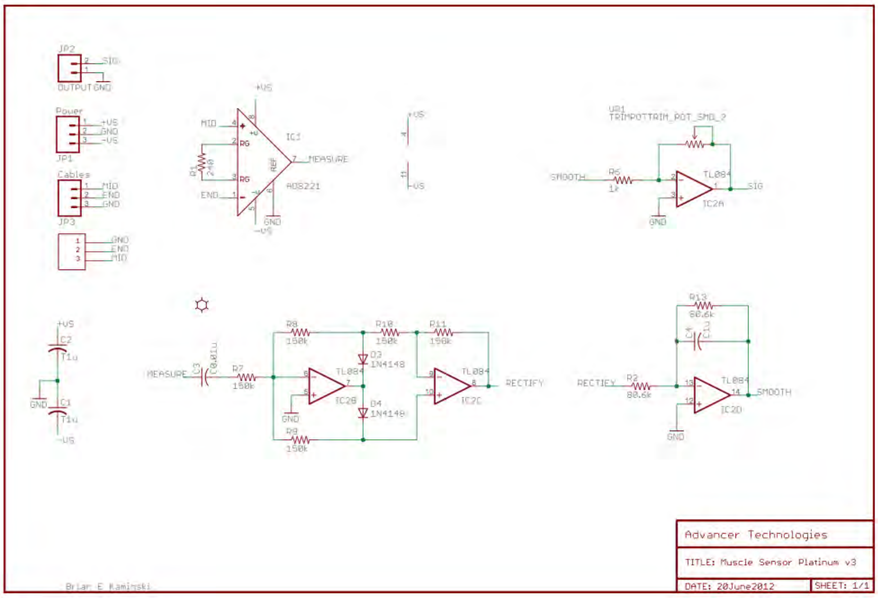


Figure 2.4: Schematic diagram for the Muscle Sensor V3 Kit

Table 2.1: Electrical specification for the Muscle Sensor V3 Kit

Parameter	Min	TYP	Max
Power Supply Voltage (Vs)	±3V	±5V	±30V
Gain Setting, Gain = 207*(X /1 kΩ)	0.01 Ω (0.002x)	50 kΩ (10,350x)	100 kΩ (20,700x)
Output Signal Voltage (Rectified & Smoothed)	0V	--	+Vs
Differential Input Voltage	0 mV	2-5mV	+Vs/Gain

2.1.6 Arduino Mega 2560

Arduino Mega 2560 is a microcontroller that can process and transfer analog and digital signal to the computer. In this project, this Arduino Mega acts as the signal-conditioning device that uses to convert the analog signal from the Muscle Sensor V3 Kit to a digital signal to be compatible with the computer. This process is done to make sure the computer is able to display the output EMG signal extracted from the Muscle Sensor V3 Kit.

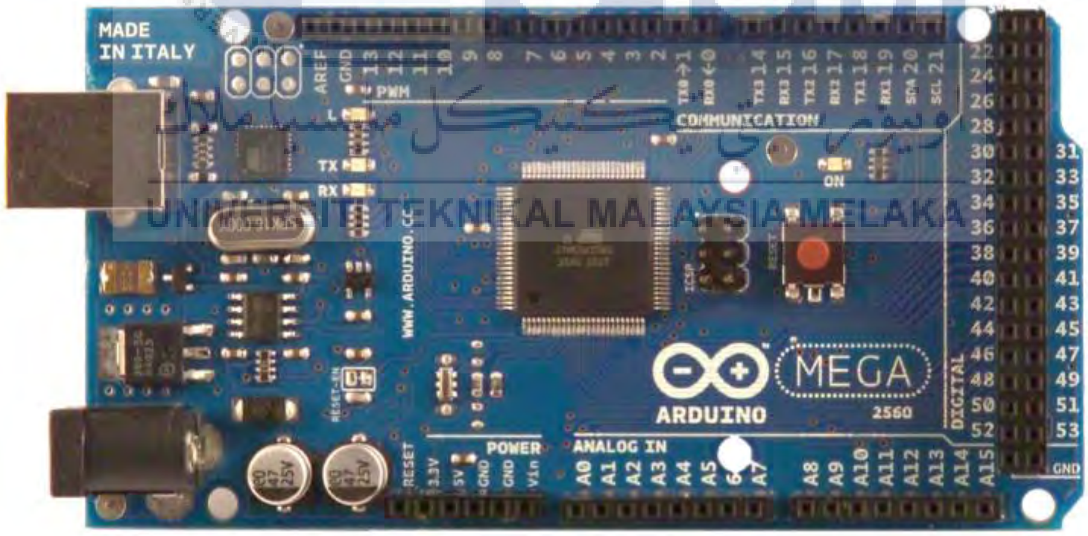


Figure 2.5: Arduino Mega 2560 board

From the datasheet, this Arduino Mega 2560 has 54 digital input and output pins, 14 of the digital pins can be used as PWM outputs, 16 analog inputs, 4 UARTs hardware serial ports, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. This Arduino Mega 2560 is complete with everything required to support the microcontroller. This Arduino is started just simply by connecting it to a computer with a USB cable or power it with an AC-to-DC adapter or battery.

2.1.7 Feature Extraction of EMG Signals

The raw EMG signal is a large number or inputs and randomness; therefore, it is impractical to feed the classifier with these signals. It is necessary to create the feature vector, where sequence is mapped into a smaller dimension vector. Feature extraction is important because the success of any pattern recognition problem depends almost entirely on the selection and extraction of features. Feature extraction for EMG signal normally falls into three categories, which are time domain, frequency domain, and time-frequency domain.

Time domain feature extraction consists of Integrated Electromyography (IEMG), Mean Absolute Value (MAV), Variance (VAR), Root Mean Square (RMS), Waveform Length (WL), Zero Crossing (ZC), Slope sign changes (SSC), Willison amplitude (WAMP), and Auto regressive coefficients (ARC). The time domain features are measured as a function of time.

Frequency domain feature extraction of EMG signals consists of Median Frequency (MDF), and Median Frequency (MNF). Frequency domain features are normally used to detect neural abnormalities, and muscle fatigue. This feature extraction is normally taken by the study of the spectrum of the EMG signals.

Time domain features are the most popular method for EMG signal for hand movement recognition. This feature is calculated on raw EMG time series. However, there is also disadvantage of the time domain features because EMG signals has the non-stationary character. Despite that, time domain features are extensively used because of their performances of signal in low noise environment and have lower computational complexity compared to the frequency and time-frequency domain features. In this research, the performance of Standard Deviation (STD) and Mean Absolute Value (MAV) will be analyzed.

2.1.7.1 Standard Deviation (STD)

From the mathematical point of view, standard deviation of a random variable, statistical population, data set, or probability distribution is the square root of its variance. It is algebraically simpler, despite the fact that in practice less robust, than the average absolute deviation. It is observed that the standard deviation of the raw EMG signal is monotonically related to the number of the activated motor units and the rate of their activation. This standard deviation is used to approximate the magnitude of the muscular electrical activity referred to as EMG amplitude. Standard deviation can be expressed as:

$$SD = \sqrt{\frac{\sum_{W=1}^{N_W} (r_w - \mu)^2}{N_W}} \tag{1}$$

2.1.7.2 Mean Absolute Value (MAV)

Mean absolute value (MAV) is calculated using the moving average of full-wave rectified EMG signal. It is calculated by taking the average of the absolute value of the EMG signal [18]. Other then that, MAV is similar to IEMG that normally used as an onset index to detect the muscle activity. MAV is the average of the absolute value of EMG signal amplitude. It is defined as

$$MAV = \frac{1}{N} \sum_{n=1}^{N} |x_n| \tag{2}$$

MAV is a simple way for detection of muscle contraction levels. Due to this, MAV is a popular feature used in EMG hand movement recognition applications and also myoelectric control application.

2.1.8 Exoskeleton Hand

In recent studies, rehabilitation device has explored the use of EMG signals. Exoskeleton hand is an example of extensively studied rehabilitation device. This exoskeleton hand is specially designed for injured parties of stroke and other cerebral vascular accident. This device provides training for people with impaired hand. An exoskeleton hand can be actively driven by muscle signals [4].

Exoskeleton is a device that has external joints and links which compatible to the human body. Exoskeleton hand supports only a few joints of parts of the human hand. This exoskeleton hand is commonly attached to the human hand. Some of the joints of the exoskeleton hand exerted torques by the actuator, whereas other joints are only passively moving.

From a research [4], the exoskeleton hand configuration consists of five fingers assemblies and a palm support platform. In addition, each of the fingers assembled is actuated by a single linear actuator (Firgelli L12). This provides two degrees of freedom (DOF) for each finger at the MCP and PIP together by the mechanical linkage system.

The proximal section rotates around the virtual centre located at the proximal interphalangeal (PIP) joint whereas the distal section rotates around the virtual centre located at the metacarpophalangeal (MCP) joint. This can be seen in Figure 2.1. From fully extended position to fully flexed position, the finger assembly provides 55 degrees and 65 degrees range of motion (ROM) for the MCP and PIP joints respectively. When under no load, the maximum contraction speed of the robotic hand is approximately two seconds to fully open or close the robotic hand. This exoskeleton hand is driven by the EMG signal of the hand of post-stroke patients. This system is designed to be portable and self-contained to allow the post-stroke patient to be able to carry it around to do daily routine.

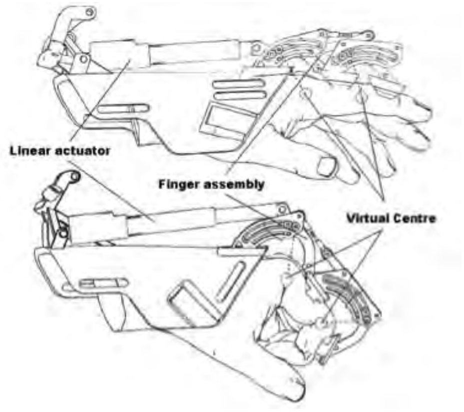


Figure 2.6: Configuration of exoskeleton hand [4]

From [12] The system is designed to support up to 20 finger joints four for each finger. The Figure 2.6 shows an overview of the hand exoskeleton system. User interface is separated from the real- time controller, which is responsible for the control loop and data acquisition. The hardware watchdog monitors the real-time controller and disables the PWM amplifiers if a time out failure occurs. This exoskeleton hand is also controlled by the EMG sensor data. This exoskeleton hand is developed to be used as a rehabilitation tool for patients that have injuries of the hand or after surgery patients; this is necessary to regain as much dexterity back as possible.

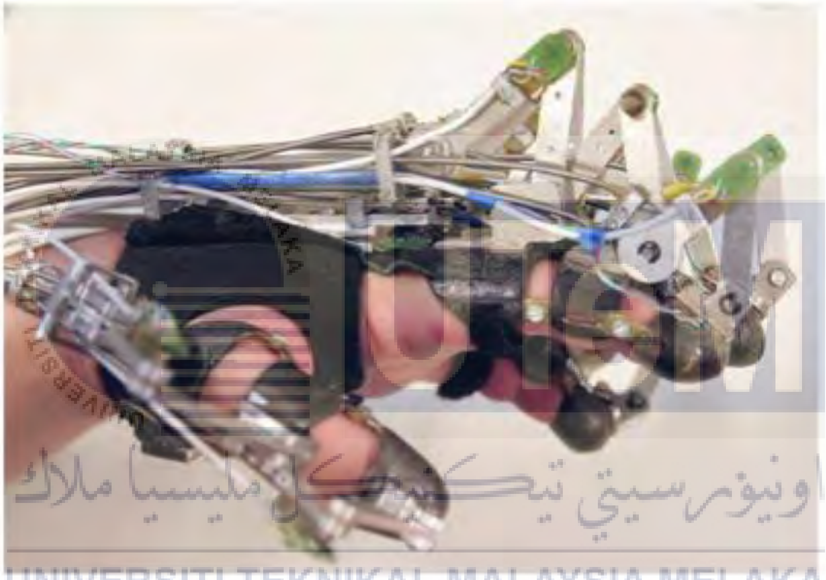


Figure 2.7: The exoskeleton hand [12]

2.2 Review of Previous Related Works

This subsection contains the previous research done by other researcher on Feature Extraction of EMG Signal. This section covers the muscle selection and type of motion, signal conditioning, feature extraction techniques, and lastly the overall summary of the review.

2.2.1 Muscle selection and type of motion

The EMG signal is applied to study skeletal muscle. The skeletal muscle tissue is attached to the bone and its contraction is responsible for supporting and moving the skeleton [13]. There are total of eight muscles that consist in a lower forearm. Different type of muscle is used on different projects that include EMG. From the journal [10][11], they used the two muscles to get their EMG signals. These muscles are the flexor carpi radialis muscle (FCR) and extensor carpi radialis longus muscle (ECRL). These muscles were used to give the signal data for different type of hand movement. These movement are wrist flexion (WF), wrist extension (WE), hand close (HC), hand open (HO), forearm pronation (FP) and forearm supination (FS). In the same approach [14], they also the used 2 different muscles, which are the FCR, Flexor Carpi Ulnaris (FCU). These muscles are used to vary the signal data of 6 DOF of wrist movement. The 6 DOF wrist movements are wrist flexion, wrist extension, hand close, hand open, radial deviation, ulnar deviation. By these journals, this can be synthesized that they selected the two different type muscles that covers the movement of flexion and extension.

The next research review [16], the movement of the forearm is experimented by using the biceps brachii muscle. This muscle is located at the upper part of the forearm. This muscle is selected because of this muscle flexes and extends the forearm. This research is to analyze the feature performance by extracting the EMG signal using the hand movement of lifting a dumbbell, hold, and releasing without moving the shoulders.

According to [17], to determine the location of the FDS we placed the palm of our hand on the medial epicondyle and extended our thumb and fingers down the forearm as shown in Fig 1. Each of our fingers and thumb will be above a particular muscle; thumb – pronator teres, index finger – flexor carpi radialis, middle finger - palmaris longus, ring finger - flexor digitorum superficialis, and little finger - flexor carpi ulnaris.

Figure 2.8: Procedure to locate the forearm muscles [17]

2.2.2 Signal Conditioning

The EMG signals are normally have to go through signal conditioning. Data Acquisition (DAQ) is a signal conditioning system used to convert the analog signal from sensor to be digitalized. This is to make the signal compatible with the computer. The signal conditioning of the EMG signals from the previous works are being discussed.

According to [18] the signal condition of the system used is the National Instruments, DAQCard-6024E. This device is used for the analog-digital converter. The sampling frequency was set at 1 kHz. Other than that, according to [16] the data acquisition of the EMG signal is done using the TeleMyo 2400T G2 (Noraxon, USA Inc.). This device is also used to convert the analog signal of the extracted EMG signal from the surface electrodes.

However, in this report, the signal conditioning will be done by using Arduino Mega 2560 device. Arduino Mega 2560 has the analog input that can be directly connected to the Muscle Sensor V3 Kit and send to the computer through MATLAB software. This Arduino Mega device is much more reliable than the DAQ where the signal can quickly received just by setting up SIMULINK block diagram.

2.2.3 Feature Extraction techniques

From the research [10], 13 features extraction methods were evaluated. The feature extractions in time domain methods that are studied in this paper are Integrated EMG (IEMG), Mean Absolute Value (MAV). Other than that, they also Modified Mean Absolute Value 1, Modified Mean Absolute Value 2, these are the method that the research come with by modifying the MAV. Mean Absolute Value Slope (MAVS), Simple Square Integral (SSI), Variance (VAR), Root Mean Square (RMS), Waveform length (WL), Zero crossing (ZC), Slope Sign Change (SSC), Willison amplitude (WAMP) and Auto-regressive (AR) coefficients. Modified Mean Absolute Value 1 (MAV1) is an extension of MAV. MAV1 uses weighting window function (w_n) to improve the robustness of MAV.

Modified Mean Absolute Value 2 (MAV2) is also performed. This MAV2 method is related to MAV1. Moreover, continuous weighting window function (w_n) in this feature is used to improve the smoothness of weighting function. Mean Absolute Value Slope (MAVS) is a modified version of MAV. The differences between the MAVs of adjacent segments are determined.

Besides that, Simple Square Integral (SSI) performed to captures the energy of the EMG signal as a feature whereas the Variance (VAR) captures the power of EMG signal as a feature. Normally, variance is mean of square of deviation of that variable. However, mean value of EMG signal is close to zero.

In the other hand, Root Mean Square (RMS) is also performed in the research. RMS is related to constant force and non-fatiguing contraction. Besides that, waveform length (WL) is the cumulative of the length of waveform over time segment. WL is similar to waveform amplitude, frequency and time. Zero crossing (ZC) is also performed in the research. ZC is the number of times that the amplitude values of EMG signal crosses zero in x-axis.

In EMG feature, threshold condition is used to avoid from background noise. ZC provides an approximate estimation of frequency domain properties. Other than that, Slope Sign Change (SSC) method is related to ZC. It is another method to represent the frequency domain properties of EMG signal calculated in time domain.

The number of changes between positive and negative slope among three sequential segments are performed with threshold function for avoiding background noise in EMG signal.

Willison amplitude (WAMP) is the number of time resulting from the difference between EMG signal amplitude of two adjoining segments that exceeds a predefined threshold, which is used to reduce background noises like in the calculation of ZC and SSC. WAMP is related to the firing of motor unit action potentials and muscle contraction level. The suitable value of threshold parameter of features in ZC, SSC, and WAMP is normally chosen between 10 and 100 mV that is dependent on the setting of gain value of instrument.

Other than that, Auto-regressive (AR) coefficients model described each sample of EMG signals as a linear combination of previous EMG samples plus a white noise error term. In addition, p is the order of AR model. AR coefficients (a_i) are used as features in EMG hand movement recognition. In this research [10], the Euclidean Distance (ED) and Standard Deviation (SD) calculation is done to analyze the feature extraction methods. The ED and SD are defined as

$$ED(p,q) = \sqrt{(p_{ch1} - q(ch_1)^2 + (p_{ch2} - q_{ch2})^2} \quad (3)$$

$$SD = \sqrt{\frac{\sum_{W=1}^{N_W} (r_w - \mu)^2}{N_W}} \quad (1)$$

The Euclidean Distance calculation is to determine the separation index, whereas the standard deviation is to determine the compactness index. This analysis method is complex and need two muscle positions. The research [10], result in having WL to have the best performance. In addition, the RMS and WAMP also have good performance.

The next research [16], performed the feature extraction by using time domain feature. The methods of RMS, SD and Maximum Amplitude (MAX) are performed. RMS and SD method explanation is the same as the previous research discussed. In the other hand, the Maximum Amplitude (MAX) is defined as the peak amplitude of a signal. MAX method is usually used when the signal is not sinusoidal. This method can be performed for a signal that swings above and below a zero value.

In the research, the performance of the feature extraction method is analyzed by using the calculation of percentage error. The percentage error (PE) defined as

$$PE = \left| \frac{feature_{clean} - feature_{noise}}{feature_{clean}} \right| \times 100\% \tag{5}$$

The feature that has lowest percentage error is the best feature extraction. The result of the research from the calculated percentage error, SD has the best performance. Where MAX and RMS are the better ones that can be use with SD as the feature vector.

2.3 Summary and Discussion of the Review

From the review, this project is going to obtain the raw EMG signal by using surface electrode method. This is because this is easy to use and non-invasive. This is because this extracting EMG signal using surface electrodes does not need any surgery to implant any device in the flesh; it is just applied on the surface of the skin.

From the forearm anatomy, the muscles that are needed to be selected for different types of movement are able to be determined. Other than that, locating the muscle on the forearm is also can be done by a simple procedure. The movements of the hands are selected which are, HO, HC, WF and WE. According to the movement, the muscle can be selected. The muscle selected for this project is FDS, FCR and ECRL. FDS is the muscle that flexes the hand; this can be easily used to obtain the data for the HO and HC movement. On the other hand, the FCR and ECRL muscle will also be used to get the EMG signals data of the WF and WE.

From the literature review, they are many methods of feature extraction that can be performed to the EMG signals. The best feature extraction by review is WL and MAX. However, the feature extraction methods that will be used to the EMG signal are the STD and the MAV. This is because, STD and MAV is popular in time domain features of EMG signals.

There are many techniques that can be done to analyze the performance of the feature extraction methods. In this research, the performance of STD and MAV feature extractions will be analyzed by computing its percentage error.

Table 2.2: The summary of literature review

No	Title	Authors	Type of muscle and electrode used	Type of motions	Method of Feature Extractions (Time Domain)
1	Feature Extraction and Reduction of Wavelet Transform Coefficients for EMG Pattern Classification	A. Phinyomark, A. Nuidod, P. Phukpattaranont, C. Limsakul	Type of muscle: flexor carpi radialis muscle (FCR) and extensor carpi radialis longus muscle (ECRL) Type of electrode: Two bipolar-surface- electrodes (3M red dot 25 mm. foam solid gel)	Wrist flexion (WF), wrist extension (WE), hand close (HC), hand open (HO), forearm pronation (FP) and forearm supination (FS).	1. Integrated EMG (IEMG) 2. Mean absolute value (MAV) 3. Modified Mean Absolute Value (MMAV) 4. Simple Square Integral (SSI) 5. Variance of EMG (VAR) 6. Root Mean Square (RMS) 7. Log detector (LOG) 8. Willison amplitude (WAMP)
2	Evaluation of EMG Feature Extraction for Hand Movement Recognition Based on Euclidean Distance and Standard Deviation	A. Phinyomark, S. Hirunviriya, C. Limsakul, P. Phukpattaranont	Type of muscle: flexor carpi radialis muscle (FCR) and extensor carpi radialis longus muscle (ECRL) Type of electrode: Two pairs of bipolar Ag/AgCl electrodes (3M red dot solid gel)	Wrist flexion (wf), wrist extension (we), hand close (hc), hand open (ho), forearm pronation (fp), and forearm supination (fs)	1. Integrated EMG (IEMG) 2. Mean Absolute Value (MAV) 3. Modified Mean Absolute Value 1 4. Modified Mean Absolute Value 2 5. Mean Absolute Value Slope (MAVS) 6. Simple Square Integral (SSI) 7. Variance (VAR) 8. Root Mean Square (RMS) 9. Waveform length (WL) 10. Zero crossing (ZC) 11. Slope Sign Change (SSC) 12. Willison amplitude (WAMP) 13. Auto-regressive (AR) coefficients

No	Title	Authors	Type of muscle and electrode used	Type of motions	Method of Feature Extractions (Time Domain)
3	Towards the Control of Individual Fingers of a Prosthetic Hand Using Surface EMG Signals	Francesco Tenore, Ander Ramos, Amir Fahmy, Soumyadipta Acharya, Ralph Etienne-Cummings, and Nitish V. Thakor	Type of muscle: A reference electrode was placed on the distal part of the olecranon and the ground electrode was placed on the clavicle. Type of electrode: 32 bipolar Ag/AgCl electrodes	Flexions and extensions	1. Mean of the absolute value (MAV) 2. Willison Amplitude(WAMP) 3. Variance (VAR) 4. Waveform length. (WL)
4	Features Extraction of Electromyography Signals in Time Domain on Biceps Brachii Muscle	Wan Mohd Bukhari W. D, Abu Bakar Yahya, Chong Shin Horng, Mohamad Fani Sulaima, and Rubita Sudirman	Type of muscle: Biceps Brachii muscle. Type of electrode: self-adhesive Ag/AgCl electrodes.	Flexions and extensions of the forearm	1. Maximum amplitude (MAX) 2. Standard deviation (SD) 3. Root mean square (RMS)
5	EMG Signal Feature Extraction Based on Wavelet Transform	K. Mahaphonchaikul, D. Sueaseenak, C. Pintavirooj, M. Sangworasil, S. Tungjitkusolmun	Type of muscle: Flexor Carpi Radialis, Flexor Carpi Ulnaris Type of electrode: two electrodes of SWAROMED Al/AgCl	6 DOF of wrist movement: wrist flexion, wrist extension, hand close, hand open, radial deviation, ulnar deviation	4. RMS and logRMS 5. Standard Deviation (SD)

CHAPTER 3

METHODOLOGY

This chapter is the methodology of the project that covers the method used of the whole research. This section includes the methodology according to the objectives of this project. Firstly, this chapter starts with the overall flowchart of this project. After that, the next part covers the methodology for the first objective, which is the forearm raw EMG signal extraction based on indirect handgrip force and wrist angle. For the first objective, there are several procedures that are muscle selection, skin preparation procedures, MVC exercise and lastly the extraction of raw EMG signals. For the second objective, which is feature extraction stage there are several procedures that include the connection of Arduino Mega 2560, feature extraction of Standard Deviation and Mean Absolute Value methods. Lastly, this chapter covers the methodology on the third objective, which, is the analysis of performance on feature extraction methods.

3.1 Flowchart

In this research, several procedures are conducted to fulfill the objectives. The flowchart of the methodology of this research is shown on Figure 3.1.

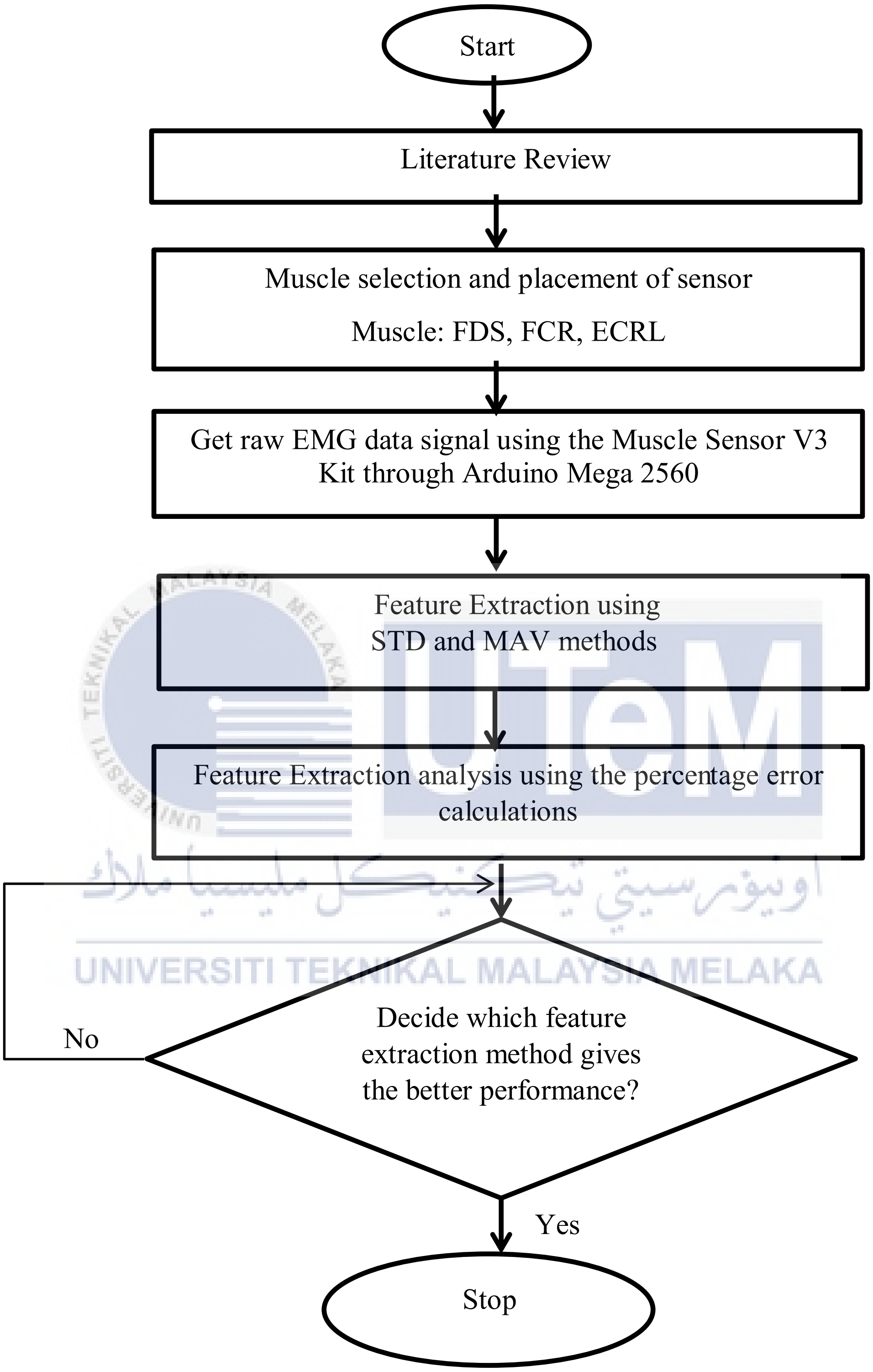


Figure 3.1: The flowchart of the methodology

3.2 Forearm Raw EMG Signal extraction Based on Indirect Handgrip Force and Wrist Angle.

The forearm raw EMG signal extraction is firstly start with muscle selections. Then, the skin preparation procedures have to be done. The EMG signal is a microvolt scaled signal. Due to this, MVC exercise is done to make calibration to the amplitude of the EMG signal. Next, the procedure of extracting the raw EMG is listed.

3.2.1 Muscle selection

The procedures of muscle selection are as follows:

1. The muscles are located by placing the palm of our hand on the medial epicondyle and extended our thumb and fingers down the forearm. This is shown in Figure 3.x.
2. The muscle selected is at index finger, which is the FCR muscle, ring finger is the FDS muscle.
3. The ECRL muscle is located at the posterior fascial compartment of the forearm.

Figure 3.2: Locating the forearm muscle

3.2.2 Skin preparation procedures

In this research, EMG signal are extracted by using the surface electrodes to get the raw EMG signal from the muscle. Skin preparation has to be carried out for better surface electrodes application and to ensure the quality of EMG signals measurements. The procedures of the skin preparation are as follows:

1. The hair on the forearm is removed to improve the adhesion of the surface electrodes. This application is usually done on humid condition or for sweaty skin type.
2. The forearm skin is cleaned by soft rubbing on the skin using a towel with pure alcohol. Alternatively can be done by sweeping a very fine sand paper on the forearm. This is done softly and controlled pressure in 3 or 4 sweeps.
3. The skin impedance is measured by ohm-resistance between the electrode pair. The recommendation range for skin impedance is shown on Table 3.1.

Table 3.1: Recommendations for skin impedance. [6]

Impedance range (KOhm)	Recommendation
1-5	Very good condition
5-10	Good and recommended if feasible
10-30	Acceptable for easy conditions
30-50	Less good and attention is needed
>50	Should be avoided or requires a second cleaning

Figure 3.3: Skin preparation using the alcohol swabs

3.2.3 MVC Exercise

To do the MVC normalization method, the exercise of the movement of the muscle is done. The movements of hand close (HC), hand open (HO), wrist flexion (WF), and wrist extension (WE) are selected. Figure 3.3 shows the hand movements.

1. The forearm is needed to be static on a fixed table.
2. Static fix at middle position within the range of motion give the best results. Due to this, the forearm is needed to be static on a fixed table.
3. For the HC and HO movement, the hand is stretched out on the table with anterior side of the hand facing up.
4. The subject is instructed to relax the hand at the beginning of the raw EMG signal extraction time. This is to produce the baseline of the raw EMG signals.
5. The HC and HO movement is done in maximum effort after 3-5 seconds.
6. The movement is hold for 3 seconds and calm for 3 seconds.
7. The movement is repeated with a pausing period of 30 to 60 seconds in between.
8. Steps 1 to 7 are repeated for the WF and WE movement.

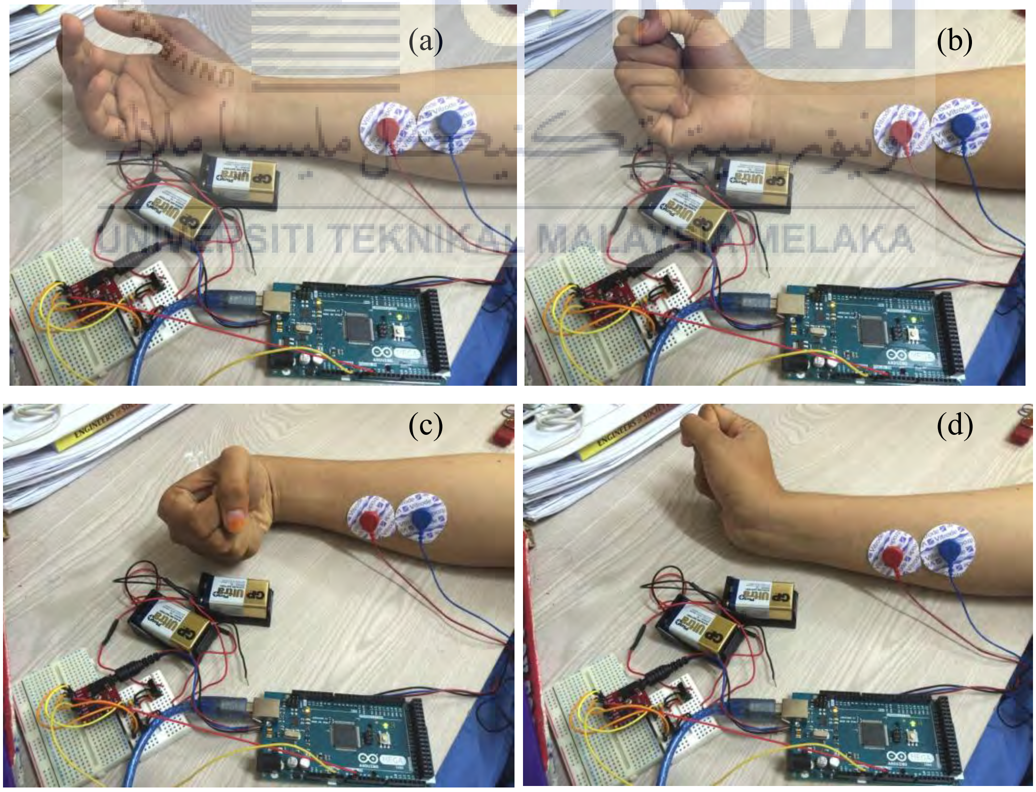


Figure 3.4: Movements of the hand. (a) Hand open (HO) (b) Hand close (HC) (c) Wrist flexion (WF) (d) Wrist extension (WE)

3.2.4 Extraction of raw EMG Signals

In this research, it is required to use the basic system to obtain the EMG signals. EMG signals are normally extracted from the human muscle using electrodes. After that, the data acquisition and signal processing is designed to produce the data to the user. Figure 3.5 shows the block diagram of the system design for extraction of raw EMG signals.

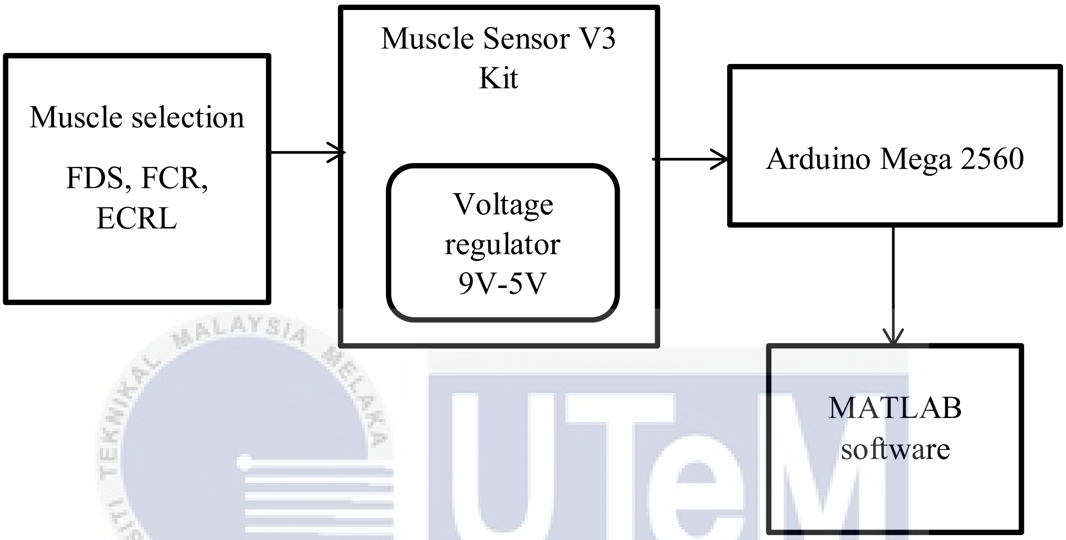


Figure 3.5: Block diagram of system design for extraction of the raw EMG signals

The procedures of extracting the raw EMG signal are as follows:

1. The Muscle Sensor V3 Kit connected with power supply of two 9V batteries.
2. The voltage regulator for the Muscle Sensor V3 kit is constructed in Multisim software. The voltage regulator is constructed to have output of 5V.
3. This voltage regulator circuit is simulated using the Multisim software.
4. The pre-gelled silver/silver chloride surface electrodes are placed on the muscles selected. General recommendation of placing the electrodes is by 2cm apart from each center point of the electrodes.
5. The electrodes are applied in parallel to the muscle fiber direction.
6. The measurements of the raw EMG signals are obtained by movement of the hand.
7. The data of the EMG signals are required to be digitalized by using the Arduino Mega 2560 device to be compatible with the computer.
8. The raw EMG signals from the Arduino Mega are sent to the computer through the MATLAB Software for further process

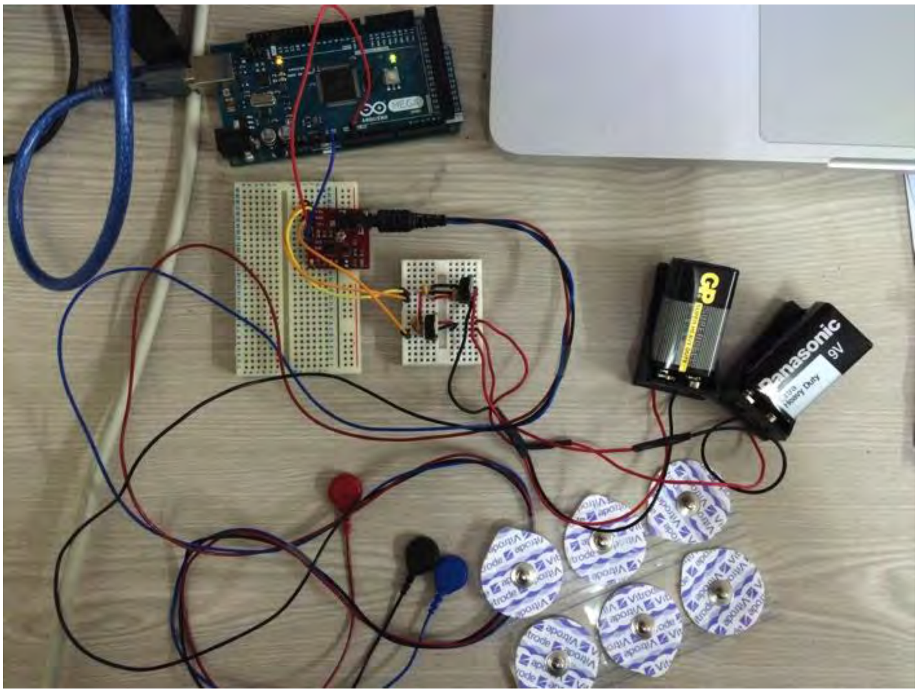


Figure 3.6: Overall circuit for extracting the EMG signal

The extraction of raw EMG signals data from the forearm muscle will be done by controlling the environment is as follows:

1. A low noise environment is set up to decrease the artifacts in the signal
2. While extracting the ra EMG signal, the subject will be seating on a chair.
3. The data of the forearm signal will be taken from male and female subjects.
4. The experiment set up is shown in Figure 3.6.

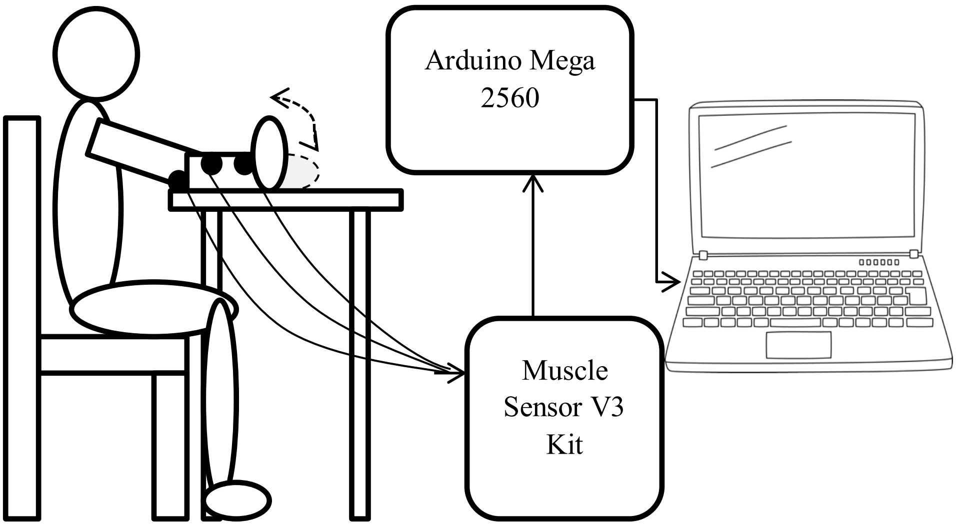


Figure 3.7: The experiment set up diagram

3.2 Feature Extraction Stage

After getting the raw EMG signal, the Arduino Mega 2560 is then connects the data from the Muscle Sensor V3 Kit to the computer. Feature extraction is performed to the EMG signals. The STD and MAV method are selected for this research.

3.3.1 Arduino Mega 2560

The Arduino Mega 2560 is the device that acts as the Analog-Digital converter for the Muscle Sensor V3 Kit. The procedures of connecting Arduino Mega are as follows:

1. MATLAB simulink block is set up for Arduino Mega Interface.
2. The analog input channel of the Arduino Mega is selected.
3. The Muscle Sensor V3 Kit is connected with Arduino Mega.
4. Arduino Mega conditioned the EMG signal by converting it from analog to digital signal.
5. The Arduino Mega is connected to the computer through MATLAB.

Figure 3.8: Arduino Mega 2560

3.3.2 Feature Extraction using the STD method

Standard deviation is stated that it is measures the spread of data from the mean. The STD feature extraction stage procedures are as follows:

1. The raw EMG signal is used to perform the STD feature extraction method.
2. The MATLAB software is used to do the feature extraction.
3. The SIMULINK block diagram is constructed in the MATLAB software.
4. The STD method is performed by adding the amplitudes of the raw EMG signals. This is simply done by using the MATLAB interface.

3.3.3 Feature Extraction using the MAV method

The MAV method is a popular feature used in EMG hand movement recognition application. The MAV feature extraction stage procedures are as follows:

1. The raw EMG signal is used to perform the MAV feature extraction method.
2. The MATLAB software is used to do the feature extraction.
3. The SIMULINK block diagram is constructed in the MATLAB software.
4. The MAV is performed by calculate the average of the absolute value of EMG signal amplitude. This is simply done by using the MATLAB interface.

3.4 Analysis of Performance on Feature Extraction Methods

The performance on feature extraction methods is analyzed. This is to determine the better feature extraction method. The analysis procedures are as follow:

1. The data of EMG signal that has been feature extracted of 5 healthy subjects with 4 hand movements are collected.
2. The data of EMG signals are presented in scattered plot.
3. The percentage errors of the feature extractions between STD and MAV are determined.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter shows the results of the research and it is also discussed. The result and discussion of this research is divided by the objectives of the research. The first section will be about raw EMG signal extractions. After that, the feature extraction methods of MAV and STD is performed, calculated and tabulated. Lastly, the result and discussion of the performance analysis by using percentage error calculation also done in this chapter.

4.1 Raw EMG Signal

This section covers the voltage regulator and Muscle Sensor V3 Kit testing, and also the raw EMG signal extraction. For the raw EMG signal extraction, the data extracted are shown and discussed according the the muscle selected which are FDS, FCR and ECRL muscles.

4.1.1 Voltage Regulator and Muscle Sensor V3 Kit Testing

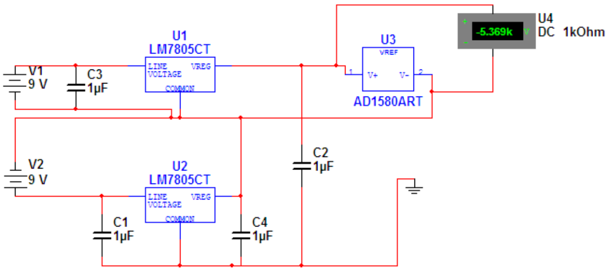


Figure 4.1: Voltage regulator constructed using the Multisim software.

The voltage regulator is drawn and simulated using the Multisim software. The voltage regulator is constructed by using two 9V batteries, two LM 7805 with four capacitors. To simulate the circuit drawn, the voltmeter is set up parallel with the output and the output of 5.369V is obtained. This voltage regulator is constructed for the Muscle Sensor V3 kit input. This is because the Muscle Sensor V3 Kit requires the input of 5V.

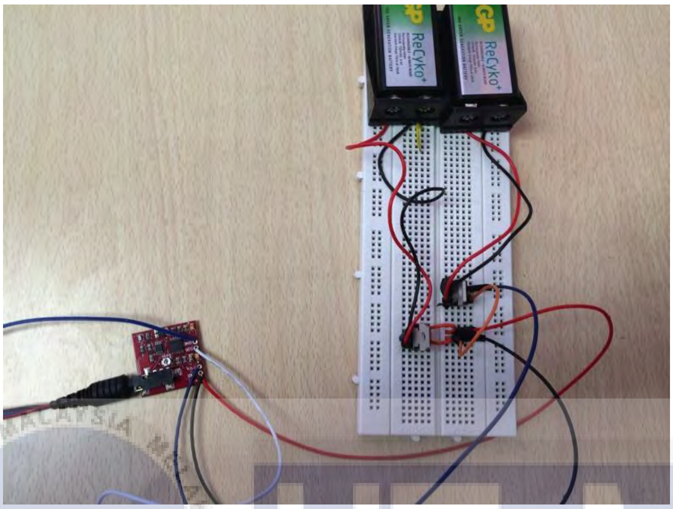


Figure 4.2: Voltage regulator constructed on breadboard

Figure 4.3: Raw EMG signal from the Muscle Sensor V3 Kit for handgrip using the oscilloscope

From the figure above, the baseline was set at the notation (1) on the left side of the picture. The maximum amplitude of this EMG signal is 1.48V whereas the minimum amplitude is 128mV. The straight baseline is the EMG signal is when the muscle is relaxed. A continuous handgrip was applied after the baseline. The first spike of the EMG signal is when the hand is gripped or hand closed (HC) movement.

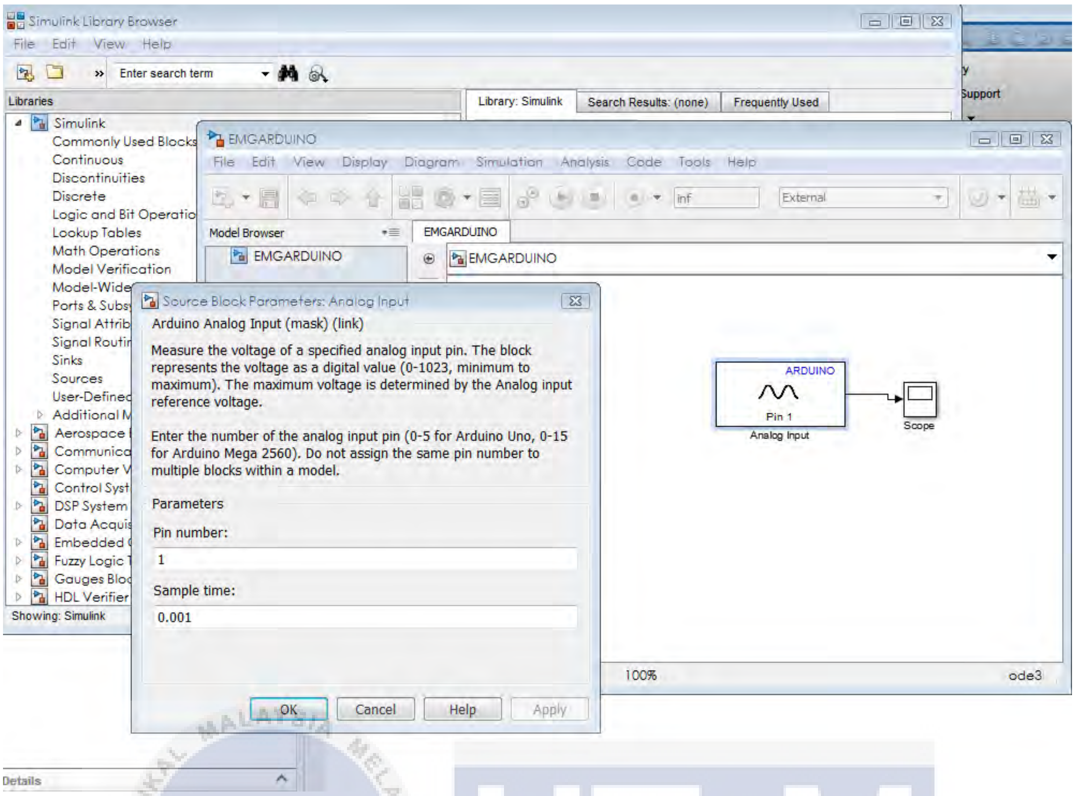
The amplitude of EMG signal increases when the contraction of muscle is higher. The contraction becomes higher when the handgrip force increase. The fluctuation of the EMG signal is caused by the inconstant handgrip. This is because the handgrip movement for this EMG signal does not consider MVC. Other than that, this handgrip EMG signal was not assisted by dynamometer.

Other than that, from the signal in Figure 4.3, after a period of time of a grip, the amplitude of the signal decreases with time. This shows that the subject is experiencing muscle fatigue. To avoid the muscle fatigue, MVC exercise will be done to collect the data of the EMG signals.

4.1.2 Raw EMG Signal extraction

The Raw EMG signal of FDS muscle is taken directly from the MATLAB software. The overall circuit is set up by using Muscle Sensor V3 Kit connected with Arduino Mega 2560 then the signal is then transfer to the computer through the MATLAB software. The data of the EMG signal is recorded for each subject.

From the MATLAB software, the SIMULINK block diagram is used. The Figure 4.4 is the construction of the SIMULINK block diagram. From the source Block Parameters: Analog input window, it shows that the analog pin number 1 is used in this experiment. Other than that, a sample time of 0.001 seconds is set up.



Source Block Parameters: Analog Input

Arduino Analog Input (mask) (link)

Measure the voltage of a specified analog input pin. The block represents the voltage as a digital value (0-1023, minimum to maximum). The maximum voltage is determined by the Analog input reference voltage.

Enter the number of the analog input pin (0-5 for Arduino Uno, 0-15 for Arduino Mega 2560). Do not assign the same pin number to multiple blocks within a model.

Parameters

Pin number: 1

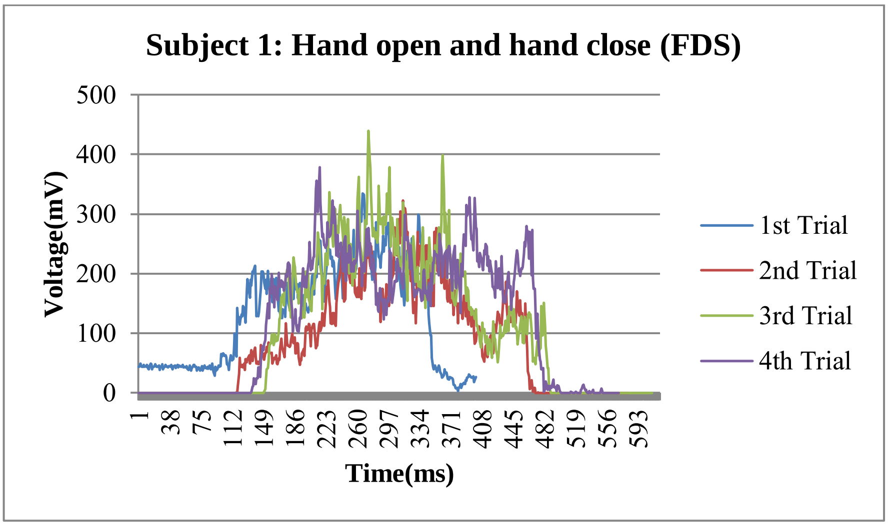
Sample time: 0.001

Figure 4.4: Simulink block diagram construction on MATLAB software

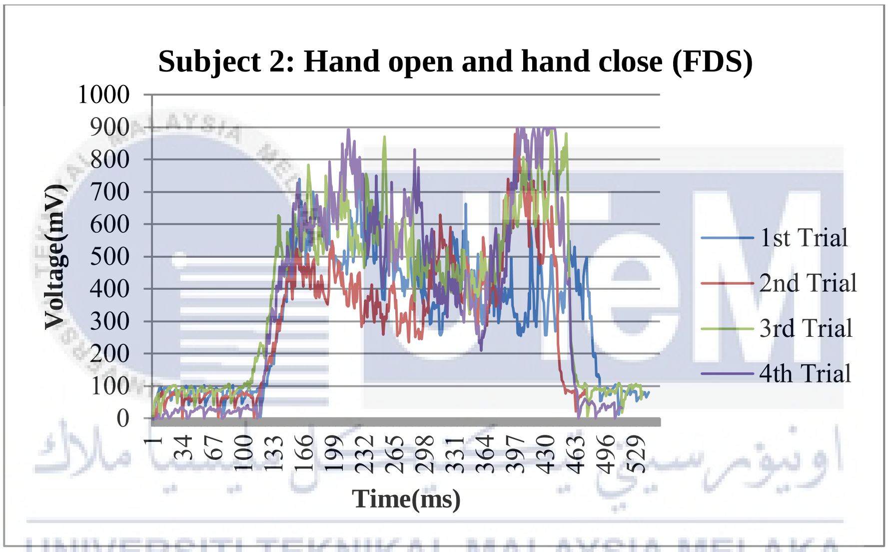
In this project, 5 heatlhy subjects are tested with the same three muscles and four hand movements. The three muscles used in this project are Flexor Digitorum Superficialis (FDS), Flexor Carpi Radialis (FCR), and Extensor Carpi Radialis Longus (ECRL). The hand movement considered in this project is hand close, hand open, wrist extension, and wrist flexion. For the hand movement, it is combined into 3 experiments, which are the hand open and hand close, wrist extension with the hand closed, and also the wrist flexion with the hand closed. This is done to differentiate the pattern of the EMG signal between the movements. For the EMG signal extraction, the data collected is explained by the muscle activities. The comparison of different muscle selection and hand movement is done for each of the subjects.

4.1.2.1 Flexor Digitorium Superficalis (FDS) muscle

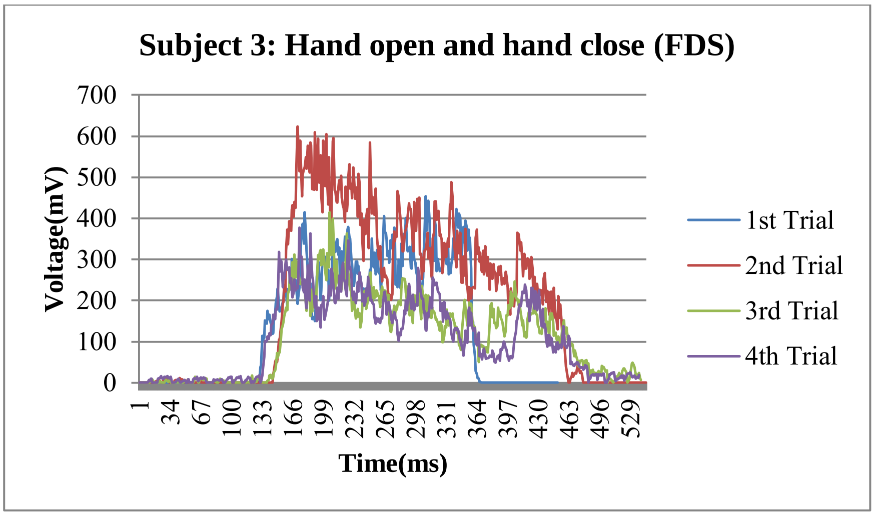
From the literature review, it is studied that FDS is the main muscle of the anterior forearm. This muscle is the main muscle that contract while gripping and also flexing. Figure 4.5 shows the EMG signal for hand open and hand close movement of 5 healthy subjects.


Subject 1: Hand open and hand close (FDS)
Voltage(mV)
500
400
300
200
100
0
1
38
75
112
149
186
223
260
297
334
371
408
445
482
519
556
593
Time(ms)
1st Trial
2nd Trial
3rd Trial
4th Trial

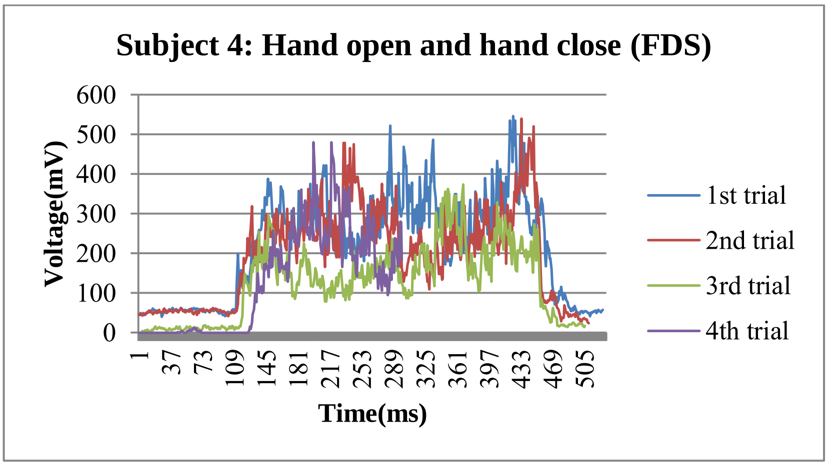
(a)


Subject 2: Hand open and hand close (FDS)
Voltage(mV)
1000
900
800
700
600
500
400
300
200
100
0
1
34
67
100
133
166
199
232
265
298
331
364
397
430
463
496
529
Time(ms)
1st Trial
2nd Trial
3rd Trial
4th Trial

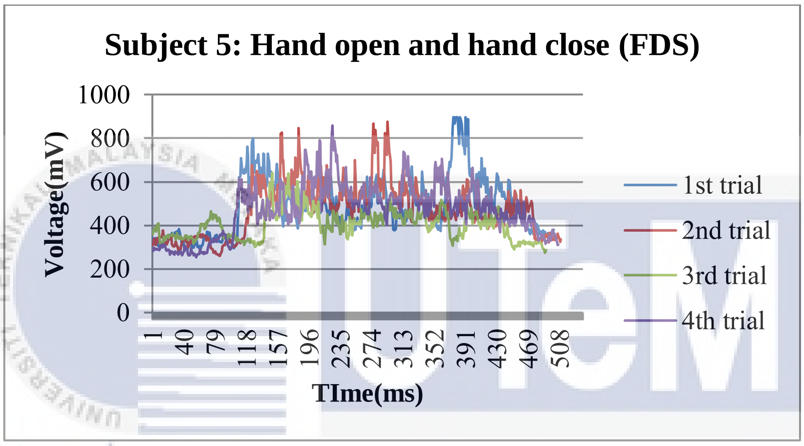
(b)


Subject 3: Hand open and hand close (FDS)
Voltage(mV)
700
600
500
400
300
200
100
0
1
34
67
100
133
166
199
232
265
298
331
364
397
430
463
496
529
Time(ms)
1st Trial
2nd Trial
3rd Trial
4th Trial

(c)



(d)

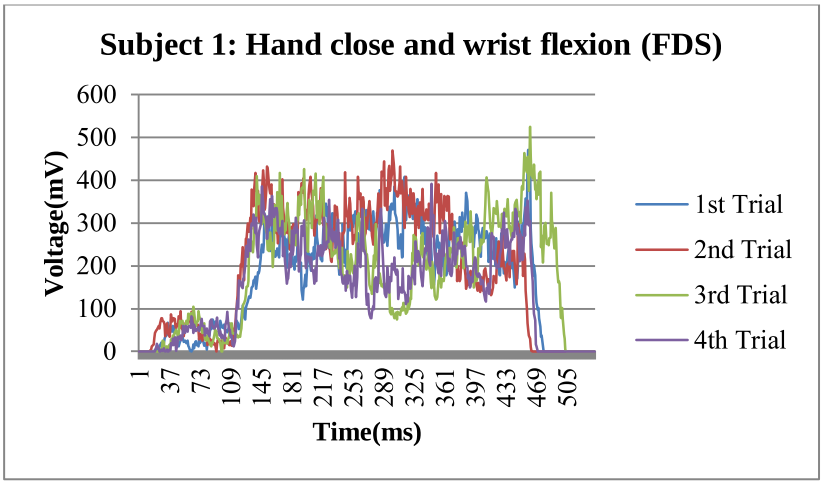


(e)

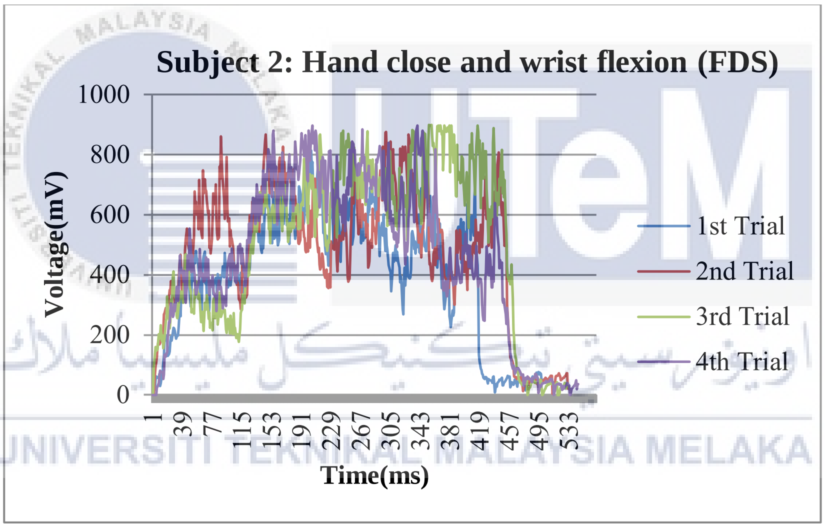
Figure 4.5: EMG signals for hand open and hand close of FDS muscle of : (a) Subject 1. (b) Subject 2. (c) Subject 3. (d) Subject 4. (e) Subject 5

For the hand open and hand close experiment, it shows that, for each subjects that when the hand is opened or relaxed, it is having an approximately 0mV of voltage difference. This is because, when the hand is relaxed, the muscle contraction is nearly does not occur. Due to this, the average voltages of the hand open movement around 0-100mV. This can be seen on the EMG signals below. The lowest voltage from the EMG signal is 0mV whereas the highest is at around 900mV according to the graphs below. From these values, we can futher on classifying the movement of hand open to be 0-100mV and hand close/handgrip to be 400-600mV for the FDS muscle.

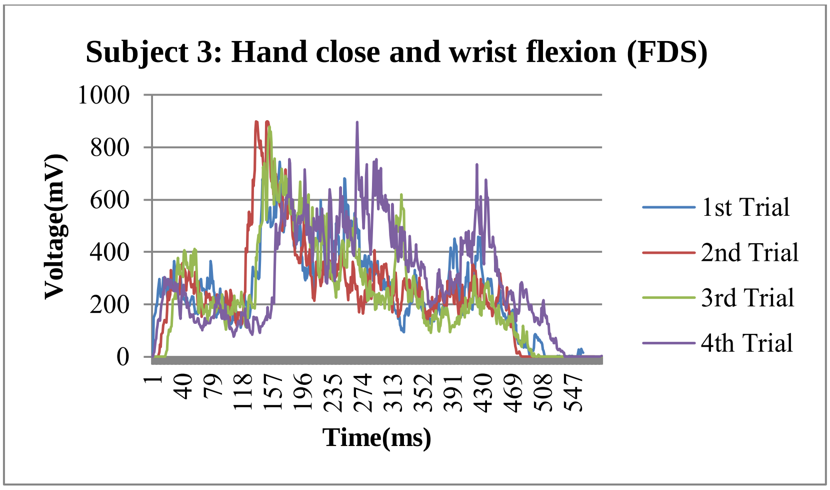
For the movement of hand close and wrist flexion, it proves that the FDS muscle controls the movement of flexion of the wrist. The experiment is done by starting with a handgrip and then the wrist is flexed to show the difference of the amplitude of the muscle activities. The EMG signals of this movement can be seen on figures below.



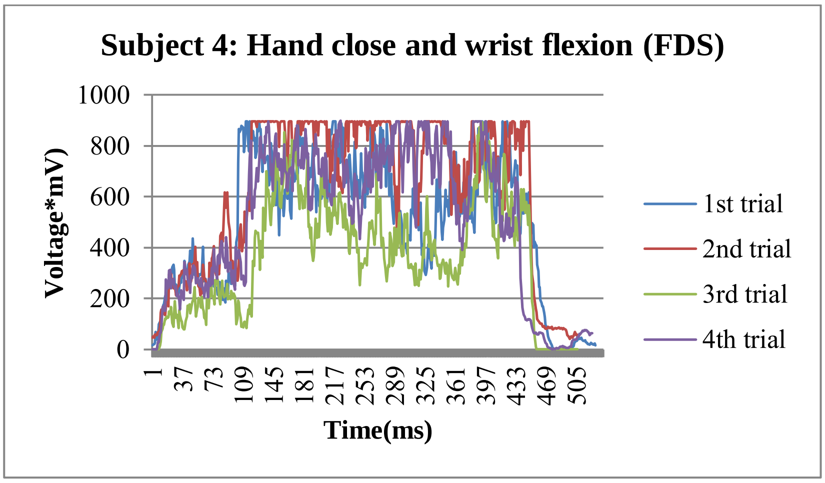
(a)



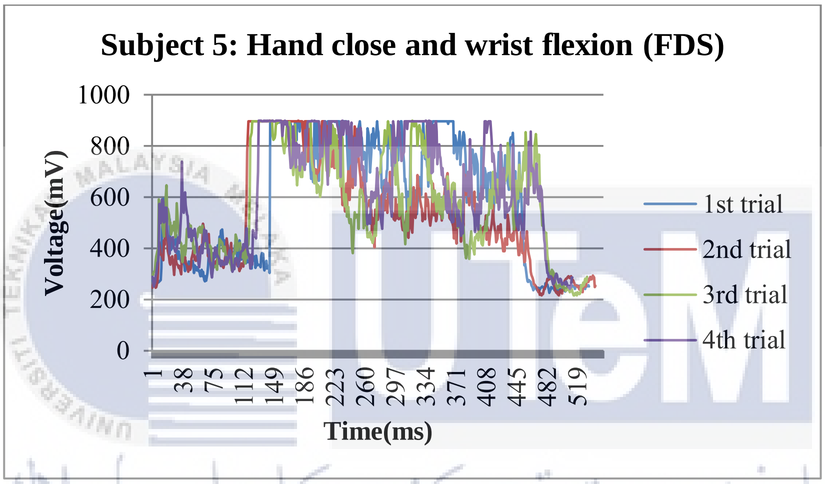
(b)



(a)



(b)

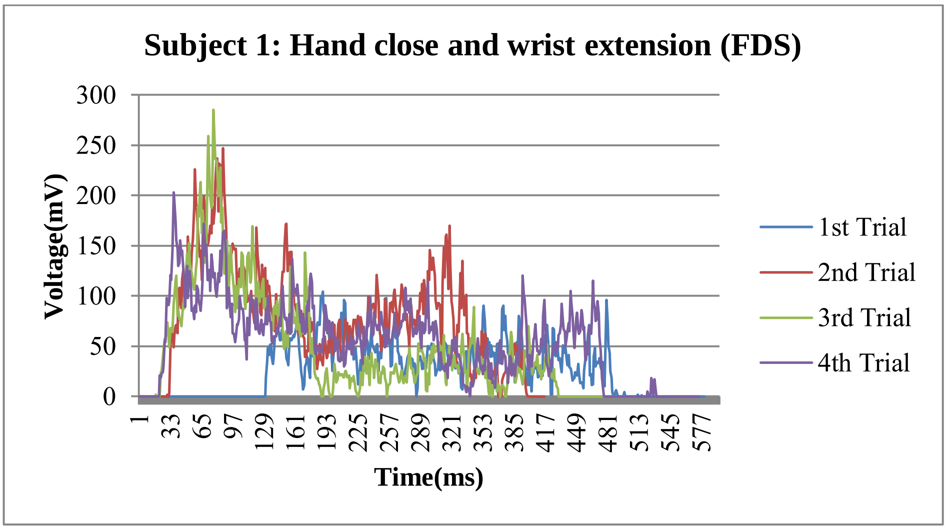


(c)

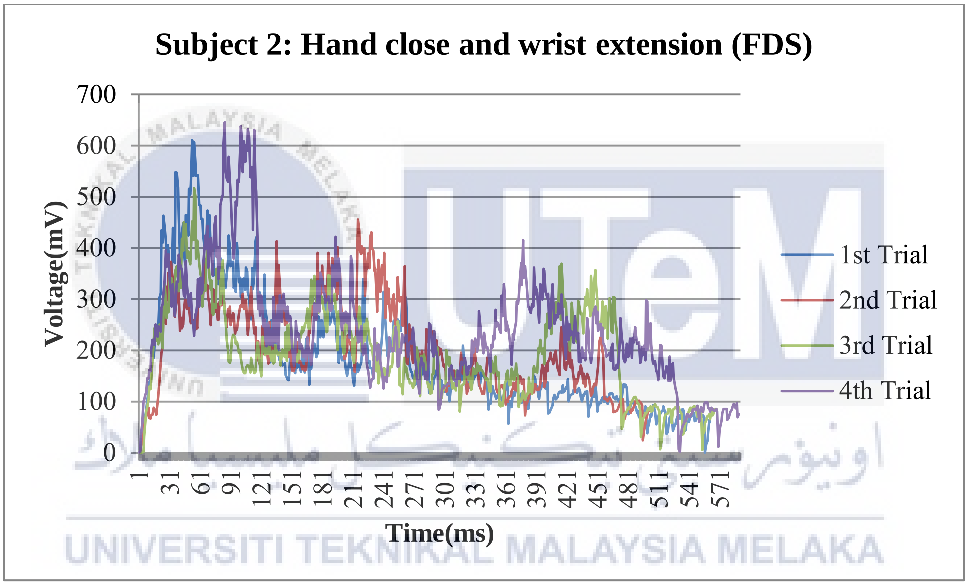
Figure 4.6: EMG signals for hand close and wrist flexion of FDS muscle of : (a) Subject 1. (b) Subject 2. (c) Subject 3. (d) Subject 4. (e) Subject 5

From the graph of the EMG signals, we can see that the signal has its own pattern for the hand close and wrist flexion movement. Other than that, the EMG signals shows that the handgrip voltage peak is lower than the flexion movement. The handgrip has the voltage value of around 400mV-600mV whereas the wrist flexion voltage value is up to around 600-800mV.

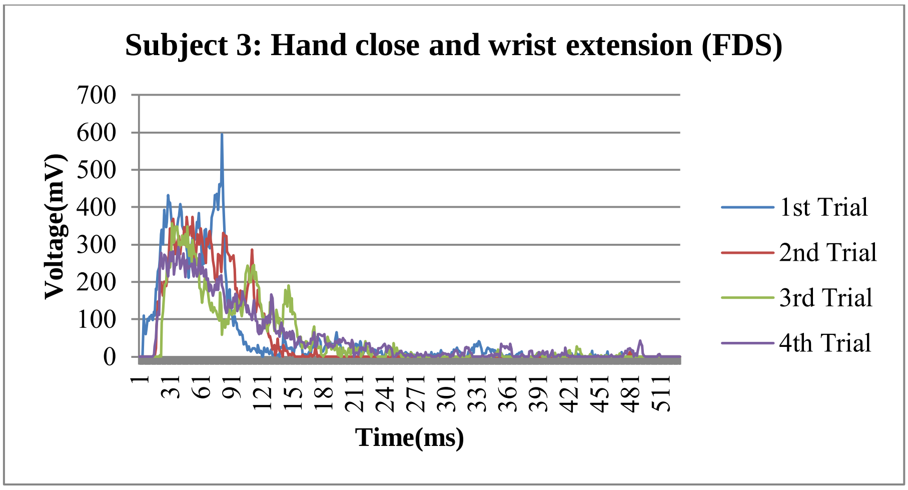
For the last movement of hand close and wrist extension, the same experiment set up is done, this can be referred to Chapter 3 of this research. The movement of hand close and wrist extension is done by starting with gripping the hand, and then the wrist is extended. The EMG signal recorded for each subjects is as below.


Subject 1: Hand close and wrist extension (FDS)
Voltage(mV)
300
250
200
150
100
50
0
1
33
65
97
129
161
193
225
257
289
321
353
385
417
449
481
513
545
577
Time(ms)
1st Trial
2nd Trial
3rd Trial
4th Trial

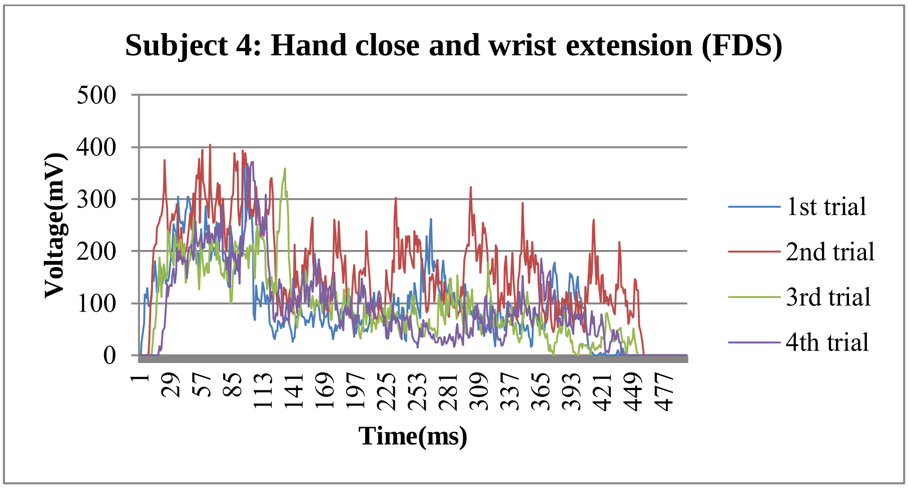
(a)


Subject 2: Hand close and wrist extension (FDS)
Voltage(mV)
700
600
500
400
300
200
100
0
1
31
61
91
121
151
181
211
241
271
301
331
361
391
421
451
481
511
541
571
Time(ms)
1st Trial
2nd Trial
3rd Trial
4th Trial

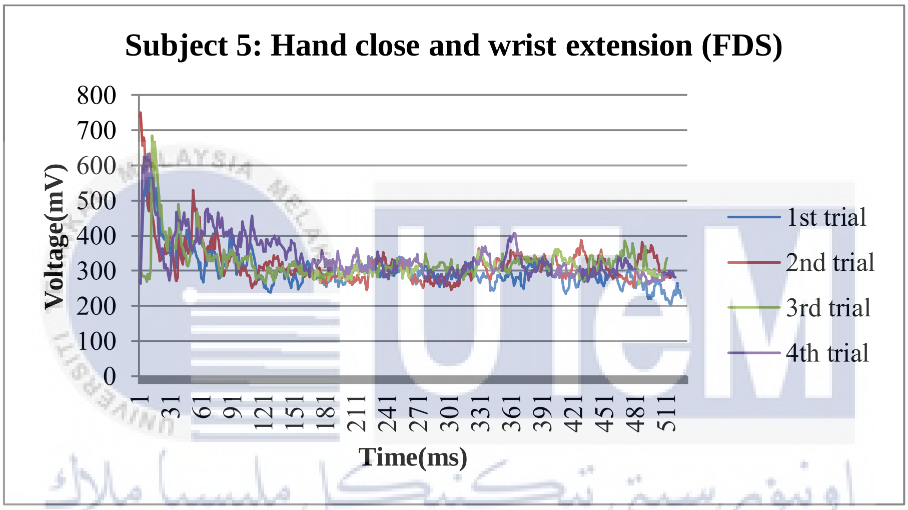
(b)


Subject 3: Hand close and wrist extension (FDS)
Voltage(mV)
700
600
500
400
300
200
100
0
1
31
61
91
121
151
181
211
241
271
301
331
361
391
421
451
481
511
Time(ms)
1st Trial
2nd Trial
3rd Trial
4th Trial

(c)



(d)



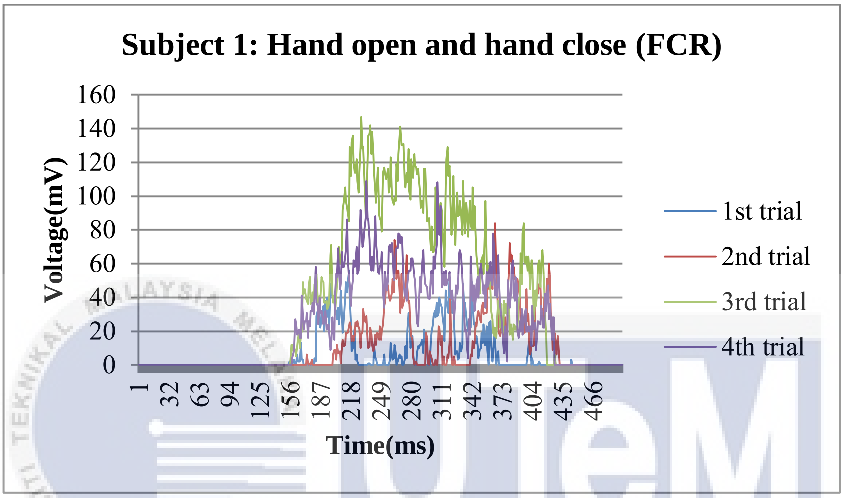
(e)

Figure 4.7: EMG signals for hand close and wrist extension of FDS muscle of : (a) Subject 1. (b) Subject 2. (c) Subject 3. (d) Subject 4. (e) Subject 5.

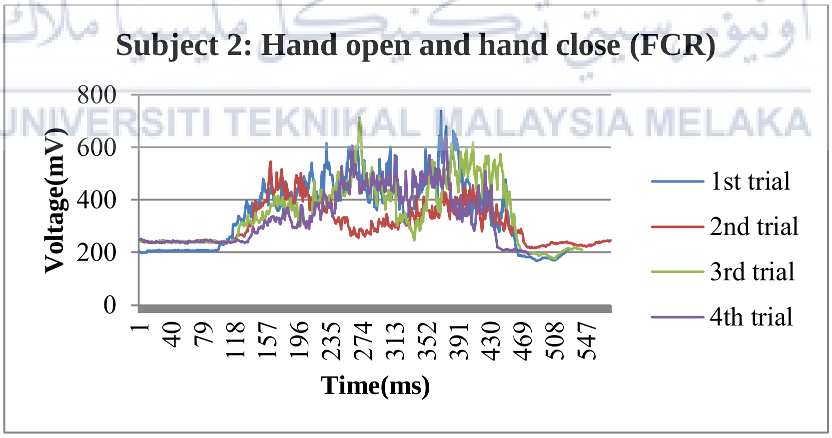
From Figure 4.7 we can see that the pattern of the EMG signal that the hand close or grip has higher voltage than the wrist extension. The same as the result of hand close and wrist flexion, the hand close has the voltage of around 400mV-600mV, whereas the wrist extension has a very small voltage, which is around 100mV-300mV for FDS muscle. The wrist extension has a small voltage value because FDR muscle does not used to extend the wrist.

4.1.2.2 Flexor Carpi Radialis (FCR) muscle

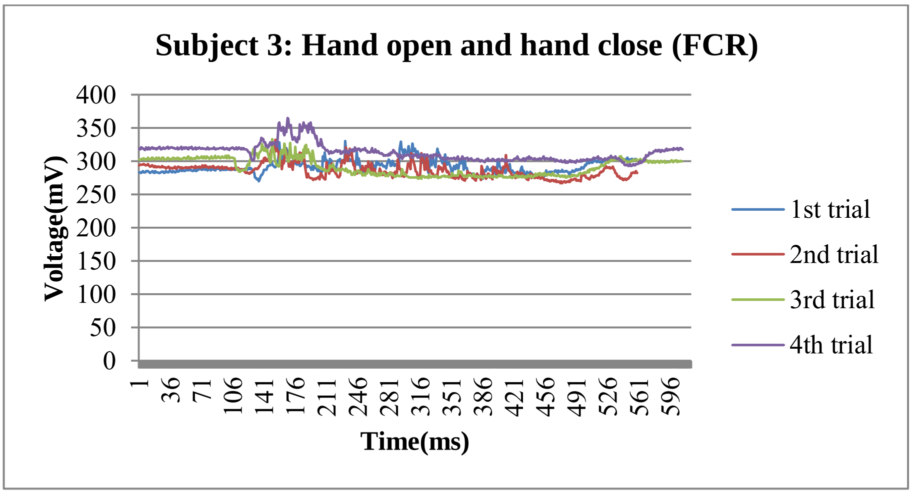
For FCR, this muscle action is to flexes and abducts hand at wrist. The movement of hand open and hand close as smaller value than muscle activity from the FDS muscle. This is because, FDS is the main muscle of the forearm, and therefore FDS has a higher muscle contraction that makes high voltage output.



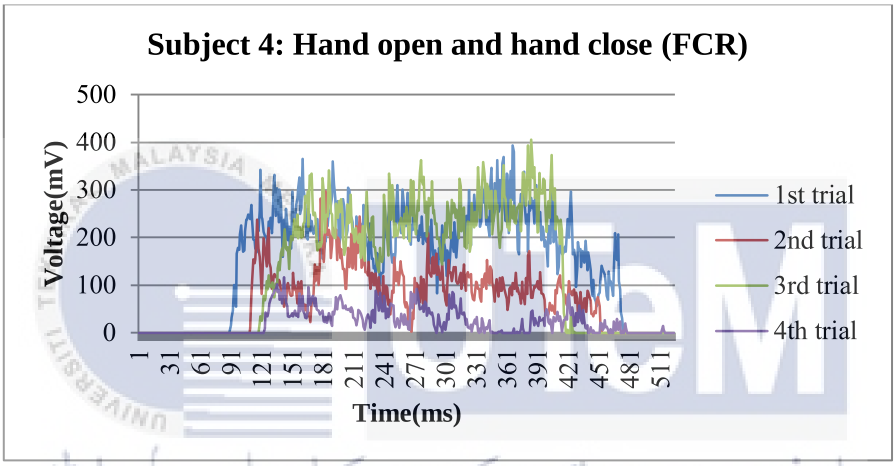
(a)



(b)



(c)



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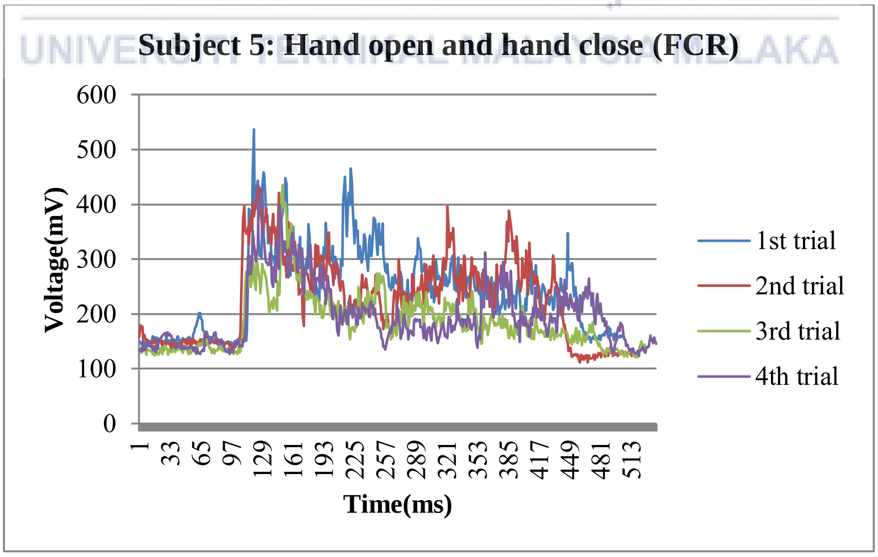
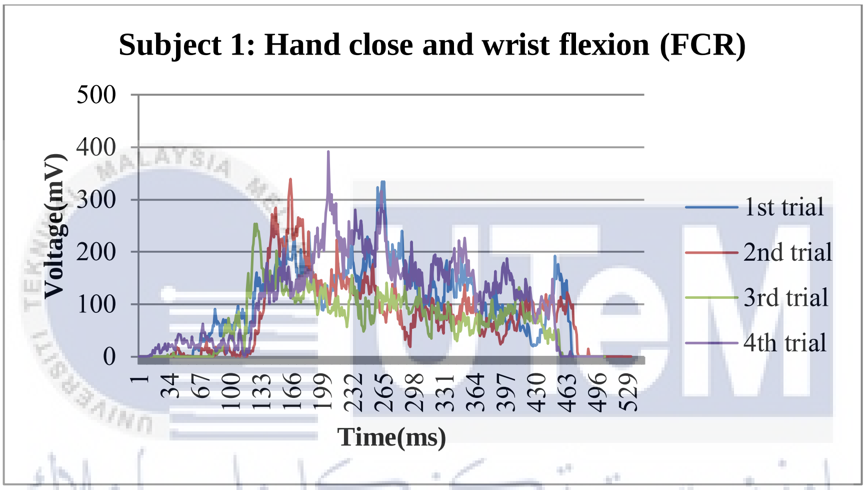


(e)

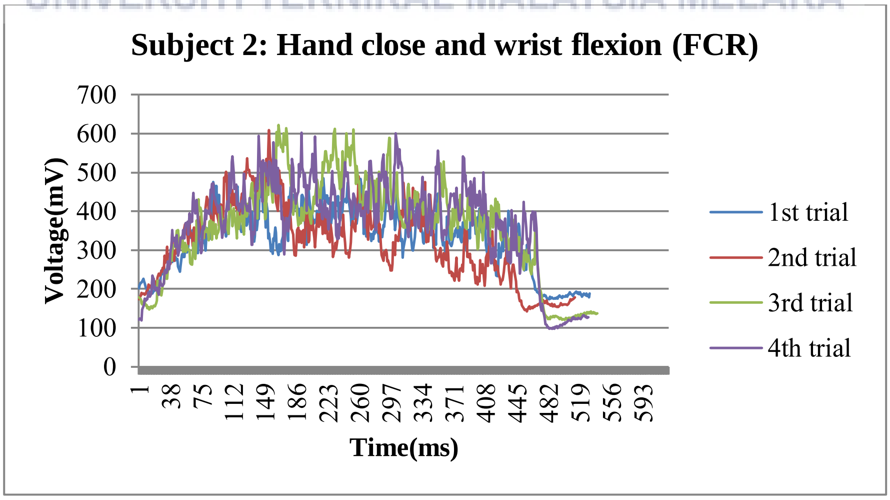
Figure 4.8: EMG signals for hand open and hand close of FCR muscle of : (a) Subject 1. (b) Subject 2. (c) Subject 3. (d) Subject 4. (e) Subject 5.

It is proven that FDS is the main muscle of the anterior forearm from the handgrip muscle activity, muscle FDS produced more voltage than the FCR muscle. Due to this, the hand close movement has a value of only 300mV-400mV whereas; the hand open is approximately having around 0mV-150mV not including those with a high noise interference. The noise interference can be seen on the EMG signal of subject 3 on Figure 4.8 (c).

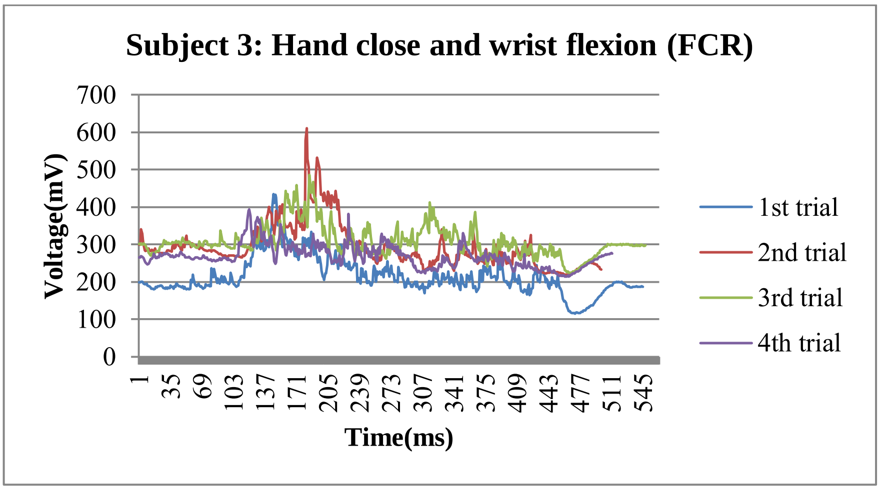
For the next movement is hand close and wrist flexion of the FCR muscle. This movement is experimented by having the subject to grip their hand and then at 3 seconds subjects are asked to flex the hand with the maximum force capable.



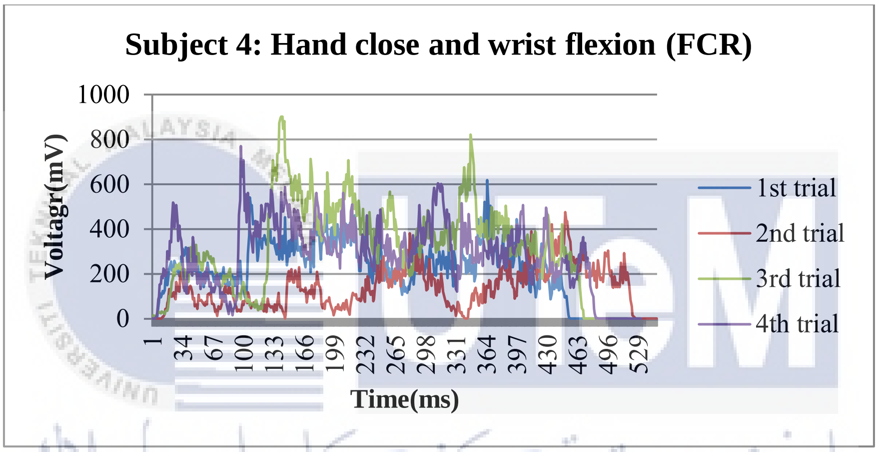
(a)



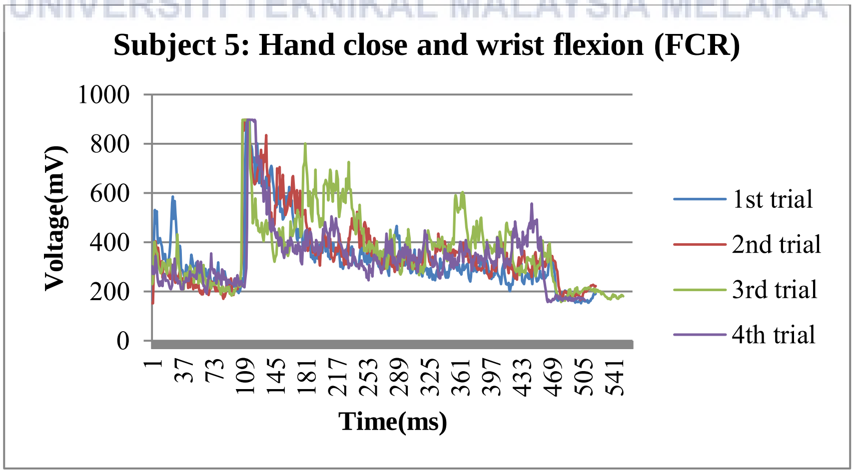
(b)



(c)



(d)

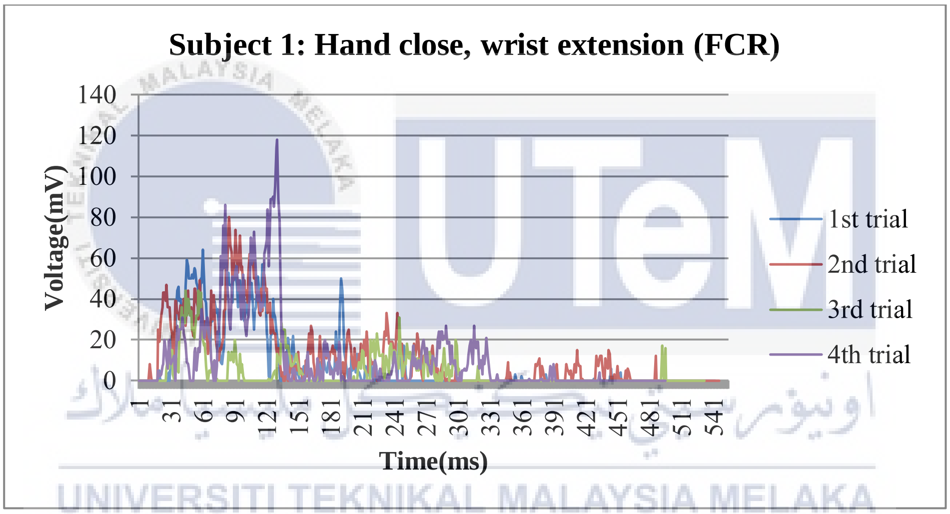


(e)

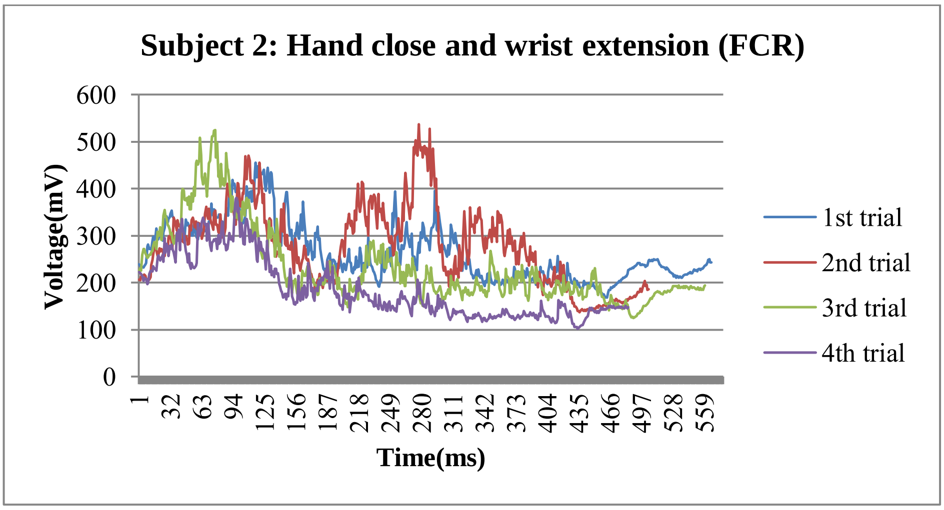
Figure 4.9: EMG signals for hand close and wrist flexion of FCR muscle of : (a) Subject 1. (b) Subject 2. (c) Subject 3. (d) Subject 4. (e) Subject 5.

From the EMG signals of the hand close and wrist flexion of FCR muscle, it shows that the pattern of the movement is almost the same as FDS. Despite that, FCR have lower amplitudes, which means lower voltage output extracted from the muscle. The hand close movement by FCR muscle produces around 50-200mV. It varies on different subjects due to different muscle capabilities. On the other hand, the wrist flexion of FCR muscle produces around 250-400mV.

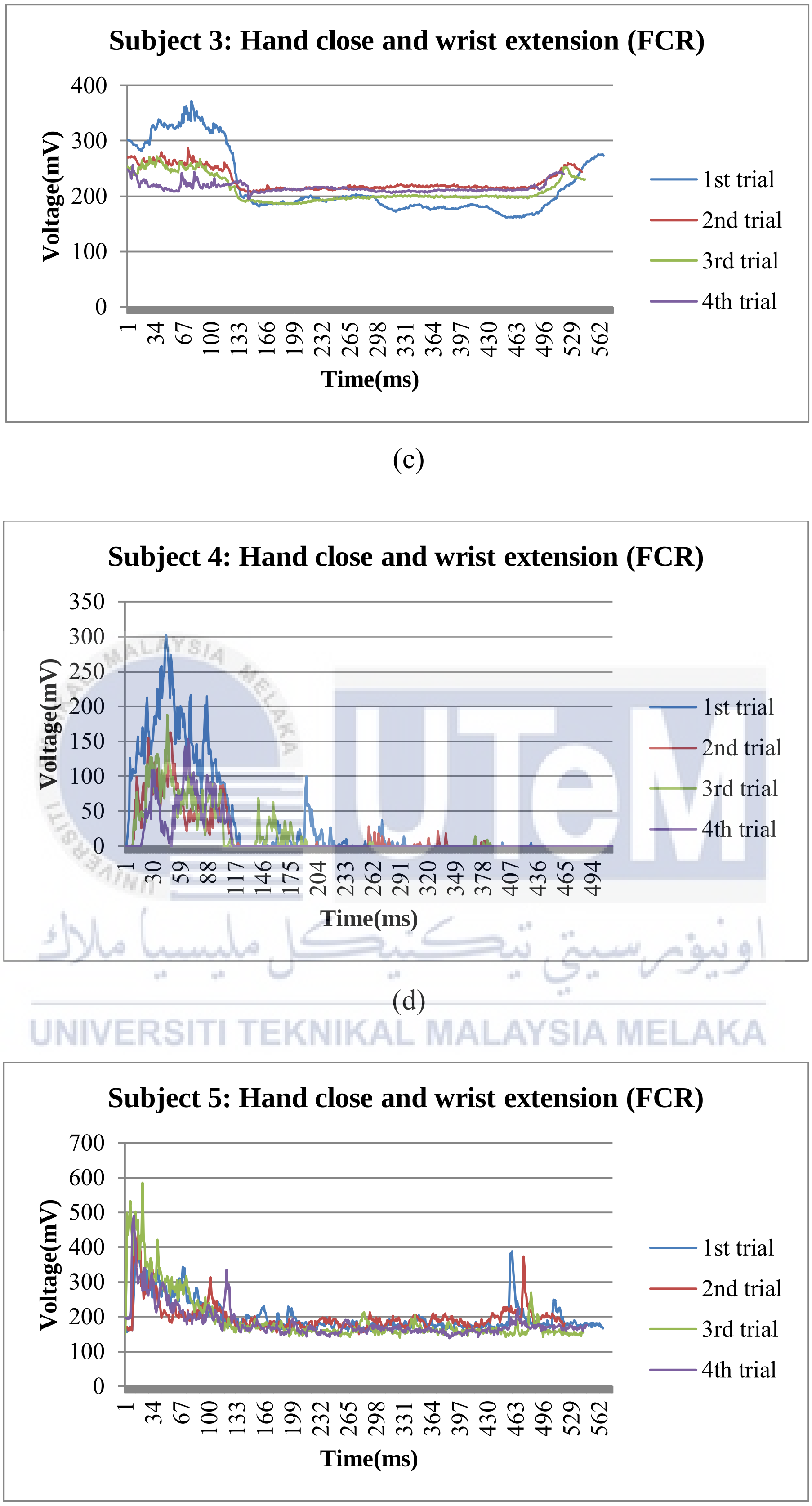
As for the next movement of the hand close and wrist extension, it shows that FCR does not control the movement of wrist extension. This is because theoretically, FCR is in control of flexion and abduction of the wrist.



(a)



(b)



(c)

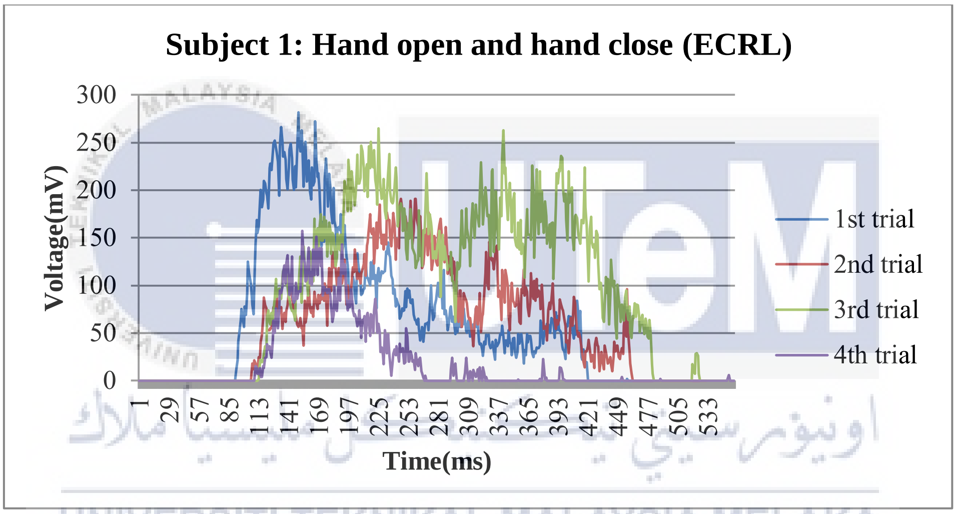
(d)

Figure 4.10: EMG signals for hand close and wrist extension of FCR muscle of : (a) Subject 1. (b) Subject 2. (c) Subject 3. (d) Subject 4. (e) Subject 5.

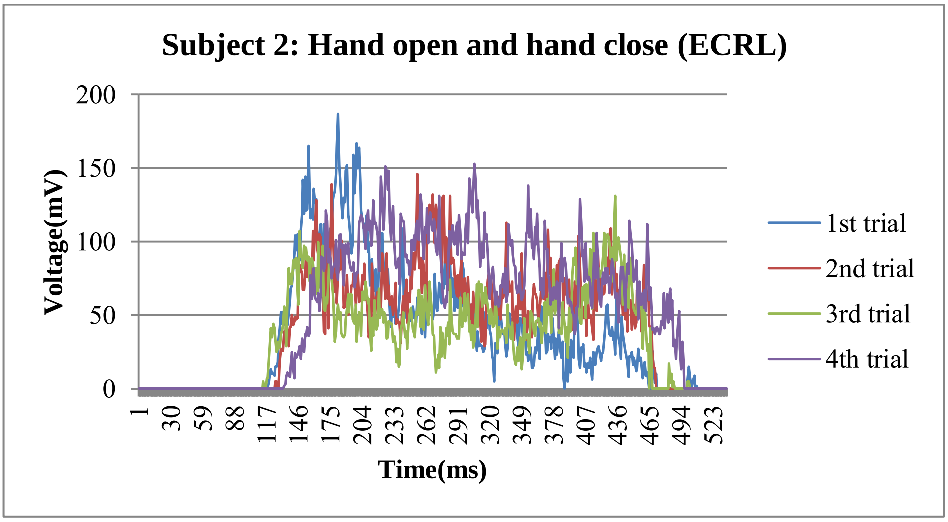
From the hand close and wrist extension movement, the FCR does not control the movement of extension. It is proven as we can see the amplitude drop from the EMG signals in Figure 4.10. The hand close of the FCR muscle produces 200-400mV whereas the wrist extension movement is having 50-100mV.

4.1.2.3 Extensor Carpi Radialis Longus (ECRL) muscle

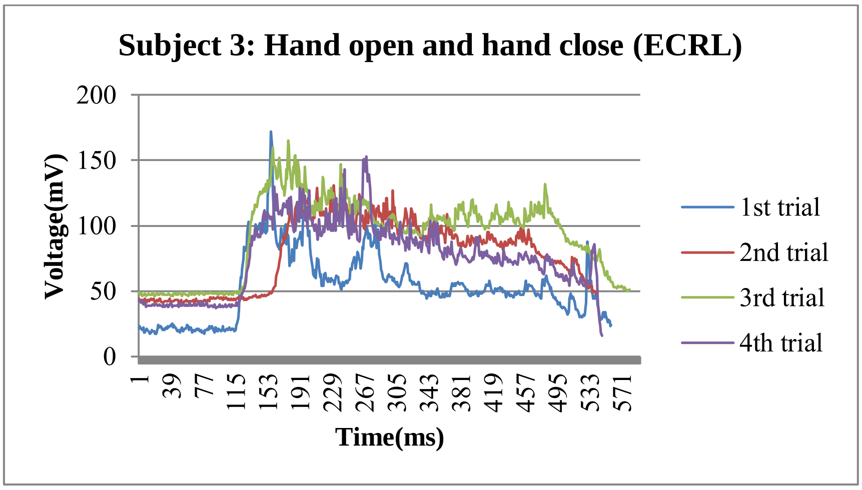
Extensor Carpi Radialis Longus (ECRL) muscle is a muscle that moves the hand specificly, extends and abducts hand at wrist joint. The first movement is hand open and hand close movement.



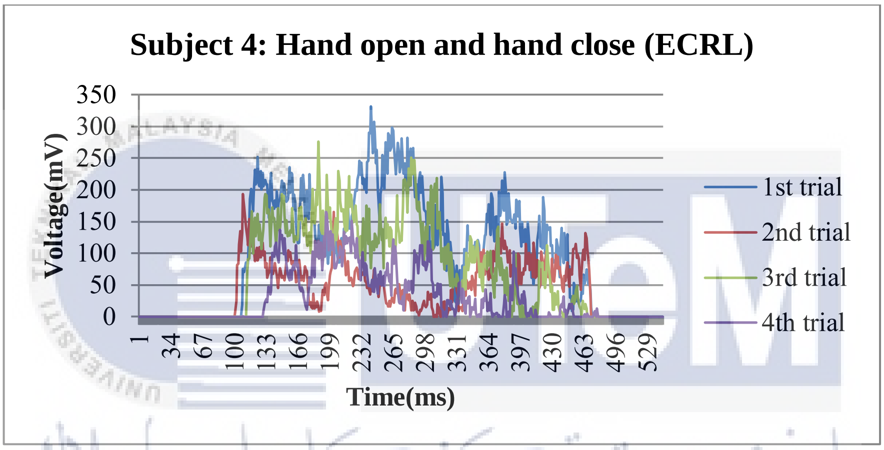
(a)



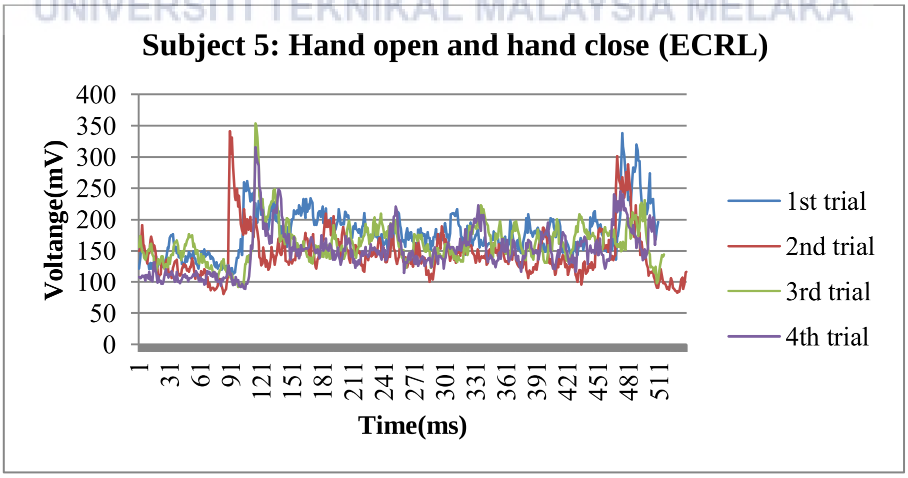
(b)



(c)



(d)

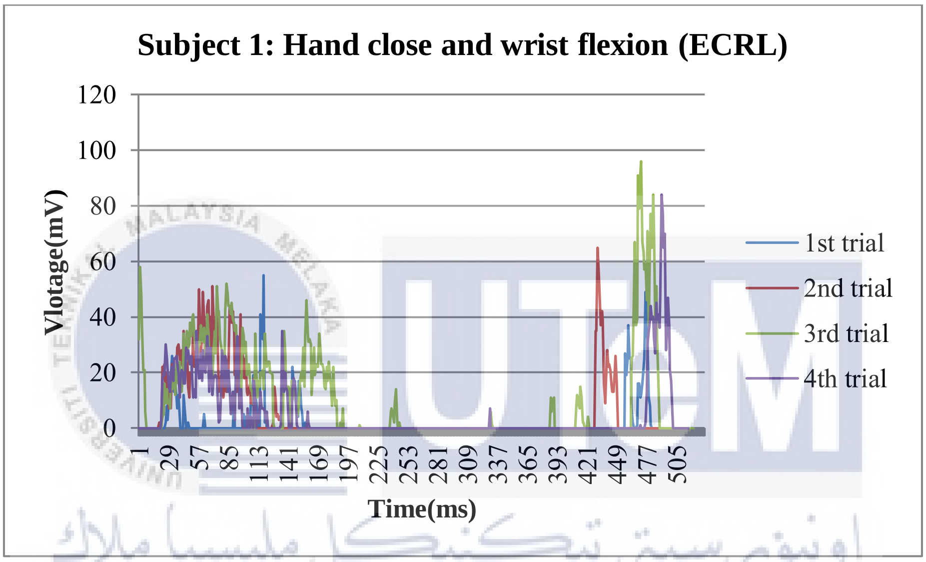


(e)

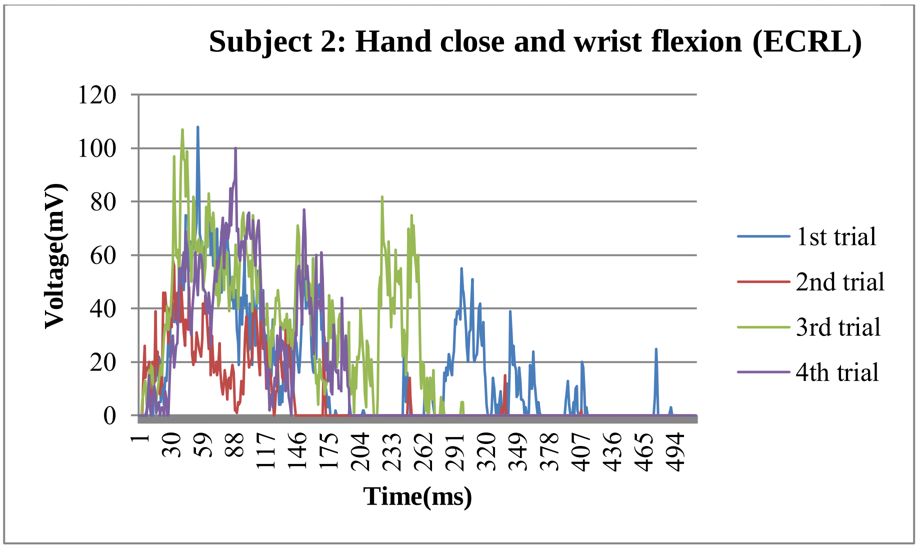
Figure 4.11: EMG signals for hand open and hand close of ECRL muscle of : (a) Subject 1. (b) Subject 2. (c) Subject 3. (d) Subject 4. (e) Subject 5.

From the EMG signals for hand open and hand close of ECRL muscle, it shows that, it produces more amplitude when the hand is extends than when the hand flexs. This shown in Figure 4.11(e) the ending of the signal shoots up it is because the subject relaxes back to hand open. When the hand is open from a hand close condition, the hand extends therefore, the ECRL muscle contracts more. Hand close movement has a value of only 100-150mV whereas; the hand open is approximately having around 0-50mV.

Next, the movement of hand close and wrist flexion of ECRL muscle is done. This experiment is the same as FDS and FCR methods.



(a)



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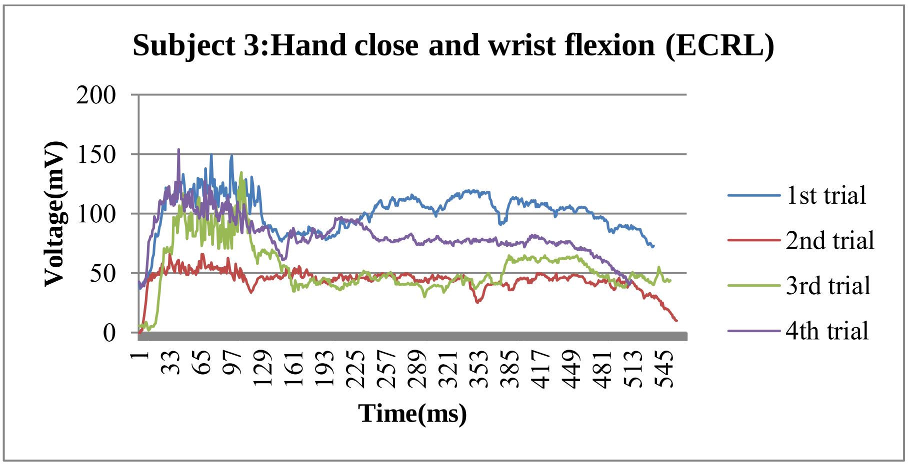
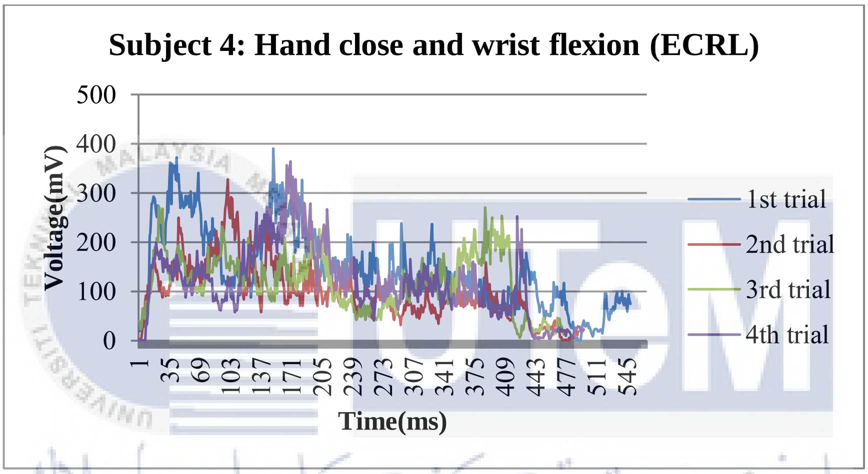
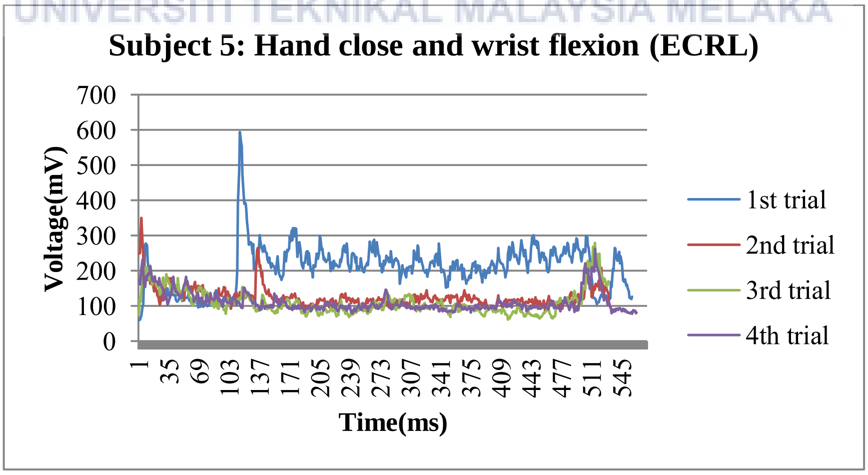


(c)



(d)

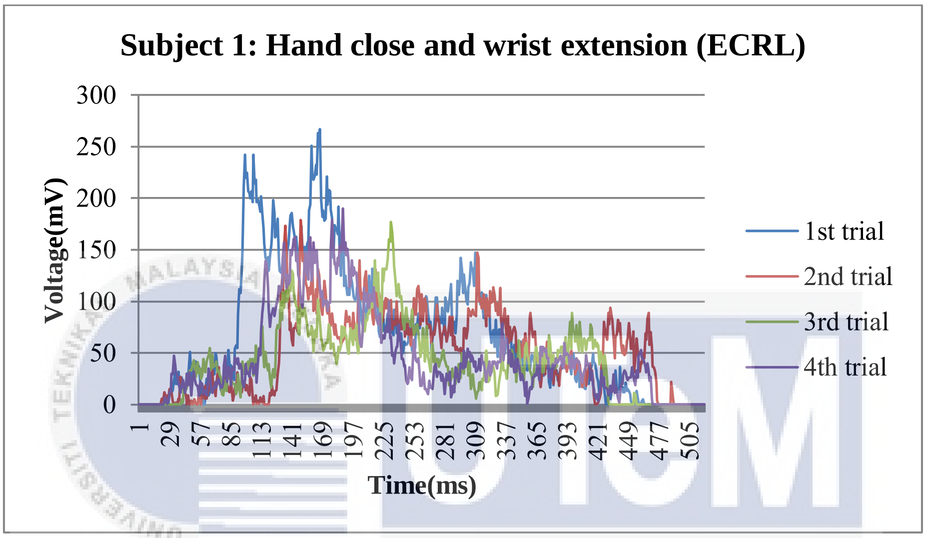


(e)

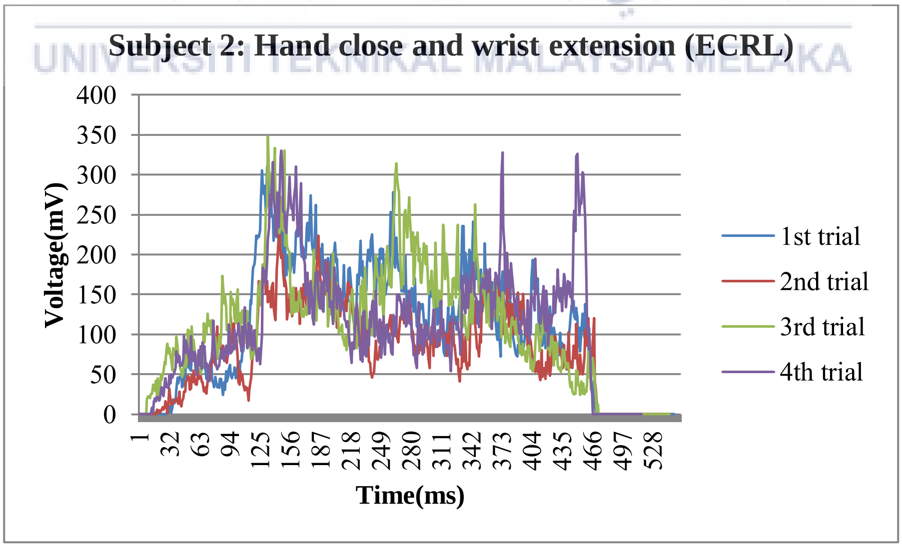
Figure 4.12: EMG Signal for hand close and wrist flexion of ECRL muscle of: (a) Subject 1. (b) Subject 2. (c) Subject 3. (d) Subject 4. (e) Subject 5.

From the Figure 4.12 it shows that ECRL muscle has higher voltage output when hand grip than wrist flexion. This is becaue ECRL muscle is used to make extension actions. The handgrip has the voltage value of around 100-200mV whereas the wrist flexion voltage value is around 10-50mV.

Last movement for ECRL muscle is hand close and wrist extension. This muscle is used to extend the wrist joint. Therefore, the extensions of the wrist should have a larger value than handgrip.



(a)



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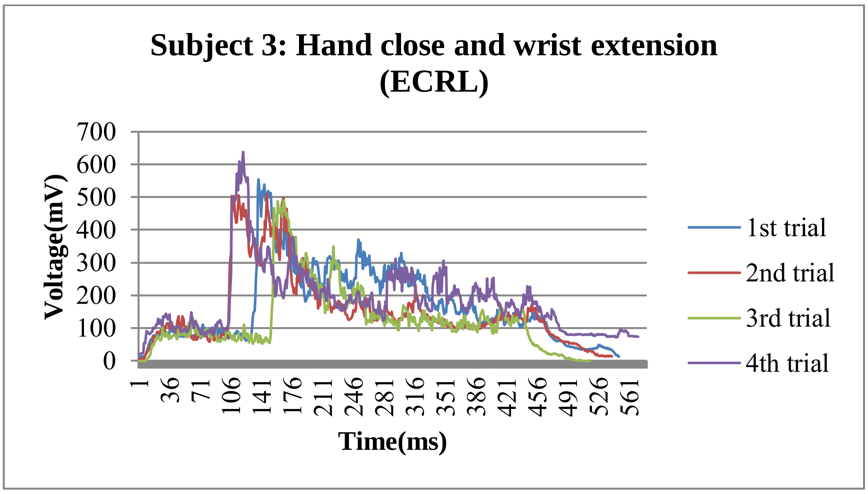
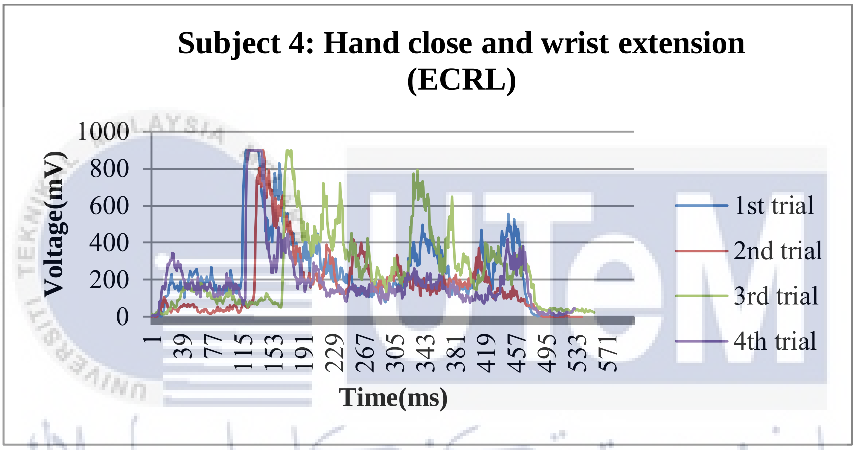
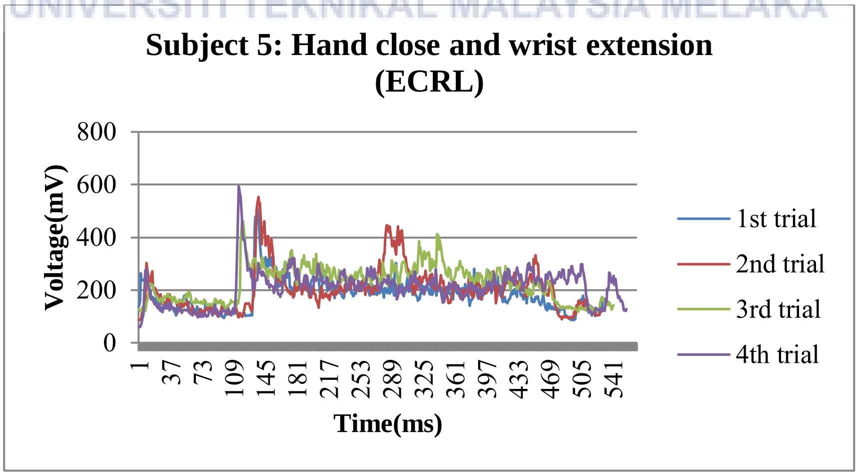


(c)



(d)



(e)

Figure 4.13: EMG Signal for hand open and hand close of FCR muscle of : (a) Subject 1. (b) Subject 2. (c) Subject 3. (d) Subject 4. (e) Subject 5.

As shown in Figure 4.13 it shows that the pattern of the EMG signal that the wrsit extension or grip has higher voltage than the handgrip. The hand close has the voltage of around 150-200mV, whereas the wrist extension has a higher voltage 300-500mV for ECRL muscle. The wrist extension has a higher voltage value because ECRL muscle is in control of the extension of the wrist.

As a conclusion, for Flexor Digitorium Superficialis (FDS) muscle, the average range of hand open movement value is 0-100mV, whereas the hand hand close movement value is 400-600mV. Other than that, the average range of wrist flexion is 600-800mV and lastly the wrist extension has the average range value of 100-300mV. As for the Flexor Carpi Radialis (FCR) muscle, the average range of hand open movement value is 0-150mV, whereas the hand hand close movement value is 50-400mV. Other than that, the average range of wrist flexion is 250-400mV and lastly the wrist extension has the average range value of 50-100mV. Lastly for the Extensor Carpi Radialis Longus (ECRL) muscle, the average range of hand open movement value is 0-50mV, whereas the hand hand close movement value is 100-200mV. Other than that, the average range of wrist flexion is 10-50mV and lastly the wrist extension has the range value of 300-500mV.

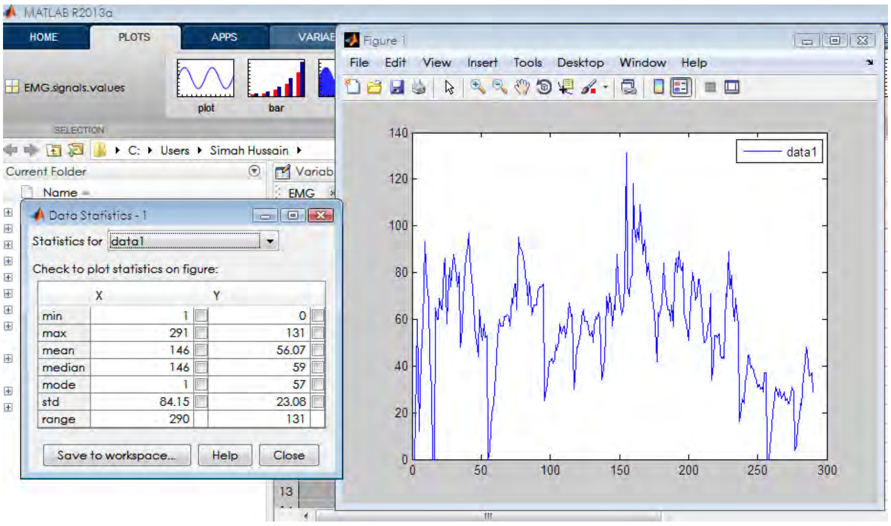
4.2 Feature Extraction

Feature extraction of the EMG signal is done by using the MATLAB software interface. In this project, 5 heatlhy subjects are tested with the same three muscles and four hand movements. The three muscles used in this project are Flexor Digitorum Superficialis (FDS), Flexor Carpi Radialis (FCR), and Extensor Carpi Radialis Longus (ECLR). The hand movement considered in this project is hand close, hand open, wrist extension, and wrist flexion.

For the hand movement, it is combined into 3 experiments, which are the hand open and hand close, wrist extension with the hand closed, and also the wrist flexion with the hand closed. This is done to differentiate the pattern of the EMG signal between the movements.

In this research, feature extracion is studied to extract feature of forearm EMG signals. This project is to prove the better feature extraction methods of Mean Absolute

Value (MAV) and Standard Deviation (STD). These feature extraction methods are performed simply by using MATLAB software interface.



Statistics for: data1

Check to plot statistics on figure:

	X	Y
min	1 ☐	0 ☐
max	291 ☐	131 ☐
mean	146 ☐	56.07 ☐
median	146 ☐	59 ☐
mode	1 ☐	57 ☐
std	84.15 ☐	23.08 ☐
range	290	131

Figure 4.14: Feature Extraction MATLAB interface

From the EMG signal plotted extracted from the Muscle Sensor V3 Kit, the tools are used to show the data statistics of the EMG signal. From the data statistics window, the mean and standard deviation is taken and recorded for each muscle activities.

Table 4.1: Feature Extractions of MAV and STD with various hand movements

SUBJECT	MOVEMENT	FDS		FCR		ECRL	
		MAV (mV)	STD (mV)	MAV (mV)	STD (mV)	MAV (mV)	STD (mV)
1	Hand close wrist extension	26.24	25.66	8.298	15.64	70.43	64.15
		77.76	53.37	11.41	16.32	49.16	40.65
		47.49	53.91	4.274	8.058	42.26	35.45
		53.98	40.64	11.01	19.64	45.82	42.93
	Hand close wrist flexion	170.4	124.9	95.74	73.51	2.032	6.647
		187.4	145.1	74.36	70.52	5.712	11.92
		167	134.3	67.84	53.63	10.69	17.28
		152.2	109.7	111.9	83.27	5.31	11.62

	Hand open hand close	131.2	86.82	6.002	11.87	68.59	74.01
		82.56	84.55	9.737	16.82	60.82	56.13
		103	110.9	39.01	45.31	96.98	80.35
		121	108.5	24.09	26.75	16.88	34.38
2	Hand close wrist extension	187.2	117.8	264.4	61.88	109.3	79.57
		207.1	90.38	279.7	85.62	80.78	55.92
		194.5	92.25	232.4	80.23	108.4	74.24
		238	114.2	185.6	63.61	113.6	73.55
	Hand close wrist flexion	404.5	215.6	329.1	81.77	15.89	21.27
		475.8	226.8	319.1	99.66	6.825	12.51
		510.4	270.7	359.1	126	21.11	26.09
		464.3	262.5	364.8	120.7	13.13	22.87
	Hand open hand close	316.6	197.2	355	132.2	38.24	41.26
		314.6	204.3	307.4	74.33	43.49	36.96
		387.4	251	348.2	118.9	36.89	30.74
		384.2	298.4	340.1	103	53.55	44.99
3	Hand close wrist extension	56.08	113.9	220.7	58.11	167.7	115.1
		50.6	103.6	228.3	20.04	153.3	111.5
		48.4	84.42	21.12	23.7	125.9	99.81
		46.74	76.77	215.2	8.921	181.7	102.2
	Hand close wrist flexion	258.3	164.1	214.6	46.77	101	16.88
		246.2	191.8	293.7	58.83	44.06	9.052
		206.8	196.9	307.4	41.58	54.16	21.02
		265.9	206.5	268.6	30.9	81.8	16.44
	Hand open hand close	173.6	126.5	292.1	10.34	52.98	25.66
		195.5	189.8	286	10.74	78.44	26.95
		112.6	96.88	291.6	13.08	92.64	30.07
		108.9	93.9	313.3	12.63	76.26	26.78

SUBJECT	MOVEMENT	FDS		FCR		ECRL	
		MAV (mV)	STD (mV)	MAV (mV)	STD (mV)	MAV (mV)	STD (mV)
4	Hand close wrist extension	95.03	76.12	33.36	65.72	261.1	201.5
		156.7	93.72	14.64	31.48	177	173.7
		88.68	72.25	15.5	32.28	245.3	202.6
		89.09	78.09	10.88	27.03	195.8	173.1
	Hand close wrist flexion	520.8	251.8	223.7	125.6	144.4	80.52
		627.9	298.1	137.7	96.22	98.15	57.74
		331.7	237.1	317.9	200.9	119	58.6
		495.6	297.4	286.5	156.2	119.1	71.9
	Hand open hand close	214	127.9	132.3	114.3	100.5	89.5
		194.6	117.5	71.42	63.22	44.96	42.24
		124.8	92.21	132.2	125.1	73.86	71.66
		139.6	124.3	21.62	25.96	29.64	40.45
5	Hand close wrist extension	301.7	54.1	200.3	45.54	185.7	60.13
		321.1	61.56	199.6	40.78	204.4	80.57
		323.3	48.5	192.9	72.36	227.1	66.41
		338.1	61.6	183.2	45.5	209.2	65.71
	Hand close wrist flexion	589.3	246.2	338.4	136.6	126.7	39.18
		526.3	210.7	356.1	144.7	126.7	29.24
		576.5	194.5	369.6	148.1	111.1	35.77
		626.2	210.7	341.7	127.1	111.6	28.99
	Hand open hand close	487.5	135.3	244.7	77.63	178.2	35.93
		470.3	122.7	226	76.74	145.3	37.7
		403.8	67.8	185.3	51.92	160.9	32.04
		468.7	121.5	197.4	57.77	149.3	35.27

From the Table 4.1, calculation of average for each movement and different muscle is calculated from the MAV and STD values. The calculation of the average value of time domain features is tabulated in Table 4.2.

Table 4.2: Average value of time domain features for three different muscles and movements

Muscle	Movement	MAV (mV)	STD (mV)
FDS	Hand close wrist extension	147.3895	75.642
	Hand close wrist flexion	390.175	209.77
	Hand open hand close	246.723	137.898
FCR	Hand close wrist extension	126.6396	41.12295
	Hand close wrist flexion	258.892	101.128
	Hand open hand close	191.174	58.4305
ECRL	Hand close wrist extension	147.6975	95.9395
	Hand close wrist flexion	65.92345	29.77695
	Hand open hand close	79.921	44.6535

4.3 Performance Analysis of Feature Extraction Methods

The performance analysis of the feature extraction of MAV and STD are compared in terms of percentage error calculation. By using the equation (5) from the literature review, the calculation can be made.

From the formula (5) it shows that it require Feature noise value to calculate the percentage error. Therefore, in this project, the feature noise is taken from the subjects EMG signal that extracted with the most noise. Table 4.3 shows the feature noise values selected.

Table 4.3: Feature noise of the EMG signals extracted

Muscle	Movement	MAV (mV)	STD (mV)
FDS	Hand close wrist extension	156.7	93.72
	Hand close wrist flexion	475.8	226.8
	Hand open hand close	403.8	67.8
FCR	Hand close wrist extension	185.6	63.61

	Hand close wrist flexion	137.7	96.32
	Hand open hand close	307.4	74.33
ECRL	Hand close wrist extension	70.43	64.15
	Hand close wrist flexion	101	16.88
	Hand open hand close	92.64	30.07

By using the formula (5) the Percentage error of each muscle and movement is calculated, Table 4.4 shows the percentage error of the feature extraction methods.

Table 4.4: Percentage error (%) of the feature extraction methods.

Muscle	Movement	MAV	STD
FDS	Hand close wrist extension	6.3	23.9
	Hand close wrist flexion	21.9	8.12
	Hand open hand close	63.7	50.8
FCR	Hand close wrist extension	46.5	37.1
	Hand close wrist flexion	46.8	4.75
	Hand open hand close	60.8	27.2
ECRL	Hand close wrist extension	52.3	33.1
	Hand close wrist flexion	53.2	43.3
	Hand open hand close	15.9	32.7

As a conclusion from the percentage error calculations that are recorded in Table 4.4, overall performance of Standard Deviation (STD) method of feature extraction is better than the Mean Absolute Value (MAV). The best performance for STD feature extraction is for hand close and wrist flexion of FCR muscle, which is only 4.75% of error. Other than that, the best MAV feature extraction performance is for hand close and wrist extension of FDS muscle, which is 6.3%. Therefore, Standard Deviation feature extraction method has better performance than Mean Absolute Value feature extraction method.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

At the beginning of the feature extraction of forearm EMG signal for exoskeleton hand research, extensive study on the literature review is done to require important information. The information of EMG signal, feature extraction and exoskeleton hand is studied throughout the research. From the literature review, it is found that the type of forearm muscle that are mostly used is the Flexor Digitorum Superficialis (FDS), Flexor Carpi Radialis (FCR) and Extensor Carpi Radialis Longus (ECRL) muscles. These muscles are mostly used to collect the signal of hand close, hand open, wrist flexion and wrist extension movements.

Other than that, it is also found that the more convenient type of electrodes is the surface electrode. This is popular due to its non-invasive characteristic. In addition, the use of Muscle Sensor V3 Kit is decided because it is more convenient to determine sets of data with the signal with linear envelope. Other than that, Muscle Sensor V3 Kit also has good accuracy and less noise.

Besides that, the methodology of each objective of this research is planned throughly. The methodology starts from the procedure on extracting raw EMG signal from the forearm. Then, the procedure of the feature extraction method is applied to the raw EMG signals that are extracted is constructed. Lastly, the procedure on calculating the performance will be analyzed by using percentage error calculations are determined.

This research is to study the forearm EMG signals for exoskeleton hand. In this research, the first objective is to obtain forearm raw EMG signals based on indirect handgrip force and wrist angle for exoskeleton hand application. Muscle Sensor V3 Kit circuit with two 9V batteries and voltage regulator are constructed. Muscle Sensor V3 Kit used for this EMG signal extraction is tested by connecting it with the oscilloscope. The EMG signal from the oscilloscope is analyzed and recorded.

From the experiment, the EMG signal are extracted from the Muscle Sensor V3 Kit successfully by connecting the Muscle Sensor V3 Kit with the voltage regulator and also by using the Arduino Mega 2560 to make the analog signal from the sensor to be able to transfer to the computer. MATLAB software is successfully used to extract the EMG signal from the Muscle Sensor V3 Kit by using SIMULINK block of Arduino. The SIMULINK block diagram can be installed directly from MATLAB by using Target Installer.

The setup of the circuit is able to be connected to the computer, raw EMG signal is also be able to extracted and recorded. Therefore, the objective one is achieved. From the EMG signals that are extracted, we can see from the graph that the signals have its own pattern with each of hand movement. As a conclusion, these patterns can be used to further in doing classification.

Other than that, using MATLAB software interface also does the feature extraction of STD and MAV. The feature extraction methods are compared and the performance is analysed by using the percentage error calculation. From the percentage error calculations, the Standard Deviation (STD) method has better performance than the Mean Absolute Value (MAV).

5.2 Recommendations

The recommendation for future research is that to make the sample of the EMG signal data by extracting EMG signal with more subjects to get more accurate results. Other than that, the percentage error calculation will be more accurate by comparing the EMG signals data with other EMG signals data that uses different device of extracting the EMG signals In addition, compare more feature extraction methods such as IEMG and RMS to improve the research. On the other hand, to get more accurate result, fatigue is also needed to be considered. This research is only studied on the time domain of the feature extraction methods, therefore by comparing the time domain and frequency domain can improve this project. For example, by considering the spectrum of the EMG signal extracted.

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APPENDIX