FEATURE EXTRACTION OF MUSCLE FATIGUE ON FOREARM USING SURFACE ELECTROMYOGRAPHY (sEMG) TECHNIQUE

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“ I hereby declare that I have read through “Feature Extraction on Forearm using Surface Electromyography (SEMG) Technique” and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation)”

Signature : ....

Supervisor‟s Name : ....

Date : ....

DECLARATION

"I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledged."

Signature: ……………………………..

Author: ……………………………..

Date: ……………………………..

Gratitude to

My family

My FYP supervisor

My coursemates

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ABSTRACT

Nowadays, musculoskeletal disorder has becoming a common disease in society. Muscle fatigue is one of the factor leads to musculoskeletal disorder. In this research, technique of surface electromyography (sEMG) signal detection and processing will be implemented. The main objective of this research is to extract features of muscle fatigue in order to evaluate the muscle fatigue condition of males and females. sEMG signal were collected from the forearm muscle - flexor carpi radialis of each volunteer. A group of 20 healthy university students were recruited in order to determine muscle fatigue occur in real life. A dynamic contraction and static contraction were implemented in order to understand the relationship between motion and fatigue and relationship between force and fatigue. Dynamic contraction experiment is done with subjects bent their wrist up to maximal joint angle; whereas static contraction experiment is done with different percentage of maximal voluntary contraction (MVC). For dynamic contraction, the feature of sEMG signal was extracted using time domain (RMS) and time-frequency domain (Scalogram). For static contraction, the feature of sEMG signal was extracted using time domain (RMS) and frequency domain (MDF). While analysing the time domain, it is found that the amplitude increased during fatigue in dynamic and static contraction experiment. For frequency domain, MDF are found to be decreased during fatigue in static contraction experiment. For time-frequency in terms of Scalogram, the energy distribution coefficients were found to be shifted to lower frequency as shown in the result and discussion part. Validity test is implemented in order to ensure the data collected is validated. Although the results were promising, there will be some limitations that need to be overcome in the future such as apply an online muscle fatigue progression test using Scalogram method for rehabilitation purpose.

ABSTRAK

Kini, keletihan otot telah menjadi satu penyakit yang biasa dalam masyarakat. Keletihan otot adalah salah satu faktor yang membawa kepada masalah muskuloskeletal. Dalam kajian ini, teknik permukaan Electromyography (EMG) pengesanan isyarat dan pemprosesan akan dilaksanakan. Objektif utama kajian ini adalah untuk mendapatkan ciri-ciri keletihan otot menggunakan analisis domain masa dan domain frekuensi. Isyarat EMG dikumpulkan dari otot lengan bagi setiap pelajar. Sebanyak 20 pelajar universiti yang sihat akan diambil untuk memahami hubungan antara pergerakan dan keletihan serta hubungan antara kekuatan dan keletihan, pengecutan yang dinamik dan statik akan dijalankan. Isyarat EMG akan dianalisiskan dengan domain masa (*RMS*), domain frekuensi (*MDF*) dan domain masa-frekuensi (*Scalogram*). Semasa isyarat signal dianalisis dalam *RMS*, ketinggian signal meningkat semasa keletihan otot. Manakala frekuensi untuk *MDF* dan taburan tenaga untuk Scalogram pula menurun. Ujian kesahihan akan dijalankan untuk memastikan data yang diambil adalah betul. Walaupun keputusan yang ditunjukkan adalah sama dengan apa yang dijangkakan, ada juga sesetengah kelemahan yang kena dibaiki pada masa hadapan dengan menjalankan kajian secara *online* untuk proses pemulihan.

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CHAPTER 1

INTRODUCTION

This chapter will describes the problem of muscle fatigue problem and the consequences of muscle fatigue experienced by human in their daily life. Therefore, sEMG techniques are recommended for muscle fatigue detection in this research. Besides, the objectives and scope will be covered in this chapter.

1.1 Project background

Nowadays, due to the advancement of industry world, the enhancement of human performance is crucial for the improvement of quality of life. Repetitive works or continuous similar types of motion happen in human's daily life. However, people are just evaluate their physical condition subjectively and ignoring their muscle status and this issue may bring them to musculoskeletal disorder such as occupational overuse syndrome (OOS) [1] and work-related musculoskeletal disorders (WMSDs) [1]. All these factors are caused by the decline in motor unit firing rates and recruitment threshold of motor units declined [25]. There are various methods to estimate body condition. However, muscle fatigue will be the only consideration in this paper. Muscle fatigue is defined as failure to maintain a desired force and it may occur due to isometric or non-isometric (dynamic) muscle contraction. Recent physiological studies have demonstrated the crucial of muscle fatigue detection in human's daily lives in order to prevent any injury in muscle and degradation in human performance efficiency. Electromyography (EMG) technique is considered as a good solution to study about muscle activity either in motion, force and fatigue. The most common technique used to evaluate muscle activity is surface electromyography (sEMG). sEMG is a non-invasive, pain-free and easy to apply approach to detect muscle activity. Result such as increasing in amplitude of EMG signals and shifting in frequency spectrum from high frequency to lower frequency during muscle fatigue have been observed by previous researchers. These changes can be measured using time domain, frequency domain and time-frequency domain analysis by calculating its mean frequency (MNF), median frequency (MDF), root mean square (RMS) and also Scalogram. Muscular fatigue decreases the MDF value within the EMG power spectral density, and increases the EMG signal amplitudes at the end of the experiment which indicates increase in RMS. These factors happen due to the variations in the activation of the muscle motor unit action potential (MUAP). Both MDF and MNF are considered as a reliable estimator of the muscle fatigue. Scalogram is a visual method for displaying wavelet transform. Energy distribution plays an important role while observing Scalogram.

1.2 Motivation

The number of patients suffers from muscle disorders are increasing. This brings the important of muscle fatigue classification especially for those who are industry field. The repetitive works by workers are able to bring an effect to their muscle tissues and hence yield some disorders such as OOS and WMSDs. These disorders will cause a uncomfortable feeling to human. Therefore, it is necessary for this research to implement an analysis of muscle fatigue with the aids of hardware and software implementation. The purpose behind this research is as a reminder how severe a muscle fatigue can affect our lives.

1.3 Problem statement

Musculoskeletal disorder has become a common disease happen in human. The necessity of muscle fatigue analysis should be apparent in order to prevent any disorders, muscle injury and human performance degradation. By detecting and classifying muscle fatigue, it adds important information to the fields of human-computer interactions (HCI), sport injuries and performance, ergonomics, diagnosis and prosthetic purposes. However, muscle fatigue is difficult to determine physically, it requires application tools. Therefore, SEMG technique will be used to study the relationship between fatigue and SEMG signals. Besides, non-fatigue condition and fatigue condition will be classified by extracting their features using time domain and frequency domain analysis respectively in order to analyze occurrence of muscle fatigue.

1.4 Objectives

The first objective of this research is to extract features of muscle fatigue using time domain, frequency domain and time-frequency domain. All the features extracted are analysed in Root Mean Square (RMS), Median Frequency (MDF) and lastly Scalogram. The second objective is to analyse surface electromyography (sEMG) signals during progression of muscle fatigue in static or dynamic contraction using statistical analysis. Therefore, there are two types of experiments that will be conducted which are dynamic contraction experiment and static contraction experiment in order to determine the significant result from statistical analysis between males and females.

1.5 Scope

This research is primarily focus in wrist muscle analysis at flexor carpi radialis using surface disposable electrodes. 20 subjects will be recruited. Dynamic contraction and static contraction experimental setup will be conducted. For dynamic contraction, 20 subjects will be recruited while for static contraction, only 12 subjects are recruited. Extracted feature from raw signal will be analyzed using time domain in terms of Root Mean Square (RMS), frequency domain in terms of Median Frequency (MDF) and time-frequency domain in terms of Scalogram. However, the correlation between hand size and grip strength will not be covered in this research.

CHAPTER 2

LITERATURE REVIEW

This chapter first gives a general introduction about sEMG signal. After that, a detailed literature review of various sEMG signal feature extraction analysis method and procedure for estimating muscle fatigue is presented.

2.1 Muscle fatigue and its relationship with sEMG signal

Muscle fatigue has being studied by many researchers and discussed in their paper in the past. The term 'muscle fatigue' was first introduced by Bills (1943) and it is divided it into three different classes: subjective fatigue, which result from psychological factors such as a lack of motivation; objective fatigue, which represents a decline in productivity; and lastly, Physiological fatigue, which refers to muscle unable to maintain a desired force [2]. Changes the nerve system and the muscle simultaneously is related to neuromuscular mechanism of fatigue, which involved central fatigue (brain fatigue), fatigue in the neuromuscular junction and fatigue occurring in the muscle (peripheral fatigue) [3]. Peripheral fatigue is the most common case for physical fatigue and this type of fatigue is widely detected using EMG technique in most studies. It take place when the normal functionality of the nerve fibers and the muscles that are contracting are impaired, that is the muscle's ability to utilize force is degrading due to the incapability of the body to reach the increased energy demand in the contracting muscles [3]. The main reason that causes muscle fatigue to occur is the release and storage of calcium ions within the muscle fibers.

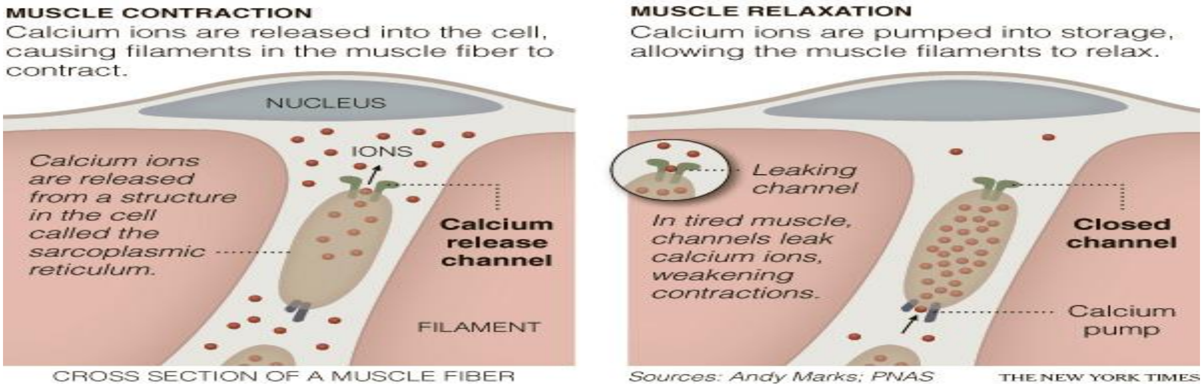


Figure 2.1: Leakage and storage of Calcium ions during muscle contraction and relaxation [4]

According to Carlo J. De Luca, the concept of muscle fatigue that applied to monitor or measure the deterioration of a performance of the human operator is unclear and often misapplied. The concept of muscle fatigue is always related to time-dependent process as fatigue will induce when a person perform a same task continuously for long hours [5]. Besides, the interest in understanding muscle fatigue index and methods development in muscle fatigue identification and quantification are widely performed in most of the previous paper [6]. Study of muscle fatigue in upper limb has been research by using various type of experimental method such as hand movement, hand grip process and et cetera. The main aim is to identify the muscle fatigue index in order to reduce the possibility of muscle injury. Also, while performing analysis in muscle fatigue, the amount of force generated, time of each contraction, and rest period between each contraction is taken in consideration in previous research as these factors will affect the muscle fatigue rate. Analysis of muscle fatigue has been made using clinical application of Human-Computer Interaction (HCI) based on surface electromyography (sEMG) or intramuscular fine needle electrode and provides pattern recognition method for several sport setting, occupational and rehabilitation purposes [7]. Besides, research in this field showed that a development in muscle fatigue correlates with changes in amplitude which in terms of root mean square (RMS) and shifting of frequency in terms of power spectrum density and this phenomenon also prove by other researchers. According to Petrofsky et al. (1982), there will be some changes happened in sEMG amplitude and center frequency during muscle fatigue [2]. Extracted feature is done in previous study either in time domain, frequency domain or time-frequency domain. In time domain analysis, when muscle fatigue occurs, it will cause an increase in sEMG amplitude [9]. However, in frequency domain analysis, it can be observed that power spectrum density is shifted to lower frequency [9]. All these changes might be a result of concentration of blood lactate, muscle pH value, blood oxygen saturation level, recruitment of motor unit action potential and motor unit firing rate [10]. These metrics are used to identify physiological phenomena during muscle contractions that lead to muscle fatigue which is performed by those biomedical field researchers. After review many of previous researcher's experimental method, the method was concluded in the flow chart shown below:

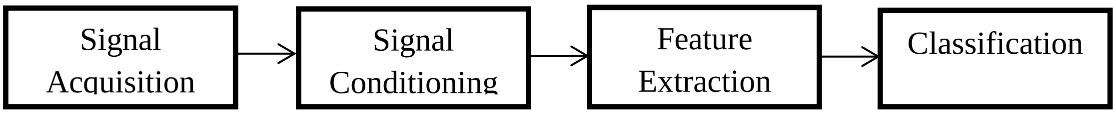


Figure 2.2: Experimental method in previous research

2.1.1 Muscle fatigue stages and its experimental implementation

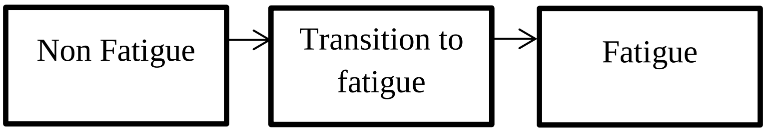


Figure 2.3: Muscle fatigue stages

Current research tends to focus on two classes of localized muscle fatigue: Non-Fatigue and Fatigue. Fatigue is relates to the onset of fatigue during a muscle contraction; while Non-Fatigue is define as the state of muscle during the contraction that occurs before the onset of fatigue. However, there is also an additional class of fatigue, known as transition to fatigue. This class is located in between of non-fatigue and fatigue. The identification of this additional class helps in the autonomous detection and prediction of muscle fatigue and differentiate between two classes of fatigue [11][12]. Although most research on muscle fatigue only focuses in Non-Fatigue and Fatigue stages, the Transition-to-Fatigue stage identified by Al-Mulla et al. is an important addition to this research field, especially for the development of real-time systems that automate the process of detecting and predicting fatigue. Previous research has conducted several researches in determining fatigue condition in both isometric and dynamic environment. Isometric contraction is often implemented by most of the researcher. For isometric contraction, the subjects will require to maintain its posture and force throughout the experiment. One of the isometric examples is conducted by Allmulla *et al.* [12]. In his research, he and his partner recorded the sEMG signal accompanied with goniometer findings. Goniometer was placed on the side of the arm to measure the elbow angle. The acquired sEMG signal is compared with the goniometer finding to ensure the sEMG classification is correct. However, isometric contraction is impractical in real life environment. To overcome this limitation, some researchers conduct a dynamic contraction experiment. Movement and amount of force exerted by each subject applied have become their main concern in dynamic contraction to evaluate muscle fatigue index. Equipment such as strain gauge [13] and elbow angle [9] are considered as they are reliable to measure muscle fatigue index and able to classify sEMG signals correctly.

2.2 Electromyography (EMG)

Electromyography is the common tool used in detecting muscle status detection. An overview about electromyography will be described in this section.

2.2.1 History of electromyography

Electric eel Nobel Prize Carlo de Luca

Figure 2.4: Development of electromyography

Figure 2.4 shows the development of electromyography. Electromyography (EMG) is widely discovered in the early 1950's by many researchers. Electromyography had its earliest roots where Greeks practice "shock" on electric eels (refer to first picture of figure 2.4) in order to make the eel to execute all the ailments out of its body. However, the origin of shock that accompanied this earliest detection and application of EMG signal was not highly appreciated. EMG techniques was first documented in early year of 1666 by an Italian, named Francesco Redi realized that the spark is actually originated from muscle tissue [14]. By the year 1773, Walsh showed that the muscle tissue of eel could generate a spark of electricity [14]. The relationship between muscle contraction and electricity was later proved by Luigi Galvani in the year 1792 [14]. Nevertheless, this relationship gets disagreement by Volta. Volta stated that the phenomenon determined by Galvani may result from the artifact of dissimilar metals touching the muscle tissue [14]. The history of EMG is continued with the discovery of electricity and the development of the ability to view through muscle activity with the aid of instruments in the year 1840s [14]. This brought four new instruments such as cathode ray tube, vacuum tube amplifiers, metal electrodes and the revolutionary needle electrode which used to detect EMG signal. In year 1849, the father of experimental electrophysiology, Du Bois-Reymond performed his experiment on subject's forearm in electrical contact with electrodes during voluntary contraction [14]. By implementing detection of muscle activity experiment, a conclusion draws that signal amplitude will increase during wrist flexion [15]. By the early 1900s, Pratt showed that the amplitude of energy associated with muscle contraction was related to the recruitment of individual muscle fibers. In the 1920s, Gasser and Newcomer used the cathode ray oscilloscope to display the signals from muscle and this brings them a Nobel Prize in 1944 (refer to second picture in Figure 2.4) [15]. Researchers began to use sEMG to study dynamic movement in the year 1940s, for example, Inman and Price. In the early 1980s, Cram and Steger introduced a clinical method for scanning muscles using handheld sEMG sensing device. Few years later, Cram and Engstrom collected signal from 104 normal subjects by scanning their muscle in different muscle area with different posture either standing and sitting. All the efforts done by previous researchers are highly appreciated and the efforts in discovering the application of EMG are still continued until now. One of the famous sEMG researchers is Carlo de Luca. (Refer to third picture in Figure 2.4)

2.2.2 Surface electromyography (sEMG) and its application

The term of electromyography has been defined by several researchers in biomedical field. According to Carlo De Luca (2006), EMG signal is the electrical manifestation of neuromuscular activation associated with a contracting muscle. Whereas according to Christos (2013), electromyography refers to bio-signal that measure the activity produced by skeletal muscles during contraction. The conclusion that can be made from the two definitions above is that, electromyography are widely used to study muscle activity. Electromyogram display an electrical signal generated by motor unit action potential (MUAP) of muscles during either voluntary or involuntary contraction and it is a result of summation of electrical of a large number of muscle fibers in the vicinity of electrodes [16]. Besides, EMG provides the information about different features of muscle activations associated with different types of contractions that are isometric and dynamic contraction. It has been widely employed as an objective tool to study on the phenomenon of muscle fatigue. EMG signals can be detected by using two types of techniques: intramuscular fine wire electrodes and surface electrodes. Intramuscular fine wire requires a needle for insertion into the muscle and this method causes pain and it is very difficult to place the needle at the same area of muscle and less repeatable [17]. However, it performs a more accurate result on muscle activity data acquisition and it is used in clinical application to study the characteristic of neurophysiologic of the peripheral nervous system and muscles [1]. On the other hand, by using surface disposable electrodes, it causes no pain since it is non-invasive. It is consider more reproducible, easier to apply, more suitable for movement and it is widely used in real world application [17]. sEMG is used by most researchers as it is more convenience compared to intramuscular fine wire. Nevertheless, there are some drawbacks using sEMG such as the possibility of “cross-talk” [19]. Cross-talk occurs when energy from one muscle group travels over into the recording field of another muscle group. This will yield difficulty in isolating the sEMG recordings from a specific muscle. Factors such as type of surface electrode used, placement of electrodes, inter-electrode distance will cause the variation in EMG signal amplitude. Researchers usually apply sEMG techniques in applications, for example, athletic training, industrial applications, physical therapy, diagnosis and prognosis of neuromuscular disorders, other clinical applications and academic research. This entire field can relate with muscle fatigue to evaluate feature of muscle fatigue in order to reduce injuries and improve human’s performance efficiency. There are three basic applications of the EMG signal relates to muscle status: to identify the activation timing of muscle, to measure the force produced by muscle and lastly is to obtain an indication of muscle fatigues via the analysis of frequency spectrum of the EMG signal [19].

2.3 Factors affecting EMG signal quality

2.3.1 EMG electrodes

EMG electrodes are place on muscle to obtain signal during isometric and dynamic contractions. EMG can be recorded from various parts of the body, but electrode placement is importance for reliable and repeatable results. Figure below shows the accurate placement of electrodes:

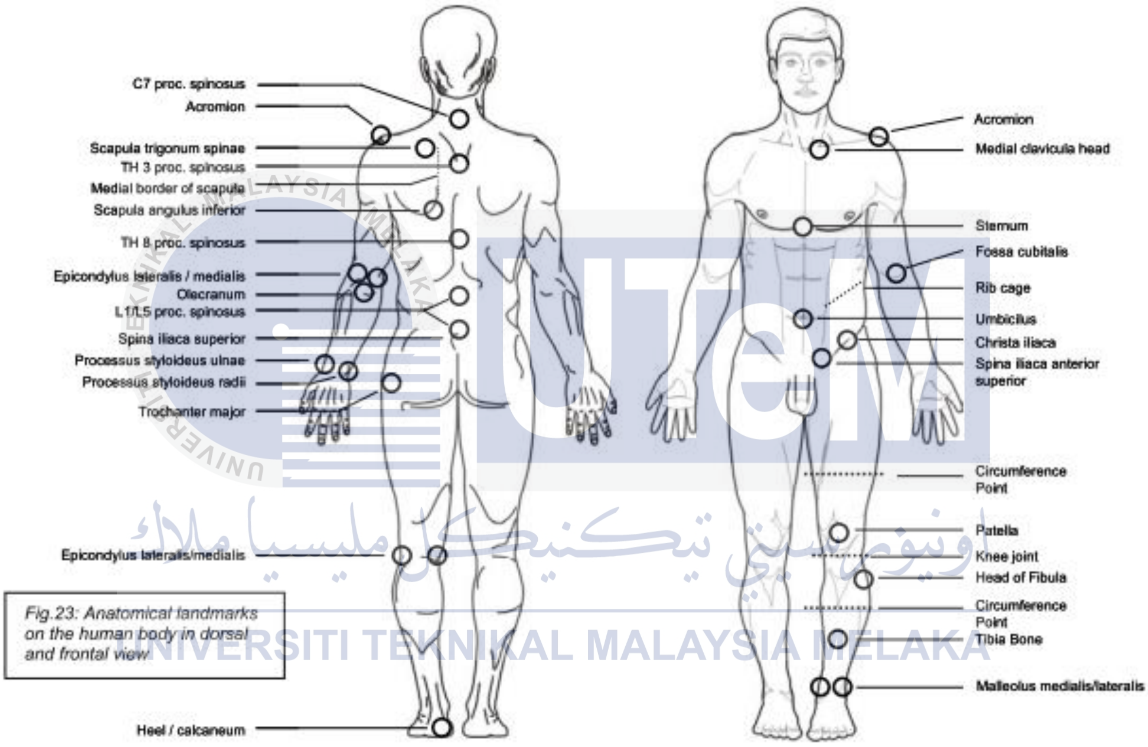


Figure 2.5: Electrode placement [20]

2.3.2 Electrode types

Electrode size and shapes are important in signal acquisition. Small electrodes are preferable in order to increase the selectivity of measurement and avoid cross-talk (this phenomenon will discuss in section 2.2. The smaller the electrode, the higher the impedance values due to its active detection area for stability of skin to prevent variation in EMG signals purposes.

2.3.4 Electrode placement and the innervation zone

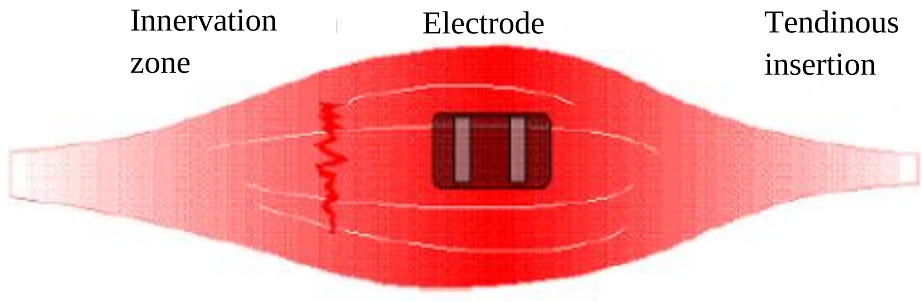


Figure 2.6: The preferred electrode location is between the innervation zone [19]

The electrode should be placed between two motor points and along the longitudinal midline of the muscle.

2.3.5 Signal noise

One of the drawbacks of EMG is the occurrence of signal noise. This limitation will cause variation in EMG signal. Noise may be come from several noises such as [20]:

- Motion artifacts or transducer noise
  This noise is produced at electrode-skin interface. This type of noise can be reduced by the electrode impedance through skin preparation and cleaning.
- Electronic noise
  This noise is inherent in all electronic devices. This can only be lessening by using high quality electronic components, intelligent circuit design and better construction techniques.
- Ambient noise
  This noise is origin from electromagnetic devices such as turning off fluorescent light or switch off any unused instrument.

2.3.6 Other factors affecting signal quality

There are other factors that affect the signal quality, such as timing and intensity of muscle contraction and properties of the overlying tissue. Besides that, the properties of the electrode and amplifier also may affect the signal quality. Therefore, electrode and amplifier selection is very essential in the data acquisition stage. Other than that, the electrical properties of the contact between electrode and the skin and distance of the electrodes for the active muscle area are also the considering factors. The electrode must place at the accurate muscle to prevent crosstalk.

2.4 SEMG signal analysis and feature characterization

sEMG signals can be analyzed to detect muscle fatigue by examining the changes occur in EMG measurements. Feature extraction is considered the most vital stage of data analysis in clinical applications as it impacts directly the performance of the developed application. The feature extraction method will discuss in section 2.3.1 until 2.3.3. However, time domain, frequency domain and time-frequency analysis in terms of Scalogram are the main discussion.

2.4.1 Time domain analysis

Time domain is analyzed where the amplitude and signal is represented in the function of time. Previously, several researchers implement time domain analysis by using the magnitude increment of myoelectric signal as an experiential measure of localized muscle fatigue using RMS value. Root Mean Square (RMS) value of a signal is the indicator of signal power and it is considered as an easy method. The values of RMS were calculated by using the following equation [21]:

$$RMS = \sqrt{\frac{1}{T}\int_{-T/2}^{T/2} EMG^2(t)} \qquad (1)$$

where EMG(t) is the amplitude of time domain and T is the sampling time for each duration.

Besides that, counting the number of zero-crossings of the myoelectric signal which proposed by Hagg, is a relative simple method in muscle fatigue measurement[20]. However, the zero crossing rates may be affected by external noise such as transducer noise and electronic noise where the influences will be diminish by introduces contracting a non-zero threshold to the signal [20]. The critical disadvantages of zero crossing rates are that the number of zero crossing is nearly linearly dependent on the force applied during the contraction at low level contraction which means when force is varies for each contraction, the zero-crossing rates will be differ [22].

2.4.2 Frequency domain analysis

Frequency domain analysis that involved power density spectrum identification is one of the parameter to represent the shifting in frequency spectrum. Shifting in frequency spectrum will be study using characteristic frequencies that have been used by several researchers. Two of the most common frequency-dependent features in sEMG analysis are the median frequency and mean frequency. Median frequency (MDF) is a frequency at which the power density spectrum is divided into two regions with equal amplitude and power, or defined as half of the total power [23]. Mean frequency (MNF) is calculated as the sum of product of EMG power spectrum and the frequency divided by the total sum of the power spectrum. The equation of MDF and MNF are shown in (2) and (3) respectively [23] :

$$\sum_{j=1}^{MDF} P_j = \sum_{MDF}^{M} P_j = \frac{1}{2}\sum_{j=1}^{M} P_j \qquad (2)$$

$$\text{MNF}= \sum_{j=1}^{M} P_j / \sum_{j=1}^{M} f_j P_j \qquad (3)$$

where

f_i is the frequency value of EMG power spectrum at frequency j,

P_j is the EMG power spectrum at the frequency

M is the length of frequency

In dynamic contractions, recent studies introduce instantaneous mean frequency (IMNF) and instantaneous median frequency (IMDF). These two parameters are used to fulfill the condition where the EMG signal information has been changed as a function of time and cannot simply be applied using Fast Fourier Theorem (FFT) [24]. However, there are some studies also have been demonstrated MNF and MDF to detect muscle fatigue primarily in isometric muscle contraction but also in dynamic muscle contraction.

2.4.3 Time-frequency domain

More recently time-frequency-domain features were recommended for the EMG being a non-stationary signal as features based on the frequency domain that is FT (Fourier Transform) can't be applied because of the non-stationary shifting frequencies overtime. Short time Fourier Transform (STFT) applied the FT on a moving window, allowing the time-localizing of frequency features [27]. The drawback of STFT is the resolution of the analysis is fixed by the size/length of the window, which provides limited information of the signal. Wavelet analysis was developed in the year of 1980s in order to overcome the problem faced by STFT with a finite-energy function (wavelet) obtained scaling and stretching by several coefficients the same a single basic wavelet (mother wavelet) [27]. Various implementations are used for previous research, like continuous wavelet transform (CWT), the computationally faster discrete wavelet transform (DWT) or the discrete wavelet pack transform (DWPT). There are many choices of mother wavelet from a large number of families, depending on the application such as Haar, Sym, Morlet and Mexican . However, only two types of mother wavelets are compared.

Table 2.1: Types of mother wavelets and its operation

Types of mother wavelets	**Operation**
Haar	Simple and fast to compute
Morlet	More complex to compute but can provide more detail information from the signal

CHAPTER 3

METHODOLOGY

This chapter provides the procedure to establish the experiment about relationship between motion and fatigue and the relationship between force and fatigue. A detailed description of the experiment protocol (subjects) for collecting sEMG signal is provided. Then, the signal processing procedure also stated in this chapter. The analysis method using time domain, frequency domain and time-frequency domain is described for both dynamic and static contraction.

3.1 Subjects

10 male students and 10 female students are volunteers for this study. None of the subjects experienced a history of musculoskeletal complaints. The specification of subjects can refer to Table 3.1. 10 males and 10 females will be carrying out the dynamic contraction and 6 males and 6 females will be carrying out the static contraction experimental setup.

Table 3.1: Subject's specification

Specifications	**Male**	**Female**
Age	20-24	
Height	$175 \pm 10cm$	$158 \pm 10cm$
Weight	54.5 kg-82.14kg	43.8kg-67.7kg
BMI	20-24.5	
Body status	Healthy, no neuromuscular disease, never undergo any surgery or injury at forearm, non-smokers	

3.2 Data pre-processing

Each subject is given a written consent before the experimental setup. The consent (Refer to Appendix C) is required to be signed by each subject to let them understand the process, rules and regulations that need to be obeyed during experiment. After simple briefing on experimental description, subject will undertake the skin preparation. Skin preparation will be done following the procedures below:

a) Removing the hair:

Hair shaving will help in the stability of skin-electrode contact and for high input impedance.

b) Cleaning of the skin:

Alcohol, wet tissues and conductive cleaning paste gels are used to remove dead skin cells and keep the skin clean from sweat and dirt.

c) Use multi-meter to check the skin impedance in order to make sure the resistance on the surface area low for good skin condition. Table 3.2 shows the recommendation for good skin impedance.

List of equipment and material is provided in Appendix B.

Table 3.2: Recommendation for electrode/skin impedance ranges

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, attention is needed
>50	should be avoided or requires a second cleaning run

3.3 Experimental procedure

Two types of experiments are carried out:

1) Dynamic contraction
2) Static contraction

3.3.1 Dynamic contraction

Dynamic contraction experiment is conducted in order to understand the relationship between motion and fatigue. Figure 3.1 shows the posture during dynamic contraction experiment. The experiment is conducted in a sitting position with relax environment. Subjects are firstly asked to maintain their posture during the experiments, including their wrist, to minimize the noise due to motion artifacts. A short briefing on how the experiment will be conducted is given to each subject. Subjects are required to have a rest period for 4 seconds firstly. Next, muscle contraction for 12 seconds with wrist moves to their maximal joint angle, and down back to original condition (refer to Figure 3.2 and 3.3). The number of continuous motion (wrist up and back to its original position) within 12 seconds is around 25 times. The dynamic contraction will be continued until the subject is exhausted. Experiments are repeated 2 times with 10 minutes intervals of rests for muscle recovery.

Figure 3.1: Posture for dynamic contraction

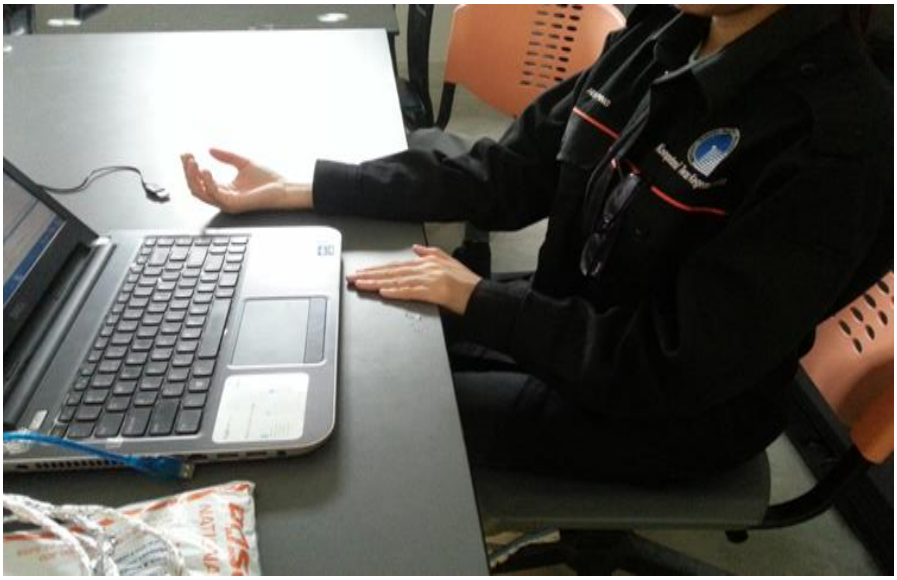


Figure 3.2: Original condition with sitting position

Figure 3.3: Wrist up to maximal joint angle

3.3.2 Static contraction

Static contraction experiment is conducted in order to investigate the relationship between force and fatigue. Figure 3.4 shows the posture during static contraction experiment. The experiment is conducted in a sitting position with relax environment. A short briefing on how the experiment will be conducted is given to each subject. Subjects are firstly asked to maintain their posture during the experiments, including their wrist, to minimize the noise due to motion artifacts. Electrode is attached on flexor carpi radialis only. A handgrip dynamometer (Vernier Software & Technology, USA) is given to subjects to measure their force level in Newton (N). Subjects are firstly exerting their maximum voluntary contraction (MVC) as a reference for determining

(a) 30% MVC - low level intensity contraction
(b) 50% MVC -high level intensity contraction and
(c) 70% MVC -high level intensity contraction

After MVC is exerted, subjects are given 35 minutes rest period for muscle fatigue recovery. This process is very important in order to prevent any internal muscle injury on subjects. Then, the experiment starts with 70% of their MVC and subjects are requested to maintain their force level until exhaust. Oral motivation will be given to each subject throughout the experiment. Time for each contraction will be recorded. The subject will be given 30 minutes before proceeding to the next procedure. The subject will then start the experiment with 50% of their MVC followed by 30% of MVC with the same procedure.

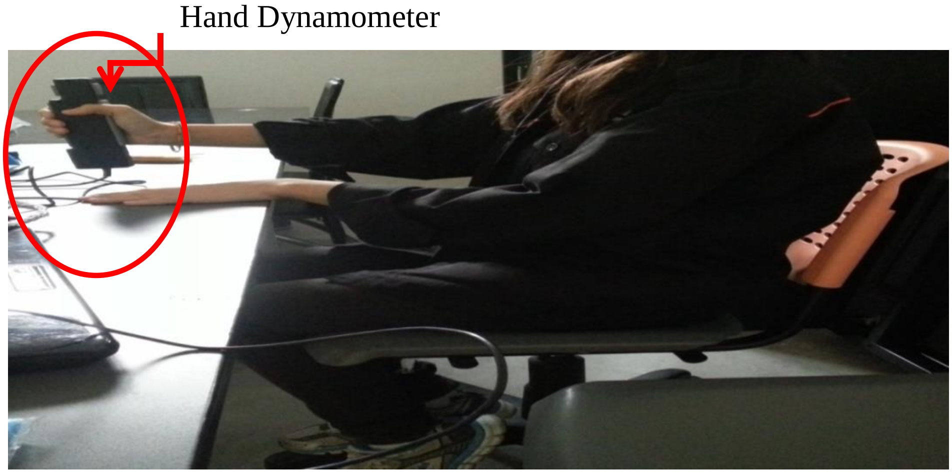


Figure 3.4: Posture for static contraction

All three percentage of MVC contractions are repeated 3 times with 10 minutes intervals of rests for muscle recovery. This experiment will be conducted in static condition where the posture will remain constant during the data acquisition process.

3.4 Experimental precaution

Raw signal obtained from surface disposable electrodes is influenced by many factors such as electronic noise, motion artifacts, location of muscles and inter-electrode distance. Therefore, in order to eliminate the influences, some precautions are done:

1) Make sure that the surrounding don't have any high power electronic devices such as air conditional, television, and refrigerator that will produce high electromagnetic field.

2) To make sure the motion artifact is reduced, subjects will be firstly asked to maintain their posture during the experiments, including their wrist, to minimize the noise.

3) Location of muscles must be determined accurately in order to prevent any crosstalk between muscles. The location of flexor carpi radialis can be determined by doing flexion of the hand at the wrist with radial deviation to activate the muscle. Figure 3.5 shows the location of muscle.

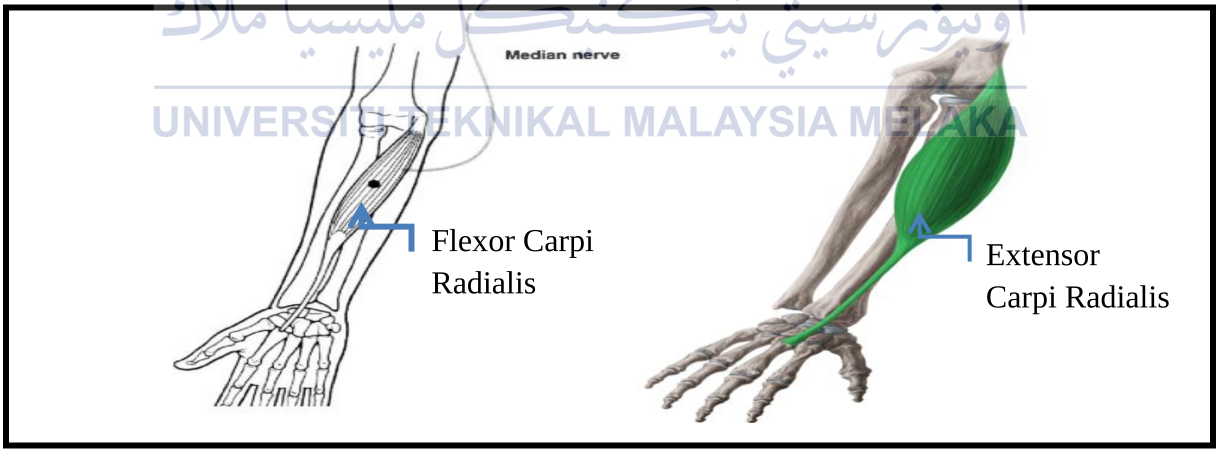


Figure 3.5: Location of muscle [25]

3.5 SEMG measurements

By referring to Figure 3.6, surface disposable electrodes are placed on Flexor Carpi Radialis. EMG signals are collected via the connection between surface disposable electrodes, Arduino Mega 2560, EMG Arduino and Personal Computer with Matlab tool. Only 1 channel was used for signal acquisition from flexor carpi radialis. Distance between two surface disposable electrodes was 30mm (measured from centre to centre). The schematic diagram of EMG Arduino is presented in Appendix D. The signals are sampled at 1 kHz and signals are collected using Simulink tools in Matlab. The signal is then sent for signal processing via Signal Processing Tool (SPTOOL) in Matlab for further analysis. All the raw signals collected were filtered with bandpass filter range from 50-150Hz with 4th order Butterworth filter [7]. The electrode wires are wrapped with aluminium as a function to reduce noise effect.

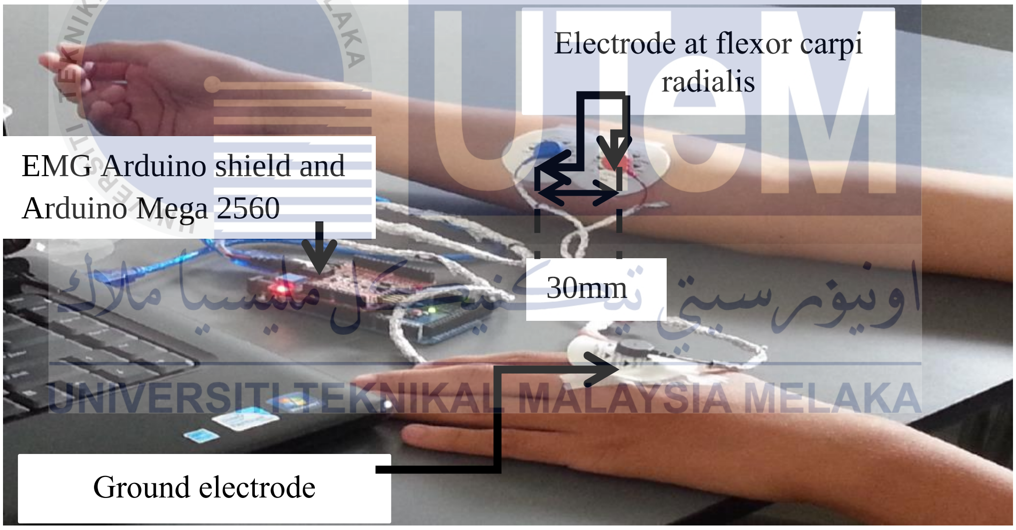


Figure 3.6: Experimental setup

3.6 Data analysis and feature extraction

The data collected is analysed offline. The data analysis will be done by time domain and frequency domain for static contraction. The recorded sEMG signal that generated during a dynamic contraction task is a non-stationary signal. For this purposes, frequency domain i.e. Fourier Transform (FT) may not provide sufficient information in muscle fatigue analysis. Therefore, the time domain i.e. RMS and time-frequency domain i.e. Scalogram will be the analysis for dynamic contraction. Frequency domain in terms of MDF will be the analysis for static contraction as frequency domain is a useful tool for stationary signal.

3.6.1 Time domain analysis

RMS is considered as appropriate indicator of the onset of muscle fatigue as it has a linear relationship with number of zero crossings and number of motor unit action potential turns at low level contractions. The RMS values before and during fatigue were obtain via SPTOOL in Matlab.

3.6.2 Frequency domain analysis

MDF is consider a better way compare to RMS as it provides sufficient information of spectral shifts as muscle fatigue occurs. Fast Fourier transform (FFT) are usually applied via personal computer on off-line basis. The equation used refers to Chapter II equation (2.1) and (2.2). However, time domain analysis will be done to compare the performance between time domain and frequency domain. All analysis was accomplished using MATLAB software with the aids of Signal Processing Tool (SPTOOL).

3.6.3 Time-frequency domain analysis

Time-frequency analysis is more advanced for analysing non-stationary signals as it provides more information about the contents of frequency occurring at any given time instant. Most widely implemented way to determine energy distribution is to plot Scalogram. Scalogram is known as the square magnitude of CWT. It presents the energy distribution over both time and scale domain. Morlet (morl) was implemented as the mother wavelet in this analysis.

3.7 Validity of data

3.7.1 Dynamic contraction

The interval of dynamic contraction is not limited. Subjects need to repeat the same movement for 12 seconds followed by rest for 4 seconds. Subjects will move their wrist up to maximal joint angle and back to original condition. 4 seconds resting period is necessary in order to let subjects rest. The number of movement within 12 seconds is fixed for every subject. However, the time used by every subject to induce fatigue is not same due to their body stamina.

3.7.2 Static contraction

30%, 50% and 70% MVC are measured from subjects. This is to analyse the effect of different force level contributing to muscle fatigue. The level of force will also induce different RMS value for muscle fatigue. The time for contraction is not limit because subjects will have different time to reach muscle fatigue level while exerting their force.

3.8 Reliability of data

After the raw signal is collected from 20 subjects for dynamic experimental setup and 12 subjects for static experimental setup, the RMS average value for fatigue will be obtained. Another 5 subjects for each experimental setup will be selected to validate that the RMS threshold value for fatigue is correct. The process to do reliability test is shown in flow chart as depicted in Figure 3.7. For frequency domain, shifting of frequency will be determined.

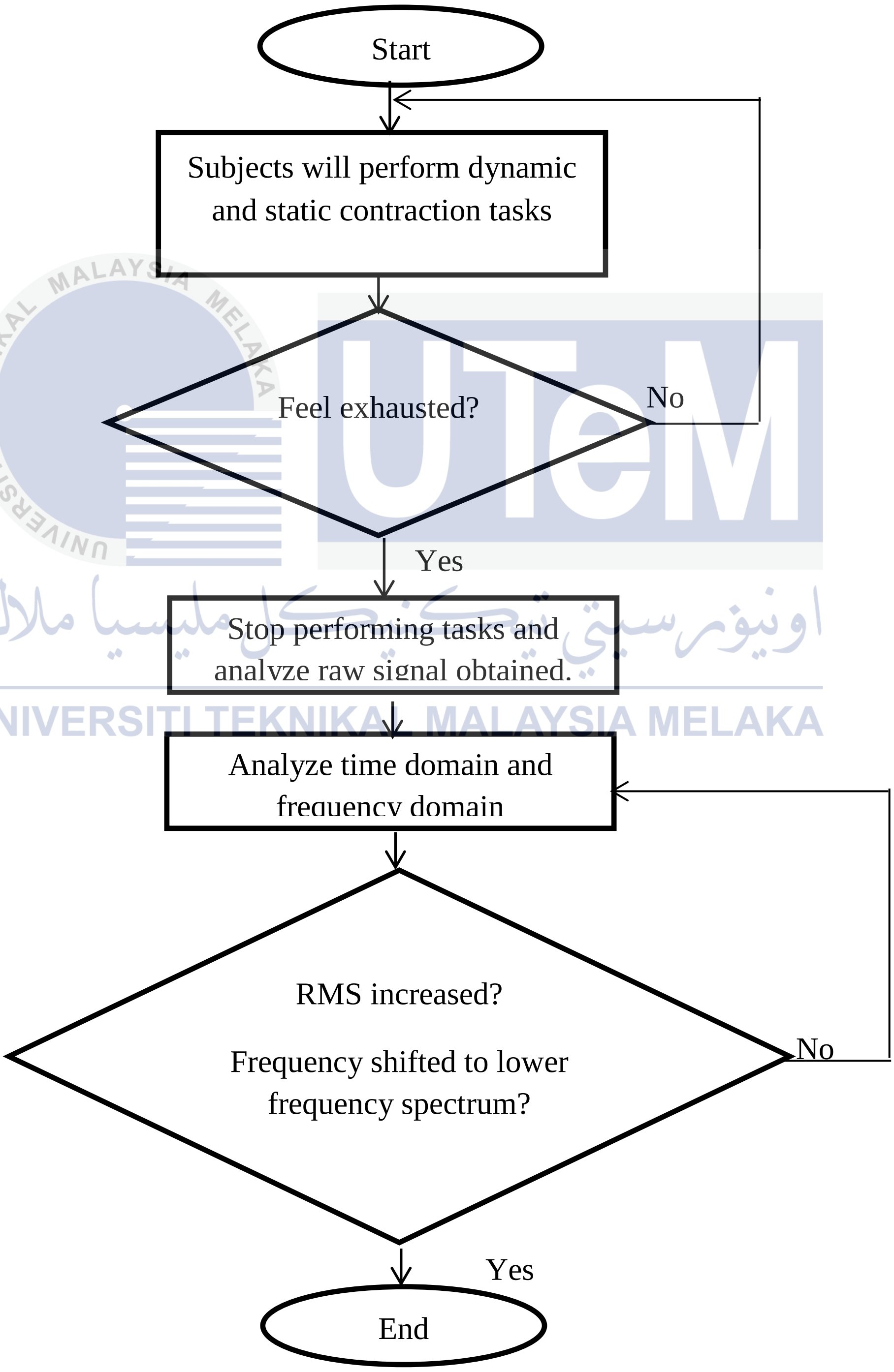


Figure 3.7: Flow chart for implementing data reliability process

CHAPTER 4

RESULT AND DISCUSSION

This chapter presents the result of dynamic and static contraction. A significant change occurs when comparing the result before and during fatigue in terms of RMS, MDF and Scalogram. In time domain analysis, increment of RMS value indicates the progression of muscle fatigue for both static and dynamic contraction. Besides, in frequency domain for static contraction, MDF shows a downwards shifting to lower frequency during fatigue. Lastly, for time-frequency domain in terms of Scalogram for dynamic contraction, it can be observed that the high percentage of energy distribution is shifted to lower frequency during fatigue.

4.1 Feature extraction in dynamic contraction

For dynamic contraction, RMS and Scalogram are the features that will be extracted. Figure 4.1 shows the raw signal of dynamic muscle contraction for flexor carpi radialis while Figure 4.2 shows the raw signal before fatigue and during fatigue. Only the first raw signal and the last raw signal are extracted as shown in the box of Figure 4.1. Before the process of feature extraction, signal processing processes such as rectification and filtering of signal are done. During rectification process (refer to Figure 4.3), the entire negative amplitude signals are converted to positive amplitude signals or reflected by the baseline (0 of the y-axis). This step provides an easier observation. Then, filtering process is done in order to filter the noise as shown in Figure 4.4 and Figure 4.5. Filtering process also applied to the raw signal before analysis during static contraction.

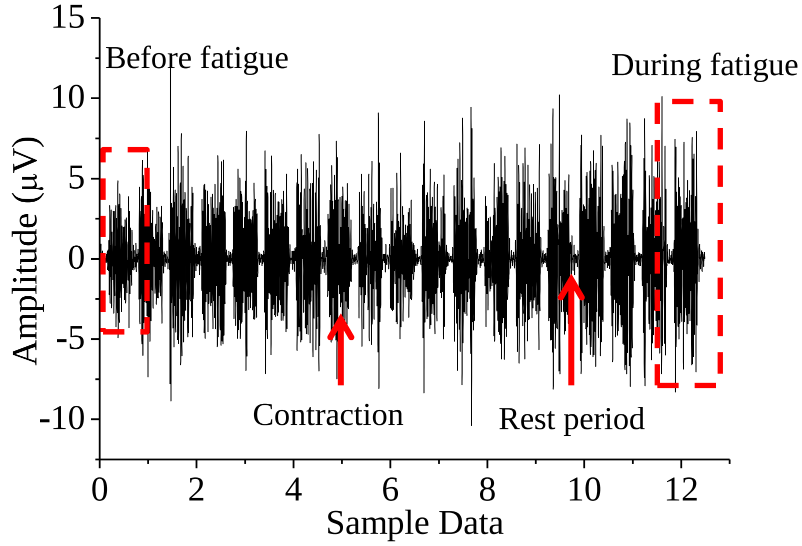


Figure 4.1: Raw signal measurement for flexor carpi radialis

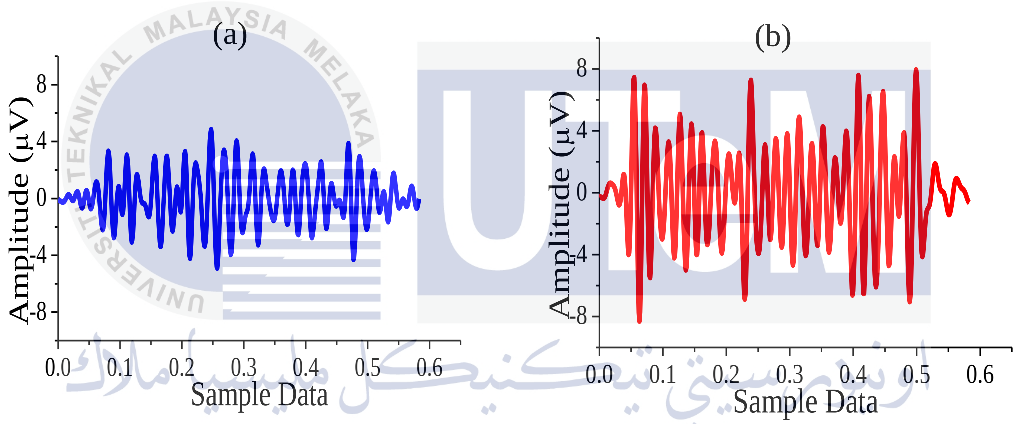


Figure 4.2: Raw signal of (a) before fatigue and (b) during fatigue

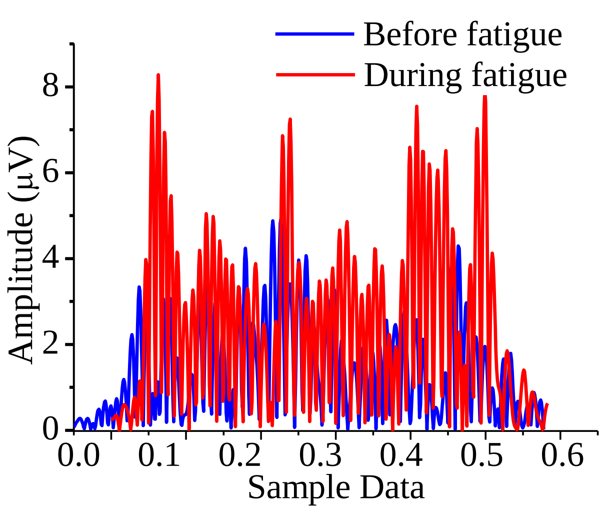


Figure 4.3 Rectification of raw signal

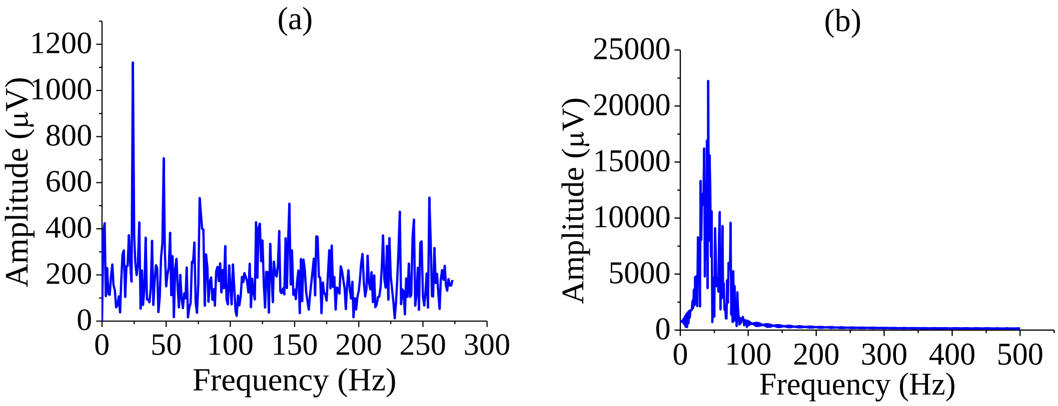


Figure 4.4: Filtering of signal using bandpass filter (a) before filter (b) after filter for before fatigue signal

4.1.1 Time domain analysis: RMS

All of the subjects experience stiffness in their muscle while performing dynamic contraction, which is expected to be caused by muscle fatigue. The entire raw signals below have a sampling time of 0.001s for better accuracy of signal. The RMS value for each raw EMG signal above is calculated using eq. (3):

$$RMS = \sqrt{\frac{1}{T}\int_{-T/2}^{T/2} EMG^2(t)} \qquad (3)$$

Figure 4.5 shows the rectified signal and moving RMS envelops for 1000ms overlap time. This step provides a visual inspection in observing the difference of amplitude of before fatigue and during fatigue. The reason of choosing 1000ms is to provide a more precise moving RMS corresponds to rectified signal. From the result tabulated in Table 4.1, the RMS values for dynamic contraction is increase from before muscle fatigue to during muscle fatigue due to recruitment of motor units. An increase of amplitude could be due to the onset of muscle fatigue. Besides, this study indicates that there is a linear correlation between motion and RMS. Other than that, according to the average value calculated in Table 4.1, it can be seen that the RMS value for females is higher than males. This shows that females have the higher index to get fatigue compared to males in dynamic contraction. The results for average value are tabulated in Figure 4.6.

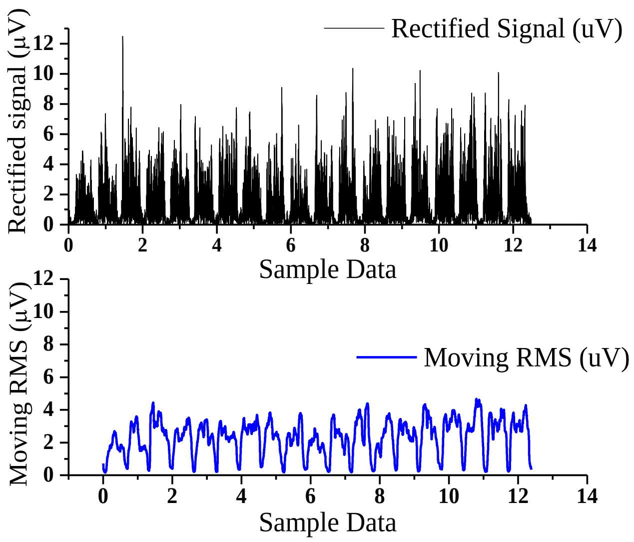


Figure 4.5: Rectified signal and moving RMS 1000ms overlap time

Table 4.1: Average RMS of males and females for dynamic contraction

Subjects	Before fatigue	During fatigue
Males	1.850	2.50
Females	2.19	2.66

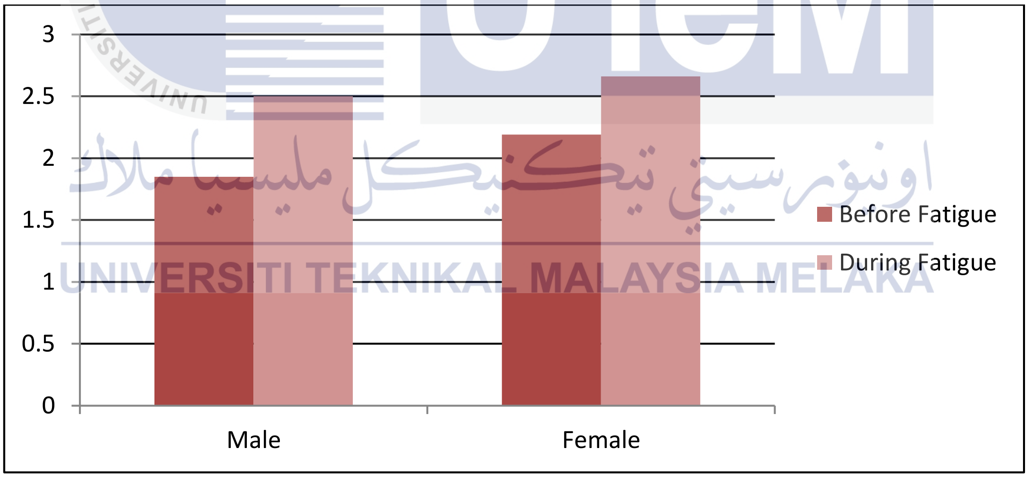


Figure 4.6: Average RMS value for before and during fatigue

4.1.2 Time-frequency analysis: Scalogram

Scalogram is also known as square magnitude of Continuous Wavelet Transform (CWT). The higher color intensity (towards red) indicates higher power strength exerted by subject. The lower color intensity (towards blue) indicates lower power strength exerted by subject. The window length *(nfft)* used to analyze Scalogram is 1024. *nfft* is the FFT length and is the maximum of 256 or the next power of 2 greater than the length of each segment of x. x is defined as the length of signal. Due to wide window length, higher scale indicates lower frequency as $s = \frac{1}{f}$, which indicates increasing scale is corresponds to decreasing in frequency. Figure 4.7 shows the sEMG signal extracted from first contraction and the Scalogram contour plot. The most dominant energy is distributed at the large signal amplitude part.

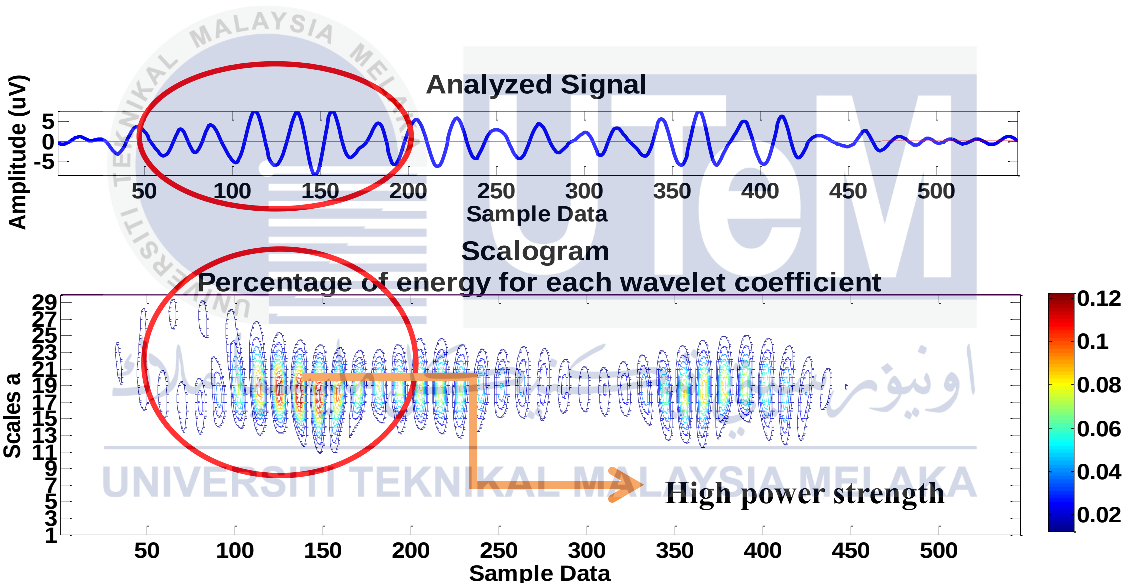
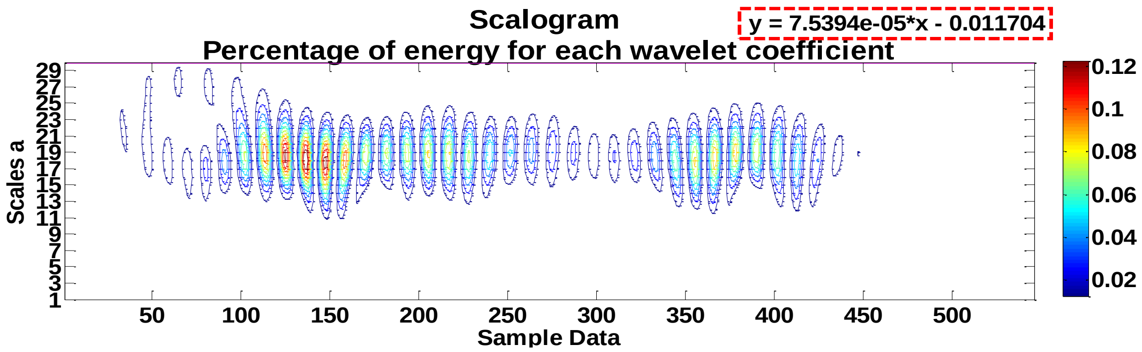


Figure 4.7: sEMG signal extracted from first contraction and the Scalogram contour plot.

By referring to Figure 4.8, the comparison of energy distribution for each wavelet coefficient of the first contraction and the last contraction with the same time interval are shown.

(a)



(b)

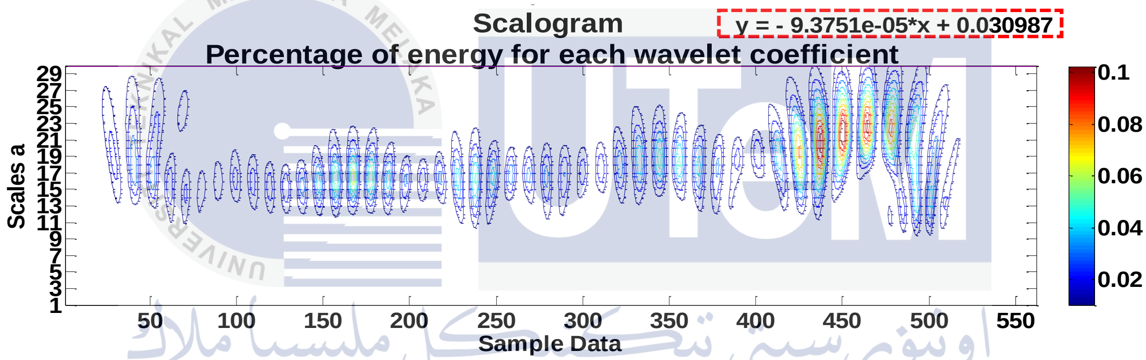


Figure 4.8: Comparison of Scalogram contour plot between (a) before fatigue and (b) during fatigue

From the Figure 4.8(b), it can be seen that the high percentage of the signal energy shifts to the lower frequency as the dynamic contraction goes on, which shows significant sign of muscle fatigue for dynamic contraction. Besides that, the linear equation shown in Figure 4.8(a) and (b) are obtained for every subject and the result of before fatigue and during fatigue for every subject showed the same:

$$\text{Before fatigue: } y = mx \pm c \tag{4}$$

$$\text{During fatigue: } y = -mx \pm c \tag{5}$$

where y is the output signal, *x* is the RMS and *c* is a constant.

Given that the linear RMS equation of EMG signal is:

$$y = mx \pm c \qquad (6)$$

When m is a positive integer, the motor units are able to support the force required to achieve strength i.e. the muscle are still not fatigue. When m is a negative integer, firing rate of motor neurons drops which causes the drops of action potentials, leading to reduction in strength or force.

4.2: Static Contraction

The subjects are required to exert their maximum force and then their 30%, 50% and 70% MVC is measured using handgrip dynamometer. Since it is quite difficult to maintain the constant force level during the experiments by the volunteer subjects, it is therefore 10-20% of tolerance for force level is accepted. Figure 4.9 is the example of raw signal collected and force display for 30% MVC, 50% MVC and 70% MVC of a subject. During static contraction, 200 sample data from the beginning of the contraction and 200 sample data near the end of the contraction will be extracted for further analysis in RMS and MDF (as shown by the red box in Figure 4.9).

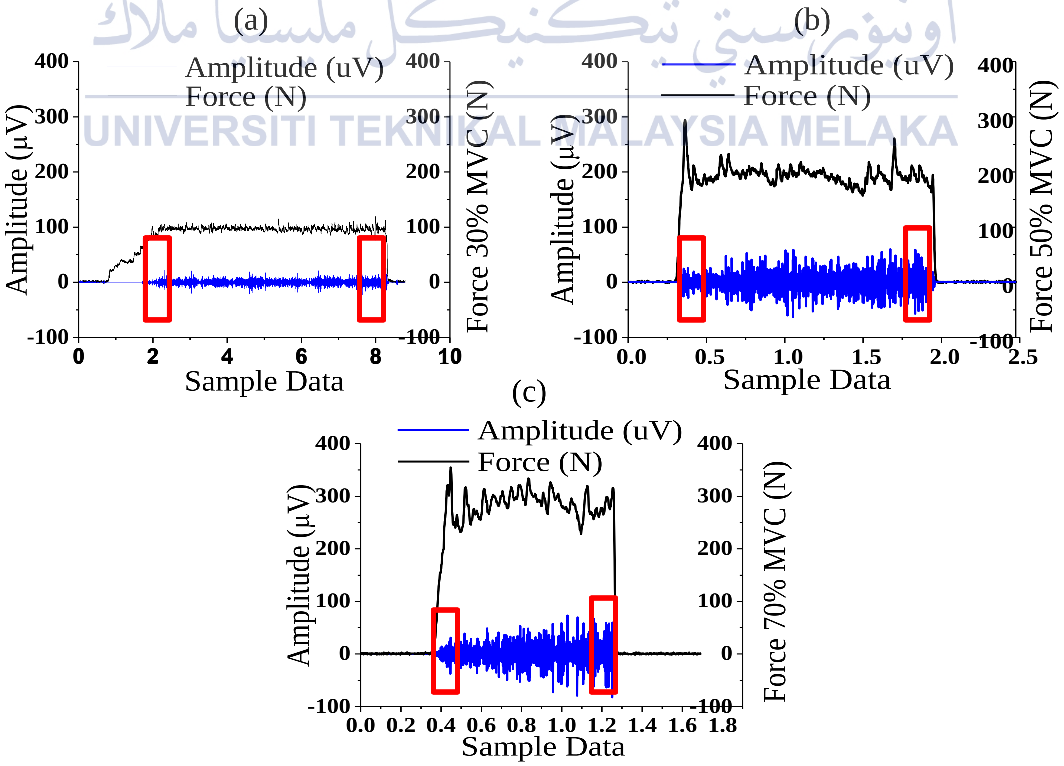


Figure 4.9: Raw signal and force display for (a) 30% MVC (b) 50% MVC (c) 70% MVC

4.2.1 Maximal Voluntary Contraction Analysis

This section will discuss about the MVC analysis. The duration for each percentage of MVC and force losses plays significant roles in fatigue analysis. Figure 4.10 depicts the performance of different percentage of MVC. During relatively low-level contraction (30% MVC), the time perform static contraction are longer. However, higher-intensity contractions (50 and 70% MVC) cause faster muscle fatigue, and thus the EMG signal only behaves as a stationary process for very short periods.

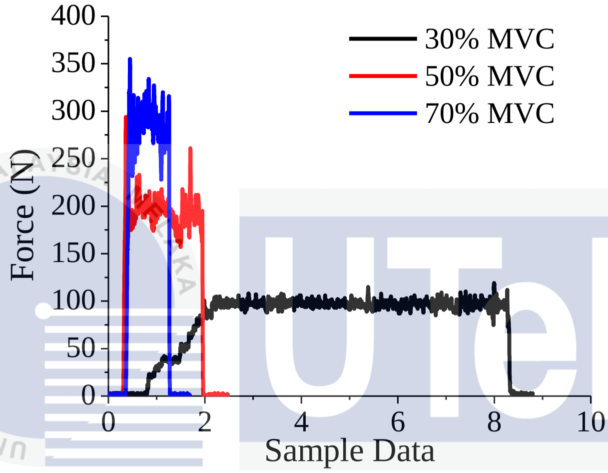


Figure 4.10: Performance of different percentage of MVC

Figure 4.11 shows one of the example of comparison between MVC that exerted by subject before they perform the experiment and MVC that exerted by subject after they perform 30% MVC.

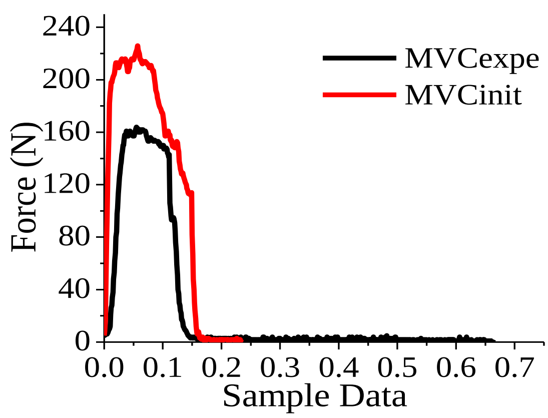


Figure 4.11: MVC determination

Force loss is determined by comparing the MVC that can be exerted by the subjects before handgrip force experiment and MVC that can be exerted by the subjects after experiment. An equation is used to calculate the force losses as shown as below:

$$\Delta MVC = \frac{MVC_{expe} - MVC_{init}}{MVC_{init}} \qquad \textbf{(5)}$$

$\boldsymbol{\Delta MVC}$ = force losses.

$\mathbf{MVC_{expe}}$ = maximum force exerted after handgrip force experiment.

$\mathbf{MVC_{init}}$ = maximum force exerted before experiment.

Table 4.2 and Figure 4.12 show the result of force losses for males and females. Based on the data tabulated in Table 4.2, there are two main observations:

Observation 1: Males have the lower force losses compared to females. This is because males have a greater proportion of muscle mass (longer limbs) than females to exert force.

Observation 2: When higher percentage of MVC is exerted (from 30% to 70%), the percentage of force losses decreases (for both males and females). As the force level increases, more motor units are recruited, indicated by the detection of motor units at higher recruitment thresholds in following contractions.

Table 4.2: Average force losses for males and females

Subjects	**30%**	**50%**	**70%**
Males	25.56%	9.98%	6.88%
Females	29.51%	21.17%	7.92%

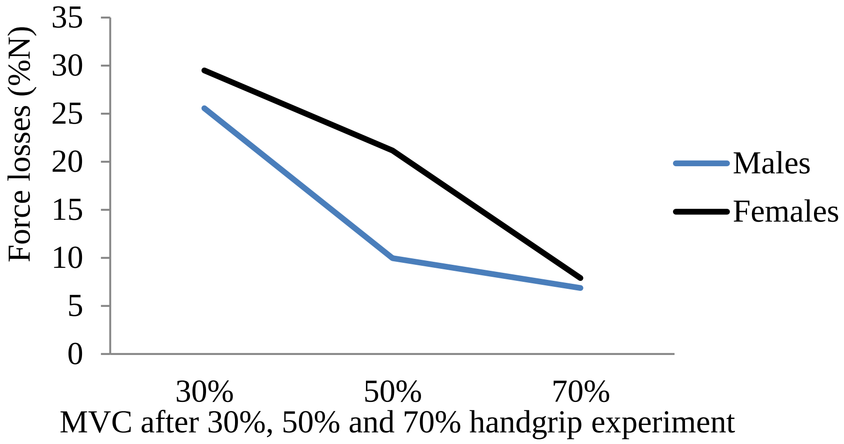


Figure 4.12: Display of force losses based on Table 4.2

4.2.2 Time domain analysis: RMS

Figure 4.13 shows the rectified signal and moving RMS at 1000ms overlap time. Figure 4.14 shows the feature extraction for different percentage of MVC from males and females. As force increase, more motor units are activated, increment of the amplitude can be observed when comparing 30% MVC, 50% and 70% MVC. This is because Type II (>50% MVC) muscles are usually recruited during higher level of contraction [26].

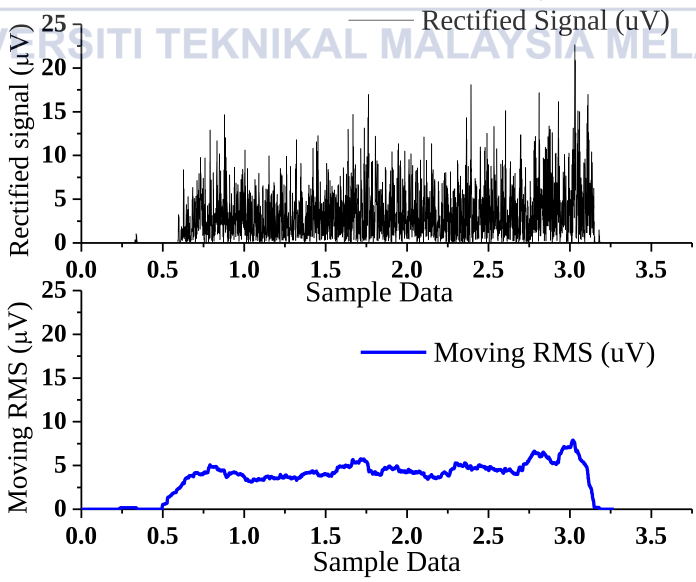


Figure 4.13: Rectified signal and moving RMS at 1000ms overlap time

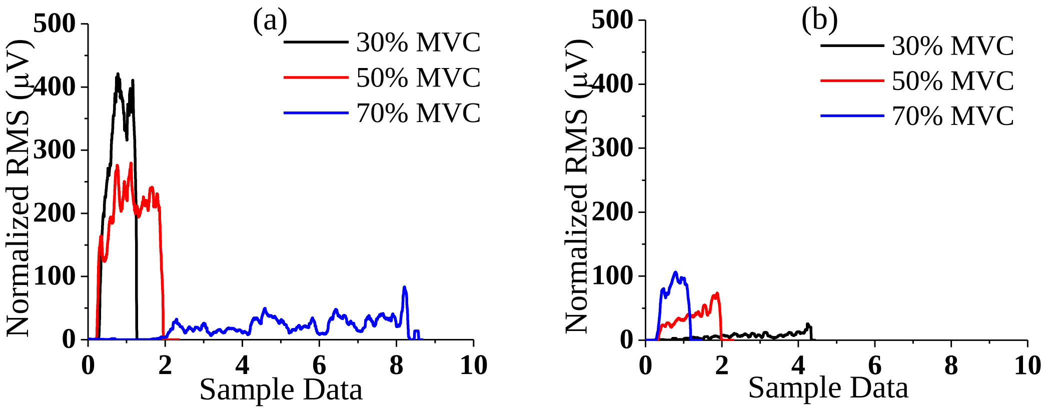


Figure 4.14: RMS feature extraction for different percentage of MVC from two subjects (a) Male (b) Female

Table 4.3 shows the average value of RMS before fatigue and during fatigue for males and females. By referring to Table 4.3, the RMS values for males are higher than females in different percentage of MVC before and during fatigue. This may due to the MVC that exerted by males are higher than females (refer to Table 4.4) which indirectly causes the RMS value of males are higher than females. Due to this factor, it is hard to say that males have higher RMS value compared to females during fatigue. Therefore, a ratio of force to fatigue is determined in the section 4.2.3.

Table 4.3: Average value of RMS before fatigue (BF) and during fatigue (DF)

Subjects	**30% MVC**		**50% MVC**		**70% MVC**	
	BF	**DF**	**BF**	**DF**	**BF**	**DF**
Males	2.44	4.93	6.36	1.190x10^{1}	9.28	1.579x10^{1}
Females	2.26	4.89	4.15	7.96	6.42	1.179x10^{1}

Table 4.4: Average value of 30%, 50% and 70% MVC for males and females

Subjects	**30%MVC (N)**	**50% MVC (N)**	**70% MVC (N)**
Males	8.37x10^{1}	1.266x10^{2}	1.660x10^{2}
Females	5.61x10^{1}	8.51x10^{1}	1.258x10^{2}

4.2.3 Ratio between force to fatigue

The ratio between force and fatigue is calculated by making force equals to 1.

Force : RMS during fatigue

A:B

$$\frac{A}{A} : \frac{B}{A} = 1 : \frac{B}{A}$$

Assuming

Force = A

RMS during fatigue = B

Based on the calculation above, the ratio calculation between force to fatigue are tabulated in Table 4.5 and Figure 4.15. Figure 4.15 is constructed based on data in Table 4.5. It can be seen that, for 30% MVC, females are actually have higher fatigue ratio compared to males. During low intensity contraction (30%), it is shown that males have greater resistance towards fatigue than females. Males are capable to sustain continuous muscle contraction at low intensities longer than females. For 50% and 70% MVC, females and males have approximately same fatigue ratio.

Table 4.5: Ratio between force and fatigue

Subjects	30%	50%	70%
Male	5.89×10^{-2}	9.40×10^{-2}	9.52×10^{-2}
Female	8.71×10^{-2}	9.35×10^{-2}	9.37×10^{-2}

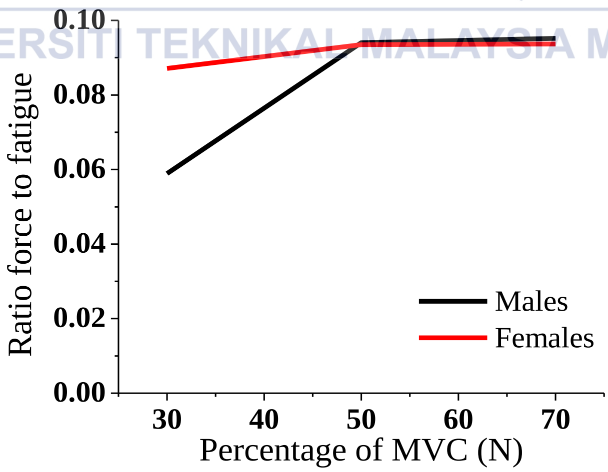


Figure 4.15: Ratio of force to fatigue between males and females

4.2.4 Frequency domain analysis: Median frequency

Figure 4.16 shows the Fast Fourier Transform (FFT) of one subject, the amplitude for during fatigue is higher than before fatigue. Besides, the median frequency has shifted to lower frequency during fatigue as shown in Table 4.6. MDF for during fatigue are downward shift of frequency spectrum for different percentage of MVC. There are several possible reasons for the changes in the EMG signal such as recruitment of firing rate, slowing of conduction velocity and synchronization of the signal. Based on Table 4.6, there are two observations that can be seen:

1) MDF increases as muscle force levels increase for males.

2) MDF decreases as muscle force levels increase for females.

According to the observations, the difference in skinfold layer is the main contributor for two difference genders. Besides the factors about skinfold layer differences, it is also suspected that the following factors mentioned below also contribute to the conflicting result such as the difference in type and distribution of muscle fibres composition and tissue filter effects. Difference genders will have different fibre diameters and types. Other than that, electrode locations across the muscle area vary for each subject throughout experiment. Lastly, limited number of subjects, level of force exhibited and existence of fatigue that resulting from the longer recording times can contribute the both observations stated above.

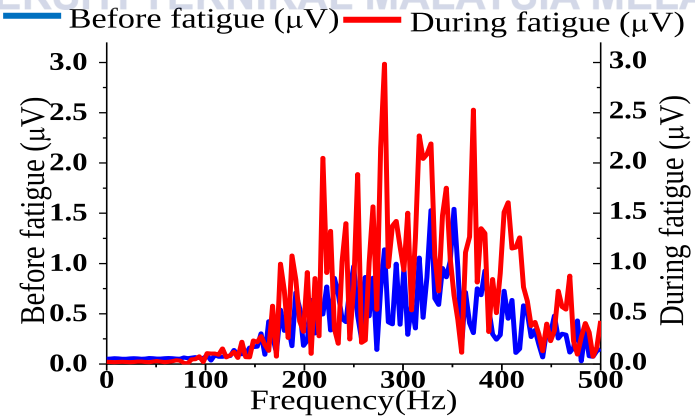


Figure 4.16: Frequency spectrum for one subject (before and during fatigue)

Table 4.6: Median frequency (MDF) before fatigue (BF) and during fatigue (DF)

Subjects	**MDF for 30% MVC**		**MDF for 50% MVC**		**MDF for 70% MVC**	
	BF(Hz)	**DF(Hz)**	**BF(Hz)**	**DF(Hz)**	**BF(Hz)**	**DF(Hz)**
Males	$3.04x10^2$	$2.91\ x10^2$	$3.07\ x10^2$	$2.97\ x10^2$	$3.11\ x10^2$	$2.98\ x10^2$
Females	$3.18x10^2$	$3.06\ x10^2$	$3.18\ x10^2$	$2.99\ x10^2$	$3.00\ x10^2$	$2.91\ x10^2$

4.3 Manifestation of muscle fatigue for dynamic and static contraction

4.3.1 Amplitude (RMS)

In this research, both dynamic and static contraction shows a linear correlation between:

1) Motion and amplitude

2) Force and amplitude

As the same motion repeated continuously throughout dynamic contraction experiment, increment of amplitude when the subjects are fatigue can be observed. For static contraction, it also can be observed that there is an increment of amplitude during the end of the contraction even though the force is kept constant during the experiment. However, by referring to Figure 4.17, when comparing the RMS values for dynamic contraction and static contraction during fatigue, the RMS values for static contraction are higher than dynamic contraction. Also, period for performing dynamic contraction experiment is longer than static contraction experiment. This implies that time to induce muscle fatigue during dynamic contraction is longer. When determining the ratio of force to fatigue in static contraction experiment, it can be seen that there are big difference of ratio during 30% MVC while stay approximately the same ratio during 50% and 70% for males and females. Apart from above observations, it can be also observed that during static contraction, the ratio of force to fatigue during 50% and 70% MVC is nearly constant for both males and females due to faster conduction velocities.

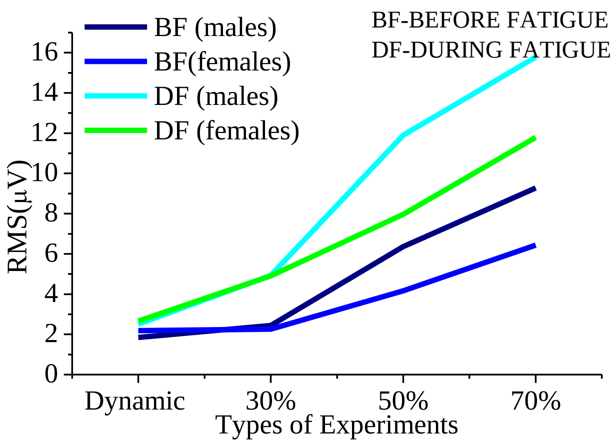


Figure 4.17: Comparison of RMS value for dynamic and static contraction

4.3.2 Median frequency (MDF) and Scalogram

The downward shift of frequency spectrum as fatigue developed is discussed in section 4.2.4. It is suspected that the shift of spectral is corresponding to the slowing down of motor unit action potential (MUAP) conduction velocity as muscle fatigue occurred. However, MDF is only applied to static contraction. For dynamic contraction, Scalogram is used and result shows that when fatigue developed, the energy distribution is shifted to lower frequency.

However, when analyzing sEMG signals during dynamic task, the important concern is that the changes of signal amplitude and frequency are not only influenced by muscle fatigue but also the changes of force level. Therefore, the effects of force level and muscle fatigue are done in order to prevent any conflict that faced while doing dynamic contraction experiment.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

As a conclusion, evaluation of muscle fatigue is very crucial in our life. The effect from muscle fatigue can cause many disorders that bring inconvenience to life. In this research, there will be two types of contraction: dynamic contraction and static contraction. During dynamic contraction, the methodology involved movements where the wrist is moving up to their maximal joint angle and back to original position. While for static contraction, the methodology involved the force exerted with the aids of handgrip dynamometer. Subjects are required to exert their maximum voluntary contraction (MVC), followed by 70%, 50% and 30% MVC. When the signal for raw EMG is analysed using time domain in terms of RMS, it is found that when fatigue induced, the amplitude is increase for both dynamic and static contraction. The major concern when analysing sEMG signals during dynamic task is the changes of signal amplitude and frequency are not only influenced by muscle fatigue, but also the changing of force level. For median frequency, it shows a shifting to lower frequency during fatigue for static contraction. Lastly for Scalogram, high percentage of energy distribution has shifted to lower frequency during fatigue. Although the results were promising, there will be some limitations that need to be overcome in the future. For example, instantaneous MDF and instantaneous MNF will be the suggested solution for dynamic contraction. Further studies to identify the differences between the effects of force level and muscle fatigue on sEMG signals should be considered. As a recommendation, the experimental setup can be implemented using wireless link in order to provide a wider space for subject as the electrodes are limiting the subjects' movement.

5.1 Future Works

Although this thesis has reported the successful estimation of muscle fatigue with healthy subjects using proposed approaches, there are some limitations. More works can be done to improve the current approaches. To achieve more robust results for fatigue detection methods, more subjects from different ages are needed to ensure the propose feature extraction methods are suitable for a wider variety of subjects. The current data collection only focuses on flexor carpi radialis. If the effect of muscle fatigue condition in different location of muscles can be compared, it will be helpful in exploring more effective approaches. Online data analysis can be done too and implement for rehabilitation purpose to prevent muscle fatigue that will cause muscle injured. Even though the proposed approaches have been shown to be feasible using sEMG signal from dynamic contraction, in the future, may be the variation of angle and force can be done in order to form a control algorithm for muscle fatigue.

REFERENCES

[1] YG. Soo, M. Nishino, M. Sugi, H. Yokoi, T. Arai, R. Kato, T. Nakamura and J. Ota. “Evaluation of frequency band technique in estimating muscle fatigue during dynamic contraction task,” in *IEEE International Conference on Robotics and Automation*, pp. 933-938, 2008.

[2] Al-Mulla, M. R., Sepulveda, F., & Colley, M. (2012, January 11). “*sEMG Techniques to Detect and Predict Localised Muscle Fatigue”* [Online]. Available: http://www.intechopen.com [Oct 20, 2013]

[3] Al-Mulla, M. R., Sepulveda, F., & Colley, M. (2011, Jan). “Sensor.” *A Review of Non-Invasive Techniques to Detect and Predict Localised Muscle Fatigue.* [On-line]. pp 3545-3594. Available: www.mdpi.com/journal/sensors. [Oct. 24, 2013]

[4] “A New Explanation of Muscle Fatigue.” *The New Yorks Times* (Feb. 11, 2008)

[5] De Luca, C.J. “The Use of Surface Electromyography in Biomechanics” *Journal Of Applied Biomechanics*, vol.13, pp.135-163, 1997.

[6] De Jesus, I. R. T., Mello, R. G., & Nadal, J. “Principal components of frequency domain electromyograms for muscular fatigue analysis”, in *IEEE EMB*, pp. 3519-3522, 2010.

[7] Ahsan, M. R., Ibrahimy, M. I., & Khalifa, O. O. “Hand motion detection from EMG signals by using ANN based classifier for Human Computer Interaction,” *in Modeling, Simulation and Applied Optimization (ICMSAO)* , pp. 1-6, 2011.

[8] Sakurai, T., Toda, M., Sakurazawa, S., Akita, J., Kondo, K., & Nakamura, Y. “Detection of Muscle Fatigue by the Surface Electromyogram and its Application,” *In Computer and Information Science (ICIS)*, pp. 43-47, 2010.

[9] Al-Mulla, M. R., Sepulveda, F., Colley, M., & Al-Mulla, F. “Statistical class separation using sEMG features towards automated muscle fatigue detection and prediction,” in *Image and Signal Processing*, pp. 1-5, 2009.

[10] Sakurai, T., Toda, M., Sakurazawa, S., Akita, J., Kondo, K., & Nakamura, Y. “Study on Detection of alternate muscles activity and its transition with muscle fatigue,” in In *IT in Medicine and Education (ITME)*, pp. 18-22, 2011.

[11] Al-Mulla, M. R., & Sepulveda, F. “A novel feature assisting in the prediction of sEMG muscle fatigue towards a wearable autonomous system,” In *Mixed-Signals, Sensors and Systems Test Workshop (IMS3TW)*, pp. 1-6, 2010.

[12] Al-Mulla, M. R., Sepulveda, F., Colley, M., & Kattan, A. “Classification

of localized muscle fatigue with genetic programming on SEMG during isometric contraction," In *Engineering in Medicine and Biology Society*, pp. 2633-2638, 2009.

[13] Oliveira, L. D., Santhomé, Peixoto, L. R. T., Guimarães, C. M., da Rocha, A. F., Soares, F. A., Gonçalves, C. A. "Electromyographic study in 5 muscles during an isometric fatiguing protocol." in *IEEE EMBS*, 2012, pp. 3592-3595.

[14] R. Cram, J, S. Kasman, G. "The Basic of Surface Electromyography." Internet: http://samples.jbpub.com [Nov. 11, 2013]

[15] Quach, J. H. "Surface Electromyography: Use, Design & Technological Overview." Internet: http://www.bfe.org Dec 10, 2007 [Nov.2, 2013]

[16] Singh, V. P., Kumar, D. K., Polus, B., & Fraser, S.. "Strategies to identify changes in SEMG due to muscle fatigue during cycling," in *Journal of medical engineering & technology*, pp. 144-151, 2007.

[17] Kim, G., Ahad, M. A., Ferdjallah, M., & Harris, G. F.. "Correlation of muscle fatigue indices between intramuscular and surface EMG signals," In *SoutheastCon*, pp. 378-382, 2007.

[18] Lowery, M. M, and O'Malley M. J, "Analysis and Simulation of Changes in EMG Amplitude During High-Level Fatiguing Contraction." *IEEE Transactions on biomedical engineering*, vol. 50, pp. 1052-1062, Sep. 2003.

[19] De Luca, C. J.. "Surface electromyography: Detection and Recording." Internet: http://www.delsys.com, Oct. 2002 [Nov. 2, 2013]

[20] Karagözoğlu, B., Sindi, W. H., & Al-Omari, A. A. "Design and Development of a Practical Muscle Fatigue Monitor," In *GCC Conference & Exhibition*, pp.1-7, 2009.

[21] Oskoei. A, M., Hu, H., & Gan, J. Q. "Manifestation of fatigue in myoelectric signals of dynamic contractions produced during playing PC games," In *Engineering in Medicine and Biology Society*, pp. 315-318, 2008.

[22] Wall, R. W. "Simple methods for detecting zero crossing," in *Industrial Electronics Society*, pp. 1-5, 2003.

[23] Phinyomark, A., Thongpanja, S., Hu, H., Phukpattaranont, P. and Limsakul, C. "The Usefulness of Mean and Median Frequencies in Electromyography Analysis." Internet: hhttp://dx.doi.org/, 2012 [Nov. 2, 2013]

[24] Roy, S. H., Bonato, P., & Knaflitz, M.. "EMG assessment of back muscle function during cyclical lifting," in *Journal of Electromyography and Kinesiology*, pp. 233-245, 1998.

[25] Leis, A. Arturo; Trapani, "*Vicente C. Atlas of Electromyography*," Oxford University Press, pp. 1-26,2000.

[26] Fengjun, B. Muscle Force Estimation and Fatigue Detection Based on sEMG Signals, National University of Singapore, Singapore, 2013.

[27] Al Zaman, A., Sharmin, T., Khan, M. A. A., & Ferdjallah, M.. Muscle fatigue analysis in young adults at different MVC levels using EMG metrics. *SoutheastCon Proceedings, IEEE* , pp. 390-394, 2007.

APPENDICES

Appendix A: Gantt Chart

Gantt Chart Year 4 Semester 1

Description	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
Experimental setup											
i) Preparation of material and equipment											
ii) Subject Selection											
iii) Data Acquisition and Pre-processing											

Gantt Chart Year 4 Semester 2

Description	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11
Experimental setup											
iv) SEMG Segmentation											

v) Analysis of extracted feature using Time Domain											
i) Analysis of extracted feature using Frequency Domain											
ii) Report preparation and submission											

Appendix B: Experimental setup for Data Acquisition

FACULTY OF ELECTRICAL ENGINEERING

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2013/2014

BEKU 4792

RESEARCH METHODOLOGY

EXPERIMENT ACQUISTION DATA FOR ELECTROMYOGRAPHY (EMG) SIGNAL

TASK	NAME	SIGNATURE	DATE
PREPARED BY	KHOO HUI PING		

TITLE:

SAMPLE DATA ACQUISTION FOR EMG SIGNAL

OBJECTIVES:

At the end of this experiment, we should be able:

1. To collect the raw EMG signal by applying time domain and frequency domain extracted features.
2. To recognize the behaviour of EMG signal.
3. To prepare the EMG signal for classification stage.
4. To identify muscle activation or deactivation
5. To understand the relationship between fatigue level and EMG signal
6. To perform a static and dynamic contraction to induce muscle fatigue.

References

1. The ABC of EMG- A practical introduction to Kinesiological Electromyography.
2. A Myosignal-based powered exoskeleton system
3. Techniques of EMG signal analysis: detection, processing, classification and applications
4. Investigation of optimum electrode locations by using an automatized surface electromyography analysis technique.

List of Equipment

1. 2 channels of EMG passive electrodes
2. 1 unit of Arduino Mega 2560 Board
3. 2 unit of EMG Arduino shield board
4. 3 unit marker pen
5. A stop watch
6. 10 unit Razor shaver
7. 100 unit Alcohol swab
8. 3 unit Wet tissue boxes
9. 1 unit of electrode paste gel
10. 1 unit of Handgrip Dynamometer

Pre task procedure

1. Firstly, subjects whom fulfill the requirement are selected.

Subject's specifications:

Specifications	**Male**	**Female**
Age	20-24	
Height	$175 \pm 10cm$	$158 \pm 10cm$
Weight	54.5 kg-82.14kg	43.8kg-67.7kg
BMI	20-24.5	
Body status	Healthy, no neuromuscular disease, never undergo any surgery or injury at forearm, non-smokers	

2. Each subject is given a written consent about the experimental setup. The consent is required to be signed by each subject to let them understand the procedure that will undergo during experiment.

3. After simple briefing on experimental protocol, subject will undertake the skin preparation. Skin preparation procedures will be stated as below.

3.1 Removing the hair:
Hair shaving will help in the stability of skin-electrode contact and for high input impedance.
3.2 Cleaning of the skin:
Alcohol, wet tissues and conductive cleaning paste gels are used to remove dead skin cells and keep the skin clean from sweat and dirt.
4. Lastly, by using multi-meter to check the skin impedance in order to make sure the resistance on the surface area low.

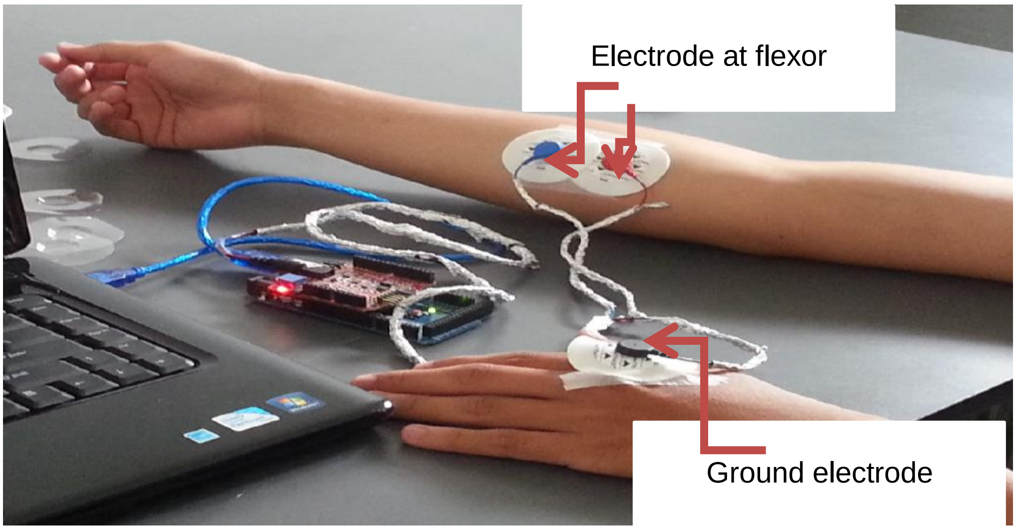


Figure 1: Location of SEMG electrode on forearm

Experimental Description:

1. Figure 1 shows the experimental setup.

2. Figure 2 and 3 show the way subject will perform throughout this experiment.

3. There will be two types of experimental setup:

i) Dynamic Contraction

ii) Static Contraction

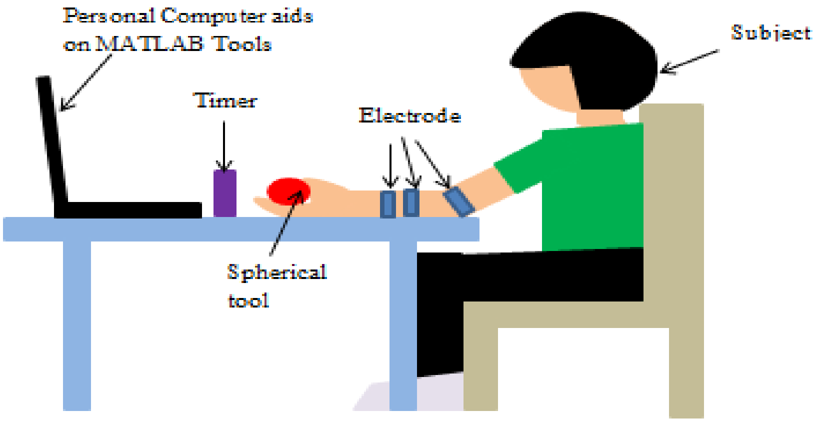


Figure 2: Original Condition with Sitting Position

Figure 3: Wrist up 90 degree

i) Dynamic Contraction

1. The experiments will conducted in a sitting position with relax environment. Subjects are firstly asked to maintain their posture during the experiments, including their wrist, to minimize the noise due to motion artifacts.

2. For the dynamic contraction experiment, each subject will asking to grip a spherical tool and move their wrist up to maximal joint angle and then back to their original position. This action will continue for 12 seconds and rest period is given 4 seconds. The test will continue until subject is fatigue.

3. This experiment overall will take about one hour average for each subject.

ii) Static Contraction

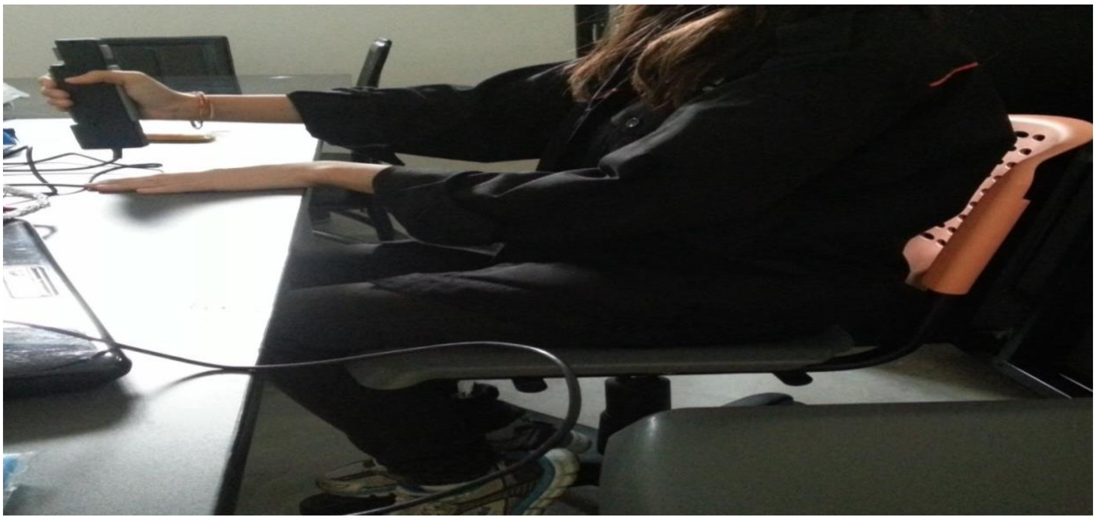


Figure 4: Static contraction experimental setup

1. The experiments will conducted in a sitting position with relax environment. Subjects are firstly asked to maintain their posture during the experiments, including their wrist, to minimize the noise due to motion artifacts.

2. For the static contraction experiment, each subject will be given a handgrip Camry dynamometer instead of spherical tool and they will ask to exert their maximum voluntary contraction (MVC). After that, subjects will take a rest around 35 minutes for muscle recovery. This process is very important in order to prevent any internal muscle injury on subject. Then, the subject will start to exert 30% of the MVC until he/she reached exhausted level. The time for each contraction will be record. Subjects will be given 30 minutes again for muscle recovery period before proceeding to next step where he/she need to exert 70% of the MVC. The process is similar to 30% of MVC mention above.

3. This experiment overall will take about one and half hour average for each subject.

Hardware Implementation

1. Electrodes will be placed on flexor carpi radialis (FCR) and one electrode is tap on bone side of the finger. The inter-electrode distance is 30 mm from centre to centre.
2. Connect the electrodes to EMG Shield. Then connect EMG shield and Arduino Mega 2560 together. Lastly connect the hardware to PC Matlab for signal monitoring.

3. A personal computer aids on with Matlab tools and timer will place in front of subject.
4. Obtain the signal display by using Simulink.
5. Analyse the signal using Root Mean Square (RMS), Mean Frequency (MNF) and Median Frequency (MDF) to determine muscle fatigue.

Appendix C: Written consent form

Declaration Form

Hereby, I am ____ Matrics No. (   ) is volunteer myself to become the subject of this experiment (Dynamic / Static contraction). I declared that I never experienced any injury of muscle, operation or surgery on wrist muscle and fulfil all the specification mentioned in the lab sheet provided. I have read the lab sheet provided and I understand all the rules, regulations and steps taken throughout this experiment. I will take the responsibility if I get any injury, risk and allergic cases during the experiment later.

_________________________ Subject's signature

_________________________ Witness's signature

Appendix D: Schematic Diagram for EMG Arduino

EMG Arduino Schematic Diagram