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EVALUATION OF MUSCLE FATIGUE IDENTIFICATION BASED ON EMG FEATURE

NUR AMELIA IZZATI BINTI MOHD AMIN

Thesis submitted in fulfilment of the requirement

for the award of the degree of

B. Eng (Hons) Mechatronics Engineering

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DEDICATION

“At the Almighty, for His praise offered and grace that he owns the Creator and the universe and knowledge in the world and in the hereafter”.

For my beloved’s parent,

Mohd Amin B. Hj. Awang

&

Che Norlia Bt. Ariffin

A lot of support and help to prepare this report.

For final year project supervisor, Dr Nizam Uddin Ahamed

Thank you for your guidance and knowledge granted.

To colleagues,

Equally share the sad and happy.

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ABSTRACT

The aim of this study was to identify muscle fatigue during sub-maximal contraction on biceps brachii and triceps muscle on upper limb muscle through EMG feature. The relationship between muscle fatigues with EMG feature was evaluated by conducting on six volunteers on their upper limb muscle. The raw EMG signal was recorded from biceps brachii muscle and triceps muscle in static posture at 30%, 50% and 70% of their maximum voluntary contraction (MVC). Band pass Butterworth filter (20-1000 Hz) and 1000 Hz of sampling frequency was applied during the experiments. The subjects was instructed to grip the hand dynamometer and the sEMG activity of the biceps brachii muscle and triceps muscle was recorded. Root mean square feature was calculated as EMG amplitude which have been computed in the filtered EMG signal recorded. Regression analysis and analysis of variance (ANOVA) were implemented to determine the significant of the feature with the muscle force. The result shows that muscle fatigue was performed at 70% of MVC at both of muscle. The relationship between 30% and 70% of force was most significant value which was 0.000 ($P<0.05$) on biceps brachii muscle while most significant value was 0.035 ($P<0.05$) resulted between 30% and 70% of force on triceps muscle.

Keywords: EMG; sEMG; maximum voluntary contraction; muscle fatigue; biceps brachii; triceps; upper limb muscle

ABSTRAK

Tujuan kajian ini adalah untuk mengenal pasti keletihan otot semasa sub-maksimum penguncupan pada bisep brachii dan triceps otot pada otot anggota badan atas melalui ciri EMG. Hubungan antara seragam otot dengan ciri EMG dinilai dengan menjalankan enam sukarelawan pada otot anggota badan atas mereka. isyarat EMG mentah direkodkan daripada bisep brachii otot dan triceps otot dalam postur statik pada 30%, 50% dan 70% daripada penguncupan sukarela maksimum (MVC). Band lulus Butterworth penapis (20-1000 Hz) dan 1000 Hz frekuensi pensampelan telah digunakan semasa eksperimen. Para subjek diarahkan untuk cengkaman dinamometer tangan dan aktiviti sEMG daripada bisep dan triceps otot otot brachii direkodkan. Punca min ciri persegi dikira sebagai EMG amplitud yang telah dikira dalam isyarat EMG ditapis direkodkan. Analisis regresi dan analisis varians (ANOVA) telah dilaksanakan untuk menentukan besar ciri-ciri yang dengan kekuatan otot. Hasil kajian menunjukkan bahawa keletihan otot telah dilakukan pada 70% daripada MVC di kedua-otot. Hubungan antara 30% dan 70% daripada tenaga adalah nilai yang paling penting iaitu 0,000 ($P < 0.05$) pada bisep otot brachii manakala kebanyakan nilai signifikan adalah 0.035 ($P < 0.05$) menyebabkan antara 30% dan 70% daripada kuasa pada triceps otot.

Kata kunci: EMG; sEMG; penguncupan sukarela maksimum; keletihan otot; brachii bisep; triceps; otot anggota badan atas

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LIST OF SYMBOLS

$\sum x$	Summation data of X
$\surd$	Square root
%	Percentage
X^2	Different X power of 2
N	Number of data points
R^2	Regression

LIST OF ABBREVIATIONS

EMG	Electromyography
sEMG	Surface electromyography
RMS	Root mean square
MVC	Maximum Voluntary Contraction
ANOVA	Analysis of variance
MPF	Mean power frequency
MUAP	Motor unit action potential
ZCI	Adjacent zero crossing
TR	Trapezius
BB	Biceps brachii
Ag/CI	Silver chloride

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Human daily life involves many physical and mental activities which mostly relate with the movement of muscle and tendon in whole body muscular system. Movement of muscle is significantly be influenced by on the muscle contraction as movement while exercise, working or writing that commonly occurs at upper limb muscle. When the muscles are not able to maintain its requirement output power while contraction, fatigue will happen.

Muscle fatigue is one of a muscular disorder that occurs due to the excessive muscle contraction at a prolonged times even it happen with small load. The asset of muscle contraction is depend on the numbers and sizes of active motor unit (MU), stimulation rate of MU and the muscle fibers types. To evaluate the muscle fatigue in different medium, surface electromyogram (sEMG) is the most consideration to measure the relative change about the muscle state condition. There are different parameters that could be used to extract the myoelectric activity over sEMG signal. Root-mean-square (RMS) is the common parameter features which could increase the sEMG signal amplitude.

1.1.1 Electromyography

Electromyography signal is a result of detecting, processing and evaluating the electrical activity (electromyogram or EMG) in the muscle that produced from muscle contraction. The muscle signal are detected by an electrodes that connecting with simple sensor that could assess the motor unit in the fiber during contraction occurs. The composition of EMG signal could be recognizes based on knowledge in anatomy and entire neuromuscular system representative.

In general, there are two types of EMG signal, which are surface EMG (sEMG) and intramuscular EMG (Chowdhury et al., 2013). Surface electromyogram (sEMG) is the electrical activity that been recorded during the muscle activation which is a combination of tissue-filtered motor unit action potentials (MUAP) that generated by an active motors unit(Arjunan, Kumar, & Naik, 2014).

Definition of motor unit is a motor neuron that all fibers innervate on it. While in performing an intramuscular EMG, there an insertion of needle together with an electrode connected with two fine wires into the muscle tissue through the skin. The action potential called impulse has been transmits through motor neuron to the muscle. Motor end plate is the region where nerve contact the muscle and all the action potential are response with the muscle fiber and cause an electrical activity that known as motor unit action potential (MUAP) (Zhou, Chen, Ma, & Zheng, 2011). This signal activity is the signal that will be evaluate during an EMG process.

1.1.2 Electrode

There are two types of electrodes, intramuscular electrodes or invasive electrode that used by insertion of a needle across the skin and surface electrode which is noninvasive electrode that attached on the skin. Needle with silver (Ag) wire are tie together to detect the electrical activity during contraction with low amplitude and low speed muscle activity result. Mostly, this approach is used for medical research or clinical diagnosis for neurophysiological evaluation.

In this study, a surface electrode will be used for sEMG evaluation because the signal is easy to record while accessing the muscle fatigue that occur on the upper limb that result from estimating the muscle contraction during the changes in muscle state condition(Arjunan et al., 2014). Surface electrode is commonly made from round metal plate in small millimeters diameter or in rectangular of silver chloride (Ag/CI). Double-face adhesive tape are fixed with the electrodes when place it on the skin surface with the estimation of muscle contraction phase will occurs in parallel orientation with muscle fibers.

1.1.3 Upper limb muscle

On the arm, there are four muscles that attached on it which are biceps brachii, brachialis and coracobrachialis where placed on anterior compartment and another one triceps muscle which located on posterior compartment. Biceps and triceps muscle are work together to move the forearm in a way of contraction on the biceps and flexes it to move towards the humerus and shoulder. While triceps is an opposite one that will contract towards ulna and get away from the humerus in lower down the arm. However, they are not move itself but with the assistance from the small muscle such as brachialis and brachioradialis that important to initiate and stabilize the arm when its movement ("Anatomy & Physiology," 2015).

1.1.4 Muscle Fatigue

According to Zhou, fatigue is consist of systemic and local fatigue where the systemic fatigue are cause from an excessive physical work then related with mental and disease disorder while local fatigue are happen due to the long working hours or bad body posture while working such as while seating on the chair(Zhou et al., 2011). The fatigue occurs when body are cannot supply enough energy to meet the demand and decrease the body performance ability during physiological activities.

1.1.5 EMG Features

During EMG signal processing, there are some noise that could affect the raw EMG signal analysis. In classify the raw EMG signal performance and there are different types of EMG features that act in detecting the optimal classification technique. Time domain is about to evaluate the amplitude against the time characteristic of EMG signal. While, frequency domain analysis is focus on the replacement of the measured signal with sinusoids to produce waveform that equivalent to the raw EMG signal. Then, the time-frequency domain is an analysis of the response of dynamic system to an input that describe as a function of time.

1.2 PROBLEM STATEMENT

Properties of EMG signal which are very large in variation, nonlinear and full with complexity are lead to the difficulty to analyze the signals. When the EMG signal occurs, the analyzing and processing process are very difficult to accumulate due to the various types of noises contaminate on it. Feature are propose to evaluate the optimal (sEMG) signal of the muscle fatigue in biceps brachii and triceps muscle. And, to analyze the relationship between each of this feature with force in the muscle fatigue based on (sEMG) signal. Besides that, the distortion of (sEMG) signal recording the acquisition system also an issue when the electrode placement on the skin.

1.3 OBJECTIVES

The objectives of this study are:

i. To identify the muscle fatigue in biceps brachii and triceps on the upper limb muscle.
ii. To analysis the muscle fatigue behavior through EMG feature.

1.4 PROJECT SCOPE

i. Rehabilitation

There are some situations after a surgery where the patient will feel muscle fatigue and need some rehabilitee session to help in recovery the affected muscle to function properly on post-surgery transfer duration.

ii. Medical research

The medical study about EMG are widely done in investigate the electrical output with activities undergoes within the muscle with two electrodes. It also have been through intramuscular electrodes procedure that conducted by a medical researcher.

iii. Biomechanics

The study of electromyography is widely exposed on the biomechanics field which results in term of combination biological concept with mechanics configuration of body movement.

iv. Sport science

During sport activities, the muscle will undergoes strong muscle contraction and release more energy until the muscle become fatigue. The EMG signal will show that the muscle have undergoes certain period with high amplitude signal that relate with the activities of the affected muscle.

1.5 CONCLUSION

This chapter was about the details of the project which include the problem statement, objectives and project scopes. Better understanding of EMG characteristics is a must to make sure all the parameters are apply while recording the muscle activities during the contraction on biceps brachii muscle and triceps muscle. Besides that, RMS feature will be apply in this study as the amplitude of EMG signal on muscle fatigue condition.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will mainly discuss about past research and studies of muscle fatigue that occur in the upper limb muscle. This paper research also will focus on the parameters used to interpret data from sEMG signal, especially during the muscle fatigue happen on the upper limb muscle. These sEMG signals will measure on the contraction of upper limb muscle on right biceps brachii and triceps muscle. All the method of these previous researches is organized properly in the table starting from the detail explanation of sEMG signal in upper limb muscle, parameters demand and subject of research. Besides that, the study material which from the latest research studies that focus on the muscle fatigue in the upper limb that related with sEMG signal.

2.2 METHOD FOR COLLECTING INFORMATION

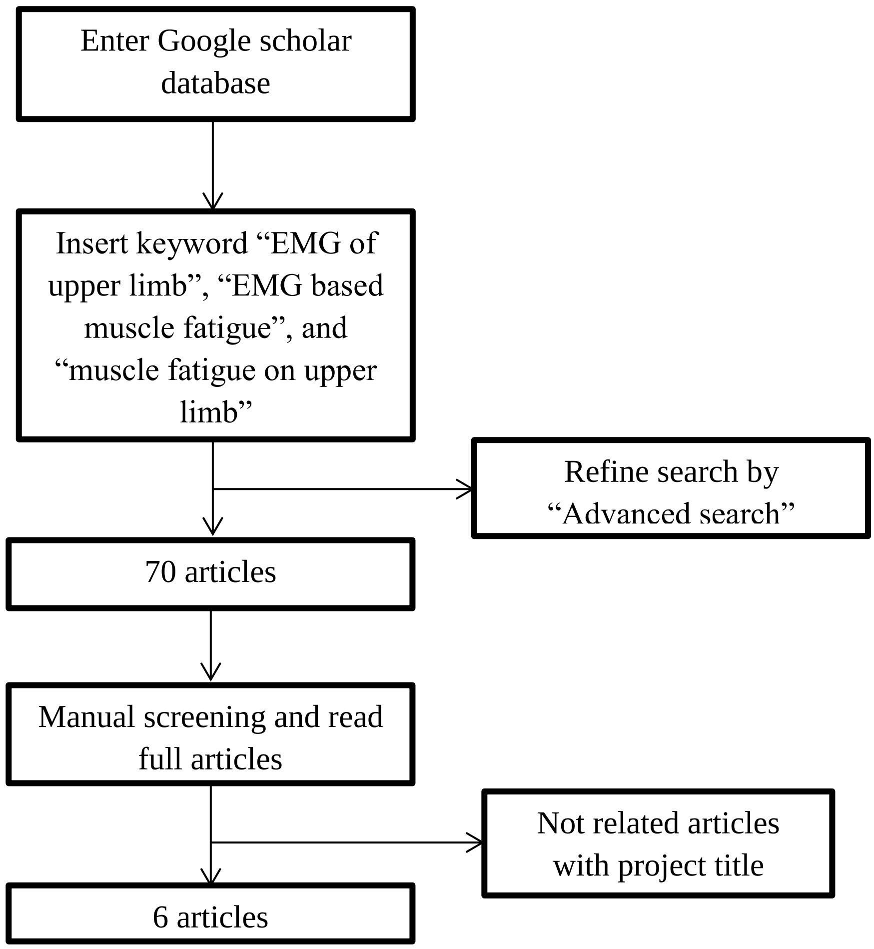

Figure 2.1: Flowchart in articles searching

2.3 LITERATURE SEARCH RESULTS

From Figure 2.1 shown that a total of 70 articles that have been searched through Advanced search in the Google scholar database with keywords; “EMG of upper limb”, “EMG based muscle fatigue” and “muscle fatigue on upper limb”. After manual screening and read full articles process, the final total articles which relate to the title are six articles. Below are the summary for each pervious research that have been used as references while conducting this study.

2.3.1 A Study on Effects of Muscle Fatigue on EMG-Based Control for Human Upper-Limb Power-Assist

The first articles found out in Google Scholar in 2012. The experiment was carried out by three healthy men who aged between 24 to 27 years old without any health history. To measure the EMG change due to the fatigue occurs, EMG electrodes with bipolar montage was used to measure EMG signal of the upper limb muscle. The right upper limb muscle that involved in this experiment was biceps brachii, deltoid-anterior, deltoid-posterior and supinator.

The methodology of this experiment was the participants were asked to do muscle fatigue exercise at four different level upper limb motion which at shoulder abduction/adduction, shoulder vertical flexion/extension, elbow flexion/extension and forearm pronation/supination. For each elbow flexion and extension, the participants needed to do three times of elbow flexion and extension motion with hold a 2kg weight in hand and the elbow motion range are between 0 to 70^0 in order to measure EMG change before muscle fatigue exercise. For second phase that means for after muscle fatigue exercises, the participants were asked to do the repetition of elbow motion flexion and extension at range 0 to 90^0 with 4kg load in hand. To constant the speed of motion, a metronome software was used and have been set to two minutes time for after muscle fatigue exercise.

The experiment was continued with same method for another shoulder abduction/adduction, shoulder vertical flexion/extension and forearm pronation/supination with five minutes as the time gap between each of experiment. The result of raw EMG signal from each motion was measured in analyzing and used to calculate the EMG time and frequency domain features. The features calculated were root mean square (RMS), mean power frequency (MPF) and Flnsm5. The sampling frequency used in the experiment is 2 kHz.

2.3.2 An alternative approach in muscle fatigue evaluation from the (sEMG) signal

The second articles found in Google Scholar in 2010. The experiment was carried out by nine males and eleven females without any neuromuscular diseases history. The muscle that used in this research was right biceps brachii muscle. The aim of this experiment was to compare the intervals of time between adjacent zero crossings (ZCI) with RMS and median frequency to analyze the muscle fatigue from sEMG signal. The surface electrodes of Ag-AgCl with diameter 1mm were used to collect the sEMG signal. Firstly, the volunteer sat on chair with position of knees and hips approximately at 90^0 and performed the maximal voluntary contraction (MVC). In each three days, a one load test was experiment with minimal interval of 48 hours' time between them: 25, 50, and 75% of MVC that consisted of isometric contraction until the volunteers felt exhaust.

The exhaustion that experienced by the participants occurs as the output force results from the muscle contraction are not possible to maintain the constant force. In this experiment, the fatigue criteria was set when the force decrease below of 30% of the target force. The gain used in this experiment is 1000 while the bandwidth frequency set between 10 to 500 Hz and the sampling frequency was set at 2 kHz. The common mode rejection ratio was set at 106 dB CMRR.

2.3.3 Evaluation of upper limb muscle fatigue based on surface electromyography

The third articles found in Google Scholar in 2011. There was thirteen young male with healthy conditions and right handed persons. The experiment was conducted by tested the maximum voluntary contraction (MVC) and set the result as standard force of isotonic muscle contractions. Next, different levels of force at 10, 30, 50 and 80% MVC were performed until fatigue occurs. The duration of the MVC testing was set for 5 s and the rest time between each test was about 3 to 20 minutes. The sEMG activity of biceps brachii were recorded when the participants drag the impact trainer using their right hand with the palm inward But, before undergo the experiment, all subjects were asked to be in relax condition and sEMG activity of the bicep brachii was recorded via biomedical signal collecting system. The purpose of this experiment are to evaluate local muscle fatigue on the biceps brachii muscle based on sEMG after experienced isometric muscle action at different force levels by using Borg scale. The function of Borg scale is to determine the subjective sensation of local fatigue of the biceps brachii when undergoes the isometric action. The action frequency was set at 1Hz and sampling frequency of sEMG are 1000 Hz.

2.3.4 Computation and evaluation of features of surface electromyogram to identify the force of muscle contraction and muscle fatigue

The fourth articles found in Google scholar database in 2014. The purpose of this study is to investigate the relationships between forces of muscle contraction with six different features method and to determine the suitable that sEMG features to estimate the muscle fatigue and force. There were 22 male and 13 female without healthy disorder participated in this experiment. The method of this experiment was volunteers sat on chair with feet were vertically flat on the floor and the upper arm rested horizontally on an adjustable desk and the forearm was in vertical position. Firstly, the participants were asked to perform three maximal contractions of 5 seconds with 120 seconds rest time between each effort to determine the maximum voluntary contraction (MVC) when the volunteers were pulled out the ring and the force of contraction was recorded.

The average reading was recorded to be set as MVC of the experiment. Besides that, there also preliminary experiments conducted to check the influences of contraction of triceps and brachioradialis by sEMG recording. The muscle fatigue was estimate from the root mean square of the sEMG and be recognizes as muscle fatigue if the result are greater than 5% MVC of biceps. The gain used in this experiment is 1000 while the bandwidth frequency set between 20 to 450 Hz and the sampling frequency was set at 1 kHz. The common mode rejection ratio was set at 92 dB CMRR with 12Db/octave roll-off.

2.3.5 Assessment of muscle load and fatigue with the usage of frequency and time-frequency analysis of the EMG signal

The fifth articles found in Google Scholar database is 2014. The subjects of this experiment were fifteen young men with active in physical and no health disorders. There were two stages in conducting the experiments. At the first stage, the maximum voluntary contraction set was from average of two reading of force effort in 10s. The muscle used in estimate the EMG signal in this experiment were biceps brachii (BB) and trapezius (TR) and continued the stage two of experiment at static load of 10,20 and 30% MVC. The bandwidth frequency set between 20 to 450 Hz and the sampling frequency was set at 4 kHz. The common mode rejection ratio was set at 92 dB CMRR with 80 dB/decade. A Bagnoli-16 device was used to measure the raw EMG signal and have been recorded with EMGWorks 3.5 software with double differential surface electrodes. The surface electrode used was 99.9% Ag with 10x1mm contact dimension and 10mm of contact space. The preamplifier gain of sensor was 10 with 92 dB CMRR and $10^{15}\Omega$ of input impedance.

2.3.6 Fatigue analysis of interference EMG signals obtained from biceps brachii isometric voluntary at various force levels

The sixth articles found in Google scholar database is 2009. There were six subjects that involved in this experiment which consisted of three men and three women without neuromuscular disorders aged between 27 to 37 years. The experiment was carried out with performed three maximal contractions for 3s with 3min rest time between them and the maximum voluntary contraction (MVC) was determined as the highest value. Next, isometric contraction were performed at 20,40,60,80 and 100% MVC until the participants felt exhaust. The fatigue was determined when the force decrease and exceeded the 10% of the target level. The rest time between the tests was set at least 1 hour. The duration during the each contaction also measured. The sampling procedure was applied on the biceps brachii on the upper limb using a bar electrode with 5mmx1mm surface area where the skin surface have been rub with Ag/AgCI gel. The band-pass filter of boundary frequency was set between 6 to 500 Hz and the sampling frequency was set at 1 kHz. All the data were recorded and digitized using a 12 bit analog-to digital converter.

Table 2.3: SUMMARIZE OF METHODOLOGIES OF LITERATURE

No	Title	Subject	Objective	Features method	Methodology			
					Method	Sampling	Sampling frequency	Types of EMG
1	A Study on Effects of Muscle Fatigue on EMG-Based Control for Human Upper-Limb Power-Assist	3M	To identify the effects of muscle on the three EMG features from raw EMG on upper limb muscle.	RMS, MPF and Flnsm5	Asked to do muscle fatigue exercise at 4 different level upper limb motion; shoulder abduction/adduction, shoulder vertical flexion/extension, elbow flexion/extension and forearm pronation/supination.	Measure the EMG signal of muscle fatigue with EMG electrodes with bipolar montage and attached two 3-axis accelerometers on the shoulder to measure shoulder angle and forearm angle.	2kHz	Surface EMG

3	Evaluation of upper limb muscle fatigue based on surface electromyography	13 M	To evaluate local muscle fatigue in the upper limb after isometric muscle action	Borg scale	Each subject was asked to drag the impact trainer using right hand with the palm inward and at the same time, sEMG activity of the biceps brachii was recorded.	The activities of sEMG was recorded and analyzed through one-third band octave at 10%, 30%, 50% and 80% of MVC before fatigue occurs.	1kHz	Surface EMG
4	Computation and evaluation of features of surface electromyogram to identify the force of muscle contraction and muscle fatigue	22 M 13 F	To investigate the relationships between forces of muscle contraction with six different features method.	NSM5 MF RMS WL NRMS IIS index	Volunteers sat on chair with feet were flat on the floor, the upper arm rested horizontally on an adjustable desk and the forearm was in vertical position.	Perform three maximal contractions of 5 seconds with 120 seconds rest time between each effort and the volunteers pulled on the erring and the force of contraction was recorded.	1kHz	Surface EMG

5	Assessment of muscle load and fatigue with the usage of frequency and time-frequency analysis of the EMG signal	15 M	To study the effect of muscle load and fatigue on the basic time, frequency and time-frequency analysis.	RMS Fourier transform Wavelet transform	During biceps brachii muscle activation, the participants were stand upright and flexed the right upper limb at 90^0 and needed to maintain the elbow flexion against resistance. Next, for trapezius muscle activation, they needed to straight the upper limbs in stand upright position.	First stage, the maximum effort (MVC) was recorded in 10s. Second stage, three orders at 10,20 and 30% of MVC were recorded to calculate with time, frequency (Fourier transform) and time-frequency(wavelet transform)	4kHz	Surface EMG
6	Fatigue analysis of interference EMG signals obtained from biceps brachii isometric voluntary at various force levels	3 F 3 M	To investigate the applicable of assessment for develop of muscle fatigue from interference EMG signals.	Frequency domain: f_{med} and f_{mean}	The participants needed to perform three maximal contractions for 3s with 3min rest time between them.	The highest maximal voluntary contraction was recorded and isometric contraction were performed at 20,40,60,80 and 100% of MVC until they felt exhaust.	1kHz	Surface EMG

2.4 SUMMARIZE OF MUSCLES USED IN PREVIOUS RESEARCH

The muscle used in the study of (Lalitharatne at.el. 2012) were biceps, brachii, deltoid-posterior, deltoid-anterior and supinator (Lalitharatne, Hayashi, Teramoto, & Kiguchi, 2012). Most of research studies (Zhou et.al (2011), Dimitrova et.al. (2009), Arjunan et.al (2014), Garcia et.al. (2010) used biceps brachii muscle to undergo the experiment on the upper limb muscle (Arjunan et al., 2014; Dimitrova, Arabadzhiev, Hogrel, & Dimitrov, 2009; Garcia et al., 2010; Zhou et al., 2011). Besides that, right side biceps brachii and trapezius(Bartuzi & Roman-Liu, 2014) muscle was used in (Bartuzi, P., & Roman-Liu,D. 2014) research study.

2.5 SUMMARIZE OF METHOD USED IN PREVIOUS RESEARCH

The method used in (Lalitharatne at.el. ,2012) was the participants were asked to do muscle fatigue exercise at four different level upper limb motion which at the shoulder abduction and adduction, shoulder vertical flexion and extension, elbow flexion and extension and forearm pronation and supination(Lalitharatne et al., 2012).

Next, in (Garcia et.al ,2010), the volunteers were sat on chair with position of knees and hips approximately at 90^0 and performed the maximal voluntary contraction (MVC)(Garcia et al., 2010). Based on (Zhou et.al ,2011), each subject was asked to drag the impact trainer using right hand with the palm inward and at the same time, sEMG activity of the biceps brachii was recorded(Zhou et al., 2011). In (Arjunan et.al ,2014) study, the volunteers sat on chair with feet were flat on the floor, the upper arm rested horizontally on an adjustable desk and the forearm was in vertical position(Arjunan et al., 2014).

According to (Bartuzi, P., & Roman-Liu,D. ,2014) method, during biceps brachii muscle activation, the participants were stand upright and flexed the right upper limb at 90^0 and needed to maintain the elbow flexion against resistance and for trapezius muscle activation, they needed to straight the upper limbs in stand upright position(Bartuzi & Roman-Liu, 2014). In (Dimitrova et.al ,2009), the method used were the participants needed to perform three maximal contractions for 3s with 3min rest time between them(Dimitrova et al., 2009).

2.6 SUMMARIZE OF SAMPLING FREQUENCY IN PREVIOUS RESEARCH

In (Dimitrova et.al (2009), Arjunan et.al (2014), and (Zhou et.al (2011), the sampling frequency used was 1 kHz (Arjunan et al., 2014; Dimitrova et al., 2009; Zhou et al., 2011). In (Bartuzi, P., & Roman-Liu,D. (2014), 4kHz was used as the sampling frequency to carry out the experiment(Bartuzi & Roman-Liu, 2014).But, in (Lalitharatne at.el. (2012) and (Garcia et.al (2010), both used 2kHz as the sampling frequency(Garcia et al., 2010; Lalitharatne et al., 2012).

2.7 RESEARCH GAP FINDING

From the six articles that have been found in the Google scholar database, there are several research gap that could be summarize in relationship between muscle fatigue recognition based on EMG signals on the upper limb muscle. In order to fulfill the gap, different features in time domain will be apply to analysis the EMG signals. Besides that, to improve the study research scope about muscle fatigue that occurs on the biceps brachii and triceps, there are some issues that have to be discuss and need to elaborate more as below:

2.7.1 Muscle Fatigue Recognition

In the previous research, most of papers recognize the muscle fatigue by calculate the maximum voluntary contraction (MVC)(Arjunan et al., 2014) and its isometric contraction at 20,30,50,70,80 and 100% MVC(Bartuzi & Roman-Liu, 2014; Dimitrova et al., 2009; Zhou et al., 2011). Thus, in this project it will be recognize with the average reading of MVC by grip the hand dynamometer until the participants feel exhaust.

2.7.2 Upper Limb Muscle

Commonly, brachii biceps muscle is the most prefer muscle that used to carry out the electromyography signal process because it easier to detect the muscle activity rather than on the other muscle in the upper limb. The muscle location are suitable to quantity the muscle activities with the bundle of fiber of muscle and function of the arm that are require to meet the body diversity in scope of speed, strength and precision in the daily human life activity such as lifting a load which cause the muscle to contract and relax in term of strength and painting or writing that need precision and speed to complete the work.

Besides that, the function of upper limb muscle is important to extend and flex the forearm at the elbow joint. Flexion occurs at brachialis, biceps brachii and brachioradialis which are located on the anterior side on the upper limb while the triceps muscle function as extensor of the forearm which locate at posterior side of the forearm at the elbow and the humerus at the shoulder(Muscles of the Arm and Hand. n.d.). Thus, in this research, biceps brachii and triceps muscle on the upper limb are used to analysis the muscle fatigue from the contraction that apply to it.

2.7.3 Type of Load Applied

Most research used hand grip as a load to carry out the experiment and cause the muscle to contract. The hand grip will give impact to the muscle when the hand grips it and continuously because the muscle contraction until fatigue occurs. So, in this experiment, hand dynamometer will be apply as load and the reading measure will be easy to record. The load will be in unit kilograms (kg).

2.8 CONCLUSION

In this chapter, the related research papers were studies to investigate the literature of each papers and each parameters used. The gaps between each research papers will be fill up in this study to bring up new topic in evaluate muscle fatigue based on EMG feature.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will briefly describe about the methodology of muscle fatigue identification on upper limb muscle during muscular contraction based on EMG signals. The main objective in this methodology is to recognize the muscle fatigue based on sEMG signal on the biceps brachii muscle and triceps muscle in the upper limb muscle. All the sampling technique and filtering processes are discuss in detail to reduce the noises while conducting the sEMG signal data analysis.

3.2 PROCESS FLOW CHART

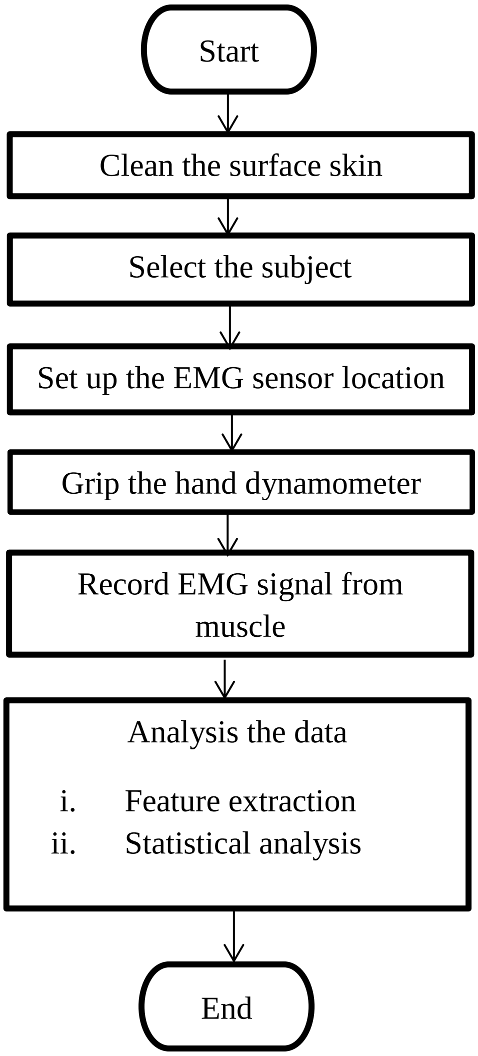

Figure 3.1: Flow chart of methodology of muscle fatigue identification based on EMG feature

3.3 EXPERIMENT EQUIPMENT

In this experiment, there was several equipment that be used to carry out the experiment which are hand dynamometer, surface electrode, Shimmer sensor and alcohol swab. Below was the following equipment with its details.

3.3.1 Hand Dynamometer

In perform muscle fatigue situation on the upper limb muscle, hand dynamometer was used as a main load when the volunteers griped it. The other functions to measure grip strength and pitch strength. The grip strength and the electrical activity were related with the muscle fatigue on the upper limb muscle.

Figure 3.2: Hand dynamometer

("Hand Dynamometer," 2015)

3.3.2 Shimmer Sensor

Shimmer EMG is a device to measure and record electrical potential waveform which associate with muscle contraction, estimate nerve conduction, muscle condition in injured tissue, muscle activation level and also could be used to evaluate the biomechanics of human and animal movement. It is a non-invasive surface EMG and thus can present the whole activity of the muscle. This device is consists of two channel EMG data with a common reference electrode.

In this study, two channels which acted as negative and positive inputs was connected with surface electrodes and placed on the biceps brachii muscle and triceps muscle separately. While another one reference electrode was placed on the bone of elbow.

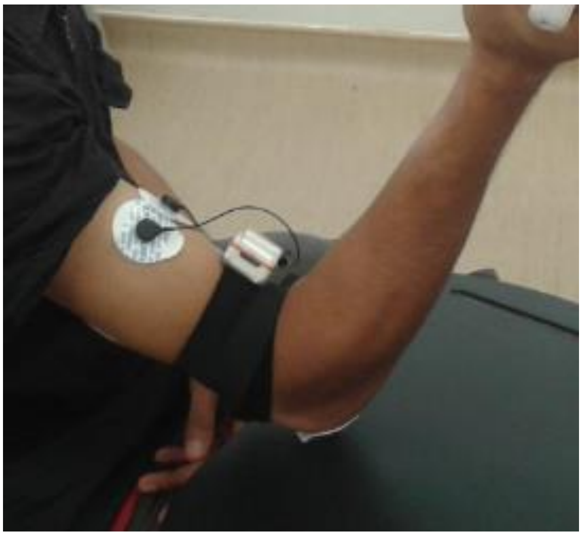

Figure 3.3: Sensor placement on biceps brachii muscle

Figure 3.4: Sensor placement on triceps muscle

Figure 3.5: SHIMMER EMG

("EKG Sensor," 2015)

3.3.3 Surface Electrode

The Ag/AgCl electrodes are the part which will be contact with the skin and make electrical contact between the sensor and the skin. The electrodes could be snap on directly with the sensor or indirectly connect with an extender cable. While undergo the experiment, there will involve three electrodes to complete the electromyography analysis which two electrodes will acts as the potential differences between the input data and the another one function as the ground and known as reference electrode that could be attach at any part of body.

Figure 3.6: Surface electrode

(Inc., 2015)

3.3.4 Alcohol Swab

In order to get good EMG signal and avoid the artifact during the analysis, the skin surface must be in proper conditions. This condition involves a preparation where the skin surface must be dry and clean before apply the surface electrode on it. The skin could be clean by using alcohol swap until it dry. Abrasive cream also could be used to replace the alcohol swap because it is function to remove dead skin.

Figure 3.7: Alcohol swab

(Corp, 2013)

3.4 METHOD

3.4.1 Experimental Protocol

Six health volunteers, three females and three males, undergraduate students of Universiti Malaysia Pahang Campus Pekan, aged 21-25 years, right handed without any history in neuromuscular problems volunteered participate in this study. The upper limb muscle tested were biceps brachii and triceps muscle.

During the experiment, the volunteers were seated on a chair while the forearm was rested horizontally on a desk and the elbow of the upper limb was in position 90^0 vertically. A hand dynamometer was used to measure the EMG signal when the muscle fatigue occurs in the muscle during muscle contraction. Details of the experiment procedures were explained briefly to the volunteers to make them familiarize while undergo the experiment.

The experiment was started with the participants griped the hand dynamometer and the sEMG activity of the biceps brachii and triceps was recorded. They needed to grip it again for three times contraction forces in 10 seconds that they could performed with 2 minute rest between each contraction occurs. The time interval was 1 minute between it. This step was to determine the Maximum Voluntary Contraction (MVC) by average calculated all the three readings and recorded. If any outlier occurs, the experiment will be repeated. Before that, an experiment was conducted to check the muscle activity of biceps brachii and triceps muscle during the contraction occurs using sEMG recording. Next, the volunteers were asked to perform sub-maximal contraction of with 30%, 50% and 70% of MVC until they experienced pain and fatigue on the biceps brachii and triceps mucles. The muscle fatigue occurs when these muscle activities was greater than 5% of the MVC that recorded through the sEMG signal.

3.4.2 EMG recording

All the sEMG signal was sampled at 1 kHz via a AC-DC converter before save it in the excel file in the computer. The cutoff frequency was between 10 to 500 Hz to remove the noises while the skin muscle integrated with the electrode. Common Mode Rejection Ratio (CMRR) is set less than 80dB and the gain are variable between 100 and 10000. Two monopolar electrodes were placed above the brachii biceps and triceps muscle where it is parallel with the muscle fiber which between the motor points of the short head and the tendons of biceps brachii and triceps. To reduce the skin electrode-impedance, the skin was and cleaned with alcohol swabs and prefer a good adhesion of the electrodes with the skin surface. The reference electrodes were attached under the elbow joint. The distance between these electrodes was estimated at 2 cm.

3.5 DATA ANALYIS

Data analysis was performed offline on Minitab 15 software. The first step was computation of feature of the data collection in Matlab software before proceed into Minitab 15 software. In Minitab 15, regression analysis was performed to identify the linearity of the relationship of EMG feature and force of contraction. Analysis of variance (ANOVA) was performed to determine the statistical significance of the relationship.

3.5.1 Feature Extraction

In this project, time domain feature was be used to evaluate the EMG signal that related with hand movement recognition. The computation of this feature was used to detect the muscle contraction, muscle activity and onset detection to achieve the best in EMG control analysis. Root mean square (RMS) feature is expressed as in Eq. (3.5.1) was used to analysis the statistical measure of the magnitude in terms of time varying signal and in form of quadratic mean. In this experiment, RMS feature was computed as amplitude to evaluate the muscle activity in order to determine if muscle fatigue occurs on biceps brachii and triceps muscle on the upper limb or not.

$$\text{RMS} = \sqrt{\frac{1}{N}\sum_{n=1}^{N} x_n^2}. \qquad (3.5.1)$$

Filtered EMG were processed by using Root Mean Square (RMS) or Average Rectified Value (ARV) in order to evaluate the magnitude of muscle activity over time that known as time domain. Commonly, RMS EMG is the square root of the average power of the filtered EMG that could calculate over certain time period.

3.5.2 Statistical Analysis

Regression analysis was performed in order to determine the relationship of the level of contraction and the EMG signal in terms of RMS feature. Computation of RMS values of EMG signal for each level of contraction of 30%, 50% and 70% in terms of force was performed in Matlab software and proceed into Minitab to evaluate the mean values, R^2 in linear regression analysis with 95% confidence intervals. Independent variable was the muscle force of each level muscle contraction while the dependent variable was EMG signal in terms of RMS feature.

In this analysis, significance of each level of force and the RMS values was been computed to identify the muscle fatigue condition on the biceps brachii muscle and triceps muscle. Analysis of variance (ANOVA) was performed with 95% confidence intervals ($P<0.05$) to identify the significant of these parameters.

3.6 CONCLUSION

Data collection process is a significant procedure on every research study in order to record the raw data and analysis it later. All the raw EMG signal will be undergo filtering process to eliminate all the noises that contaminates during recording process. Amplitude of electrical signal during the contraction will be compute by applying EMG feature.

CHAPTER 4

DATA COLLECTION AND ANALYSIS

4.1 INTRODUCTION

This chapter was mainly discussed about the data collection and result analysis on muscle fatigue identification based on EMG feature. Data collecting process only focused on biceps brachii and triceps muscle on upper limb muscle. Raw EMG signal was saved in form of CSV file before been transfer to Excel file. In order to calculate the RMS feature of each level, MATLAB software was used to compute it.

4.2 RESULTS

4.2.1 Data Collection

Table 4.2.1.1: Force of contraction on biceps brachii muscle

Subject	Force of contraction on biceps brachii muscle (kg)			
	100%	70%	50%	30%
1	42.7	29.93	21.38	12.83
2	33.2	27.86	19.90	11.95
3	37.16	26.02	18.58	11.15
4	10.86	7.61	5.43	3.25
5	15.77	11.03	7.88	4.73
6	15.60	10.92	7.80	4.68

Table 4.2.1.2: Force of contraction on triceps muscle

Subject	Force of contraction on triceps muscle (kg)			
	100%	70%	50%	30%
1	39.43	27.60	19.72	11.83
2	38.50	26.95	19.25	11.55
3	27.16	19.02	13.58	8.15
4	14.56	10.19	7.28	4.36
5	14.00	9.80	7.00	4.20
6	14.97	10.47	7.48	4.49

Table 4.2.1.1 and 4.2.1.2 shows the force during the muscle contraction on each level of force contraction on biceps brachii and triceps muscle. These result were obtained during experiments on six subject where they needed to grip the hand dynamometer for 5s for each level of force. For 100% level of force, the subject were undergoes three times data recording for 5 seconds with 2 minutes rest gap and continued the experiments with sub-maximal contraction of 30%, 50% and 70% for another 5 seconds without rest gap between it as shown in Figure 4.1 and 4.2 below. Hand dynamometer was showed up the reading in kilogram (kg) scale unit as shown in Figure 3. For data recording of 100% level of contraction, the average reading of hand gripping results were calculated for each subject. While for sub-maximal, the results of 100% level of contraction were being multiple with 30%, 50% and 70% to obtain each results. For example, from Table 4.2.1.1, result of 100% level for subject 1 was 42.70 kg and 30% from 42.70 kg was 29.90 kg.

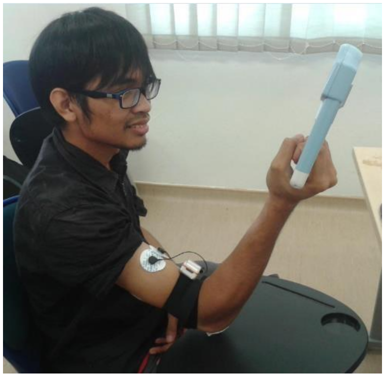

Figure 4.1: Hand gripping experiment on biceps brachii

Figure 4.2: Hand gripping experiment on tricep

Figure 4.3: Data showing in SHIMMER EMG

4.2.2 RMS Feature

EMG feature that have been used in this study was root mean square (RMS) is a statistical measure of the magnitude of a time varying signal. All of calculation of RMS feature was done in MATLAB software.

Table 4.2.2.1: RMS value for 30% level of contraction on biceps brachii muscle

FORCE (kg)	RMS(mV)
9.74	3.70
8.30	3.43
9.10	4.03
10.10	2.06
9.80	2.06
7.65	2.06
9.54	2.07
9.78	2.07
10.10	2.06
8.10	2.05
7.85	2.05
7.55	2.06
9.20	2.07
9.11	2.05
8.00	2.05
9.80	2.04
8.71	2.05
9.33	2.04

Table 4.2.2.2: RMS value for 50% level of contraction on biceps brachii muscle

FORCE (kg)	RMS (mV)
13.87	2.06
14.5	2.06
12	2.06
14.9	2.05
15.7	2.05
17.8	2.05
14.7	2.06
15.4	2.06
13.8	2.05
10.87	2.05

11.93	2.05
12.45	2.05
10.9	1.98
13.5	1.99
14.6	1.97
12.3	1.98
10.9	1.98
11.2	1.98

Table 4.2.2.3: RMS value for 70% level of contraction on biceps brachii muscle

FORCE (kg)	**RMS (mV)**
16.43	2.06
15.76	2.06
16.98	2.06
16.98	2.05
16.55	2.06
16.98	2.06
16.65	1.98
16.00	2.00
17.20	2.01
13.90	2.05
11.20	2.05
12.80	2.05
15.30	0.33
12.00	0.72
13.30	0.56
11.70	1.97
12.85	1.97
10.80	1.90

Table 4.2.2.4: RMS value for 100% level of contraction on biceps brachii muscle

FORCE (kg)	**RMS (mV)**
45.00	2.08
41.9	2.07
41.40	2.08
33.20	2.05
43.10	2.05
43.20	2.05
35.80	2.06
39.50	2.06
36.20	2.06
10.50	2.18
14.80	2.55
7.30	2.09

15.20	2.06
16.20	2.05
15.90	2.05
15.30	2.06
16.50	2.06
15.00	2.06

Table 4.2.2.5: RMS value for 30% level of contraction on triceps muscle

FORCE (kg)	RMS (mV)
7.91	2.05
8.19	2.06
10.30	2.05
8.94	2.05
7.03	2.06
8.00	2.05
10.70	1.82
9.22	1.89
9.50	1.86
7.94	2.05
8.43	2.05
7.10	2.05
10.90	2.01
11.32	2.04
9.10	2.05
10.90	2.05
10.43	2.05
11.65	2.03

Table 4.2.2.6: RMS value for 50% level of contraction on triceps muscle

FORCE (kg)	RMS (mV)
13.40	2.06
12.80	2.06
10.80	2.06
15.50	2.06
16.70	2.06
12.90	2.07
14.98	1.94
15.64	1.87
13.54	1.82
10.90	1.98
12.10	1.97
11.40	1.97

17.20	2.04
16.40	2.03
13.10	2.03
13.80	1.98
14.10	1.98
12.32	1.56

Table 4.2.2.7: RMS value for 70% level of contraction on triceps muscle

FORCE (kg)	RMS (mV)
16.43	2.10
15.76	2.14
16.98	2.09
16.98	2.05
16.55	2.05
16.98	2.05
16.65	1.93
16.00	1.88
17.20	1.82
13.90	1.93
11.20	1.96
12.80	1.91
15.30	1.98
12.00	1.74
13.30	1.60
11.70	0.11
12.85	0.33
10.80	0.14

Table 4.2.2.8: RMS value for 100% level of contraction on triceps muscle

Force (kg)	RMS (mV)
37.80	2.07
39.60	2.10
40.90	2.07
35.10	2.05
42.20	2.85
38.20	2.06
26.60	2.08
26.80	2.07
28.10	2.08
14.00	2.26
15.30	2.05
14.40	2.06

15.30	2.08
12.00	2.05
14.70	2.05
16.90	2.04
13.50	2.04
14.50	2.05

From the tables above, there was different RMS value in for each of contraction. It was happened because due to the variation of muscle ability of each subject when gripping the hand dynamometer and the tendency to hold in gripping it for a certain time of durations. For biceps brachii muscle, most of the subjects were able to achieve high force of gripping the hand dynamometer, compared with triceps muscle, the ability of gripping were reduced due to the muscle condition that were easy to became fatigue.

4.2.3 Statistical Analysis

In order to determine the relationship between the levels of contraction on the RMS values, an analysis of variance (ANOVA) was conducted in Minitab software. In Table 4.2.3.1 below, it show the results of RMS value for each level of contraction on biceps brachii muscle. It was conclude that fatigue condition was occurred during 70% level of contraction with the lowest RMS value which was 18.89 kg. And, in Table 4.2.3.2, the fatigue condition was happened on triceps muscle also during 70% level of contraction with the lowest RMS value which was 1.66 kg.

Table 4.2.3.1: RMS value for each level of contraction on biceps brachii

Level of contraction	**100%**	**70%**	**50%**	**30%**
Force (kg)	25.88	18.89	13.49	8.09
RMS (mV)	2.10	1.77	2.03	2.33

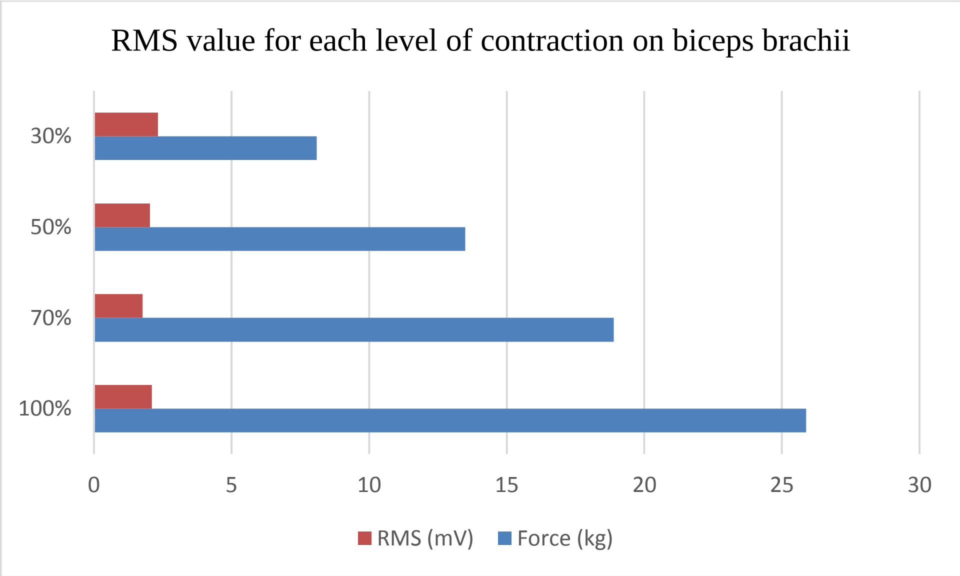

Figure 4.4: RMS value for each level of contraction on biceps brachii

Table 4.2.3.2: RMS value for each level of contraction on triceps

Level of contraction	100%	70%	50%	30%
Force (kg)	24.77	17.34	12.39	7.43
RMS (mV)	2.12	1.66	1.98	2.02

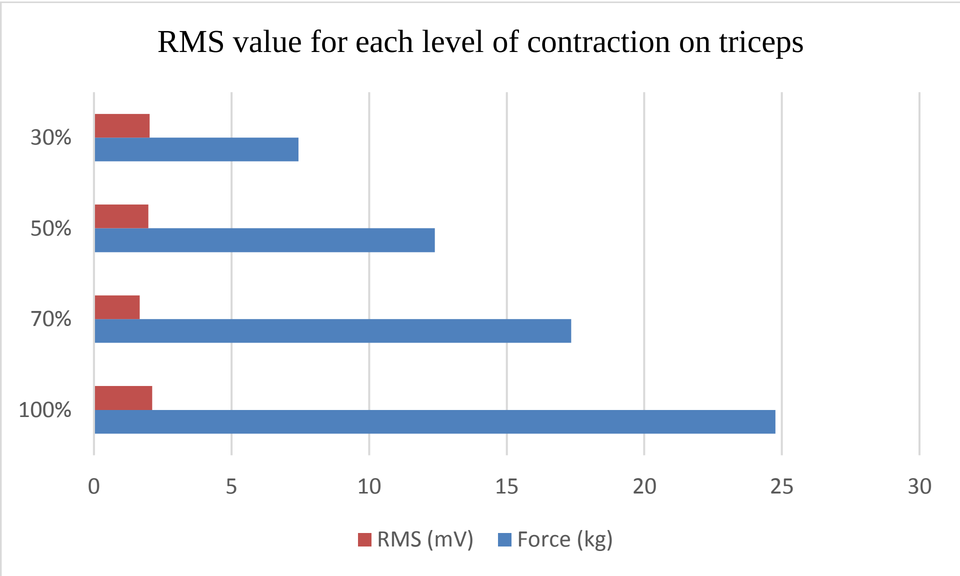

Figure 4.5: RMS value for each level of contraction on triceps

```
Sample  N   Mean  StDev  SE Mean
1       4  2.062  0.228     0.11
2       4  1.946  0.198    0.099


Difference = mu (1) - mu (2)
Estimate for difference:  0.117
95% CI for difference:  (-0.272, 0.505)
T-Test of difference = 0 (vs not =): T-Value = 0.77  P-Value = 0.475  DF = 5
```

Figure 4.6: Mean analysis between RMS of biceps brachii and triceps muscle.

In Figure 4.6, P-value of RMS between biceps brachii and triceps muscle is 0.475 which are more than 0.05 (P<0.05). It concluded that the means analysis between them is not significant and there have a differences between the muscle activation in the both of muscles.

While, in regression analysis, the relationship between the levels of contraction with EMG feature was determined. The EMG feature was computed from the EMG signal that were recorded during the contraction. This regression analysis was conducted in Minitab software.

Table 4.2.3.3: Regression analysis of level of contraction on biceps brachii muscle

Level of contraction (%MVC)	**P-value (P<0.05)**
30% and 50%	0.057
30% and 70%	0.000
50% and 70%	0.003
70% and 100%	0.002
50% and 100%	0.004
30% and 100%	0.144

Table 4.2.3.4: Regression analysis of level of contraction on triceps muscle

Level of contraction (%MVC)	**P-value (P<0.05)**
30% and 50%	0.217
30% and 70%	0.035
50% and 70%	0.064
30% and 100%	0.001
50% and 100%	0.000
70% and 100%	0.012

In Table 4.2.3.3, the regression analysis was conducted between the levels of contraction of the forces. Form the result, it show that the level of contraction between 30% and 70% of force was most significant value which was 0.000 (P<0.05). And in Table 4.2.3.4, most significant value was resulted between 30% and 70% of force. The RMS value for 100% MVC was ignored because it was the basis result for normalization of the rest of the data collection.

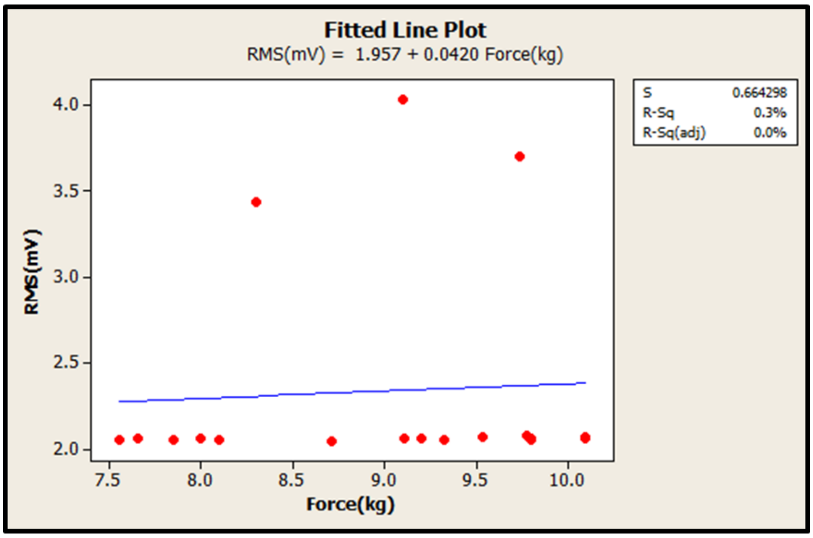

Figure 4.7: Regression analysis for 30% force of contraction on biceps brachii

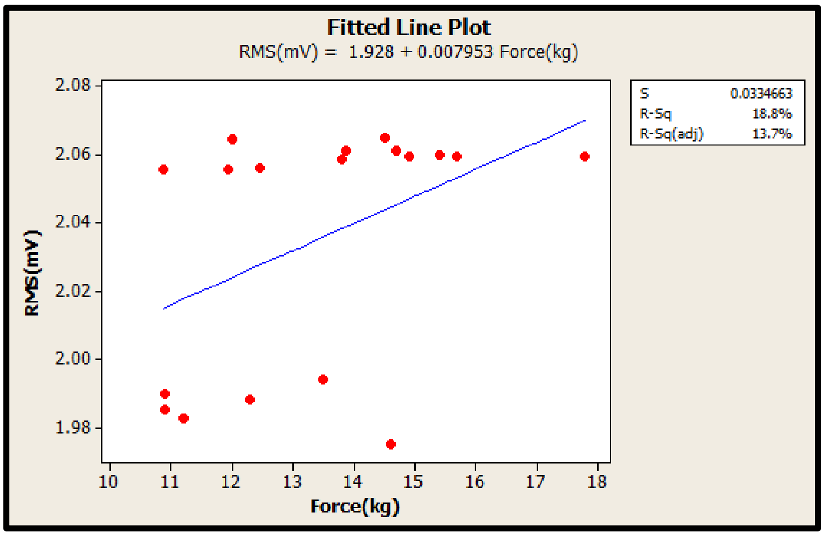

Figure 4.8: Regression analysis for 50% force of contraction on biceps brachii

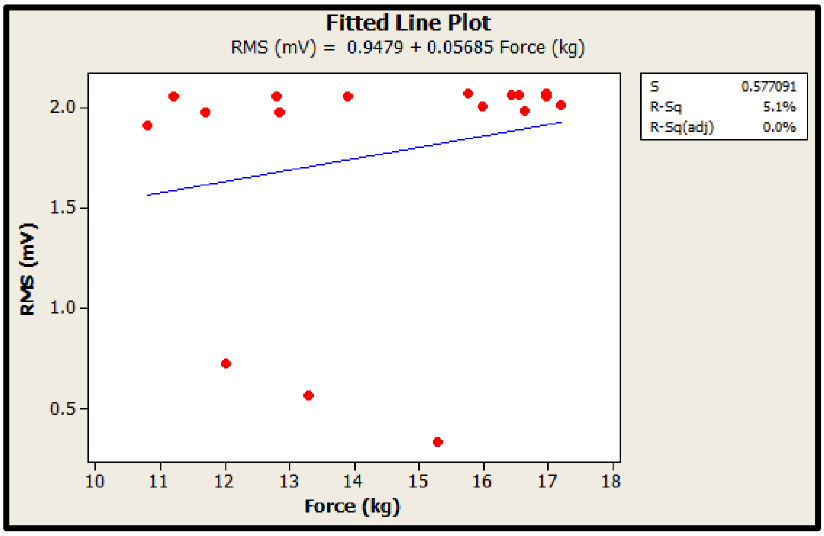

Figure 4.9: Regression analysis for 70% force of contraction on biceps brachii

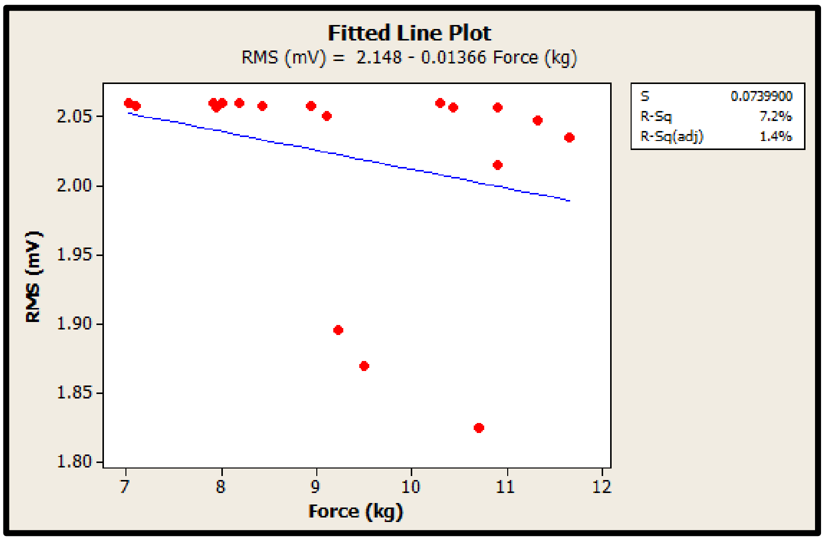

Figure 4.10: Regression analysis for 30% force of contraction on triceps

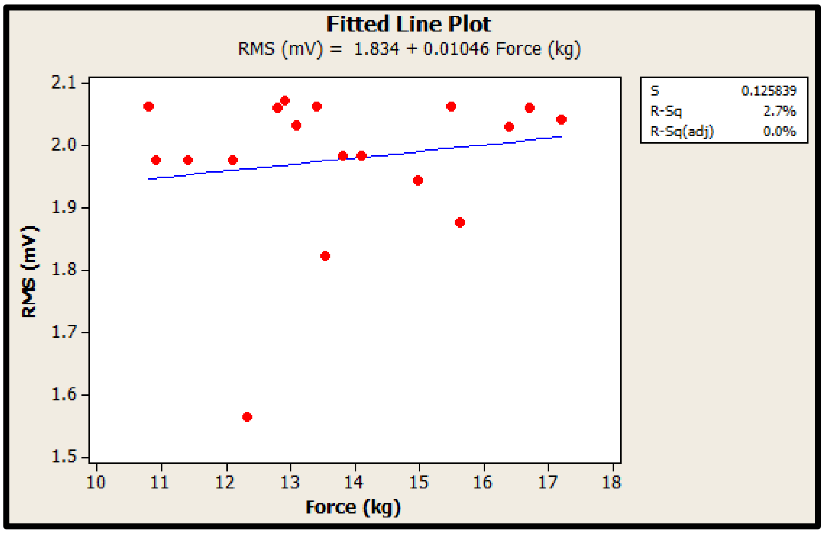

Figure 4.11: Regression analysis for 50% force of contraction on triceps

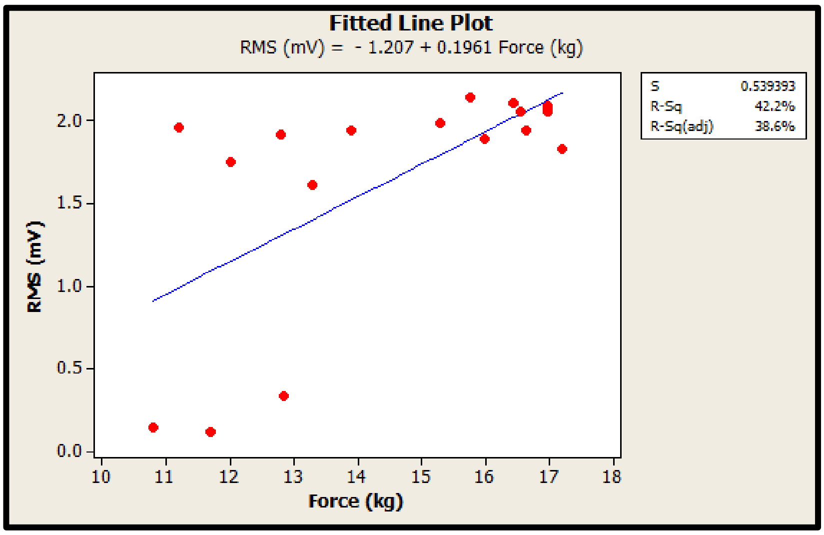

Figure 4.12: Regression analysis for 70% force of contraction on triceps

Regression analysis for each level of contraction is for analysis the significant between the force and RMS value with the line plot. On biceps brachii muscle, the most significant R^2 value is on 50% force of contraction with 18.8%, shown in Figure 4.8. While in Figure 4.12, for triceps muscle, the most significant R^2 value is on 70% force of contraction with 42.2%.

4.3 CONCLUSION

Muscle fatigue condition have been achieved during the hand gripping experiments that show in Table 4.2.3.1 and 4.2.3.2. These tables showed the value of amplitude of EMG or RMS value where it stated that the lowest RMS value was a condition where the muscles became fatigue. Most of the subject tend to achieved higher amplitude of EMG on both muscles at 100% level of contraction and it slowly decrease due tendency of muscle activation to fatigue.

Regression analysis was done to show the relationship between the grip forces of the subjects proportional to the amplitude or RMS of EMG signal during fatigue happened in each level of contraction. More higher the grip force in each of level contraction, more significant the RMS with the plot line.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

In this chapter, it will explain about the conclusion and recommendation of muscle fatigue identification based on EMG feature. After data collection and analyzing process of EMG feature, muscle fatigue condition was have been identify by RMS feature extraction. This feature shows how the EMG signal was accumulated during contraction happened on biceps brachii muscle and triceps muscle. There are a lot recommendation techniques that could be apply in the future research in order to investigate the relationship between muscle fatigue identification through EMG feature.

5.2 RECOMMENDATION

5.2.1 Improvement on Data Collection Procedure

- During recording the EMG signal, there will was a problem in detecting the electrical signal that activated during the contraction. This kind of problem should be avoid in order to get the proper signal without distraction with doing several preliminary test to determine the exactly place of muscle that contract during data collection process.
- Replace surface electromyography with intramuscular electromyography procedure which could record EMG signal precisely.
- Use an electrode with large longitudinal dimension to have larger surface area contact with skin to record the signal.

5.2.2 Increase the sub-maximal contraction test

- When increasing the sub-maximal contraction test, the value of RMS will in small range and could analyze the fatigue accurately.
- The average of taking data of each sub-maximal contraction test can be more than three times.
- Number of muscle activated also be increase when low level of load has apply.

5.2.3 Apply another EMG features

- There are a lot of EMG feature that could be applied to identify the muscle fatigue condition such as wave length (WL), normalized root mean square (RMS), as well as frequency domain such as median and mean feature. All of these feature will have different sensitivity in assessing muscle fatigue and the results also could be compare precisely.

5.3 CONCLUSION

The main objectives for this research have been achieved which it were able to identify the muscle fatigue condition by applied the EMG feature. This muscle fatigue condition will be able to show the ability of upper limb muscle to contract in certain amount of force with the extraction of EMG feature analyses.

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Appendices A

GANTT CHART

FYP1

Description	Status	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Title registration	Plan														
	Action														
Meet and discuss the tiltle with supervisor	Plan														
	Action														
Identify the problem statement and project objective	Plan														
	Action														
Study the previous journal and articles	Plan														
	Action														
Proposal preparation	Plan														
	Action														
Prepare the slide preparation	Plan														
	Action														
Submit the presentation slide and proposal	Plan														
	Action														
FYP 1 presentation	Plan														
	Action														
Preparation of FYP 1 report	Plan														
	Action														
Submit FYP 1 report	Plan														
	Action														

Figure 6.1: GANTT chart FYP 1

FYP 2

Work Progress	Status	Weeks														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Data collection	Plan															
	Action															
Data analysis and result interpretation	Plan															
	Action															
Recommendation and conclusion	Plan															
	Action															
Report Writing	Plan															
	Action															
Viva for FYP2 presentation	Plan															
	Action															
Submission of full thesis	Plan															
	Action															

Figure 6.2: GANTT chart FYP 2

Appendix B

Consent Form

Universiti Malaysia PAHANG

Engineering • Technology • Creativity

CONSENT FORM

Project title: Evaluation of muscle fatigue identification based on EMG feature.

Project researcher: Nur Amelia Izzati Bt. Mohd Amin (FB12014)

Department: Faculty of Manufacturing Engineering

Address of correspondence: University Malaysia Pahang, 26600 Pekan, Pahang, Malaysia.

Please initial the boxes:

1. I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions. ☑
2. I understand that my participation is voluntary and that I am free to withdraw at any time,
   without giving reason. ☑
3. I agree to take part in above study. ☑
4. I understand that relevant sections of my medical notes and data collected during the study may be looked at by individuals from [University Malaysia Pahang], from regulatory authorities, where it is relevant to my participation in this research. I give permission for these individuals to have access to my records. ☑
5. I agree to the research team having the following personal details. ☑

MUHAMAD AZAM	6/4/16	
Name of participant	Date	Signature

Universiti Malaysia PAHANG

Engineering • Technology • Creativity

CONSENT FORM

Project title: Evaluation of muscle fatigue identification based on EMG feature.

Project researcher: Nur Amelia Izzati Bt. Mohd Amin (FB12014)

Department: Faculty of Manufacturing Engineering

Address of correspondence: University Malaysia Pahang, 26600 Pekan, Pahang, Malaysia.

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5. I agree to the research team having the following personal details. ☑

Fatin Zulaika	30-3-2016	[signature]
Name of participant	Date	Signature

Universiti Malaysia PAHANG
Engineering • Technology • Creativity

CONSENT FORM

Project title: Evaluation of muscle fatigue identification based on EMG feature.

Project researcher: Nur Amelia Izzati Bt. Mohd Amin (FB12014)

Department: Faculty of Manufacturing Engineering

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5. I agree to the research team having the following personal details. ☑

Norfatin Nabilah Fuad	30/3/16	[signature]
Name of participant	Date	Signature

Universiti Malaysia PAHANG

Engineering • Technology • Creativity

CONSENT FORM

Project title: Evaluation of muscle fatigue identification based on EMG feature.

Project researcher: Nur Amelia Izzati Bt. Mohd Amin (FB12014)

Department: Faculty of Manufacturing Engineering

Address of correspondence: University Malaysia Pahang, 26600 Pekan, Pahang, Malaysia.

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5. I agree to the research team having the following personal details. ☑

NUR SYAHIRAH	6/4/16	[signature]
Name of participant	Date	Signature

Universiti Malaysia PAHANG
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CONSENT FORM

Project title: Evaluation of muscle fatigue identification based on EMG feature.

Project researcher: Nur Amelia Izzati Bt. Mohd Amin (FB12014)

Department: Faculty of Manufacturing Engineering

Address of correspondence: University Malaysia Pahang, 26600 Pekan, Pahang, Malaysia.

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5. I agree to the research team having the following personal details. ☑

MUHAMAD SAUFI	30/3/16	[signature]
Name of participant	Date	Signature

Universiti Malaysia PAHANG
Engineering • Technology • Creativity

CONSENT FORM

Project title: Evaluation of muscle fatigue identification based on EMG feature.

Project researcher: Nur Amelia Izzati Bt. Mohd Amin (FB12014)

Department: Faculty of Manufacturing Engineering

Address of correspondence: University Malaysia Pahang, 26600 Pekan, Pahang, Malaysia.

Please initial the boxes:

1. I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions. [/]
2. I understand that my participation is voluntary and that I am free to withdraw at any time,
   without giving reason. [/]
3. I agree to take part in above study. [/]
4. I understand that relevant sections of my medical notes and data collected during the study may be looked at by individuals from [University Malaysia Pahang], from regulatory authorities, where it is relevant to my participation in this research. I give permission for these individuals to have access to my records. [/]
5. I agree to the research team having the following personal details. [/]

Tan Tian Xiang	23/3/16	[signature]
Name of participant	Date	Signature

Appendix C

Data Collection Form

Universiti Malaysia PAHANG
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EVALUATION OF MUSCLE FATIGUE IDENTIFICATION BASED ON EMG FEATURE

Investigator: Dr Nizam Uddin Ahamed

Co-investigator: Nur Amelia Izzati Bt. Mohd Amin (FB12014)

DATA COLLECTION FORM

Session 1: Familiarization. (5 minutes)

Session 2: Subject and anthropometric details (10 minutes)

A. Subject's details (To be filled by subject and will be kept confidential)

Name	Muhammad Azam bin Abang Affandi
Year	4
Phone	014-5506875

B. Subject's anthropometric details (To be filled by the investigator)

Gender	Male	Age (Years)	24
Weight (Kg)	54	Height(cm)	165

Session 3: Introducing arm keeping protocol for trial (5 minutes)

Session 4; Grip force recording

Arm keeping position: at the way of the shoulder abduction by scapula fixed and the elbow in full extension with the forearm in pronation during each trial.

A. **Determination of maximum isomeric contraction (MVC):** duration of each trial = 5 seconds; 2 minutes rest between trials; [(5 seconds x 3) + (2 minutes x (3-1)] = 4 minutes 15 seconds.

On biceps brachii muscle

1st trial	Unit in kg	45.00	MVC = 100%
2nd trial		41.90	

On triceps muscle

1st trial	Unit in kg	37.80	MVC =100%
2nd trial		39.60	

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EVALUATION OF MUSCLE FATIGUE IDENTIFICATION BASED ON EMG FEATURE

Investigator: Dr Nizam Uddin Ahamed

Co-investigator: Nur Amelia Izzati Bt. Mohd Amin (FB12014)

DATA COLLECTION FORM

Session 1: Familiarization. (5 minutes)

Session 2: Subject and anthropometric details (10 minutes)

A. Subject's details (To be filled by subject and will be kept confidential)

Name	FATIN ZULAIKA HASAN
Year	4
Phone	012-4671643

B. Subject's anthropometric details (To be filled by the investigator)

Gender	Male	Age (Years)	23
Weight (Kg)	45	Height(cm)	159

Session 3: Introducing arm keeping protocol for trial (5 minutes)

Session 4; Grip force recording

Arm keeping position: at the way of the shoulder abduction by scapula fixed and the elbow in full extension with the forearm in pronation during each trial.

A. **Determination of maximum isomeric contraction (MVC):** duration of each trial = 5 seconds; 2 minutes rest between trials; [(5 seconds x 3) + (2 minutes x (3-1)] = 4 minutes 15 seconds.

On biceps brachii muscle

1st trial	Unit in kg	15.3	MVC = 100%
2nd trial		16.5	
3rd trial	15.6	15	

On triceps muscle

1st trial	Unit in kg	16.9	MVC =100%
2nd trial		13.5	
3rd trial	14.97	14.5	

B. sEMG signals recording during sub=maximal to maximal contractions for muscle fatigue test. 10 minutes rest following MVC trial; duration of each contraction = 90 seconds; 10 minutes rest between sub-maximal contraction; Total time = 5 minutes + [(15 seconds x 3) + {2 minutes x (3-1)}] = 9 minutes and 45 seconds.

On biceps brachii muscle

30%MVC	50%MVC	70%MVC
4.64	7.80	10.92

On triceps muscle

30%MVC	50%MVC	70%MVC
4.49	7.49	10.48

Location upper limb muscle: Biceps brachii and triceps

Universiti Malaysia PAHANG
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EVALUATION OF MUSCLE FATIGUE IDENTIFICATION BASED ON EMG FEATURE

Investigator: Dr Nizam Uddin Ahamed

Co-investigator: Nur Amelia Izzati Bt. Mohd Amin (FB12014)

DATA COLLECTION FORM

Session 1: Familiarization. (5 minutes)

Session 2: Subject and anthropometric details (10 minutes)

A. Subject's details (To be filled by subject and will be kept confidential)

Name	Nurfatin Nabilah bt. Faiid
Year	4
Phone	012-5803591

B. Subject's anthropometric details (To be filled by the investigator)

Gender	Male	Age (Years)	23
Weight (Kg)	49	Height(cm)	158

Session 3: Introducing arm keeping protocol for trial (5 minutes)

Session 4; Grip force recording

Arm keeping position: at the way of the shoulder abduction by scapula fixed and the elbow in full extension with the forearm in pronation during each trial.

A. **Determination of maximum isomeric contraction (MVC):** duration of each trial = 5 seconds; 2 minutes rest between trials; [(5 seconds x 3) + (2 minutes x (3-1)] = 4 minutes 15 seconds.
On biceps brachii muscle

1st trial	Unit in kg	10.5	MVC = 100%
2nd trial		14.8	
3rd trial	10.87	7.3	

On triceps muscle

1st trial	Unit in kg	14.0	MVC =100%
2nd trial		15.30	
3rd trial	14.56	14.40	

B. sEMG signals recording during sub=maximal to maximal contractions for muscle fatigue test. 10 minutes rest following MVC trial; duration of each contraction = 90 seconds; 10 minutes rest between sub-maximal contraction; Total time = 5 minutes + [(15 seconds x 3) + {2 minutes x (3-1)}] = 9 minutes and 45 seconds.

On biceps brachii muscle

30%MVC	50%MVC	70%MVC
3.26	5.43	7.61

On triceps muscle

30%MVC	50%MVC	70%MVC
4.37	7.28	10.19

Location upper limb muscle: Biceps brachii and triceps

Universiti Malaysia PAHANG
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EVALUATION OF MUSCLE FATIGUE IDENTIFICATION BASED ON EMG FEATURE

Investigator: Dr Nizam Uddin Ahamed

Co-investigator: Nur Amelia Izzati Bt. Mohd Amin (FB12014)

DATA COLLECTION FORM

Session 1: Familiarization. (5 minutes)

Session 2: Subject and anthropometric details (10 minutes)

A. Subject's details (To be filled by subject and will be kept confidential)

Name	Nur Syahirah bt. Mohd Noor
Year	4
Phone	0149099653

B. Subject's anthropometric details (To be filled by the investigator)

Gender	Male	Age (Years)	23
Weight (Kg)	62	Height(cm)	160

Session 3: Introducing arm keeping protocol for trial (5 minutes)

Session 4; Grip force recording

Arm keeping position: at the way of the shoulder abduction by scapula fixed and the elbow in full extension with the forearm in pronation during each trial.

A. **Determination of maximum isomeric contraction (MVC):** duration of each trial = 5 seconds; 2 minutes rest between trials; [(5 seconds x 3) + (2 minutes x (3-1)] = 4 minutes 15 seconds.

On biceps brachii muscle

1st trial	Unit in kg	15.20	MVC = 100%
2nd trial		16.20	
3rd trial	15.77	15.90	

On triceps muscle

1st trial	Unit in kg	15.30	MVC =100%
2nd trial		12.00	
3rd trial	14.0	14.70	

B. sEMG signals recording during sub=maximal to maximal contractions for muscle fatigue test. 10 minutes rest following MVC trial; duration of each contraction = 90 seconds; 10 minutes rest between sub-maximal contraction; Total time = 5 minutes + [(15 seconds x 3) + {2 minutes x (3-1)}] = 9 minutes and 45 seconds.

On biceps brachii muscle

30%MVC	50%MVC	70%MVC
4.73	7.89	11.04

On triceps muscle

30%MVC	50%MVC	70%MVC
4.20	7.00	9.80

Location upper limb muscle: Biceps brachii and triceps

Universiti Malaysia PAHANG
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EVALUATION OF MUSCLE FATIGUE IDENTIFICATION BASED ON EMG FEATURE

Investigator: Dr Nizam Uddin Ahamed

Co-investigator: Nur Amelia Izzati Bt. Mohd Amin (FB12014)

DATA COLLECTION FORM

Session 1: Familiarization. (5 minutes)

Session 2: Subject and anthropometric details (10 minutes)

A. Subject's details (To be filled by subject and will be kept confidential)

Name	MUHAMMAD SAUFI SANUSI
Year	4
Phone	014-7172040

B. Subject's anthropometric details (To be filled by the investigator)

Gender	Male	Age (Years)	24
Weight (Kg)	71	Height(cm)	175

Session 3: Introducing arm keeping protocol for trial (5 minutes)

Session 4; Grip force recording

Arm keeping position: at the way of the shoulder abduction by scapula fixed and the elbow in full extension with the forearm in pronation during each trial.

A. **Determination of maximum isomeric contraction (MVC):** duration of each trial = 5 seconds; 2 minutes rest between trials; [(5 seconds x 3) + (2 minutes x (3-1)] = 4 minutes 15 seconds.
On biceps brachii muscle

1^{st} trial	Unit in kg	33.20	MVC = 100%
2^{nd} trial		43.10	
3^{rd} trial	39.80	43.20	

On triceps muscle

1st trial	Unit in kg	35.10	MVC =100%
2nd trial		42.20	
3rd trial	38.50	38.20	

B. sEMG signals recording during sub=maximal to maximal contractions for muscle fatigue test. 10 minutes rest following MVC trial; duration of each contraction = 90 seconds; 10 minutes rest between sub-maximal contraction; Total time = 5 minutes + [(15 seconds x 3) + {2 minutes x (3-1)}] = 9 minutes and 45 seconds.

On biceps brachii muscle

30%MVC	50%MVC	70%MVC
11.95	29.90	27.86

On triceps muscle

30%MVC	50%MVC	70%MVC
11.55	19.25	26.95

Location upper limb muscle: Biceps brachii and triceps

Universiti Malaysia PAHANG
Engineering • Technology • Creativity

EVALUATION OF MUSCLE FATIGUE IDENTIFICATION BASED ON EMG FEATURE

Investigator: Dr Nizam Uddin Ahamed

Co-investigator: Nur Amelia Izzati Bt. Mohd Amin (FB12014)

DATA COLLECTION FORM

Session 1: Familiarization. (5 minutes)

Session 2: Subject and anthropometric details (10 minutes)

A. Subject's details (To be filled by subject and will be kept confidential)

Name	Tan Tiang Xiang
Year	4
Phone	019-5911617

B. Subject's anthropometric details (To be filled by the investigator)

Gender	Male	Age (Years)	24
Weight (Kg)	70	Height(cm)	173

Session 3: Introducing arm keeping protocol for trial (5 minutes)

Session 4; Grip force recording

Arm keeping position: at the way of the shoulder abduction by scapula fixed and the elbow in full extension with the forearm in pronation during each trial.

A. **Determination of maximum isomeric contraction (MVC):** duration of each trial = 5 seconds; 2 minutes rest between trials; [(5 seconds x 3) + (2 minutes x (3-1)] = 4 minutes 15 seconds.
On biceps brachii muscle

1st trial	Unit in kg	35.80	MVC = 100%
2nd trial		39.50	
3rd trial	37.17	36.20	

On triceps muscle

1st trial	Unit in kg	26.60	MVC =100%
2nd trial		26.8	
3rd trial	27.17	28.10	

B. sEMG signals recording during sub=maximal to maximal contractions for muscle fatigue test. 10 minutes rest following MVC trial; duration of each contraction = 90 seconds; 10 minutes rest between sub-maximal contraction; Total time = 5 minutes + [(15 seconds x 3) + {2 minutes x (3-1)}] = 9 minutes and 45 seconds.

On biceps brachii muscle

30%MVC	50%MVC	70%MVC
11.15	18.58	26.02

On triceps muscle

30%MVC	50%MVC	70%MVC
8.15	13.58	19.02

Location upper limb muscle: Biceps brachii and triceps

Appendix D

Data Calculation in Matlab

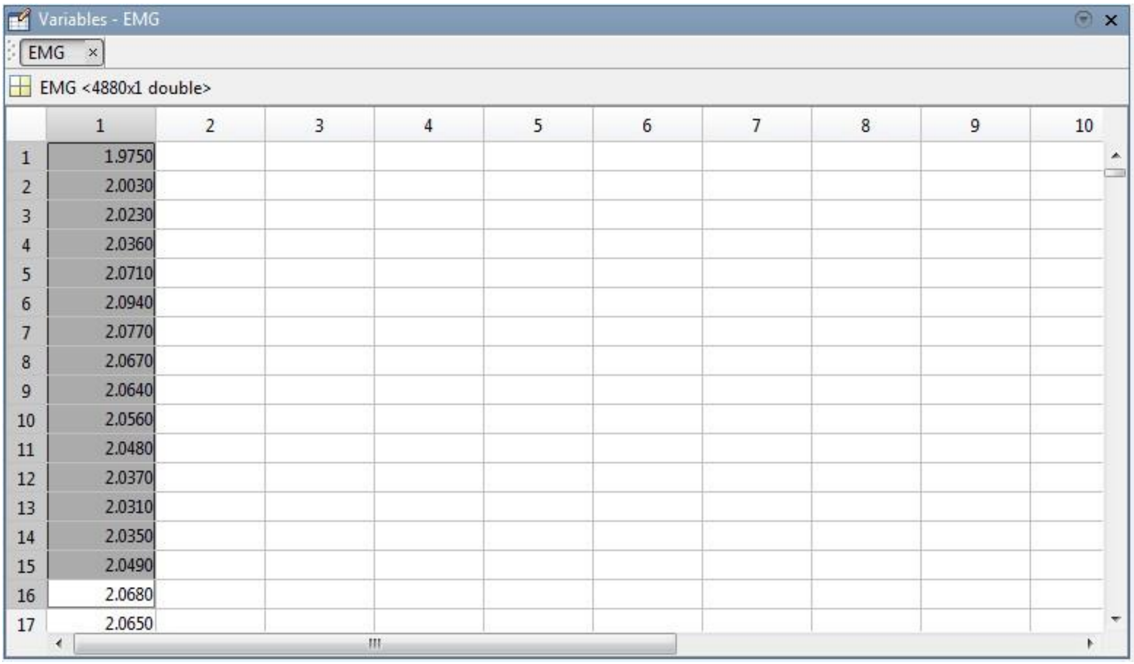

Figure 6.15: Filtered EMG signal in Matlab

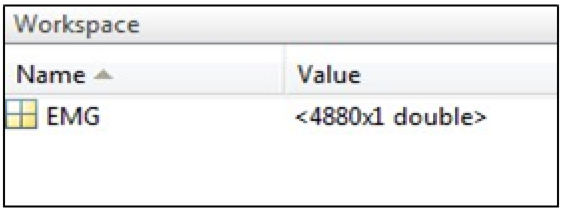

Figure 6.16: Data in spreadsheet in Matlab

```
>> seg=4880;
>> RMS1=sqrt(((1/seg)*sum(EMG.^2)));
>>
```

Figure 6.17: Command of RMS formula in Matlab

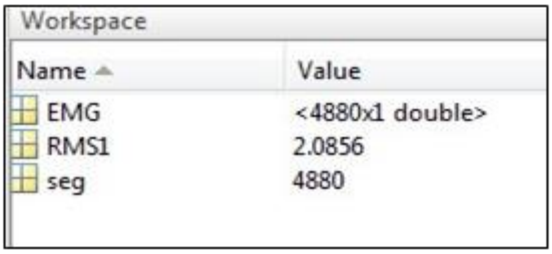

Figure 6.17: Result of RMS calculation