SURFACE EMG (ELECTRICAL SIGNAL) BASED FATIGUE ANALYSIS DURING REPETITIVE WORK

WAN NURUL SYAHIRAH BINTI WAN LANANG

This thesis is submitted as partial fulfilment of the requirements for the award of the Bachelor of Mechatronics Engineering (Hons.)

Faculty of Manufacturing Engineering
UNIVERSITI MALAYSIA PAHANG

JUN 2015

ABSTRACT

Muscle fatigue is defined as a reduction in the force generating capacity of a muscle due to previous or repetitive activity. The powerful use of muscles might cause a decline in body's performance. In this study, the effects of muscle fatigue involving only *biceps brachii* muscle were investigated during the course of dynamic contractions were produced by the volunteered subjects. The experiment was conducted to monitor the progress of muscle strength among the students. Eight male students (age: (23.3±0.46) years, height: (166.8±4.46) cm, weight: (64.9±11.8) kg) and two female students (age: (23.0±0) years, height: (151.0±2.83) cm, weight: (54.5±0.71) kg) were participated in this study. Electrodes were placed on the middle of the *biceps brachii* muscle to record the electromyography (EMG) signals. Each subject participated in two different experiments with 3 trials where first experiment involved 2 minutes rest between each trial and second experiment involved 5 minutes rest for each trial. Muscle fatigue was analysed and compared between the two experiments EMG data. The results were evaluated by calculating the average EMG, root mean square (RMS), and the maximum absolute value (MAV) during dynamic contraction of the muscle. The RMS and MAV value helped in efficiently assessing muscle fatigue. Most of the results indicated that muscle fatigue mostly happened in the second experiment with 5 minutes rest between each trial. The current finding regarding the muscle *biceps brachii* might prove to be useful in developing effective injury prevention and rehabilitation.

ABSTRAK

Keletihan otot diistilahkan sebagai pengurangan dalam kapasiti penjanaan kuasa otot yang disebabkan oleh aktiviti yang terdahulu atau yang berulang-ulang. Penggunaan otot yang kuat mungkin akan menyebabkan penurunan dalam prestasi badan. Dalam kajian ini, kesan keletihan otot yang melibatkan otot *bisep brachii* sahaja disiasat semasa kontraksi dinamik yang dihasilkan oleh subjek secara sukarela. Eksperimen ini dijalankan untuk memantau perkembangan kekuatan otot di kalangan pelajar. Lapan pelajar lelaki (umur: (23.3±0.46) tahun, tinggi: (166.8±4.46) cm, berat: (64.9±11.8) kg) dan dua pelajar perempuan (umur: (23.0±0) tahun, tinggi: (151.0±2.83) cm, berat: (54.5±0.71) kg) telah mengambil bahagian dalam kajian ini. Elektrod diletakkan di tengah-tengah otot *biseps brachii* untul merekod signal Electromyography (EMG). Setiap subjek telah mengambil bahagian dalam dua eksperimen berbeza dengan 3 ujian di mana eksperimen pertama melibatkan 2 minit rehat antara setiap percubaan dan eksperimen kedua melibatkan 5 minit rehat bagi setiap percubaan. Keletihan otot dianalisis dan dibandingkan antara kedua-dua eksperimen berdasarkan data EMG. Keputusan akhir pula dinilai dengan mengira purata EMG, punca min kuasa dua nilai mutlak (RMS), dan nilai maksimum mutlak (MAV) semasa kontraksi dinamik otot. RMS dan nilai MAV membantu menilai keletihan otot dengan lebih efisen. Keseluruhan keputusan menunjukkan bahawa keletihan otot kebanyakannya berlaku dalam eksperimen kedua dengan 5 minit rehat antara setiap percubaan. Penemuan mengenai otot *biseps brachii* ini mungkin dapat membuktikan ianya berguna dalam mengembangkan pencegahan kecederaan dengan lebih berkesan termasuk juga dalam proses pemulihan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

EMG	Electromyography
sEMG	Surface Electromyography
RMS	Root Mean Square
MAV	Maximum Absolute Value
SD	Standard Deviation
CoV	Coefficient of Variance
GUI	Graphical User Interface

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

For the last 40 to 70 years before, the analysis of Electromyography (EMG) signal has been widely used in order to gain or provide a full understanding of the muscle function (signal). EMG can be clarified into two different kinds which are surface EMG and intramuscular EMG (needle and fine wire). Surface EMG (sEMG) signals are a class of bio-signals that described the electrical activity of the neuromuscular system. This sEMG also can be described as a graphic record of micro-voltage presence in the muscle, whether in static or active contraction which can be sensed or measured by the sensors placed upon the skin. The electromyographic activity is captured through the surface electrodes that represent the overall activity or signal during muscle contraction.

Muscles are responsible for generating the required force any movement either simple or aggressive one; carried by it respective contracting mechanisms. In addition, muscle can slowly or gradually enter into the state of fatigue in a continuous contracting process. Fatigue is referred as a feeling of tiredness or exhaustion or a need to rest that can be caused by the lack of energy or repetitive work. Hence, muscle

fatigue is defined as a reduction in the force generating capacity of a muscle due to the previous activity.

The advantages of EMG are it's a non-invasive, simple operation and easy to accept for the patients. The biological signals recorded for sEMG through the electrode surface reflects the status of the nerve and the muscle. Hence, EMG is an effective way to do the studies of muscle fatigue. Furthermore, the typical benefits of EMG are the EMG enables to directly look into the muscle, computing or surveying the muscular performance, and analysis the data to improve sport activities. Next, EMG also helps in decision making both before and after surgery and helps patients to signal and train their muscle.

The experts have found that the analysis conducted based on fatigue during repetitive work, EMG signal appears in a phenomenon where the amplitude of EMG signal increase while power spectrum moves towards low frequency. Mostly, this effect caused by changes in the nerve conduction velocity. The results show that this particular method can carry on the evaluation or analysis of muscle fatigue.

In this project, the small electric current, or signal which comes from active muscles is detected by sensors is placed on the skin directly above the muscles. The pattern of the signal is seen on a computer and is analysed by using Mat Lab; a software programming. The data then will be undergoing the filtering step in order to remove any noise or obstacles during the EMG process.

1.2 PROBLEM STATEMENT

Muscle fatigue of the upper limb muscles follow most recurrently due to repetitive movements in our day-to-day activities. The powerful use of muscles might cause a decline (electromyography signal) in performance. Surface electromyographic (sEMG) is a well-known and acceptable measuring technique to analyse the muscle fatigue during repetitive work. In the last four decades, it has become quite common to evaluate local muscle fatigue by means of sEMG signal processing, however the exact signal performance based on electrode placement sites, different anthropometric parameters and elbow angle movements are still a matter of discussion.

1.3 OBJECTIVE

The objective of this project is to;

1. Detect muscle fatigue in EMG using amplitude analysis (increasing amplitude value).
2. Identify muscle fatigue by decreasing value in the frequency components of the EMG signal.
3. Analyse the EMG signal with root mean square (RMS) value from different protocols (filtering, sampling etc).

1.4 PROJECT SCOPE

During this project, there are many related issues that should be heavily addressed in order to achieve the main objectives of the project. The listed project's scope below is used as a guideline alongside the project progress;

1. Clinical
2. Sport activities
3. Ergonomics
4. Human kinesiology
5. Biomedical physiology

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter aims to review the existing literature that mainly discusses the overview and fundamental concepts including the methodologies used for fatigue based analysis using the surface electromyography measurements. The studies on all related articles will be used as a reference to determine the purpose and direction of this project.

2.2 METHOD OF SEARCHING CRITERIA

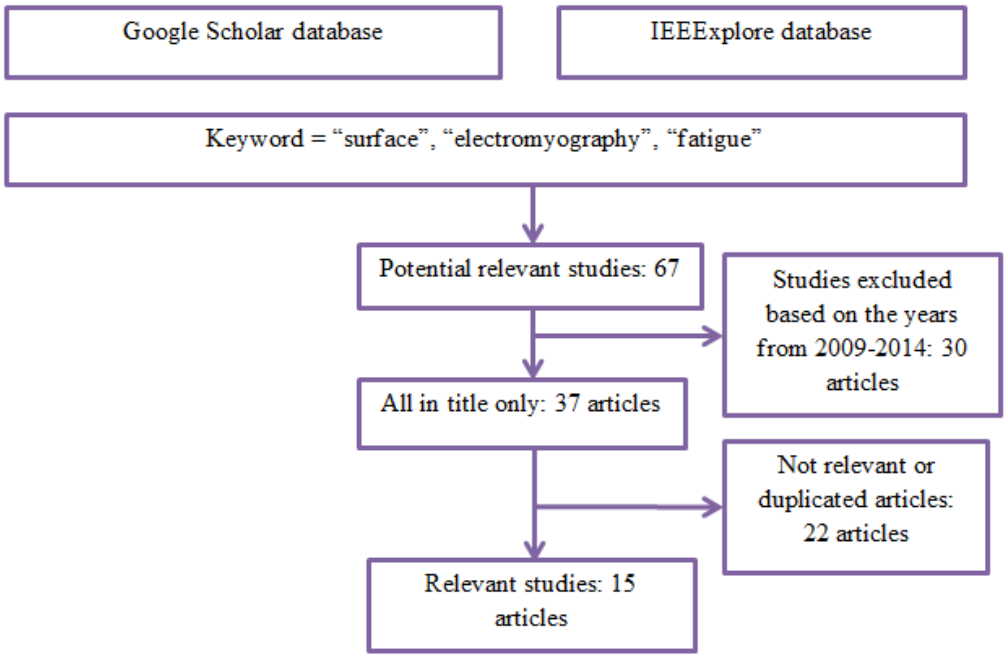

Figure 2.1: The PRISMA flowchart of study selection process. PRISMA, (Preferred Reporting Items for Systematic Reviews and Meta-Analysis)

The present systematic review is regulated based on the ground rule of Preferred Reporting Items for Systematics Reviews and Meta-Analysis (PRISMA).

2.3 SEARCH FINDING STRATEGY

A literature search is conducted for the period of 2009-2014 in order to identify the studies concerning the based-fatigue analysis of surface electromyography (EMG) using the google scholar and IEEExplore databases. The research strategy was used according to the PRISMA statements. The following keywords were used during the reviews: "surface," "electromyography," and "fatigue". Moreover, the references and citation given in the relevant publications were also searched.

2.3.1 Study Selection

Inclusion criteria. A literature review was performed to locate the relevant articles according to the project title. The inclusion criteria of the studies were as follows:

1. The fatigue-based analysis was investigated.
2. Surface electromyography (EMG) were used to analyse muscle fatigue in healthy subjects.
3. Researched studies were published in English language.

Exclusion criteria. Studies using needle EMG was used and the articles which was not in the English language were excluded.

2.3.2 Literature Search Results

The literature search yielded 67 potentially eligible articles on the application of the surface electromyography in fatigue-based analysis. Of these, 30 articles were excluded based on the years from 2009-2014, leaving 37 articles which were all in the title only. The inclusion criteria were only met by 15 articles including the non-relevant or duplicated articles. The most important reasons for the exclusion criteria were that the articles were not in English language and the needle EMG were used.

Only one of the 15 studies (serial No.5) that only applied on non-healthy subjects (Table 2.1), other than that, all research were applied in healthy subjects. In all of these studies, median frequency was shown to be a reliable EMG parameter to assess the muscle fatigue.

2.3.3 Discussion

The present study was carried out to systematically review published studies from 2009-2014 concerning the surface electromyography fatigue based analysis in

healthy or/and unhealthy subjects. 15 studies were met the inclusion criteria and were reviewed. Despite some methodological flaws identified in previous studies such as non-listed muscle part where analysis is done, the unidentified objective of the study, lack of standardized location of the electrode, and others, the results of this review indicate that surface electromyography can be considered as a useful and reliable tool to analyse and evaluate muscle fatigue in healthy or/and unhealthy subjects.

According to the results of this study, different electromyography (EMG) parameters including median frequency, mean power frequency, maximum voluntary contraction, instantaneous median frequency, median frequency slope, and root mean square were used to measure muscle fatigue. Furthermore, they were also different protocols reported such as manually transfer containers from two different places, static trunk extension at different levels of maximum voluntary contraction, riding a motorcycle for the required time, and biceps curl exercise. Even though the variety of EMG parameters among studies with different reported methodology (Table 2.1), median frequency parameters was found to be a comparatively more reliable EMG parameter compared with other variables in the evaluation protocols.

2.3.4 Gap Findings In The Future

Based on the studies done on all 15 articles, it is identified that surface EMG can allow the researcher to analyse the muscle activity. Most of the project required the subjects to sit during the analysis, only one of the study asked the subject to stand comfortably before the experiment is done, and another one asked the subject to lay comfortably on the air bed mattress. There were 9 studies reported to analyse biceps brachii muscle, while another 6 studies mostly analyse other muscles such as trapezius, deltoid, quadriceps and more. From the biceps brachii muscle analysis, all the subjects were asked to sit on the chair where there is still no protocol to do the experiment when the subject need to stand. In addition, there is only one attempt using the Labview and Microsoft excel to analyse the signal, and there is still no attempt to

combine the Mat Lab and Microsoft Excel software to analyse the EMG signal taken during the experiment.

Therefore, this project will examine about 15 healthy subjects' biceps brachii EMG signal to compute the muscle fatigue of ability of the selected muscle under concentric and eccentric contraction. The fatigue analysis in this study included the calculation of root mean square value, spectral mean frequency and median mean frequency of EMG signal with the sampling rate of 1kHz and frequency between 10 to 500 Hz.

2.4 CONCLUSION

The most commonly used surface EMG parameters were median frequency, mean power frequency, and root mean square which reflects the muscle fatigue during different tasks and positions. Many factors including the lack of standardized EMG protocols, the type and location of electrodes, temperature of the muscle and skin, and the force produced by the muscle contraction may all affect the quality of signals and measurements using the surface electromyography (sEMG).

No.	Title	Objectives	Subjects	Muscle	Methodology	Result	Protocol
1	Changes in surface electromyography signals and kinetics associated with progression of fatigue at two speeds during wheelchair propulsion [01].	To determine whether muscle balance is influenced by fatigue in a recordable way, toward creating novel defensive activity strategies for manual wheelchair users (MWUs).	-14 non-disabled participants	-Anterior del-toid (AD). -Middle deltoid (MD). -Posterior deltoid (PD) -Pectoralis major (PM). -Upper trapezius (UT). -Biceps brachii (BB). -Triceps brachii (TB).	-Kinetic data analysis -Time frequency analysis. -Maximum Voluntary. -Isometric Contraction Test. -Wheelchair Propulsion on Ergometer. $\mathrm{MPF} = \frac{\sum_k f_c(k) i_k}{\sum_k i_k}$	- By setting the actual endurance time in each case as 100 percentand dividing it into five equal windows expressed as percentendurance time. -kinetic mean value.	- Perform two trials of wheelchair pro-pulsion with trial order block randomized, one at 0.9 m/s and one at 1.6 m/s. - 10 minutes of rest was given between trial
2	Muscle fatigue and contraction intensity modulates the complexity of surface electromyography [02].	NA.	-12 male paricipants.	-Biceps brachii (BB). -Brachioradialis (BR). -Triceps brachii (TB).	-Signal processing performed using Matlab. -Multiscale sample entropy. $y_j^{\tau_s} = \frac{1}{\tau_s} \sum_{i=(j-1)\tau_s+1}^{j\tau_s} x_i$	-Multiscale entropy parameter optimization. -Surface electromyography multiscale entropy.	-Performed three sessions separated by a minimum of three days. -Participants sat in an adjustable chair and maintained 90deg shoulder flexion and

					$C_{\tau_s} = \sum_{\tau_s=1}^{\max \tau_s} \text{SampEn}(m, r, \tau, N_s).$ -Statistical analysis.		internal rotation, such that the palm of the participant's dominant hand faced their chest.
3	Discrete wavelet transform analysis of surface electromyography for the fatigue assessment of neck and shoulder muscles [03].	To establish DWT analysis as a suitable method to conduct quantitative assessment of neck and shoulder muscle fatigue under dynamic repetitive conditions.	-10 healthy engineering graduate and undergraduate male students.	- Right upper trapezius and left sternocleidomastoid muscles (contra-lateral to the direction of head rotation).	-Obtaining frequency bandwidth at different decompisition level. $B = f\_s/2\hat{}(L+1)$ -Statistical analysis.	-Fatigue induced spectral changes in the SEMG signal by repetitive exertions were assessed using DWT analysis. -Continuously performed repetitive exertions significantly increased the subjective discomfort in the regions of the neck and shoulder corresponding to the locations of the right	-Participant performed repetitive upper extremity exertions to manually transfer 30 cylindrical containers from surface 1 to surface 2. -Once removed, participant began the un-stocking operation, i.e. transferring the containers back to surface 1 from surface 2.

						upper trapezius and left sternocleidomastoid muscles, confirming the development of fatigue in these muscles.	
4	Estimation of Muscle Fatigue During Dynamic Contractions Based on Surface Electromyography and Accelerometry [04].	Estimation of the fatigue which uses an accelerometer to determine the SEMG segments within which the movement artefacts are resolved and the widesense stationarity holds.	-3 subjects.	-Biceps brachii.	-The MDF. -The relevant SEMG segments, employ the detection of movement which uses the acceleration measured during the dynamic contractions.	The method employed the electromyography and the accelerometry technique to indicate the fatigue.	-subjects were instructed to perform 10 repetitions of the biceps curl exercise with the weight of 3kg. -(did not feel the fatigue). Then, the subjects were instructed to perform the same exercise but with the weight of 12kg.

5	Detection and Alert of muscle fatigue considering a Surface Electromyography Chaotic Model [05].	Improve one of the most important drawbacks in physiotherapy which is referred to electro-therapy dosage.	Paraplegic patient.	NA	-Total wavelet entropy (TWE). $S_{wt} = -\sum_{n=0}^{n} p_j \ln p_j$ $TWE = \frac{S_{wt}}{\ln N}$	-The CWT was applied to signals generated by the model and the resulting vector was obtained through Total Wavelet Entropy (TWE). -In this sense, the presented work propose a viable and practical alert and detection algorithm for muscle fatigue.	NA
6	Assessment of neck and shoulder muscle fatigue using discrete wavelet transforms of surface electromyography [06].	Establish discrete wavelet transform (DWT) analysis as a suitable method to conduct quantitative assessment of	-6 male participants.	-Arm. -Neck.	-Signal decomposition (high pass filter – high frequency, low pass filter – low frequency). -Frequency badwidth. $B = fs/2\hat{}(L+1)$ -Effect of fatigue	-Mean discomfort increased after the loading and unloading task.	-Participants performed material handling task by manually transfering 20 cylindrical boxes between the stnd on the surface 1 and the surface 2. -Continuously performed for a

		neck and shoulder muscle fatigue caused by dynamic exertions.			induced by the repetitive exertions is analyzed using a mixed model analysis of variance (ANOVA).		duration of 20 minutes (1st session) followed by a rest period of 5 minutes.
7	Detecting motorcycle rider local physical fatigue and discomfort using surface electromyography and seat interface pressure [07].	To detect physical fatigue due to motorcycle riding for an hour using surface electromyography (sEMG) and seat interface pressure.	-20 male participants.	-Extensor carpi radialis (ECR). -Biceps brachii (BB) -Trapezius medial (TM) -Latissimus dorsi (LD). -Erector spinae (ES).	-Seat pressure analysis. -Heart rate and blood pressure analysis. -Subjective analysis -Statistical analysis	-Participants rated the highest pain score on the buttocks region and lowest score on the palm region. -The occurrence of fatigue in some postural muscle groups (erector spinae and latissimus dorsi medial) during the motorcycle riding. -Motorcycle riders become	-Sampling rate of 1000 Hz. -Filtered using 20-450 Hz band pass filter and 47-51 band stop filter.