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

KHOO HUI PING

A report submitted in partial fulfilment of requirements for the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation) with Honors

Faculty of Electrical Engineering
Universiti Teknikal Malaysia Melaka

2014

" 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

ACKNOWLEDGEMENT

In preparing this final year report, I was contacted with many people like Dr. Chong Shin Horng who is my final year project supervisor. First of all, I would like to express my gratitude Dr. Chong Shin Horng because she is willing to spend her precious time to guide me throughout my final year and provide me with useful information. Besides, I would like to express my sincere appreciation to my family for their providing everything such as money and moral support to help me in accomplishing this final year project.

I would like to thanks my senior, Mr. Abu Bakar bin Yahya that had provided me lots of guidance and help in this final year project. Moreover, I would like to express my sincere appreciation to Universiti Teknikal Malaysia Melaka (UTeM) because provided me an opportunity to accomplish this final year project by my own at this beginning stage. Besides, I would like to express my deepest appreciation towards Mr. Wan Bukhari and Dr. Soo that had provided me some useful information during seminar FYP 1.

Last but not least, I wish to express again my appreciation to all the lecturers that had taught me and guide me throughout my final year project. In addition, thanks to Mr. Lee Yi Ming for his support, ideas and suggestions to help me solve my confusion during completing this project and also my friends. Their view and ideas are useful for me and the whole project really bought us to the true value of friendship and respect to each other.

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.

LIST OF PUBLICATION

CONFERENCE PAPER (SUBMITTED)

1. "Feature Extraction of Muscle Fatigue on Forearm using Surface Electromyography (sEMG) Technique", IEEE-EMBS, 2014.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

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.

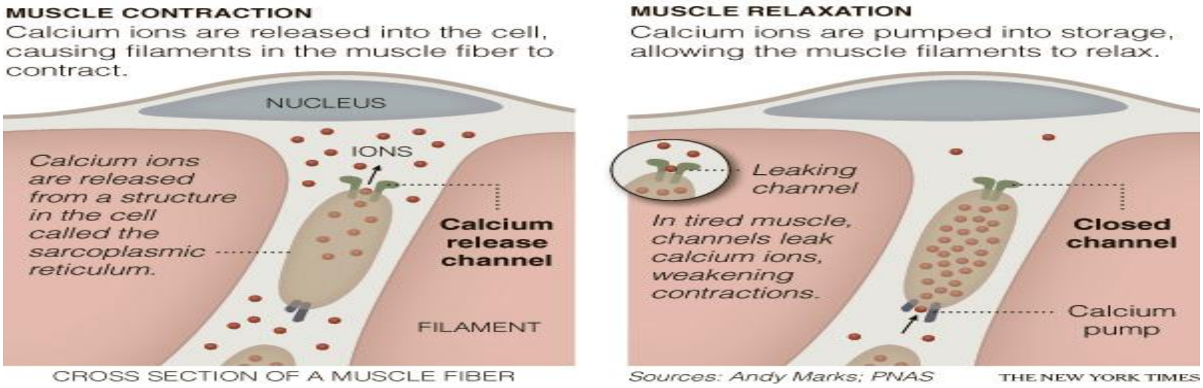

Figure 2.1: Leakage and storage of Calcium ions during muscle contraction and relaxation [4]

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:

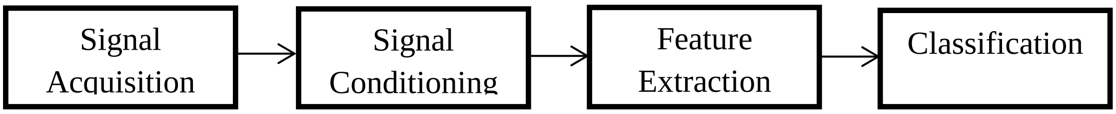

Figure 2.2: Experimental method in previous research

2.1.1 Muscle fatigue stages and its experimental implementation

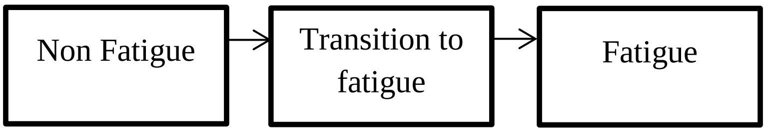

Figure 2.3: Muscle fatigue stages

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