UNIVERSITI PUTRA MALAYSIA

INFLUENCE OF SURFACE ELECTROMYOGRAPHY ELECTRODE PLACEMENT ON SIGNAL ACCURACY AT FOREARM MUSCLES DURING WRIST MOVEMENTS

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By

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Surface Electromyography (SEMG) is a technique to detect and monitor the muscles contraction during movements. Applying SEMG signal has difficulties due to complexity nature of this signal. Different type of noise like location of electrodes can affect SEMG signal during data acquisition. Electrode location can significantly important to conquer different type of noises during data collection. There are two ways to overcome this difficulty; 1) finding the best electrode position and 2) finding inter-electrode distance.

To find the best electrode location in bipolar recording mode, it was designed and implemented a 6 channel SEMG acquisition system to detect and acquire the upper limb muscles' SEMG signal. After that, the present study investigated electrode position and inter-electrode distance (IED) for wrist movements over forearm muscles. This study is based on the muscle physiology such as origin, innervation zone (IZ) and tendon zone (TZ) location. Three different electrode positions and three different IED are investigated over thirty volunteers participated during seven daily wrist movements such as wrist extension, flexion, radial deviation, ulnar deviation, wrist rotation and fingers extension and flexion.

To find out the best electrode position, the collected signal were analyzed in time and frequency domain. The best electrode location selected where SEMG signal had higher value in time and frequency domain (Mean Absolute Value, Root Mean Square, Power Spectra Density) with lower cross-talk value (Cross-Correlation). The results show a significant differences between various electrode positions in both time and frequency domain. This study recommends the best electrode position over FCR, ECR and ED muscles near muscle origin and IZ with 40mm IED. The best electrode position for ECU and FCU recommend between muscle origin and IZ with 20mm IED. This study also suggests the electrode site for FD muscle is between IZ and TZ with 20mm IED. The presented method should be observed as an important step in every SEMG application and research to guarantee the signal quality.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains.

PENGARUH PENEMPATAN SURFACE ELECTROMYOGRAPHY ELEKTROD PADA KETEPATAN SIGNAL PADA OTOT LENGAN SEMASA PERGERAKAN PERGELANGAN

Oleh

HOSSEIN GHAPANCHI ZADEH

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Permukaan elektromyografi (SEMG) adalah satu teknik untuk mengesan dan memantau pengecutan otot semasa pergerakan. SEMG mengandungi maklumat penting berkaitan pengecutan otot and arah pergerakan. SEMG telah banyak digunakan untuk pelbagai aplikasi seperti mengesan aktiviti otot dan diagnosis mampatan saraf atau kecederaan. Walaubagaimanapun, terdapat kesukaran dalam penggunaan SEMG disebabkan isyarat ini yang kompleks. Amplitud SEMG dalam julat frekuensi 0-1000Hz adalah kecil (0-2mV puncak ke puncak). Maka, jenis hingar yang berbeza seperti lapisan permukaan tisu, zon inervasi yang luas (IZ), isyarat dari otot yang berhampiran, saiz elektrod and lokasi elektrod diletakkan boleh mempengaruhi isyarat. Terdapat dua kaedah untuk menyelesaikan masalah ini; 1) mencari kedudukan elektrod terbaik dan 2) mencari jarak dalaman elektrod. Kajian ini umumnya membentangkan dua bahagian yang berbeza. Bahagian pertama telah mereka dan membuat sistem pemperolehan SEMG enam saluran untuk mendapatkan isyarat dari otot bahagian atas badan.

Bahagian kedua kajian ini mengesyorkan posisi elektrod dan jarak dalam elektrod untuk pergerakan tangan sekitar otot lengan. Kajian ini berdasarkan posisi otot asalan, IZ dan zon tendon (TZ). Tiga posisi elektrod yang berbeza dengan dua sentimeter jarak di antara bipolar elektrod, dan tiga jarak antara elektrod yang berberza disiasat. Isyarat SEMG diambil daripada otot flexor carpi ulnaris (FCU), extensor digitorum (ED), fexor carpi radialis (FCR), extensor carpi ulnar (ECU), extensor carpi radialis (ECR), dan flexor digitorum (FD) sewaktu pergelangan tangan digerakkan. Seramai 30 sukarelawan menyertai kajian ini. Sukarelawan diminta melakukan lapan pergerakan pergelangan tangan harian seperti melanjut dan membengkukan pergelangan tangan, sisihan radial, sisihan ulnar, pusingan pergelangan tangan dan lanjutan dan bengkukan jari.

Untuk mengetahui kedudukan terbaik elektrod, kaedah pemproses berikut dilaksanakan; purata nilai (MAV), punca kuasa dua (RMS), variance (VAR) dan kuasa kepadatan isyarat (PSD). Isyarat silang yang paling rendah adalah komponen utama bagi kualiti

isyarat SEMG yang baik. Oleh itu, teknik korelasi silang (CC) dikira di antara otot yang berkaitan untuk setiap pergerakan, dengan otot berdekatan untuk mencari isyarat silang yang paling rendah. Untuk mengesahkan kedudukan elektrod dan IED yang dipilih, nisbah isyarat kepada hingar (SNR) digunakan. SNR yang tinggi menunjukkan nisbah isyarat yang dikehendaki kepada isyarat yang tidak dikehendaki.

Keputusan menunjukkan perbezaan besar di antara kedudukan elektrod dalam kedua-dua domain masa dan frekuensi. Tambahan lagi, perbezaan IED mempengaruhi kadar isyarat silang. Kajian mengesyorkan kedudukan elektrod terbaik bagi otot FCR, ECR, dan ED berdekatan dengan otot asalan dengan IZ 40mm. Kedudukan elekrod terbaik baik ECU dan FCU disyorkan di antara otot asalan dan IZ dengan IED 20mm. kajian ini juga mengesyorkan bahawa kedudukan elektrod bagi FD adalah di antara IZ dan TZ dengan IED 20mm. kaedah yang dibentangkan perlu diperhatikan sebagai langkat penting bagi setiap aplikasi SEMG dan penyelidikan untuk memastikan kualiti isyarat.

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I certify that a Thesis Examination Committee has met on 22 February 2016 to conduct the final examination of Hossein Ghapanchi Zadeh on his thesis entitled "Influence of Surface Electromyography Electrode Placement on Signal Accuracy at Forearm Muscles During Wrist Movements" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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- The research conducted and the writing of this thesis was under our supervision;
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LIST OF ABBREVIATIONS

Ag	Silver
ANOVA	Analysis of Variance
BPS	Band Pass Filter
CC	Cross-Correlation
Cl	Chloride
CMR	Common Mode Rejection
DAQ	Data Acquisition
DOF	Degrees of Freedom
ECG	Electrocardiogram
ECR	Extensor Carpi Radialis
ECU	Extensor Carpi Ulnaris
ED	Extensor Digitorum
EEG	Electroencephalography
EMG	Electromyography
FCR	Flexor Carpi Radialis
FCU	Flexor Carpi Ulnaris
FD	Flexor Digitorum
FDS	Flexor Digitorum Superficial
FFT	Fast Fourier Transformer
FL	Forearm Length
IED	Internal Electrode Distance
IZ	Innervations Zone
LOG	Logarithm
LSD	Least Sinificant Difference
MAV	Mean Absolute Value
MAX	Maximum
MMG	Mechanomyography
MU	Motor Unit
MUAP	Motor Unit Action Potential
PSD	Power Spectra Density
RMS	Root Mean Square
SEMG	Surface Electromyography
SEMGR	Surface Electromyography Reveal
SENIAM	Surface Electromyography for the Non Invasive Assessment of Muscles
SI	Summing Inverting
SNR	Signal-to-Noise Ratio
SRD	Shield and Reference Electrode Driver
TTL	Transistor-Transistor Logic
TZ	Tendon Zone
VAR	Variance

CHAPTER 1

INTRODUCTION

Electromyography (EMG) is a technique to monitor and store the electrical activity generated by the skeletal muscles during muscle contraction. EMG signals contain significant information, which can be used to detect a movement. EMG signals are collected in two ways: surface EMG (SEMG), and intermuscular EMG [20]. SEMG and intermuscular EMG can be collected by using non-invasive and invasive electrodes respectively. Recently, SEMG are preferably used to acquire information of muscles activities [21]. The SEMG signals are considered as the most advantageous method of electrophysiological signals in many areas such as medical and engineering.

During past decade, the information and application of SEMG significantly increased. Using SEMG provide beneficial information such directly analyze the muscle behavior, easy to detect signals by surface electrodes, electrodes are nearby applications, detect more movement contrast with other type of signals, cheaper to use and more comfortable for user.

The SEMG has amplitude between 0-2mv (peak-to-peak) or 1.5mv (rms) with 0-1000Hz frequency band [22]. Different kinds of noise including subcutaneous tissue layers [23], spread of the innervations zone (IZ) [23], cross talk from neighbor muscles [24], electrode size and electrode position [25, 26] can affect SEMG signal. This problem can be conquered by finding the best electrode position and IED as the most important step of SEMG acquisition. Therefore, this study aimed to determine the best electrode position and IED to obtain SEMG over upper limb during wrist movement.

SEMG has used in many areas such as detecting muscle activities [27] and diagnosis the nerve compression or injury [28, 29]. SEMG system has included electrode placement and signal acquisition parts. Electrode position can significantly mislead the description of SEMG statistically and spectrally factors.

Although there are a few number of researches presented the SEMG electrode position during the last decade, but there is no universal and pervasive method for acquisition and, therefore, electrode position [17, 26, 30, 31]. The Surface Electromyography for the Non Invasive Assessment of Muscles (SENIAM) project published the electrode position to evaluate the SEMG [32]. The SENIAM project presented electrode position for 22 various muscle were accorded on the workshops conclusion and SENIAM's member's studies. However, the SENIAM projects does not included forearm muscles for wrist movements which are used in daily life activities.

H.J Hermens et al., 2000, D.Farainar et al., 2001 and K.Nishihara et al., 2013 who published after the SEINAM project and concluded that the IZ and tendon zone (TZ) are not suitable for electrode placing because the SEMG signals which were collected from IZ and TZ were unstable and unsubstantially magnitude estimation and references [8, 33, 34] shows the IZ shift during activities. Consequently, the recommended electrode sites were between IZ and TZ to ensure a better quality signal.

The second part of SEMG is signal acquisition step. After placing the electrode, a system is needed collect the SEMG signals through electrodes in different position over various electrode types. A few number of studies focused on this important part of SEMG data acquisition. Z. Hanquing et al., 2013 [35] introduced a wireless sensor accusation system. The presented system in this study included bipolar wireless sensor with constant internal distance and programmable receiver, and they just focused on programming and electrode types. SEMG has used in different areas like detecting myoneural junction [36]. Consequently, for various studies like matrix electrode, H. Mok et al., 2003 designed a system with flexibility and elasticity linear shield of SEMG electrode [37]. The system which was introduced by H. Mok et al., can be rounded to the muscle and connected to the amplification circuit. In addition, recent study by X. Zhang et al., 2012 provides portable SEMG system [38]. The portable device is comprised of various units such as central processing, amplification, transition circuit and band pass filter. SEMG Electrode and data accusation system have been investigated and developed for different application. However, the current technology still needs to improve

1.1 Problem Statement

The SEMG signal is significantly used in many areas such as the prostheses body member and rehabilitation robot. Although SEMG has many advantages, there are still some challenges to use it for application of SEMG signal based.

SEMG is a complex signal and exhibits an amplitude between 0 to 2 mv (peak-to-peak) or 1.5 mv (rms) with a frequency band of 0–1000 Hz [39]. Various noises affecting SEMG include subcutaneous tissue layers [23], spread of innervation zone (IZ) [23], crosstalk from neighbour muscles [24], electrode size, and electrode position [26, 40]. The electrode position can significantly reduce or increase this type of noise especially cross-talk [32]. The significant difficulty in SEMG is to identically collect SEMG signal of the targeted muscle with lower cross-talk, lower noise and maximum amplitude and power of frequency [31, 41-43].

Various studies presented the effect of electrode placement on SEMG signal over forearm muscles. However, only a few studies addressed the methodological manner to find correct electrode position. Recent studies, electrodes were placed over a bully area or between innervation zone and tendon zone without the specific symptoms of the points along the length or shape of the muscle. In addition, the inter-electrode distance varied in different studies and there is no specific guideline to place electrode over forearm muscles during wrist movements.

Quantitative studies on the sensitivity of the signal feature extracted from the SEMG signal on the recording type, including electrode position and inter-electrode-distance, for forearm muscles related to wrist movements are scarce. This limitation is significantly crucial for the repeatability of the results and the feasibility of comparing the data from various studies.

1.2 Aims and Objectives

The main objective of this thesis is to present a simple and easy guideline to identify the best electrode position for upper limb during wrist movements. The specific objectives of this research are include:

- To investigate the electrode placement and internal distance of the electrodes
- To provide recommendation guide line for muscle position and electrode site

The sub objectives to accomplish the second research aim which is electrode position the sub objectives are as following:

- Different electrode site
- Various IED
- Suitable for both time and frequency domain signal processing

1.3 Thesis Scope

The first part of this study is the interfacing between the electrode and the computer for monitoring and recording. Therefore, a low-cost multichannel SEMG acquisition system is developed. This system is product for laboratory research and limited to six channels.

The second part is to explore the best electrode position over forearm muscle. This study aimed to identify the optimal electrode position to acquire SEMG over the upper limb during wrist movement by using a commercial adhesive electrode. The selection of the movements are limited to seven movements; wrist extension/flexion, wrist ulnar/radial deviation, wrist rotation and fingers flexion/ extension. Selected movements are the most significant daily wrist movements. To record the SEMG signal related to the movements three different electrode position with three various IED over six forearm muscle was investigated.

1.4 Thesis Contribution

This study contribute the dissertation in purpose of mentioned objectives as follows:

- To investigate the electrode site based on electrode position and IED to achieve high-quality SEMG signals with low-noise during wrist movements
- To develop the guideline to identify the electrode positions for the upper limb.

1.5 Thesis Outline

The structure of this study reflects the process of developing the SEMG acquisition system for monitoring and recording SEMG signal and the sequence of mapping electrode site over upper limb. The organization of thesis is as follows:

Chapter two will take the reader through the publications and studies over related works on background of myoelectric signal, SEMG acquisition system and electrode position in the recent years as literature review and highlight the expressive achievements.

Chapter three will start the short introduction of SEMG and current studies. Furthermore, the methodology of developing six channel SEMG acquisition system will be discussed. This chapter presents the methodology to find the best electrode position and IED over forearm muscles during wrist motion. Three different electrode positions and three IED over forearm muscle of 30 different subjects will recorded. After recording the SEMG data, two different signal preprocessing techniques and six processing methods will apply to the raw signal to find the best electrode position.

The result of the proposed method will present in chapter 4. Chapter 4 will present the results and validating the result of the presented system and differences between various electrode sites and the effect of electrode placement or displacement over upper limb.

Chapter 5 draws the conclusions from chapter 4 which present methodology and result of the research. Furthermore, the noteworthy points of electrode placements will present. Therefore, the method of finding the best electrode position will conclude and lastly, the future work will offered.

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