Faculty of Electrical Engineering

ANALYSIS OF SPINAL EMG SIGNAL WHEN SWINGING AN OBJECT

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Bachelor of Mechatronic Engineering

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ANALYSIS OF SPINAL EMG SIGNAL WHEN SWINGING AN OBJECT

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A report submitted in partial fulfill the requirements for the degree of Bachelor of Mechatronic Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2017

DECLARATION

"I declare that the report entitles "**Analysis of Spinal EMG Signal When Swinging an Object**" is the result of my own research except as cited in the references. The report has not been accepted for any degree and it is not concurrently submitted in candidature of other degree."

Signature :

Name : TOO JING WEI

Date :

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APPROVAL

“I hereby declare that I have read this report entitles “**Analysis of Spinal EMG Signal When Swinging an Object**” and in my opinion this report is sufficient in terms of scope and quality for the award of degree in Bachelor of Mechatronic Engineering.”

Signature :

Supervisor’s Name : MOHD BAZLI BIN BAHAR

Date :

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DEDICATION

Specially dedicated to

My beloved mother,

To my family and friends

Thank you for all the encouragement and support

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ABSTRACT

Electromyography (EMG) is a bio signal record the electricity generated by muscles during muscle contraction. Due to lack of research that emphasis on the recognition of EMG signal at spinal muscle, robotic or rehabilitation studies faces difficulties in designing the best response to overcome spinal injuries. Moreover, the surface EMG is affected by the noise environment, inconsistent due to bodily fatigue and inaccuracy of surface EMG pattern recognition. For data gathering, the MVC normalization method is applied to determine the spinal EMG signal on lumbar multifidus muscle when swinging an object. The MVC test shows that a higher percentage of MVC resulted in higher normalized amplitude. In order to analyse the identical and recognition of spinal EMG signal, three statistical analyses are done. One-way ANOVA analysis shows that the means value among all 15 subjects are different in the % MVC test. In addition, RMS analysis indicates that the muscle activity is increased when the muscle contraction is increased. In boxplot analysis, it shows that the increment of percentage MVC resulted in greater median, normalized amplitude and the interquartile range. Besides, this paper presents a further investigation on determining the average median and interquartile range difference from 0% until 100% MVC by applied 8^{th} order Gaussian function in curve fitting and exponential weight moving average filter in boxplot analysis. The 8^{th} order Gaussian function shows the greatest difference in median and lowest difference in interquartile range when there is an increment on the percentage of MVC, thus it produces more identical and consistent data after go through boxplot analysis. Furthermore, the median is the best feature in the boxplot analysis to show the difference in increment of %MVC. Additionally, this works also found that the thicker fat layer affects the strength of the signal received from the muscle.

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ABSTRAK

Electromyography (EMG) adalah satu rekod isyarat bio elektrik yang dihasilkan oleh otot semasa penguncupan otot. Kerana kekurangan penyelidikan yang menekankan pengiktirafan isyarat EMG pada otot tulang belakang, kajian robotik atau pemulihan menghadapi kesukaran dalam mereka bentuk jawapan yang terbaik untuk mengatasi kecederaan tulang belakang. Selain itu, EMG dipengaruhi oleh persekitaran bunyi bising, tidak konsisten akibat keletihan badan dan ketidaktepatan pengiktirafan corak permukaan EMG. Untuk pengumpulan data, kaedah normalisasi MVC digunakan untuk menentukan isyarat EMG tunjang pada otot multifidus lumbar apabila manghayon objek. Ujian MVC menunjukkan bahawa peratusan yang lebih tinggi MVC menghasilkan amplitud normal lebih tinggi. Dalam usaha untuk menganalisis pengiktirafan serupa dan isyarat EMG tulang belakang, tiga analisis statistik telah dilakukan. ANOVA sehala analisis menunjukkan bahawa nilai cara di kalangan semua 15 subjek adalah berbeza dalam% ujian MVC. Di samping itu, analisis RMS menunjukkan bahawa aktiviti otot bertambah apabila pengecutan otot bertambah. Dalam analisis boxplot, ia menunjukkan bahawa kenaikan peratusan MVC menghasilkan median, amplitud pulih dan julat antara kuartil yang lebih besar. Selain itu, kertas kerja ini membentangkan siasatan lanjut untuk menentukan median dan perbezaan julat antara kuartil dari 0% hingga 100% MVC dengan menggunakan 8^{th} order Gaussian function dan exponential weight moving average filter dalam analisis boxplot. 8^{th} order Gaussian function menunjukkan perbezaan yang paling besar dalam median. Apabila terdapat kenaikan pada peratusan MVC, ia menghasilkan data yang lebih sama selepas melalui analisis boxplot. Tambahan pula, median adalah ciri terbaik dalam analisis boxplot untuk menunjukkan perbezaan dalam kenaikan %MVC. Tambahan lagi, kerja ini juga menunjukkan lapisan lemak tebal memberi kesan kepada kekuatan isyarat yang diterima daripada otot.

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The purpose of this report is to analyze the EMG pattern recognition in spinal muscular. Electromyography (EMG) is defined as an evaluation and recording of the myoelectric signal from the skin surface. Myoelectric signal is a signal that generated by muscle electrical activity [1]. Almost 85% of the caregivers are experienced in lower back pain and the prevalence of low back pain shows an increment in the point prevalence of 57.9%, 49.5%, and 35.1 % in 12 months, one month, and in 7 days respectively among automotive industry worker. The overall number of humans who had gait disabilities risen together with the needs of appropriated rehabilitation treatment. In the past 100 years, a lot of rehabilitation treatment had been proposed. With EMG, patients with spinal control injury were able to recover their sensory motor function [2]. Recently, there were a lot of robots involve with EMG pattern recognition such as robotic arms and a wheelchair controlled by human brains. So, EMG pattern recognition has the ability to mimic human. But there were a lot of researchers reported of having difficulties to achieve high accuracy signal due to noise environment and robustness of EMG pattern recognition [3], [4].

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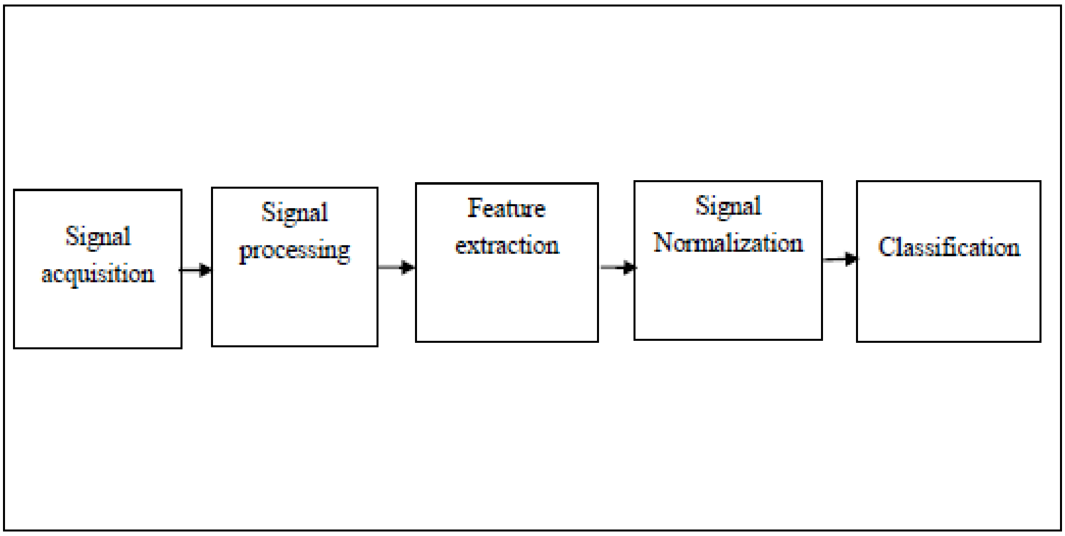

Figure 1. 1: Block diagram of electromyography pattern recognition [5]

By referring the block diagram in Figure 1. 1 , signal acquisition is a process to measure the EMG signal. Signal processing is a process of transferring of the EMG signal. Feature extraction is an important in extracting the valuable information from EMG signal. Normally, feature extraction will easily affect the accuracy of the result due to error and noise. Lastly, signal normalization is another challenge process and it is important in generalized all EMG data acquired from inter and intra samples [5].

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1.2 Motivation and Significant of Study

Every year, there will be 12 to 53 humans with new spinal injury over the million populations and there was a monthly case of spinal injury occurred at Sarawak General Hospital. The ratio of men with spinal injury is higher than women and most of the patients are still young. The spinal cord is important to control the movement of the body. Therefore, the EMG is developed in order to help the patient with spinal injuries in physiotherapy. This research will contribute the method for data acquisition and analysis of the EMG signal. Besides, develop a feature which was more robust to noise in order to achieve high accuracy of the EMG signal. Moreover, with the involvement of EMG in robotic, robot has the ability to mimic human especially in motion. Lastly, the robot was able to use more effectively in rehabilitation, therapy, and medical test.

Recently, researcher was focused on the development of an upper limb rehabilitation training system [6], the relation between surface EMG signal and ideal motor muscle [7]. Besides, some of them focus on improving the process speed and response of EMG device [8], [9]. In addition, the investigation on the performance with the implement of two electrode system in electromyogram detection was also done[10]. Due to lack of research that emphasis on the recognition of EMG signal at spinal muscle, robotic or rehabilitation studies faces difficulties in designing the best response to overcome spinal injuries.

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1.3 Problem Statement

This section contains an elaboration of the problem on surface EMG when applied to human motion. The surface EMG is affected by the noise environment and its feature was not robust. The robust feature of EMG signal determines the noise depend on the strength of the signal. According to Thongpanja et al., 2016, the transformation of measure EMG signals into a reduced set of features is normally extracted in time domain and frequency domain [4]. However, the robust features of surface EMG still didn’t meet the expectation until today.

Furthermore, inconsistent due to bodily fatigue affected the capability of the surface EMG pattern recognition. Fatigue inconsistency happened at different times due to different subjects. In addition, environmental issues such as temperature and humidity result in inconsistency fatigue. Thus, the time taken for a resting period between each %MVC test must be taken into consideration.

Lastly, the inaccuracy of surface EMG pattern recognition affected the results. The review shows that a lot of researchers having difficulties in getting high accuracy of surface EMG pattern recognition [4], [11], [12].

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1.4 Objectives of Research

From the research questions in the problem statement and in order to achieve the aim, two objectives were highlighted.

1. To implement 8th order Gaussian function in Curve Fitting and Exponential Weight Moving Average Filter to the spinal EMG signal.
2. To analyze the spinal EMG signal using statistical analysis methods which are one-way ANOVA, RMS and boxplot analysis.

1.5 Scope of Research

The following are the list of scopes:

1. The experiment was done in the laboratory.
2. Subjects of experiment were between 20 to 30 years old and they must be healthy males.
3. All subjects must not have any accident history on their spinal.
4. Experiments only focus on lumbar multifidus muscles located at spine.
5. Bipolar electrode was used to collect the EMG data.
6. The analysis was done by using Matlab.
7. The experiment focuses on swinging.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will discuss the description on EMG system overview which consists of the theoretical background of EMG, muscle organization, surface electromyography and lumbar multifidus muscle. The review presents the experiment methodology on surface EMG testing and muscle identification. Besides, the robust feature of surface EMG is clearly shown. Lastly, it discusses on factor affects and influence the EMG signal. Research shows that mostly the factor affects the results of the surface EMG experiment is the accuracy pattern recognition of the EMG signal. At the end of this chapter, the method of surface EMG experiment and knowledge are presented.

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2.2 Theoretical background

In this subchapter, the theory and principle of electromyogram (EMG), muscle organization and human spinal anatomy are reviewed.

2.2.1 Electromyogram (EMG)

Electromyogram (EMG) is a bio signals that recorded the electrical activity produced by muscles at rest and during muscle contraction. When there is an exchange of ions pass through the muscle fibre membrane, an electrical current is generated. Generally, the electrical current generated by active muscles usually proportional to the level of muscle activity. Electromyography is a method used to evaluate and record electromyogram signal. Simplest way to understand EMG signal is the way muscles generated bioelectric signal, spinal cord and muscle anatomy [3], [13], [14].

2.2.2 Surface Electromyography

Surface electromyography is a technique used for electrical recording and analyzing of muscle activity from the skin surface. Besides, surface EMG is the most common method of measurement and it is non-invasive electrical recording that recorded procedure obviates the need to infiltrate the skin. Superposition of the large number of transients having semi-random temporal and spatial separation is the results from surface EMG. For surface EMG, the electrodes and EMG sensors are attached to the user skin and the detection of abnormalities and activation level of human development is done by analyzing the shape, size and frequency of motor unit potential produced by muscle fiber [1], [15].

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2.2.3 Muscle and Motor Units

Motor units (MUs) are a group of muscle, which consist a large number of muscle fibers. It is known as the basic level of the neuro motor system of motor and they are controlled by a single motor neuron. The electrical stimulus travels down the motor neuron to activate the muscle fiber by the change in polarity travels down neuron and liberate neurotransmitter from terminal [1].

Muscle contractions cause by motor neuron simulations. Muscle contractions divided into three categories which are isometric, concentric and accentric. Isometric contraction happened when muscle contractions attend upon muscle length. Concentric contraction results in muscle shortening. Muscle lengthens take place during accentric contraction. Isometric contraction is different compared to concentric and accentric contractions thus they are known as un-isometric contractions [1], [16].

Process that motor units selected to take part in muscle contraction is known as recruitment process. It is a process that motor units build up a small number of muscle fibers are engaged and larger levels of contraction necessitates involvement of motor units incorporating an ample number of muscle fibers [1], [7].

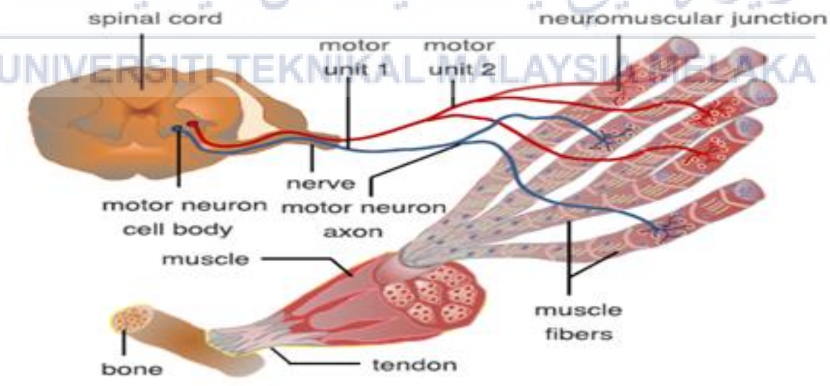

Figure 2. 1: Motor neuron and motor units [1]

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2.2.4 Lumbar Multifidus Muscle

Lumbar multifidus muscle is one of the back muscles. The most outstanding superficial back muscles are latissimus dorsi and trapezius and they are related to upper limb movements. Lumbar Multifidus Muscle is a small and powerful muscle and it provides support to the spine. The adjacent vertebrae are connected to each other from the cervical to the lumbar region by multifidus muscles. Besides, multifidus muscle begins to contract prior to actual movement before an action is performed [17], [18]. As the result, lumbar multifidus muscle is suitable for surface EMG.

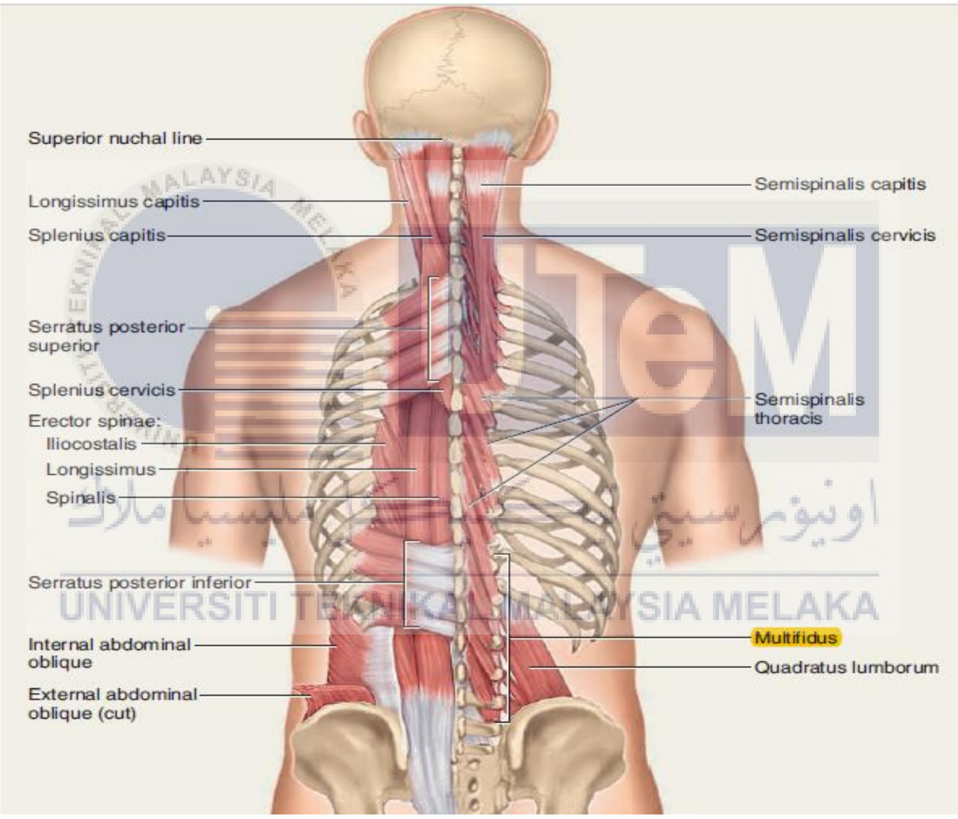

Figure 2. 2: Muscle Acting on the Vertebral Column [18]

2.3 Experiment Methodology

2.3.1 Subject

There are 6 to 14 subjects included males and females are participating in this study. All subjects were provided informal consent before the experiment. All subjects were required to make sure their healthy states were in good condition. Age of subjects should be in the range of 20-30. All the detail such as age, weight, height, gender, perimeter of biceps brachii muscle when contracts, perimeter of biceps brachii muscle when extends, pulse bits and length of the hand from the subject have been recorded [15], [19]–[22]. But the research shows that the number of samples is not sensitive enough, thus the number of sample had to increase for a better result.

2.3.2 Pre-Experiment

All equipment is prepared and placed simultaneously to the subjects. This set-up is able to save the time and avoiding the tiredness of the subject [21]. Devices such as multiple-channel surface EMG system as surface EMG recording of forearm and muscles of subjects. Before electrode placement, subject took several minutes to rest, then put alcohol to shave the skin of a subject, lightly abraded and cleaned it. All the above methods must be conducted to prevent any harm to the skin from rubbing [2], [15]. The time taken for the samples to rest had to be long enough to make sure samples had a good performance on tests and increase the accuracy of data collected.

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2.3.3 Experiment Protocol

Several EMG electrodes were used in the experiment. Size of electrode was 10 mm in diameter while the recording surface was 5 mm in diameter. The sEMG sensor is placed on the right forearm, wrist while electrodes placed on four muscle groups on forearm, which are anterior deltoid, pectoralis major, biceps brachii and posterior deltoid as shown in Figure 2. 3. Each subject was comfortably seated on a chair with test forearm relaxed on height-adjustable table. Subjects were instructed to perform several tests, including power grip, cylindrical grip and tool grip. In order to get the effective signals, each channel using bi-polar configuration and distance between two electrodes is chosen at 15mm [15], [19], [23], [24].

In the process of lifting task, there is an increment of 10% maximum voluntary contraction (MVC) from 0% to 100% MVC. By using the data acquisition (NI-6009) and set the sampling frequency to 1 kHz. The Experiment consisted of several repetitions to increase the accuracy of data [25]. In addition, the people who set the experiment must be the same to prevent error while counting the time.

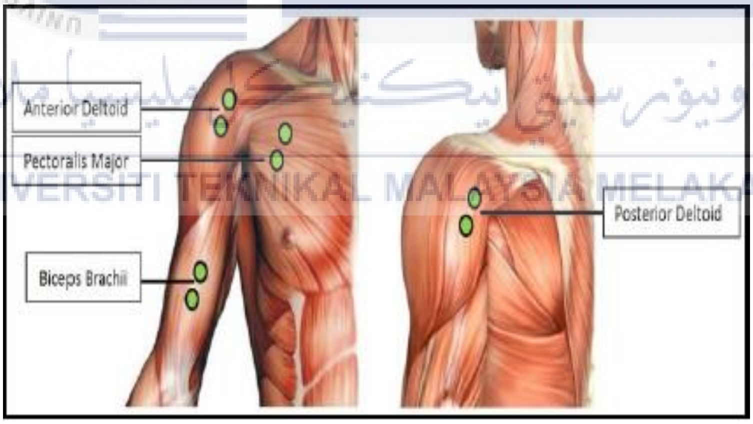

Figure 2. 3: EMG sensor position [19]

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2.4 Robust feature

Feature extraction is one of the challenging parts in surface EMG pattern recognition. It is important in noise reduction in EMG signal. Usually, EMG signal contains a great amount of noise and robust feature is needed in order to get the best surface EMG pattern recognition [25].

The integrated EMG (IEMG) is the sum of absolute values of EMG signal amplitude. It is the detection of muscle activity assistive device control. It can be express as:

$$IEMG = \sum_{n=1}^{N} |X_n| \qquad (2.1)$$

Where N represents the length of the signal and X_n stands for the EMG signal in specific segment.

Means absolute value (MAV) is used for calculation of mean value of the linear envelope. It can be express as:

$$MAV = \frac{1}{N}\sum_{n=1}^{N} |X_n| \qquad (2.2)$$

Where N represents the length of the signal and X_n stands for the EMG signal in specific segment.

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Root mean square (RMS) is model modeled by the amplitude modulated Gaussian random process. It can be computed as:

$$RMS = \sqrt{\frac{1}{N}\sum_{n=1}^{N} X_n^2} \qquad (2.3)$$

Where N represents the length of the signal and X_n stands for the EMG signal in specific segment.

Standard deviation feature represents EMG signal confidence interval between statistical data. It can be express as:

$$STD = \sqrt{\frac{1}{N-1}\sum_{n=1}^{N} X_n^2} \tag{2.4}$$

Where N represents the length of the signal and X_n stands for the EMG signal in specific segment.

Modified mean absolute value 1 (MMAV 1) is a assemble feature based on MAV and it can be expressed in mathematical form as:

$$MMAV = \frac{1}{N}\sum_{n=1}^{N} w_n|x_n|$$
$$w_n = \begin{cases} 1, & if\ 0.25N \le n \le 0.75N \\ 0.5, & otherwise \end{cases} \tag{2.5}$$

where N is the length of signal; w_n is the weighing window function of sampling signal and x_n represents the EMG signal in a specific segmentation.

Modified mean absolute value 2 (MMAV 2) is an assemble feature based on MAV with continuous weighing window function and it can be expressed in mathematical form as:

$$MMAV\ 2 = \frac{1}{N}\sum_{n=1}^{N} w_n|x_n|$$
$$w_n = \begin{cases} 1, & if\ 0.25N \le n \le 0.75N \\ \frac{4n}{N}, & if\ 0.25N > n \\ \frac{4(n-N)}{N}, & if\ 0.75N < n \end{cases} \tag{2.6}$$

where N is the length of signal; w_n is weighing window function of sampling signal and x_n represents the EMG signal in a specific segmentation.

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Simple square integral (SSI) is define as summation absolute energy of EMG signal. It can be simplified as:

$$SSI = \sum_{n=1}^{N} |X_n|^2 \tag{2.7}$$

Where N represents the length of the signal and X_n stands for the EMG signal in specific segment.

Variance is defined as the square deviation of variables from its mean value and it can be expressed in mathematical form as:

$$VAR = \frac{1}{N-1} \sum_{n=1}^{N} x_n^2 \tag{2.8}$$

where N represents the length of signal and x_n is the EMG signal in specific segmentation.

Median frequency (MDF) is calculated of median frequency value based on spectrum of EMG signal. It can be express as:

$$MDF = \frac{1}{2} \sum_{j=1}^{M} P_j \tag{2.9}$$

Where P_j the power spectrum of EMG signal and M is represents the length of power spectrum.

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Mean frequency (MNF) of power spectrum represents the average frequency value. It can be defined in mathematical form as:

$$MNF = \frac{\sum_{j=1}^{M} f_j P_j}{\sum_{j=1}^{M} Pj} \tag{2.10}$$

where P_j is the power spectrum of EMG signal. M is the length of power spectrum and f_j is the frequency of power spectrum at frequency in j.

2.5 Benefit of EMG

Human characteristics normally based on neuromuscular dynamics may vary due to muscle fatigue. EMG developed the methods to estimate muscle torque from bio-signals that can be measured. A technology applies the EMG into robotic for human motion had been introduced in order to provide support for human needed. There are a lot of people with spinal injuries today, this technology enables humanity to gain their moving ability again [2], [16]. Besides, EMG gives rehabilitation support to human. Rehabilitation exercise had developed and real-time biofeedback simulation module able to provide muscle detection on the surface EMG threshold in real time [19], [26]. Lastly, EMG provided motor recovery and allowed patient lived as normal people [2]. In the future, an EMG signal plays an important role in rehabilitation and enable human motion with just sending signals.

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2.6 Factors affect EMG Signal

Accuracy of EMG signal is important in the successful execution of research applications. There are four factors affect the EMG signal pattern recognition and these factors cause the error in investigation of muscle activity. The factors are electrode configuration, environmental noise, the limitation of current technology and the degree and angle of muscle flexion.

2.6.1 Electrode Configuration

The diameter of electrodes and area of electrode surfaces determined the number of active motor unit detected by virtue of the number of muscle fibers. The position of electrodes placed affects the accuracy of the signal. Besides, the distance between the electrodes and human skin surface influenced the electrical properties of detecting signal. In addition, location of electrodes with respect to motor points in muscle affected the amplitude of the signal and the orientation of the recording surfaces relative to the direction of the muscle fibers [3], [15], [27].

In order to achieve high quality of EMG signal, the position of electrode had to install correctly at the muscle. The experiment should repeat several times to improve consistency and accuracy of signals.

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2.6.2 Environmental Noise

There are five different types of noise which are Electrocardiography (ECG) interference, many spurious background spikes, white Gaussian noise, motion artifact and power line interference at various levels of signal-to-noise ratio (SNR). The bio potential signals will look toward high source impedance and noise from preparation of electrode, skin, environment and instrument when collecting the data. As the result, these noises influenced the detected signal [4], [10].

Since there are many sources of noise generated through the experiment, therefore an indoor experiment is recommended. In addition, filter the EMG signal is considered as a good method in noise reduction.

2.6.3 The Limitations of Current Technology

The blood flowed in the muscle that determined the rate at which metabolites removed during contraction. Depth and location that electrode detected through the skin surface to the active muscle. In addition, lack of technology in removing noise of EMG signals [5].

2.6.4 The Degree and Angle of Muscle Flexion

Generally, the muscle action potential was formed by the source of myoelectric prosthesis and they were remaining issue which can incarnate human movement information. Different in degree and angle of initial and rest positions results in different EMG signal amplitude. As a result, the amplitude of the EMG signal affected by the angle and degree of muscle flexion neither rest nor initial position [12], [28].

Therefore, the position and the angle either rest or initial must be the same in order to overcome this factor.

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2.7 Conclusion

Reviews of surface EMG experiment have been done by a lot of researches. The reviews generally explain the methods, experiment done in EMG testing. The reviews define the EMG signal, muscle contractions and surface electromyography. Moreover, the experiment methodology divided into subject, pre-experiment, experiment protocol and data analysis. Increasing number of samples were able to increase sensitivity and getting better results. The rest period had to be considered as an important factor to make sure samples had a good performance on testing thus increase the accuracy of data.

Lastly, factors influence the signal are electrodes, degree and angle of muscle flexion, limitation of current technology and noise environment. In order to achieve high quality of EMG signal, the position of electrode had to install correctly at the muscle and the experiment should repeat several times to improve consistency and accuracy of signals. In addition, an indoor experiment is recommended and filter the EMG signal is considered as good methods in noise reduction. Moreover, the position and the angle either rest or initial must be the same in an experiment.

The reviews stated that the experiment had been done with a lot of muscles such as biceps brachii muscle but not in lumbar multifidus muscle yet. Lastly, a proper method is used for analysis and evaluates the EMG signal on lumbar multifidus muscle and describe in detail on how it works in the following chapter, CHAPTER 3.

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CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter starts with the discussion of the flowchart of methodology and data gathering by using the maximal voluntary contraction (MVC) normalization method. After that, the experiment is explained and it divided into the objective of the experiment, subject, pre-experiment and experiment protocol. Lastly, the data analysis and statistical analysis are conducted. In data analysis, 8^{th} order Gaussian function in Curve Fitting and Exponential Weight Moving Average Filter are applied to filter and smooth the spinal EMG signal data. Statistical analysis consists of three methods which are one-way ANOVA analysis, root mean square (RMS) analysis and boxplot analysis. One-way ANOVA analysis uses to determine the difference in mean value of 15 subjects. Root mean square analysis shows the muscle performance on muscle by evaluating the root mean square (RMS) value. Lastly, the boxplot analysis shows the features of spinal EMG signal.

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3.2 Flowchart

The flowchart shows in Figure 3. 1 illustrates the methodology and procedure conducted for the analysis of spinal EMG signal.

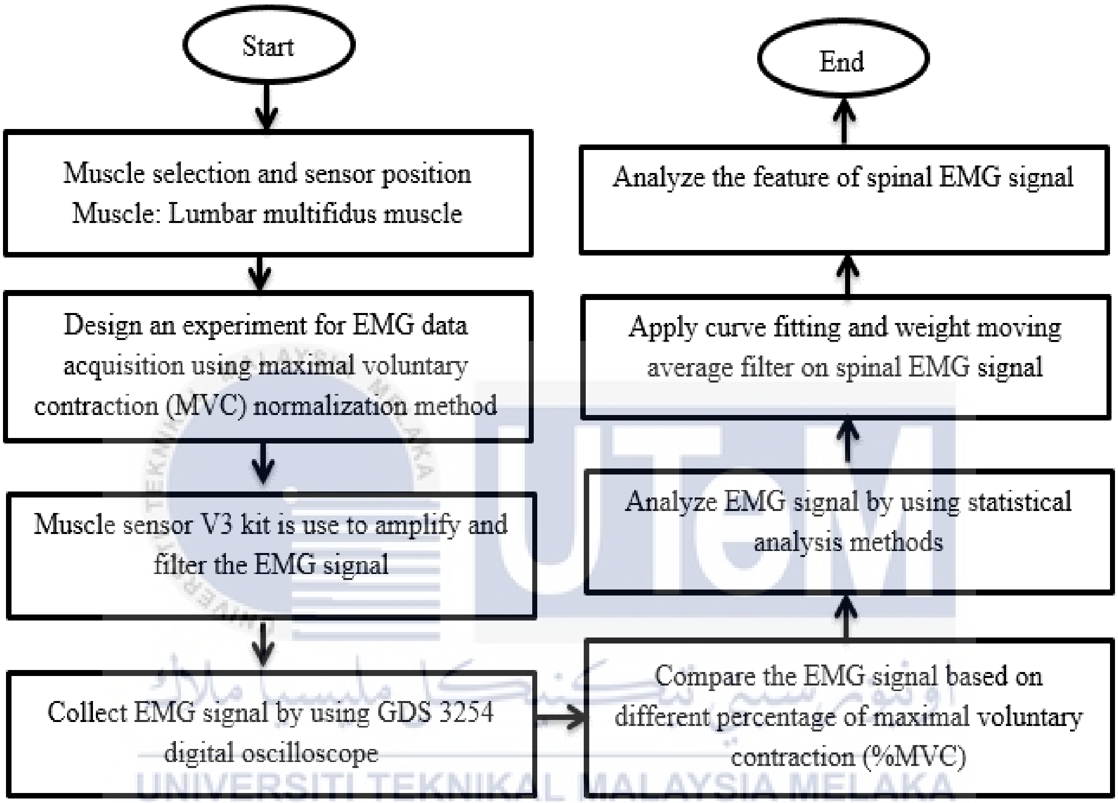

Figure 3. 1: The flowchart of methodology

3.3 Data Gathering

Data gathering is important in measuring the information on variables and determine the outcome. Fatigue is a feeble symptom and it is always happening after muscle activity. The review showed there is no relation between fatigue awareness on subjects and physiological measures of fatigability [29]. Several variables such as load, task repetition, number of tasks and trials, time to rest and type of task had to be concerned in order to achieve a good prescription in the experiment. The data are collected from the spinal muscle for evaluation. A reference is needed to overcome the problem in real muscle strength comparison since human has different muscle strength [5]. Due to this issue, percentage of maximal voluntary contractions are the best solution to represent different level of muscle contraction.

3.3.1 Maximal Voluntary Contractions (MVC)

An amplitude analysis technique applies to EMG signal is known as MVC normalization. The MVC normalization method is widely used in EMG field and it is an act of subject own free will when the muscle contract at the maximum contraction based on muscle status. Besides, it used a recording maximum root means square (RMS) value to normalize the series of EMG data [25], [30]. When there is a movement a force is produced and MVC can be used to measure the percentage ratio force applied on maximal voluntary contraction. Normalization based on MVC is useful to increase the consistency in isometric contraction. Maximal voluntary isometric contraction is a common method for extraction of reference amplitude in EMG normalization [5], [31].

Furthermore, maximal voluntary contraction (MVC) method can use to evaluate muscle function and it acts as a treatable indicator of muscle damage [32]. Improper activities result in misjudging. Activity with overload will increase the chance and risk of injury, thus result in inconsistency result.

MVC normalization method is used to measure the relative force at the beginning. Then, each subject is asked to perform a swinging motion with load based on their muscle strength which are 100%, 75%, 50%, 25%, and 0% of their maximum voluntary contraction and the trials is repeated. The normalization is completely done and stops at the moment when the muscle of subject reached maximum and could not swing the load. One minute resting period was given between trials [33].

Figure 3.2 shows the summary of the MVC normalization method. The solid box shows the process of data gathering by applying MVC while the dash box represents the data analysis process.

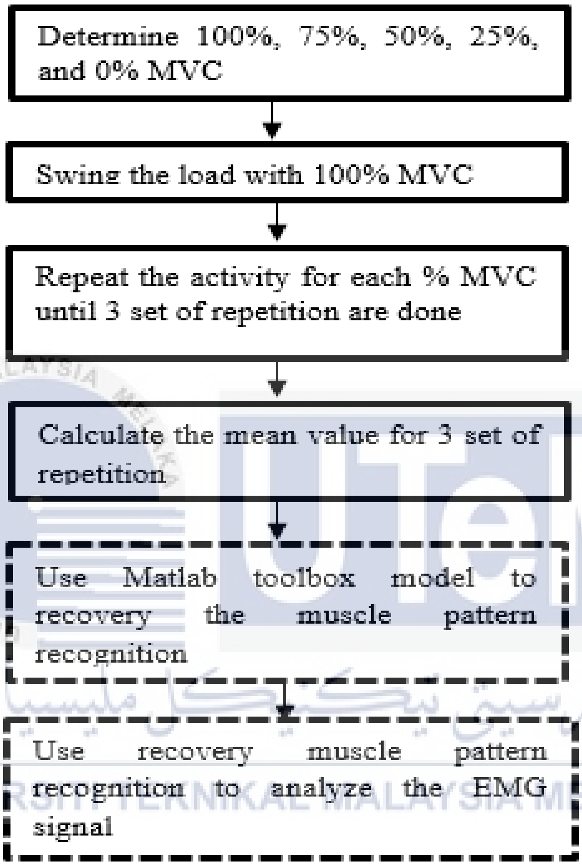

Figure 3. 2: Summarization of MVC normalization method

3.4 Experiment

First and foremost, experiments are needed in order to obtain the data required. There are five sets of experiments were done and all the experiments done in the laboratory in order to reduce the environmental noise. The experiment is using MVC normalization method. It is a method that widely used in normalizes the series of EMG data. The following section will explain in detail about the objectives of the experiment, subject, pre-experiment and experiment protocol.

3.4.1 Objective of experiment

The following are the list of objectives:

1. To record the EMG signal of spinal muscle.
2. To investigate the behavior of EMG signal on spinal muscle.
3. To investigate the characteristic of spinal EMG signal.

3.4.2 Subject

Subjects are required in the experiment and all the subjects are randomly selected. The experiment consists of 15 subjects and the genders of subjects are males. Subjects of the experiment were between 20 to 30 years old. All 15 subjects are in healthy condition and have no history of accident on their spine. All the detail of subject such as age, weight, and height were recorded.

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3.4.3 Pre-experiment

The pre-experiment is the preparation of equipment for experiment. Firstly, there will be a briefing session for the subject. The briefing will explain in detail about the experiment procedure. Next, subjects are required to fill in the consent.

After that, there is a preparation session and the subject need to follow the sequence in order to achieve high accuracy of EMG data and signal because there are a lot of factors needed to be controlled. One of the preparations is skin preparation, skin preparation procedure is important to control the signal to noise ratio (SNR) quality. Skin preparation divided into 2 sessions. First session is removing the hair of skin while second session is cleaning the skin. The purpose of removing the hair on the selected muscle skin is to increase the strength of bonding between electrodes and muscle skin and to prevent the humidity condition and sweaty skin. The next session is cleaning the skin, it consists of 3 phases. Phase 1 is removing of the dead skin cell and sweat from the skin layer by using the conductive cleaning pastes. Phase 2 is a soft cleaning process of skin by using a good quality sand paper while phase 3 is using the alcohol together with a towel and shave alcohol on the skin of subjects.

All sessions must be conducted in order to avoid harm on the skin from rubbing. All equipment is prepared and placed simultaneously to the subjects. This set-up is able to save the time and avoiding the tiredness of the subject. The skin resistance has to be measured in order to achieve high signal to noise ratio (SNR).

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Furthermore, a muscle sensor V3 kit shown in Figure 3. 3 is used to extract the EMG data of spinal muscle. In addition, it is designed to amplify and filter the EMG signal since the EMG signal has a lot of noise and data of EMG signal is inaccurate without amplify.

Figure 3. 3: Muscle sensor V3 kit

Table 3. 1: Standard experiment protocol

Parameter	Value/Type	Unit
Skin resistance	Less than 30k	Ohm (Ω)
Inter electrode distance	2	Centimeter (cm)
Size of electrode	10	Millimeter (mm)
Weight of load	20	Kilogram (kg)
Electrode material	Ag/AgCl	-
EMG sensor	Bipolar	-

Table 3. 2: Location and position of electrode

Parameter	Location/Position
Location of electrode	Lumbar multifidus muscle (Four fingers across the side of spine at waistline)
Direction of electrode	Parallel to muscle fibre
Location of the reference electrode	On spine
Starting position	Standing on the floor

3.4.4 Experiment protocol

Experiment protocol is described about the experiment setup. The experimental procedure needed to be followed in order to achieve good results. Total five sets of experiments had been conducted. The experiment is using the MVC normalization method to determine and evaluate the presence of an inconsistent issue in the experiment. After all the preparation is done, the motion lab EMG sensor and electrode is placed on the lumbar multifidus muscle. The position of the sensor and electrode are shown in Figure 3.4, positive electrodes are connected to the lumbar multifidus muscle, while negative electrode is connected to the bone.

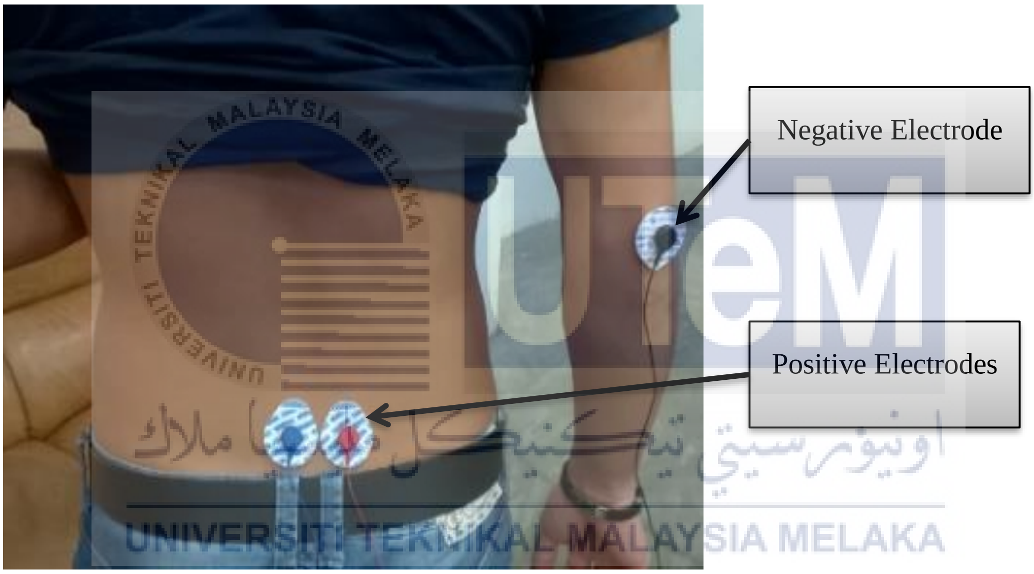

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Figure 3. 4: Location of electrodes on lumbar multifidus muscle

After putting the electrode on the lumbar multifidus muscle, the procedure followed by a connection phase. A device named as model GDS 3254 digital oscilloscope is used. The motion lab EMG sensor is connected to the muscle sensor V3 kit. This sensor is used to estimate the filtered and rectified electrical activity of a muscle. Then, it connected to the digital oscilloscope for data acquisition.

The myoelectric signal is collected by electrode from muscle and then the signal is transferred to computer via USB. After obtaining the data, the data is integrated and analyze by using Matlab. Figure 3. 5 shows the process flow of the experiment.

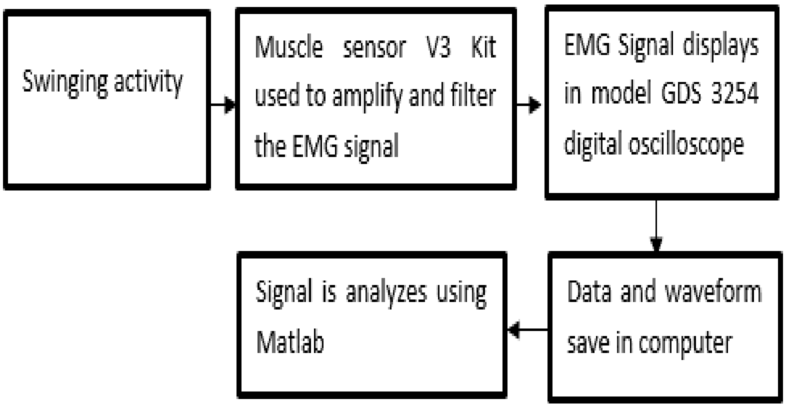

Figure 3. 5: Process flow of the experiment

By following the sequence in sub chapter 3.1, the experiment started with the maximal voluntary contraction (MVC) normalization method. This procedure is followed the experiment procedure done by Sabri [5]. All the experiment setup, task and activity must be the same in order to reduce the inconsistency issue. Even though the experiment is done in the laboratory, but there are still many inconsistency problems exist and uncontrollable. So, the statistical analysis is conducted in order to evaluate the accuracy and consistency of signal.

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Firstly, the MVC normalization method is tested on the muscle of subjects and the data are recorded. The initial of hand position was set at 90 degrees and the subject swing the load from a position of 90 degrees to 180 degrees as shown in Figure 3.6. All subjects were asked to swing the load starting from the 100% of the maximal voluntary contraction (MVC) with standing position. Two minutes resting period was given between each %MVC Test and 30 second resting period was given between each repetition.

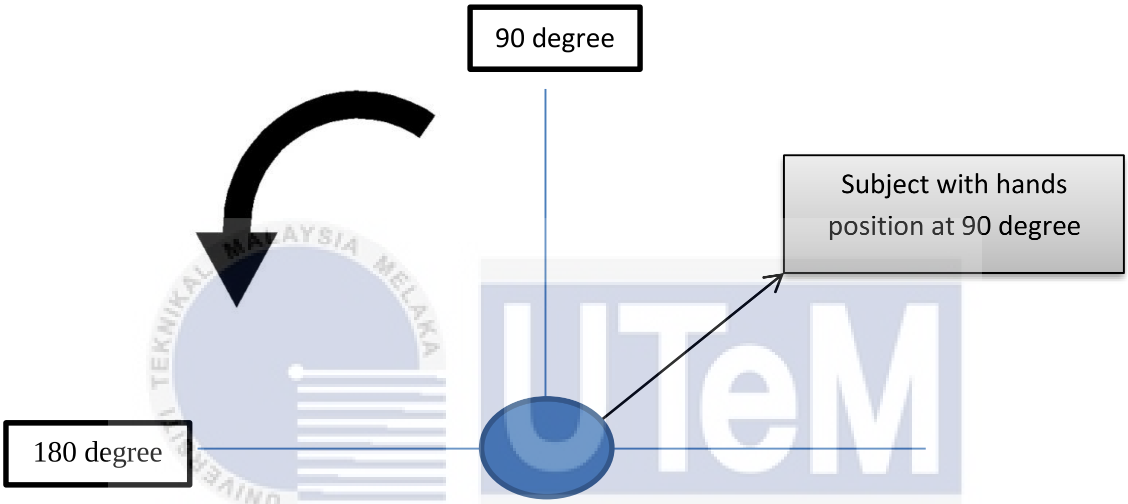

Figure 3. 6: Movement of subject in swinging phase

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3.5 Raw EMG signal

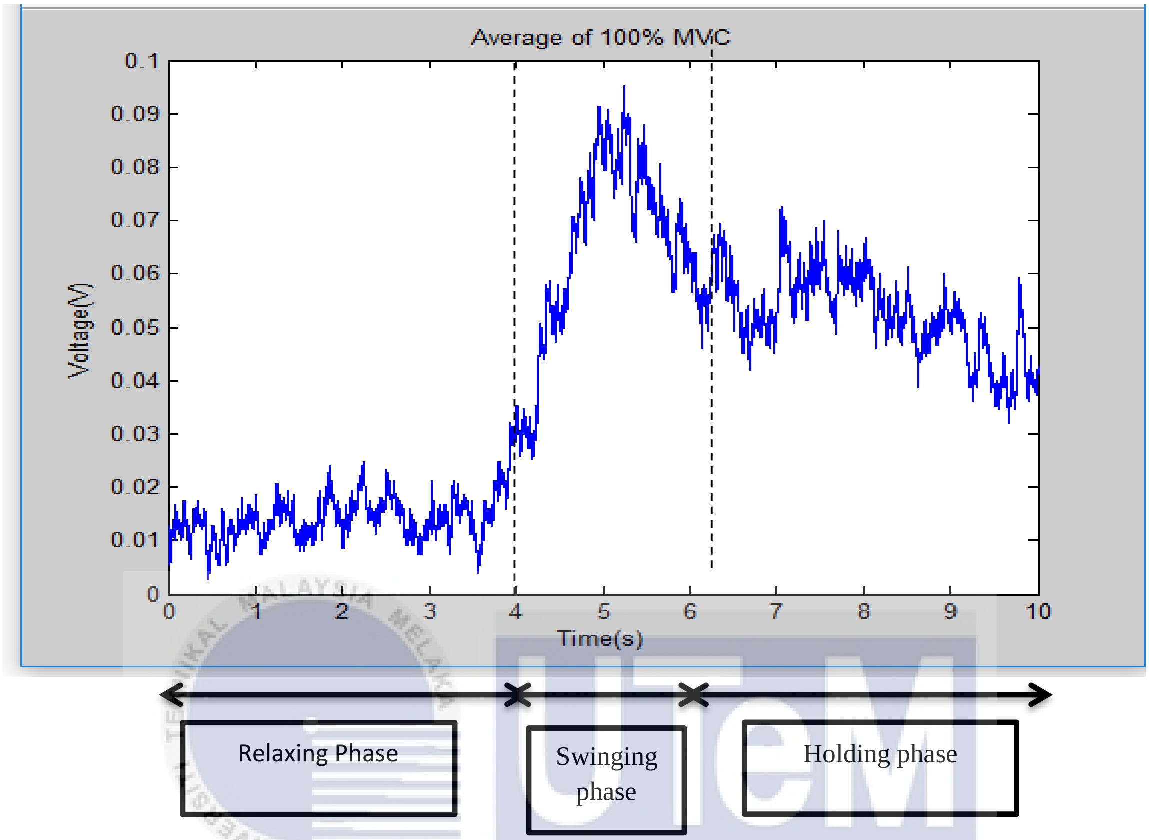

Figure 3. 7: Raw EMG signal

Figure 3. 7 shows the EMG waveform that recorded via oscilloscope in the laboratory. X-axis refers to the time in second while the y-axis refers to the normalized amplitude in volt. The experiment divides into three phases. The first phase is relaxing phase, which starts from 0 second to 4 second to observe the EMG signal when there is no muscle contraction. The second phase is swinging phase where the subject swings an object based on % MVC and it consists of nearly 2 second. Lastly, the third phase is holding phase where subject holds the position after swing an object and it is starts from 6 to 10 second.

3.6 Data Analysis

After all the EMG signal have been gathered, the signal is analysed. The analysis is based on two types of filter which are curve fitting and weight moving average filter.

3.6.1 8^{th} order Gaussian function in Curve Fitting

A curve fitting tool is used to model the pattern of muscle recovery behaviour that obtained from pre experiment to be the truth of normalization method. It performs exploratory data analysis, pre-process data, post-process data and remove outliers. The 8^{th} order Gaussian function is the best examination of all subject data, thus muscle recovery behaviour can be defined in mathematical form as:

$$f(x) = \sum_{i=1}^{n} a_i e^{-(\frac{x-b_i}{c_i})^2} \tag{3.1}$$

3.6.2 Exponential Weight Moving Average Filter

An exponential weight moving average filter is used to smooth the signal and remove unwanted line noise. The exponential weight moving average filter is similar to Gaussian expansion filter and it is applied in order to remove the unwanted noise from the signal. By applying this filter, the observer is able to see the tendency in the signal.

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3.7 Statistical Analysis

This section discusses about the data and signal analysis of the EMG signal. Data obtained from actions and activity which the electromyograms (EMG) were recorded by using the EMG sensors. The statistical analysis methods had been applied to analyse muscle activation and they are good in indicate muscular activities.

Statistical analysis consists of three methods and these methods are showing good results in previous work done. The statistical methods are one-way ANOVA analysis, root mean square (RMS) analysis and boxplot analysis.

3.7.1 One-way ANOVA Analysis

One-way ANOVA method is used to analyze and determine the effect of the EMG signal on the classification performance of lumbar multifidus muscles [34]. Besides, it can be used to test the feature in order to observe the characteristic of each feature between different classes [35]. One-way ANOVA analysis integrated normalized EMG activities of lumbar multifidus muscle for each respective phase [2]. Some assumptions are making and taking into consideration. An assumption state that:

Null hypothesis, H_o: $\mu_1 = \mu_2 = \mu_3 = \cdots = \mu_k$

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In this work, one-way ANOVA analysis was used to compare the means and variance between 15 subjects in MVC normalization method. A signal that achieves a common mean of $p > 0.05$ and it means there are no significant differences between all subjects. On the other hand, when the significant level $p < 0.05$, the mean value for 15 subjects are not all the same. The null hypothesis is rejected. Therefore, the tests are known as significant when the variance of tests is small as compared to the variance between subjects [5], [36].

In one-way ANOVA analysis, the ANOVA table is needed in testing the population mean. There are many sources of variable such as DF, SS, MS, F and P. DF refer to the degree of freedom among the sources, SS means the sum of square, MS is the mean sum of square, F-statistic is the ratio of the mean squares and P-value represents the probability that the F-statistical value greater than computed test statistical value. Table 3. 3 shows the sample of the ANOVA table for data calculation.

Table 3. 3: Sample of ANOVA table

Source	SS	df	MS	F	*p*-value
Group (Between)	SSR	$k-1$	MSR = SSR/($k-1$)	MSR/MSE	$P(F_{k-1,N-k}) > F$
Error (Within)	SSE	$N-k$	MSE = SSE/($N-k$)		
Total	SST	$N-1$			

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3.7.2 Root mean square (RMS) analysis

In order to identify the performance of EMG signal pattern recognition, the analysis on the root mean square (RMS) value for the % MVC test is done. When swinging an object, the RMS value of the EMG signal is used to obtain the data of percentage of maximal voluntary contraction (% MVC). Generally, the parameter of RMS is mostly applied in the scientific fields. RMS value shows a better response in the levels of muscle activity during muscle contraction.

3.7.3 Boxplot analysis

Boxplot shows the graphical layout and it consist the basic of five values which are the minimum value and maximum value in the dataset, lower hinge (first quartile), upper hinge (third quartile) and median. Boxplot used in illustration of small data sets. Besides, boxplot further enable summarization of outliers and determination of trimmed mean value. An extreme observation can significantly affect the data measured in a larger data set [37].

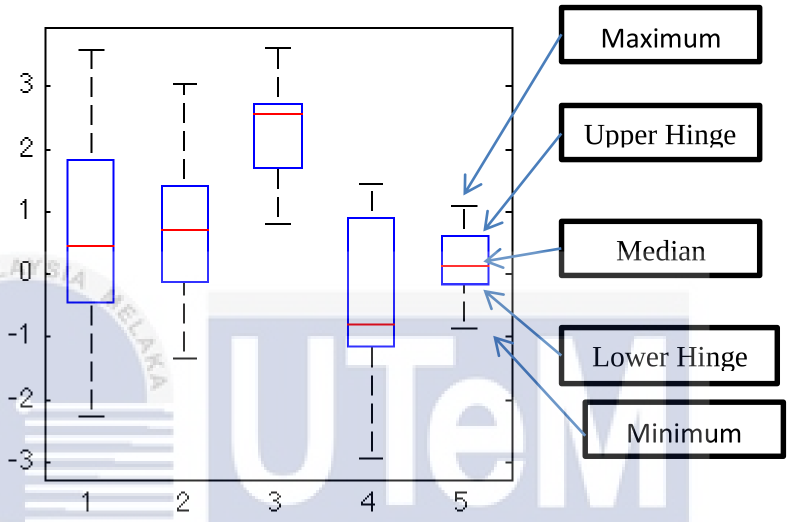

Figure 3. 8: Sample of boxplot graph

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The objective of boxplot is to investigate the distribution of data. In the boxplot graph, there are two axes which are x-axis and y-axis. By applying boxplot analysis into EMG, the y-axis represents the normalization EMG signal amplitude while the x-axis demonstrates the numbers of subject. The red line that divided the box into two parts represents the middle quartile (median) which illustrates the value of midpoint for normalized amplitude of the EMG signal.

3.8 Analyse the effect of fat layer thickness on spinal EMG signal

The fat layer thickness is one of the factors that affect the strength of the EMG signal. From the research, it state that an increase in the fat layer thickness reduces the normalized amplitude [38]. The investigation of the effect of fat layer thickness on spinal EMG signal is done by applying boxplot analysis. The boxplot analysis is used to analyse and determine the effect of fat layer thickness on spinal EMG signal among 15 subjects. The body mass index (BMI) is a good indicator in measure how much fat the subject carry. It is not a perfect measure, but it considered as a fairly accurate measurement [39]. It can be express as:

$$BMI = \frac{x}{y^2} \tag{3.2}$$

Where x represented the bodyweight in kilogram and y stand for the height in meter

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Table 3. 4: BMI Table WHO

BMI (kg/m^2)	**World Health Organization (WHO) Classification**
Less than 18.50	Underweight
18.50 – 24.99	Normal
25.00 – 29.99	Overweight
30.00 – 34.99	Obesity class I
35.00 – 39.99	Obesity class II
40.00 and above	Obesity class III

3.9 Conclusion

There is one method proposed which is MVC normalization method. This chapter explains in detail the theory of MVC method and how it worked. The normalization method based on MVC determines the percentage of maximal voluntary contraction (%MVC) for the entire subject and carry out with an experiment. Besides, this chapter discusses the data analysis and statistical analysis used to analyze the EMG signal and data. In data analysis, 8^{th} order Gaussian function in Curve Fitting and Exponential Weight Moving Average Filter are applied to filter the spinal EMG signal. Statistical analysis which are boxplot analysis, one-way ANOVA analysis and root mean square (RMS) analysis are used to validate the MVC normalization and evaluate the EMG signal. In addition, another boxplot analysis is used to analyze the effect of fat layer thickness on spinal EMG signal among 15 subjects. Lastly, the result of the experiment, analysis and discussion will be discussed in the following chapter, CHAPTER 4.

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CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter discusses the result of data collected from the MVC experiments and it will mainly focus on the analysis of 0%, 25%, 50%, 75% and 100% MVC test. Firstly, the discussion starts with the raw EMG signal and followed by the comparison of different %MVC test. Besides, there is a detailed discussion in swinging phase for different %MVC test. Moreover, the statistical analysis methods which are one-way ANOVA analysis, root mean square (RMS) analysis and boxplot analysis are done. In addition, the 8^{th} order Gaussian function in curve fitting and Exponential weight moving average filter is also done in boxplot analysis. Lastly, another boxplot analysis is done on 15 subjects to investigate the effect of fat layer thickness on spinal EMG signal. The data collected were analyzed and evaluated by using Matlab and the result of the statistical analysis is discussed.

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4.2 Comparison between 0%, 25%, 50%, 75% and 100% MVC

As shown in Figure 4.1– 4.5, there are five graphs which illustrate the average of 0%, 25%, 50%, 75% and 100% MVC test. The graph of the average of 0 % MVC in Figure 4.1 shows the lowest maximum normalized amplitude which is -25.75mV while the graph of average of 100% MVC in Figure 4.5 shows the highest maximum normalized amplitude which is 667mV.

From 0 to 4 second, graphs in Figure 4.1-4.5 show that the normalized amplitude of the spinal EMG signals is low. It states that at relaxing position, the body is relaxed and there is less muscle contraction in lumbar multifidus muscle. In relaxing phase, the normalized amplitude of the spinal EMG signal is increased when the percentage of MVC increased. It indicates that the muscle contraction is increased when the weight of the object is increasing even though there is no swinging motion. From 4 to 6 second, there is a swinging motion and the graphs in Figure 4.1-4.5 show a huge increase in normalized amplitude. From 6 to 10 second, there is a holding position, the graphs in Figure 4.1-4.5 show that the normalized amplitude started to decrease and become unstable.

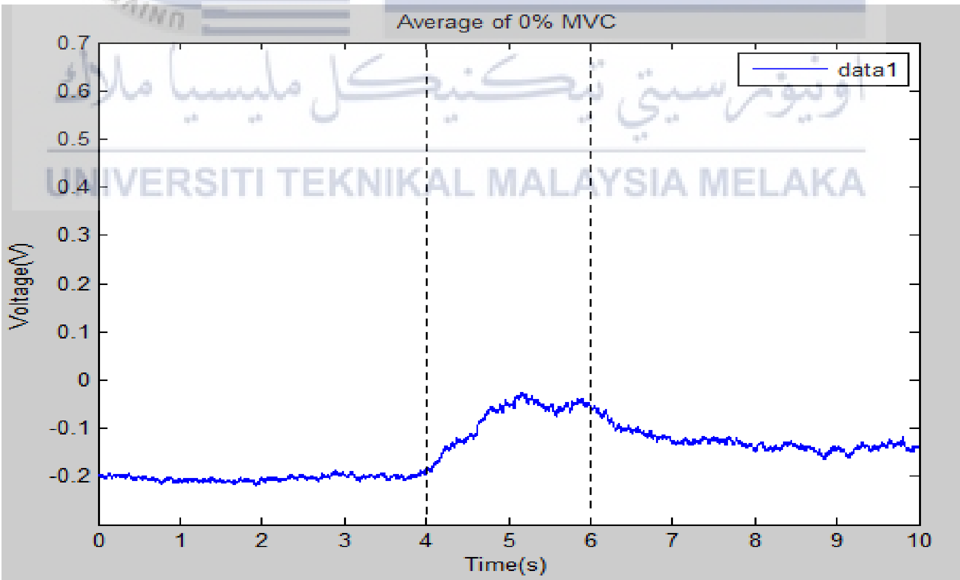

Figure 4. 1: Graph of average 0% MVC

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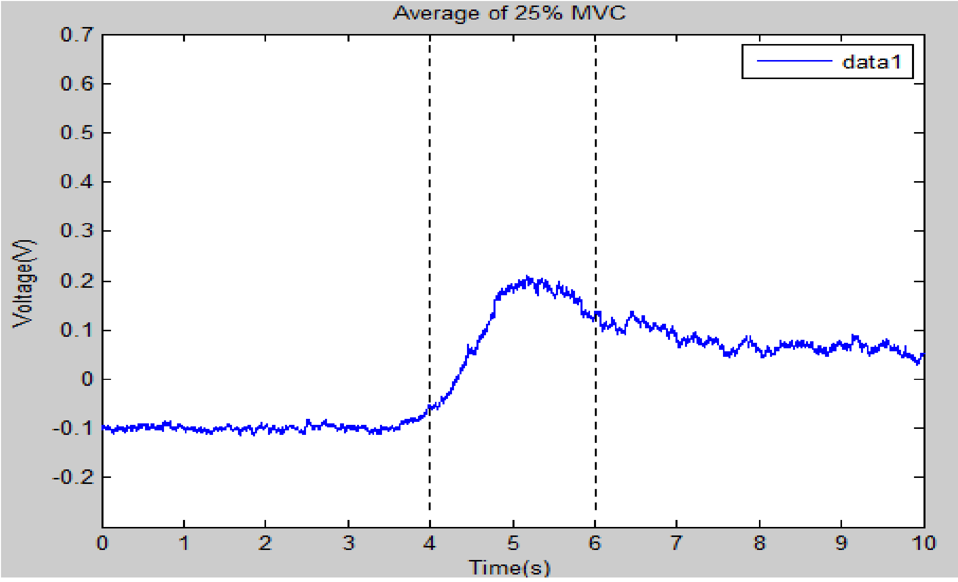

Figure 4. 2: Graph of average 25% MVC

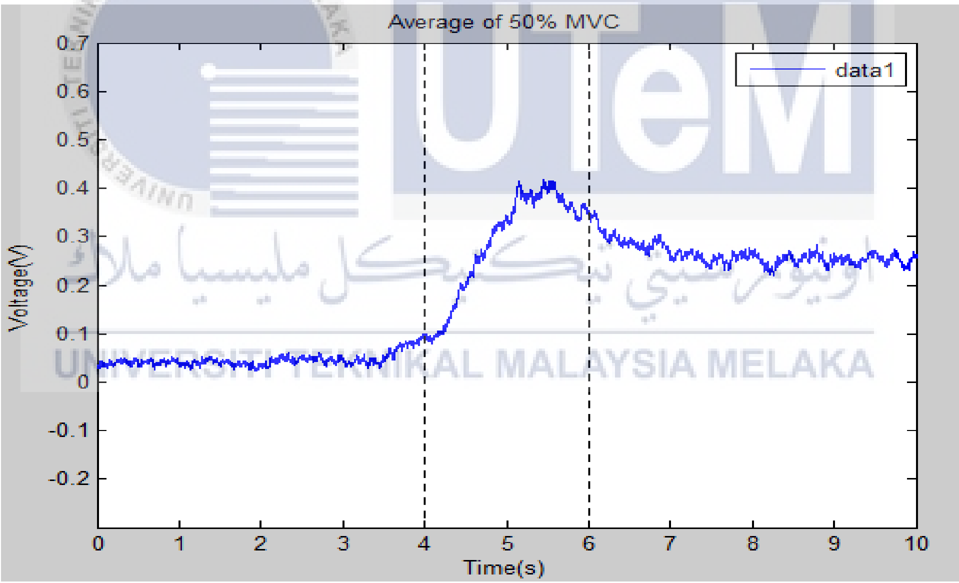

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Figure 4. 3: Graph of average 50% MVC

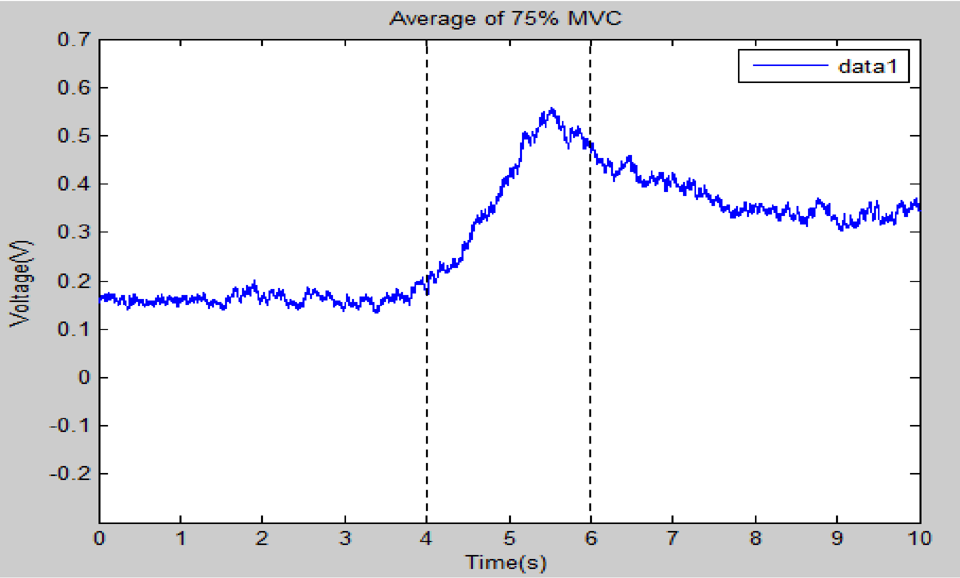

Figure 4. 4: Graph of average 75% MVC

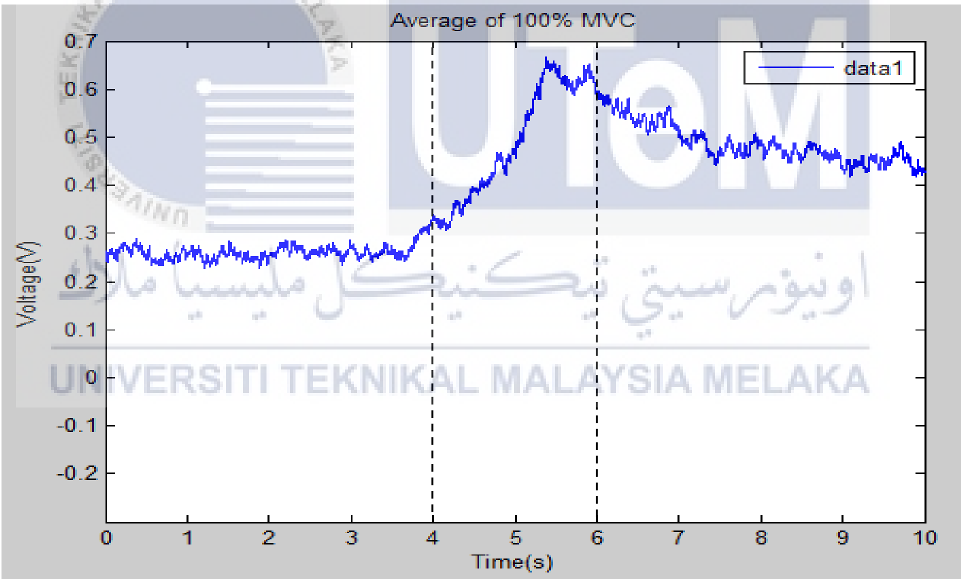

Figure 4. 5: Graph of average 100% MVC

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4.3 Comparison of %MVC in swinging phase

Figure 4.6 shows the average result of 0%, 25%, 50%, 75% and 100% of MVC test among 15 subjects in swinging phase. The result shows that the higher percentage of MVC resulted in greater normalized amplitude of the spinal EMG signal. It also shows that the greater the load, the greater the muscle contraction. Thus, more myoelectric is generated by the muscle.

At 0% and 25% MVC, the normalized amplitude is falling below 0V. This is due to the greater distance between positive and negative electrodes. However, this setup was consistently used for others %MVC where it will not affect the recognition process.

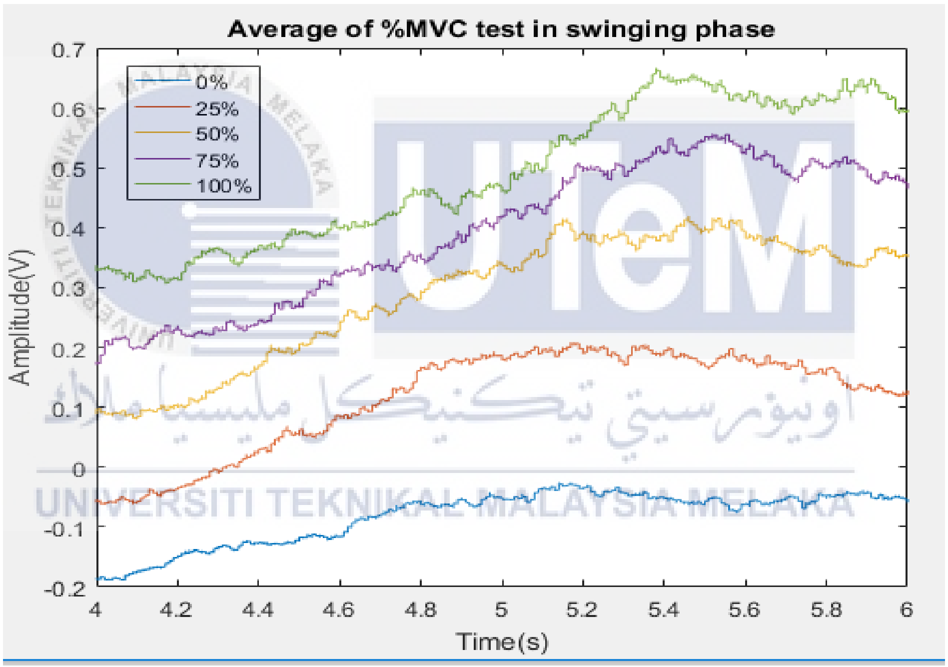

Figure 4. 6: Average of % MVC in swinging phase

4.4 One-way ANOVA analysis

The one-way ANOVA analysis is done in swinging phase of the average of %MVC. In One-way ANOVA analysis, the significant level set $p < 0.05$ for all the data and allocate variance to different trials. The one-way ANOVA analysis for 100% MVC in swinging phase is shown in table 4.1, the p value is 2.79721e-254 which is less than 0.05. The results are same for another 0%, 25%, 50%, and 75% MVC, the p-values are less than 0.05 as shown in Table 4.2, Table 4.3, Table 4.4 and Table 4.5. The results show that the differences between mean and variance are statistically significant. In addition, it states that the mean and variance from all the 15 subjects are not all same. The null hypothesis, H_o state in the method section is rejected and the difference between the means are great enough for the researcher to exclude sampling error explanation. This difference was due to subject body condition that difficult to control. From this analysis, it shows that direct recognition was not possible due to each subject produce a different EMG signal at same %MVC.

Table 4. 1: One-way ANOVA analysis for 100% MVC

ANOVA Table

Source	SS	df	MS	F	Prob>F
Columns	162.14	14	11.5814	276.26	2.79721e-254
Error	25.782	615	0.0419		
Total	187.921	629			

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Table 4. 2: One-way ANOVA analysis for 75% MVC

ANOVA Table

Source	SS	df	MS	F	Prob>F
Columns	149.614	14	10.6867	320.98	1.09105e-271
Error	20.476	615	0.0333		
Total	170.089	629			

Table 4. 3: One-way ANOVA analysis for 50% MVC

ANOVA Table

Source	SS	df	MS	F	Prob>F
Columns	133.347	14	9.52477	344.55	5.04745e-280
Error	17.001	615	0.02764		
Total	150.348	629			

Table 4. 4: One-way ANOVA analysis for 25% MVC

ANOVA Table

Source	SS	df	MS	F	Prob>F
Columns	104.223	14	7.44451	313.28	7.5625e-269
Error	14.614	615	0.02376		
Total	118.837	629			

Table 4. 5: One-way ANOVA analysis for 0% MVC

ANOVA Table

Source	SS	df	MS	F	Prob>F
Columns	55.3596	14	3.95426	426.17	1.95641e-305
Error	5.7064	615	0.00928		
Total	61.0659	629			

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4.5 Root mean square (RMS) analysis

The RMS analysis is done in swinging phase of the average of %MVC. The results with calculation of RMS value are tabulated in Table 4.6. The RMS is calculated to provide the most insight on the amplitude of the EMG signal. Table 4.6 shows that the higher the %MVC, the higher the RMS value. As the results, RMS value of % MVC indicates that the muscle activity is increased when the muscle contraction, or indirectly the load is increased.

Table 4. 6: RMS and Mean results for average of %MVC

	0% MVC	**25% MVC**	**50% MVC**	**75% MVC**	**100% MVC**
Mean (mV)	-82.27	115.1	288.3	393.1	492
RMS (mV)	**93.6**	**142.8**	**307.2**	**410.4**	**505.7**

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4.6 Boxplot analysis

All the boxplot analysis is done in swinging phase for each average of %MVC. The 8^{th} order Gaussian function in curve fitting and exponential weight moving average filter are done for the analysis of data in boxplot analysis.

Figure 4.7 shows the boxplot analysis of 0%, 25%, 50%, 75% and 100% MVC. X-axis refers to different %MVC while the y-axis refers to the normalized amplitude of the EMG signal. There are five boxes are shown and the red line in the box represents the median for each %MVC. Besides, the boxes show the maximum and minimum normalized amplitude for each %MVC. In Table 4.7, 100% MVC has the highest median, interquartile range and maximum normalized amplitude compared to others. As the result, it shows that higher %MVC result in greater median.

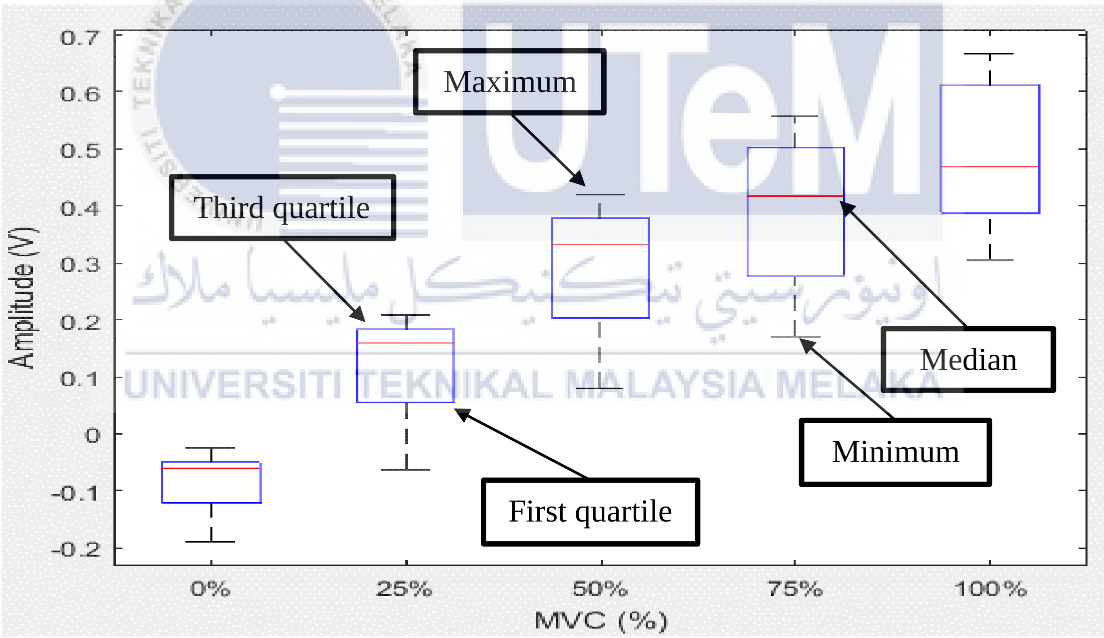

Figure 4. 7: Boxplot analysis of % MVC

Interquartile range (IQR) is the difference between first quartile and third quartile of the box. The average median difference from 0% until 100% MVC is 132.72075mV while the average IQR different from 0% until 100% MVC is 38.5925mV. At 0% MVC, IQR is the smallest among %MVC so it has the highest consistency. The maximum amplitude in boxplot analysis is 667.02mV. The value of each feature was stated in Table 4.7 and Table 4.8.

Table 4. 7: Result of boxplot analysis

MVC (%)	**Median (mV)**	**IQR (mV)**	**Maximum Amplitude (mV)**
0	-60.953	71.03	-25.753
25	157.91	128.025	208.82
50	331.42	175.26	419.29
75	417.03	225.67	556.91
100	469.93	225.94	**667.02**

Table 4. 8: Average median and IQR difference in boxplot analysis

MVC (%)	**Median difference (mV)**	**IQR difference (mV)**
0-25	218.863	56.995
25-50	173.51	47.235
50-75	85.61	50.41
75-100	52.9	-0.27
Total	530.883	154.37
Average	**132.72075**	**38.5925**

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4.6.1 8^{th} order Gaussian function in curve fitting

Figure 4.8 shows the boxplot analysis after applying the curve fitting with the 8^{th} order Gaussian function for 0%, 25%, 50%, 75% and 100% MVC test. The average median difference from 0% until 100% MVC is 133.20475mV while the average IQR difference from 0% until 100% MVC is 37.645mV. The maximum amplitude in boxplot analysis is 653.6mV. The value of each feature was stated in Table 4.9 and Table 4.10.

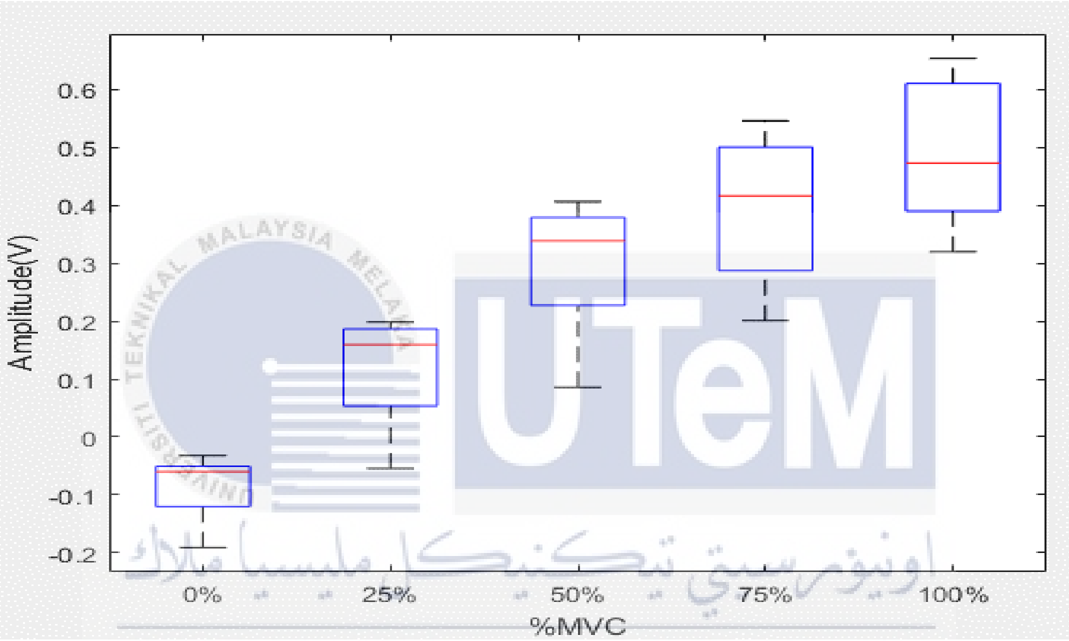

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Figure 4. 8: Boxplot analysis of % MVC (8^{th} order Gaussian function)

Table 4. 9: Result of boxplot analysis (8^{th} order Gaussian function)

MVC (%)	Median (mV)	IQR (mV)	Maximum Amplitude (mV)
0	-60.069	69.78	-31.941
25	159.28	133.187	198.16
50	338.64	151.35	406.18
75	416.09	213.06	546.01
100	472.75	220.36	**653.6**

Table 4. 10: Average median and IQR difference ($\mathbf{8^{th}}$ order Gaussian function)

MVC (%)	Median difference (mV)	IQR difference (mV)
0-25	219.349	63.407
25-50	179.36	18.163
50-75	77.45	61.71
75-100	56.66	7.3
Total	532.819	150.58
Average	**133.20475**	**37.645**

4.6.2 Exponential weight moving average filter

Figure 4.9 shows the boxplot analysis after applying the exponential weight average filter for 0%, 25%, 50%, 75% and 100% MVC test. The average median difference from 0% until 100% MVC is 40.21425mV while the average IQR difference from 0% until 100% MVC is 124.118475mV. The maximum amplitude in boxplot analysis is 743.79mV. The value of each feature was stated in Table 4.11 and Table 4.12.

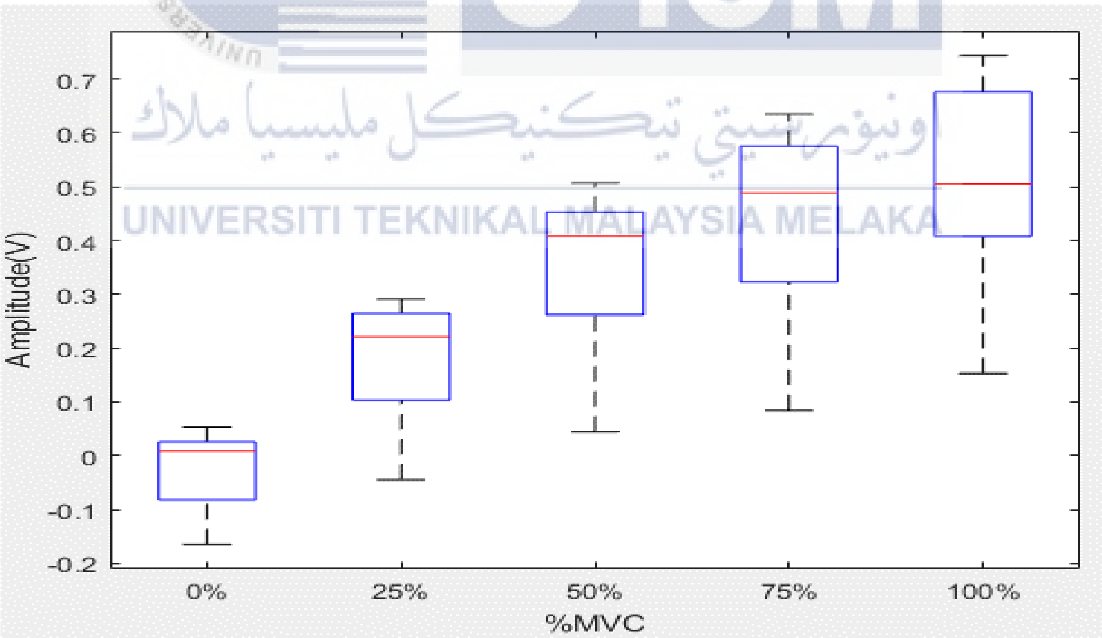

Figure 4. 9: Boxplot analysis of % MVC (Exponential weight moving average filter)

Table 4. 11: Result of boxplot analysis (Exponential weight moving average filter)

MVC (%)	Median (mV)	IQR (mV)	Maximum Amplitude (mV)
0	8.5461	107.693	53.292
25	220.51	161.21	291.18
50	408.55	190.7	506.96
75	488.15	251.8	634.75
100	505.02	268.55	**743.79**

Table 4. 12: Average median and IQR difference (Exponential weight moving average filter)

MVC (%)	Median difference (mV)	IQR difference (mV)
0-25	211.9639	53.517
25-50	188.04	29.49
50-75	79.6	61.1
75-100	16.87	16.75
Total	496.4739	160.857
Average	**124.118475**	**40.21425**

Table 4.13 shows the standard deviation for median and IQR difference from 0% until 100% MVC in boxplot analysis. Standard deviation is used to quantify the amount of variation of a set of data values in statistical analysis. Based on the result, median and IQR difference show a low standard deviation. Moreover, IQR difference shows the lowest standard deviation. The results indicate the median and IQR difference illustrate high concentrated of data since the data point are close to the mean.

Table 4. 13: Result of standard deviation

SD / Boxplot	σ (median difference)	σ (IQR difference)
Original	0.066474	0.022712
8th order Gaussian function in Curve fitting	0.068042	0.025215
Exponential weight moving average filter	0.079509	0.017880

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From the boxplot analysis, the median did not lie at half of the first quartile and the third quartile. Therefore, the distribution is not symmetrical. IQR is a more appropriate measure of variability than standard deviation if the data is not symmetrical [40]. Higher %MVC results in greater median and IQR. The larger the IQR, the data set is more variable while the smaller the IQR, the data has higher consistency.

For the average IQR difference from 0% until 100%, the EMG signal undergo 8^{th} order Gaussian function in curve fitting is the smallest, 37.645mV while the signal undergo exponential weight moving average filter is the highest, 40.21425mV. It shows that the EMG signal undergo exponential weight moving average filter has a lower consistency of data, but more variable the data set is.

The EMG signal undergo Exponential weight moving average filter has the greatest maximum amplitude, 743.79mV among three different boxplot analysis. Besides, EMG signal undergo 8^{th} order Gaussian function in curve fitting has the greatest average median difference from 0% until 100% MVC which is 133.20475mV while EMG signal undergo exponential weight moving average filter has the smallest average median difference which is 124.118475mV. Based on results, median shows the greatest increment from 0% until 100% MVC as compare to IQR. Thus, median is the best feature in boxplot analysis to shows the difference in increment of %MVC. Furthermore, 8^{th} order Gaussian function in curve fitting produce more identical and consistent data after go through boxplot analysis.

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Lastly, the increment of the median and IQR for each percentage of MVC is getting smaller from 0% to 100% MVC in the boxplot analysis. Based on the standard deviation of the median and IQR difference, it shows that in order to determine an accurate percentage of MVC when swinging an object, multiple reference is needed.

4.7 Analyse the effect of fat layer thickness on spinal EMG signal

The analysis is done in swinging phase. Figure 4.10 shows the boxplot analysis of 100% MVC for 15 subjects and the analysis is done to determine the effect of fat layer thickness on spinal EMG signal. Firstly, the 100% MVC is selected for this analysis because the highest percentage of MVC shows the maximum performance of muscle contraction. The median is selected as the best feature for this analysis due to the previous result of boxplot analysis.

Table 4.14 shows the value of the median for each subject with their BMI and body statement. In Table 4.14, subject 3, 5 and 8 are considered as overweight due to the BMI greater than 24.99, thus their fat layer is thicker than others. Figure 4.10 shows that subject 3, 5 and 8 result in lower normalized amplitude due to thicker fat layer. It shows that the thicker fat layer reduces the strength of spinal EMG signal. Due to the thicker fat layer surround the muscle, the signal received from the muscle getting weaker. In addition, the outliers in Figure 4.10 shows that the data is too far away from the central value and they are known as bad data point which can be eliminated after consideration.

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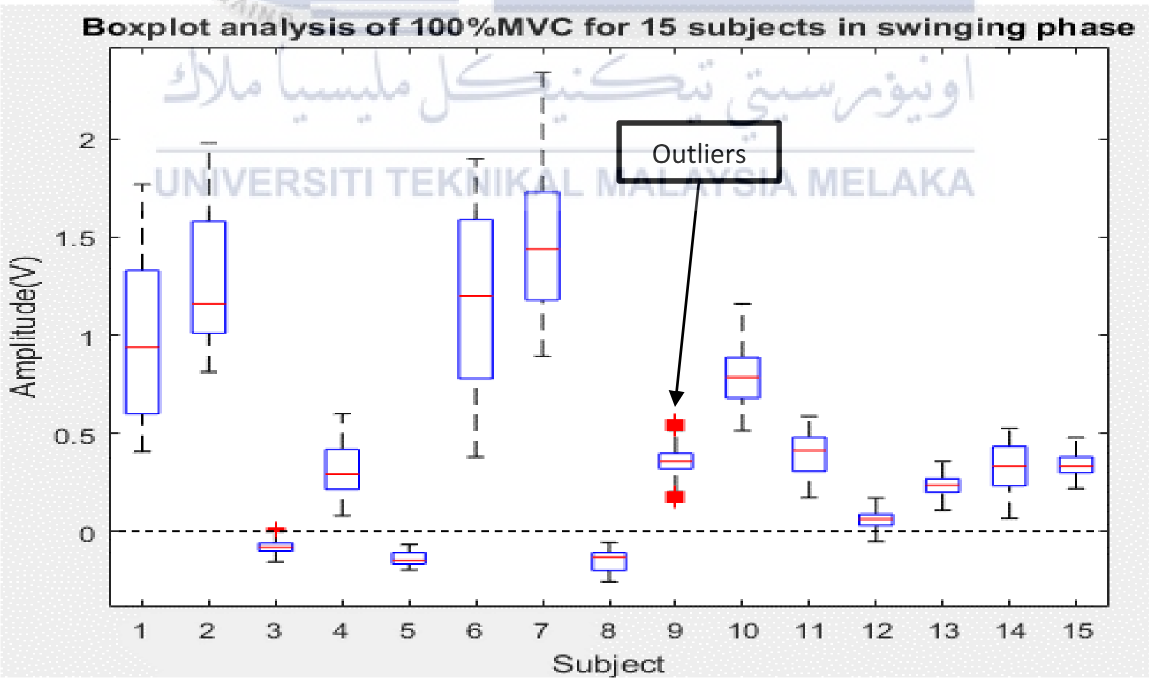

Figure 4. 10: Boxplot analysis of 100% MVC for 15 subjects (Swinging phase)

Table 4. 14: Subjects information and median value for 100%MVC (Swinging phase)

Subject	Median (V)	Height (cm)	Weight (kg)	BMI (kg/m^2)	Body statement
1	0.94	180	60	18.5	Normal
2	1.16	164	57	21.2	Normal
3	**-0.08**	**171**	**73**	**25**	**Overweight**
4	0.293	168	48	17	Underweight
5	**-0.147**	**170**	**93**	**32.2**	**Obesity class I**
6	1.2	175	70	22.9	Normal
7	1.44	183	55	16.4	Underweight
8	**-0.131**	**170**	**74**	**25.6**	**Overweight**
9	0.357	174	65	21.5	Normal
10	0.787	164	60	22.3	Normal
11	0.413	167	50	17.9	Underweight
12	0.064	166	68	24.7	Normal
13	0.237	173	65	21.7	Normal
14	0.333	170	74	24.7	Normal
15	0.333	173	65	22	Normal

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4.8 Conclusion

In this chapter, it explains the differences between 0%, 25%. 50%, 75% and 100% MVC test. The results showed that the normalized amplitude has a huge increase when perform a swinging motion for each %MVC test. In swinging phase, it shows that the increment of the percentage of MVC increases the normalized amplitude of the spinal EMG signal. It also shows that the greater the load, the greater the muscle contraction. Thus, more myoelectric is generated by the muscle.

Furthermore, the one-way ANOVA analysis shows that the mean from the 15 subjects are not the same, thus the MVC normalization method is considered as a good method for analyses the spinal EMG signal. From this analysis, it shows that direct recognition was not possible due to each subject produce different EMG signal at same %MVC. RMS analysis indicated that the muscle activity is increased when the muscle contraction is increased. The boxplot analysis for original signal, signal undergo the 8^{th} order Gaussian function in curve fitting and signal undergo Exponential weight average filter show that the higher the percentage of MVC, the greater the maximum amplitude, IQR and median. EMG signal undergo 8^{th} order Gaussian function shows the greatest average median difference from 0% until 100% MVC. As the result, 8^{th} order Gaussian function produces more identical and consistent data after go through boxplot analysis. Besides, median shows the greatest increment from 0% until 100% MVC as compare to IQR in boxplot analysis. The results show that the median is the best feature to use as recognition for each %MVC. Moreover, the subject with BMI greater than 24.99 which is known as an overweight result in negative normalized amplitude for 100% MVC. It was due to the thicker fat layer affect the strength of the signal received from the muscle. Lastly, the conclusion will be discussed in CHAPTER 5.

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CHAPTER 5

CONCLUSION

5.1 Conclusion

First and foremost, research and literature review are done in collecting the information and understanding of EMG. The information, feature, benefit, experiment and analysis of EMG signal are studied throughout the research. Moreover, research on the spinal muscle for muscle selection is done and lastly the lumbar multifidus muscle was selected. Lumbar multifidus muscle is selected because it is a small and powerful muscle, which related to upper limb movement and provide support to the spine.

There are two objectives stated and they have been analyzed and determined by using the method described in this thesis. Maximal voluntary contraction (MVC) normalization method is used for carry out the experiment. The experiment is divided into subject, pre-experiment and experiment protocol. The data is collected based on 0%, 25%, 50%, 75% and 100% MVC test. The results show that the normalized amplitude has a huge increase when perform a swinging motion for each %MVC. Besides, it shows that the increment of the percentage of MVC increases the normalized amplitude of the spinal EMG signal when swing an object. As the result, the greater the load, the greater the muscle contraction. Thus, more myoelectric is generated by the muscle.

The objective is achieved by proposing one-way ANOVA analysis, root mean square (RMS) analysis and boxplot analysis. All the statistical analysis focuses on the swinging phase of the average of %MVC. The one-way ANOVA analysis shows that the mean and variance from the 15 subjects are not the same and the difference between the means are great enough for the researcher to exclude sampling error explanation. From this analysis, it shows that direct recognition was not possible due to each subject produce a different EMG signal at same %MVC and MVC normalization is good method. Moreover, RMS analysis indicated the muscle activity is increased when the muscle contraction is

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increased. In addition, boxplot analysis analyses the feature of the spinal EMG signal which is median, interquartile range, maximum and minimum normalized amplitude for each %MVC test. The 100% MVC has the highest median, IQR and maximum normalized amplitude compared to others. As the result, it shows that higher %MVC result in greater median, IQR and maximum normalized amplitude.

The 8^{th} order Gaussian function in curve fitting and Exponential weight average filter are applied in boxplot analysis. The boxplot analysis for original signal, signal undergo the 8^{th} order Gaussian function and signal undergo exponential weight average filter show that the higher the percentage of MVC, the greater the maximum amplitude, IQR and median. Spinal EMG signal undergo 8^{th} order Gaussian function shows the greatest average median and lowest IQR difference from 0% until 100% MVC. As the result, the 8^{th} order Gaussian function produces more identical and consistent data after go through boxplot analysis. Besides, median shows the greatest increment from 0% until 100% MVC as compare to IQR in boxplot analysis. The result shows that the median is the best feature to use as recognition for each %MVC. Lastly, the investigation on the effect of fat layer thickness on spinal EMG signal is done in boxplot analysis. The result shows that the subject with a thicker fat layer affect the strength of the signal received from the muscle.

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5.2 Recommendation

As future work, the number of subjects will increase in order to make further analysis on the effect of multi-layer of skin and fat tissue on spinal EMG signal. This analysis will provide a great support and improve the strength of EMG signal based on the different level of skin layers and fat tissue of the subject.

Furthermore, the development of exoskeleton software in analysis of EMG signal will improve the accuracy and consistency of exoskeleton. It will ensure the performance of exoskeleton in the rehabilitation process.

Future works will focus on the implementation of the median as a recognise signal to identify unknown spinal EMG signal when performing the swinging motion. Percentage of accuracy will be measured to identify the performance before further implementation made. Lastly, the combination of recognition, identification, will be implemented for the development of rehabilitation and assistive robotics.

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APPENDIX

APPENDIX A - EXPERIMENT PROTOCOL

FACULTY OF ELECTRICAL ENGINEERING

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016/2017

BEKU 4894

RESEARCH METHODOLOGY

EXPERIMENT OF ANALYSIS OF SPINAL EMG SIGNAL WHEN SWINGING AN OBJECT

TASK	NAME	DATE	SIGNATURE
PREPARED BY	TOO JING WEI		
CONFIRMED BY	MOHD BAZLI BIN BAHAR		

Title:

Analysis of spinal EMG signal when swinging an object

Objective:

1. To record the EMG signal of spinal muscle.
2. To investigate the behavior of EMG signal on spinal muscle.
3. To investigate the characteristic of EMG signal.

Scope:

All the experiment must be conducted in the laboratory and the experiment only focus on lumbar multifidus muscle. The control method focuses on swinging.

Subject Standard

1. Male
2. No injury on spinal and hands
3. 20 to 30 years' old
4. Random selected

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List of Equipment

1. Model 5352DC digital oscilloscope
2. Stop watch
3. 20 kg dumbbell
4. Measurement tape
5. Two channel of motion lab stainless electrode with gain 300
6. Meter ruler

List of Materials

1. Alcohol prep pad
2. Adhesive tape

Pre Experiment

1. Firstly, there is a briefing session explains about the detail of experiment to all the subjects.
2. All subjects are required to fill up the consent form if they agree with the experiment conducted.
3. Next, there is a demonstration of experiment procedure in order to improve the understanding of subjects.
4. After that, subjects are necessary to undertake the skin preparation.
5. Lastly, a multi-meter is used to measure the skin resistance and make sure the resistance of skin region is less than 30kΩ.

Skin preparation procedure

Skin preparation has 2 sessions which are removing of the hair on skin and cleaning of skin. The skin preparation is started with the removing of hair on the skin around the lumbar multifidus muscle in order to avoid humid condition and sweaty skin. Next, the cleaning of skin has three phases which are phase 1, phase 2 and phase 3 and all the phases must be conducted.

Phase 1:
Remove the dead skin cell and sweat from the skin layer by using the conductive cleaning pastes.

Phase 2:
Use a good quality sand paper and perform a soft cleaning process on skin.

Phase 3:
Use the alcohol together with a towel and shave the alcohol on the skin of subject.

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Experiment Procedure: Maximal Voluntary Contraction (MVC)

1. Record the overall detail such as height, weight, age and etc. from subject at the beginning of the experiment.
2. Subject is asked to swing the maximum load (100%MVC) until they cannot swing.
3. Record the maximal voluntary contraction (MVC) of muscle of the subject.
4. Put an electrolyte gel on surface of skin.
5. Place the electrode accurately on the lumbar multifidus muscle as shown in figure 1.
6. Start the experiment with the normalization test based on maximal voluntary contraction (MVC)
    a) Test 1: 100% MVC test
    b) Test 2: 75% MVC test
    c) Test 3: 50% MVC test
    d) Test 4: 25% MVC test
    e) Test 5: 0% MVC test
7. Firstly, the subject is standing and start with 100% MVC test.
8. Subject is asked to take 4 second for relaxing. Then, subject swing the load with 100% MVC within 2 second and hold the position for 4 second.
9. Observe the EMG waveform and record the data.
10. Repeat the step 7 to 9 for 3 times and subject is required to take a rest period of 30 second for every repetition.
11. Subject is required to take 2 minutes rest before taking another test.

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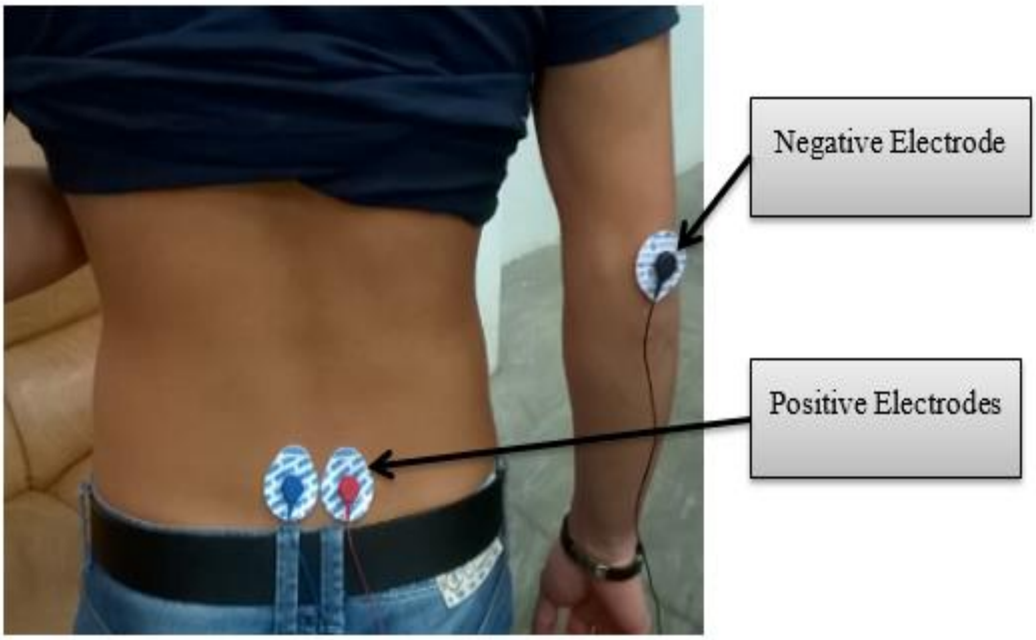

Figure 1: Position of positive and negative electrode on spinal muscle

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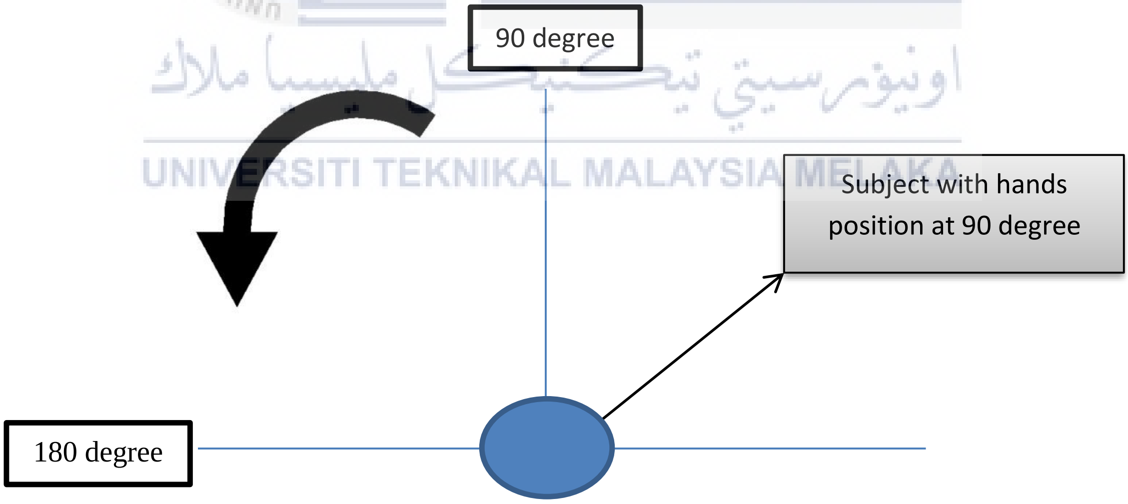

Figure 2: Movement of subject in swinging phase

Result

Table of Experiment

Percentage of maximal voluntary contraction (%MVC)	1^{st} repeat	2^{nd} repeat	3^{rd} repeat
100			
75			
50			
25			
0			

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APPENDIX B - CONSTENT FORM

CONSENT FORM

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CONSENT TO PARTICIPATE IN EMG STUDY

AIM OF THE STUDY

1. To record the EMG signal of spinal muscle.
2. To verify the raw data of EMG signal in term of time and frequency domain.
3. To investigate the characteristic of EMG signal.

PRE EXPERIMENT

1. Firstly, there is a briefing session that explains about the detail of experiment for all the subjects.
2. All subjects are required to fill up the consent form if they agree with the experiment conducted.
3. Next, there is a demonstration of experiment procedure in order to improve the understanding of subjects.
4. After that, subjects are necessary to undertake the skin preparation.
5. Lastly, a multi-meter is used to measure the skin resistance and make sure the resistance of skin region is less than 30kΩ.

EXPERIMENT PROCEDURE

1. Record the overall detail such as age and etc. from subject at the beginning of the experiment.
2. There are total of 5 normalization test based on maximal voluntary contraction (MVC)
    a) Test 1: 100% MVC test

b) Test 2: 75% MVC test
c) Test 3: 50% MVC test
d) Test 4: 25% MVC test
e) Test 5: 0% MVC test

3. Repeat each test for 3 times and subject is required to take a rest period of 30 second for every repetition.
4. Subject is required take a rest period of 2 minute for every test.
5. Observe the waveform and record the data.

POTENTIAL RISKS AND DISCOMFORTS

1. Risk shaving the spine hair if there is any high impedance that affects the EMG signals.
2. Risk in skin allergic when using electrolyte gel if subject has skin allergic.

POTENTIAL BENEFITS TO PARTICIPANTS OR SOCIETY

1. EMG can used to overcome the spinal injury such as back pain.
2. Data acquisition of EMG can help the aging people.

TIME INVOLVEMENT

Your participation in this experiment will take 30 minutes.

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CERIA LAB

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

HANG TUAH JAYA.

76100, DURIAN TUNGGAL, MELAKA

017-8845938 (James)

TO THE PARTICIPANT: You have the right as participant to be informed about your condition and your identity will not be disclosed. You can make a decision whether or not to undergo experiment after knowing the risks involved.

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Name of Participant

____________________________ ____________________

Signature of participant Date

TO THE WITNESS

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Name of Witness

____________________________ ____________________

Signature of witness Date

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FYP 1	WEEK													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Title discussion														
Research and journal finding														
Literature review														
Set the objective and scope														
Muscle selection														
Research on methodology														
Design experiment														
Selection of component and equipment														
Testing and trial														
Primary analysis and result														
Report Submission														

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FYP 2	WEEK													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Literature review	■	■												
Testing and trial			■											
Experiment				■	■	■	■							
Simplify and analyze the result					■	■	■							
One-way ANOVA analysis								■	■					
RMS analysis									■					
Boxplot analysis									■	■	■	■	■	
Review on signal filtering										■	■			
Smooth and filter the signal										■	■	■		
Analyze effect of fat layer thickness													■	
Report Submission														■

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