STUDY OF THUMB ATTITUDE RELATIONSHIP TO EXTRINSIC MUSCLES CHARACTERIZATION

BY

MUHAMMAD MUKHLIS BIN SUHAIMI

A thesis submitted in fulfilment of the requirement for the
Master of Science Engineering.

Kulliyyah of Engineering
International Islamic University Malaysia

MARCH 2023

ABSTRACT

In the case of amputees, the development of cybernetic hands that closely resemble the functions of real hands is essential for comfort and functionality purposes. Controlled by intrinsic and extrinsic muscles, the human thumb plays a major role in differentiating hand gestures. For those who have lost their intrinsic hand muscles, any information about muscle activities that can be obtained from the extrinsic muscles is essential to control the thumb. Thus, focusing on transradial amputees, this research investigates the relationship between extrinsic muscles to characterise thumb posture. A High-Density surface Electromyogram (HD-sEMG) device and a portable thumb force measurement system were used to collect forearm HD-sEMG signals from a total of 17 subjects. For the flexion motion, the subjects were asked to repetitively place their thumb at rest before exerting 30% of their individual maximum voluntary contraction (MVC) on a load cell by following a designated trajectory presented on a developed graphical user interface (GUI). The measurement system was set to four different postures namely zero degrees, thirty degrees, sixty degrees, and ninety degrees. Feature extraction was then performed by extracting the absolute rectified value (ARV), root mean square (RMS), mean frequency (MNF) and median frequency (MDF) values of the forearm HD-sEMG signals before being classified using four different classifiers namely linear discriminant analysis (LDA), support vector machine (SVM), k-Nearest Neighbour (KNN), and TREE-based classifier. The results revealed that the LDA classified RMS and ARV-RMS features, which were extracted from both posterior and anterior hand sides successfully achieved the highest correctly classified percentage of 99.7%. The findings of the study are significant for the development of a dedicated model-based control framework for prosthesis hand development to be used by transradial amputees in the near future.

ملخص البحث

بالنسبة للأشخاص المبتورين، تطوير اليد الإلكترونية التي تشبه اليد الحقيقية في العمل أمر مهم للراحة والأداء الوظيفي. إن العضلات الداخلية والخارجية تتحكم بالإبهام ، فيلعب الإبهام دورًا رئيسيًا في إنتاج حركات اليد المختلفة. بالنسبة لأولئك الذين فقدوا عضلات يدهم الداخلية ، فأي معلومات حول أنشطة العضلات التي يمكن الحصول عليها من العضلات الخارجية ستكون ضرورية للتحكم في الإبهام. يركز هذا البحث على مبتوري المرفق ، فيبحث هذا البحث في العلاقات بين العضلات الخارجية لتصوير وضعية الإبهام الحقيقية. قد استُخدمَ جهازٌ تسجيل مخطط كهربية العضل السطحي عالي الكثافة أو ما يعرف أيضا ب (HD-sEMG) ونظامٌ قياس قوة الإبهام المحمول لجمع إشارات تخطيط كهربائي العضل (EMG) من إجمالي 17 شخصًا. بالنسبة لحركة الانثناء ، طُلب من المشاركين وضع إبهامهم في حالة الراحة بشكل متكرر قبل ممارسة 30 ٪ من الحد الأقصى للانكماش الطوعي (MVC) الفردي على خلية تحميل باتباع مسار معين معروض على واجهة مستخدم رسومية (GUI) معينة. تم ضبط المسار على أربعة أوضاع مختلفة وهي درجة الصفر ، وثلاثين درجة ، وستين درجة ، وتسعين درجة. ثم تم استخراج البيانات عن طريق استخراج المطلقة القيمة المقومة (ARV)، وجذر متوسط مربع (RMS)، قيمة متوسط التردد (MNF) وقيم التردد المتوسط (MDF) لإشارات الساعِدِ HD-sEMG قبل تصنيفها باستخدام أربعة مصنفات مختلفة وهي التحليل التمييزي الخطي (LDA) ، وشعاع الدعم الآلي (SVM) ، وكي أقرب جار (KNN) والمصنف المستند إلى (TREE based classifier) TREE. أظهرت النتائج أن بيانات RMS و ARV-RMS لمصنفة LDA التي نستخرجها من HD-sEMG من كلا الجانبين الخلفي والأمامي لليد قد حققت بنجاح أعلى نسبة مصنفة بشكل صحيح بنسبة 99.7٪. تعتبر نتائج البحث مهمة لتطوير إطار تحكم قائم على النموذج لتطوير اليد الاصطناعية يستخدمه مبتوري المرفق في المستقبل.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science (Mechatronic Engineering).

....
Aimi Shazwani Ghazali
Supervisor

....
Ahmad Jazlan Haja Mohideen
Co-Supervisor

....
Shahrul Na'im Bin Sidek
Co-Supervisor

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science (Mechatronic Engineering).

....
Muhammad Ibn Ibrahimy
Internal Examiner

....
Wan Khairunizam B. Wan Ahmad
External Examiner

This thesis was submitted to the Department of Mechatronic Engineering and is accepted as a fulfilment of the requirement for the degree of Master of Science (Mechatronic Engineering).

……………………………….
Ali Sophian
Head, Department of Mechatronics Engineering

This dissertation was submitted to the Kulliyyah of Engineering and is accepted as a fulfilment of the requirement for the degree of Master of Science (Mechatronic Engineering).

……………………………….
Sany Izan Ihsan
Dean, Kulliyyah of Engineering

DECLARATION

I hereby declare that this thesis is the result of my investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Muhammad Mukhlis bin Suhaimi

Signature:……………………… Date:……1/3/2023……

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

DECLARATION OF COPYRIGHT AND AFFIRMATION OF FAIR USE OF UNPUBLISHED RESEARCH

STUDY OF HIGH-DENSITY EMG SIGNAL-BASED THUMB ATTITUDE RELATIONSHIP TO EXTRINSIC MUSCLES CHARACTERIZATION

I declare that the copyright holder of this thesis are jointly owned by the student and IIUM.

No part of this unpublished research may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without prior written permission of the copyright holder except as provided below

1. Any material contained in or derived from this unpublished research may only be used by others in their writing with due acknowledgement.

2. IIUM or its library will have the right to make and transmit copies (print or electronic) for institutional and academic purpose.

3. The IIUM library will have the right to make, store in a retrieval system and supply copies of this unpublished research if requested by other universities and research libraries.

By signing this form, I acknowledged that I have read and understand the IIUM Intellectual Property Right and Commercialization policy.

Affirmed by Muhammad Mukhlis bin Suhaimi

1/3/2023

……………………………… …………………..

ACKNOWLEDGEMENTS

To Allah, the Almighty, whose Grace and Mercies have sustained me during my study, be all the honour. The process of finishing this thesis has been challenging, but His Mercies and Blessings on me have made it easier.

I would like to thank my supervisor, Aimi Shazwani binti Ghazali who gave many opinions that helped towards the success of this study. With patience, thoroughness, friendship, her detailed comments, and helpful suggestions have launched and facilitated the study so that I can complete this thesis and also successfully publish journals and conference papers. I am also grateful to my co-supervisor, Ahmad Jazlan bin Haja Mohideen and Prof. Shahrul Na'im bin Sidek whose support and cooperation contributed to the outcome of this work. The moral support they gave me was certainly a motivation that helped the construction and writing of this research work draft. Thank you also to all of the laboratory members who shared their knowledge and helped with data collection for this study.

Lastly, my gratitude goes to my beloved parents; for their prayers, understanding, encouragement and moral support throughout my studies.

We praise Allah once more for His unending kindness toward us, one of which is allowing us to successfully complete the writing of this thesis. Alhamdulillah.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

EMG	Electromyogram
sEMG	Surface Electromyography
HD-sEMG	High-Density Surface Electromyogram
AP	Abductor Pollicis
FPB	Flexor Pollicis Brevis
OP	Opponens Pollicis
FDI	First Dorsal Interosseous
MVC	Maximum Voluntary Contraction
GUI	Graphical User Interface
TD	Time Domain
FD	Frequency Domain
ARV	Absolute Rectified Value
MAV	Mean Absolute Value
RMS	Root Mean Square
KNN	K-Nearest Neighbour
TPR	True Positive Rate
FN	False Negative

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

The human hand is an important body part that is used to control and handle daily activities such as grasping, pinching, and gripping (Yan Li, 2019). For normal people, the hand has five digits which consist of four fingers and a thumb. According to WHO (World Health Organization, 2004), 0.5% of the population in a developing country has a disability that necessitates the use of a prosthesis or orthosis. This prediction suggests that approximately 160,000 of Malaysia's current population of 32 million require prosthetic or orthotic devices. In additional, based on a record, there are approximately 1.6 million individuals living with limb loss in the United States, and it is estimated that the number will double by 2050 (Ziegler-graham et al., 2008). The common loss of limbs is due to accidents, wars, and diseases. There are also congenital cases where a person is born without a fully functional hand. These groups of people are known as amputees.

There are two categories of amputees, namely transradial and transcarpal. As demonstrated in Figure 1.1, transradial amputation occurs in the forearm area, in which the incisions are typically made on a ratio of 1 to 1 of the form length. It may cause the loss of interconnection between two main types of muscles, namely the intrinsic and extrinsic muscles. Meanwhile, transcarpal amputation is a common type of amputation that occurs for a variety of reasons such as diabetes and accidents, which in some cases will eventually result in amputation (removal through surgery). In general, more hand muscle activity data can be extracted from transcarpal amputees than transradial amputees since the flexion and extension of the wrist are still preserved. As such, transcarpal amputees can achieve higher recovery of overall hand function compared to transradial amputees (Maduri & Akhondi, 2020).

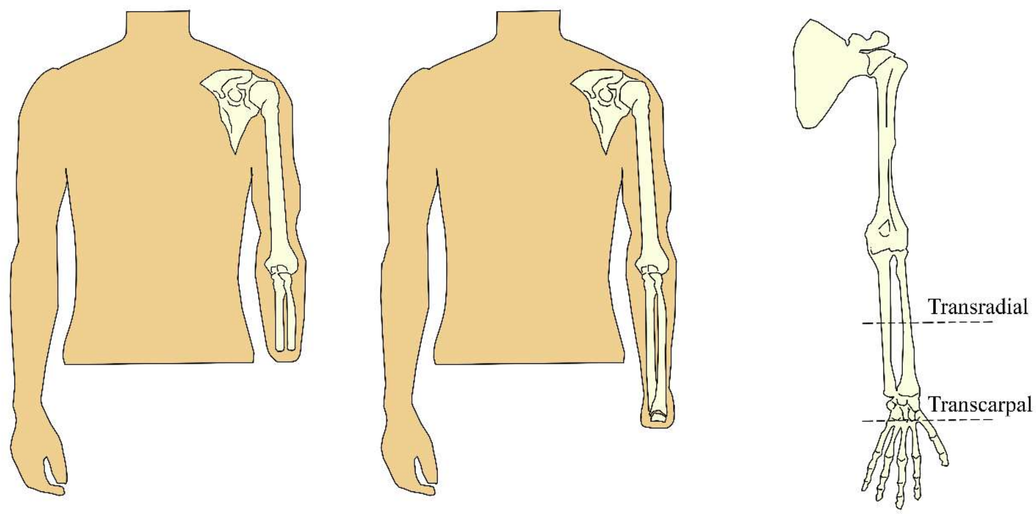

Figure 1.1: Transradial and Transcarpal

Research findings in neurophysiology and neuroscience have been utilised in the latest surgical procedures to incorporate prosthetic elements such as hand prostheses, osseointegration and myo-controllers (Kanitz et al., 2018). Over the last decade, earlier researches have achieved significant progress in the field of prosthetic hand development that utilises Electromyogram (EMG) measurements (Sánchez-velasco et al., 2019), which have given huge benefits to amputees in assisting in their daily activities to resemble normal limb functions. Based on one study (Cordella et al., 2016), hand prostheses are typically controlled by the sampling features taken from surface Electromyography (sEMG) signals obtained from the amputee's limb residual muscles. There are two types of EMG, namely invasive and non-invasive. Non-invasive sEMG is more common in prosthesis development (Chowdhury et al., 2013) and clinical usage, such as in physiology (Enoka, 2019), as this technique is painless and easily reproducible.

The thumb is the first digit of the human hand which is also known as *pollex* in its scientific term. Since the thumb is the only opposable digit to the other four fingers, it plays a critical role in hand function. Controlling this finger is vital for the realisation of different hand grip attitudes. Also, the contribution of the thumb towards hand functions and movements is inherently indispensable since the thumb is the only opposable digit that controls grip formation. Injury or loss of function of the thumb can severely limit overall hand function and movement (Xu et al., 2018).

To control and maximise the attitude and force of this digit, the thumb demands a combination activation of all the connected muscles (Drake et al, 2015; Wohlman & Murray, 2013). Critically, the thumb cannot be simulated accurately via individual intrinsic muscle contribution (Wohlman & Murray, 2013). The technique to record the sEMG signal to replicate thumb gestures is centred on the thumb musculature by measuring the activities of the intrinsic muscle in the palm area as demonstrated in Figure 1.2. The other extrinsic muscles governing the thumb lie on the forearm as shown in Figure 1.3. This interplay between extrinsic and intrinsic muscles is mostly reduced or lost for transcarpal and transradial amputees. Yet, the remaining residual forearm muscles (the extrinsic muscles) are still accessible for both types of amputees and could be useful to control a myoelectric-based prosthetic hand.

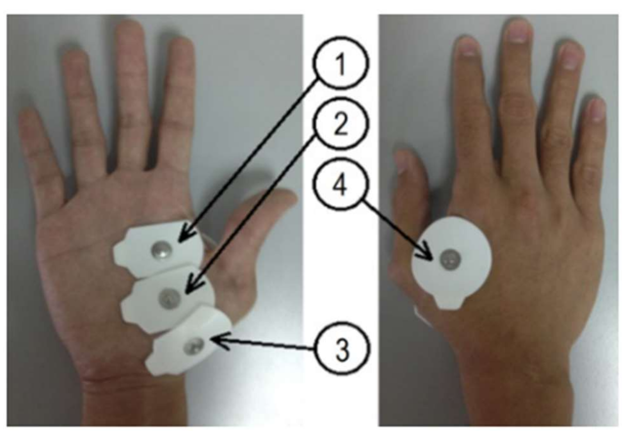

Figure 1.2: Positions of the electrodes; (1) AP, (2) FPB, (3) APB, (4) FDI (Sidek et al., 2018)

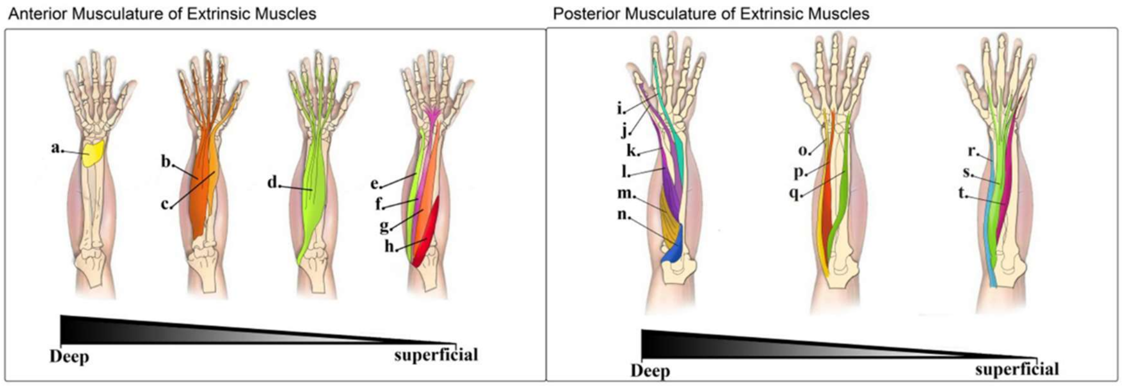

Figure 1.3: (Left) Muscles in the **anterior** compartment of extrinsic muscles (flexor muscles of the forearm). The muscles of the anterior compartment of the forearm are depicted in this image from the deepest layer (left) to the most superficial one (right)

(Right) Muscles in the **posterior** compartment of extrinsic muscles (extensor muscles of the forearm). The muscles of the posterior compartment of the forearm are depicted in this image moving from the deepest to the most superficial layer (Aranceta-Garza and Conway, 2019)

The biomechanics of the skeleton, thumb joint, and muscle-tendon action of the extrinsic muscle are the factors that influence thumb activities. Due to the lack of detailed studies on other factors influencing thumb characteristics, biomechanical prosthetics have limitations in function and performance (Wohlman & Murray, 2013; Xu et al., 2018). These limitations of prosthetics can cause phantom or telescoped sensations on the amputees' remaining hand limb. Phantom is a situation in which the proximal limb has shrunk, where in some cases, the amputees feel as if the limb is still present (Wijk & Carlsson, 2015).

There are continuous developments in cybernetic hands that can help create improved hand prostheses for transradial and transcarpal amputees (Wijk & Carlsson, 2015). As it is a crucial need for disabled individuals, opportunities for research and development on these cybernetic hands are still open for further improvements. With a newer EMG technology called the High-Density surface Electromyogram (HD-sEMG), existing technologies can be further improved. The HD-sEMG uses multiple electrodes that are arranged in a specific array. Previous studies (Amma et al., 2015; Stegeman et al., 2012) have shown that the effect of electrode numbers on recognition performance improves recognition accuracy.

1.2 PROBLEM STATEMENT

There are millions of hand amputees around the world, and unfortunately, these numbers increase each year. Hand prosthetics provide some functionalities of the human hand for amputees. However, current prosthetic hands lack accuracy in replicating hand gestures due to the lack of information that can be extracted from the muscles. Centring on the thumb, there are still gaps in research that focus on the synergy of targeted muscles on thumb movements.

Additionally, the limited information obtained from the placement of conventional sEMG electrode results in insufficient representations of overall muscle activity (Garcia and Vieira, 2011). As a result, smooth movements especially for prosthetic hand applications are hard to achieve due to the missing data from the targeted muscles.

Importantly, the main muscles that control the thumb attitude are the five intrinsic muscles that have easy access to the thumb. The other four extrinsic muscles that govern the thumb are located in the deep compartment of the forearm and contribute indirectly to thumb attitude. Despite the loss of access to the intrinsic muscles, any information from the extrinsic muscles is non-negotiable for transradial amputees.

Previous studies have focused on specific thumb attitudes, especially on abduction (Aranceta-Garza and Conway, 2019). However, different attitudes such as flexion and extension as presented in this work have not yet been covered.

1.3 RESEARCH OBJECTIVE

The main objective of this research, therefore, is to investigate (and establish) the relationship between the synergy of the HD-sEMG signal from extrinsic musculature and the thumb postures to be replicated on prosthetic hands for transradial amputees.

The main objective can be divided into four sub-objectives as follows:

1) To upgrade an existing portable thumb muscles platform and establish a standard sEMG recording setup for the HD-sEMG patch for consistent measurement of signals from the forearm musculature.
2) To determine the optimised feature extraction method and the best selection of features for the HD-sEMG data collected.
3) To determine the best classifier and validate the performance of the developed system by classifying HD-sEMG data collected.

1.4 RESEARCH METHODOLOGY

The execution plan for the research has been divided into five phases. An overview of the methodology, including the methods and materials of the experimental design, is described as follows and is summarised in Figure 1.4;

1.4.1 Phase-I

1. Conduct a comprehensive review of the existing literature on the development, design, control, implementation, and application of prosthetic limbs (particularly hand and thumb prostheses).
2. Study the related thumb muscles and finalise the targeted muscles.
3. Request for ethical clearance from the IIUM Research Ethics Committee (ID no: IREC 2020-080).

1.4.2 Phase-II

1. Upgrade the existing thumb measurement system to accommodate different thumb postures, specifically for flexion activities. Set four different postures for the study: zero-degree, thirty-degree, sixty-degree, and ninety-degree angles.
2. Finalise the experimental protocol needed for the collection of raw data sets of HD-sEMG signals. The protocol includes data collection procedures, electrode placement, and the number of records for each subject.

3. Test the system on pilot subjects (members of BioMechatronics Lab). Improve the necessary study protocol besides analysing and evaluating the results.
4. Purposively sample and select 17 subjects among IIUM students with no huge accident history and disease on the targeted hand that may affect the result.

1.4.3 Phase-III

1. Finalise the set up for the thumb measurement system and the experimental procedure to collect HD-sEMG data from the subjects' forearm musculature at different thumb postures.
2. Perform feature extraction in terms of time domain and frequency domain analysis, followed by selecting the features that yield the highest correctly classified instances using several classifiers.
3. Apply classification techniques to establish the relationship between HD-sEMG signal features and various thumb angles (flexion activities). Finalise an appropriate classifier based on the highest percentage of correctly classified data to classify the collected data.

1.4.4 Phase-IV

1. Formulate the conclusions of the study and recommendations for future works.
2. Write a final thesis and publish several journal and conference papers.

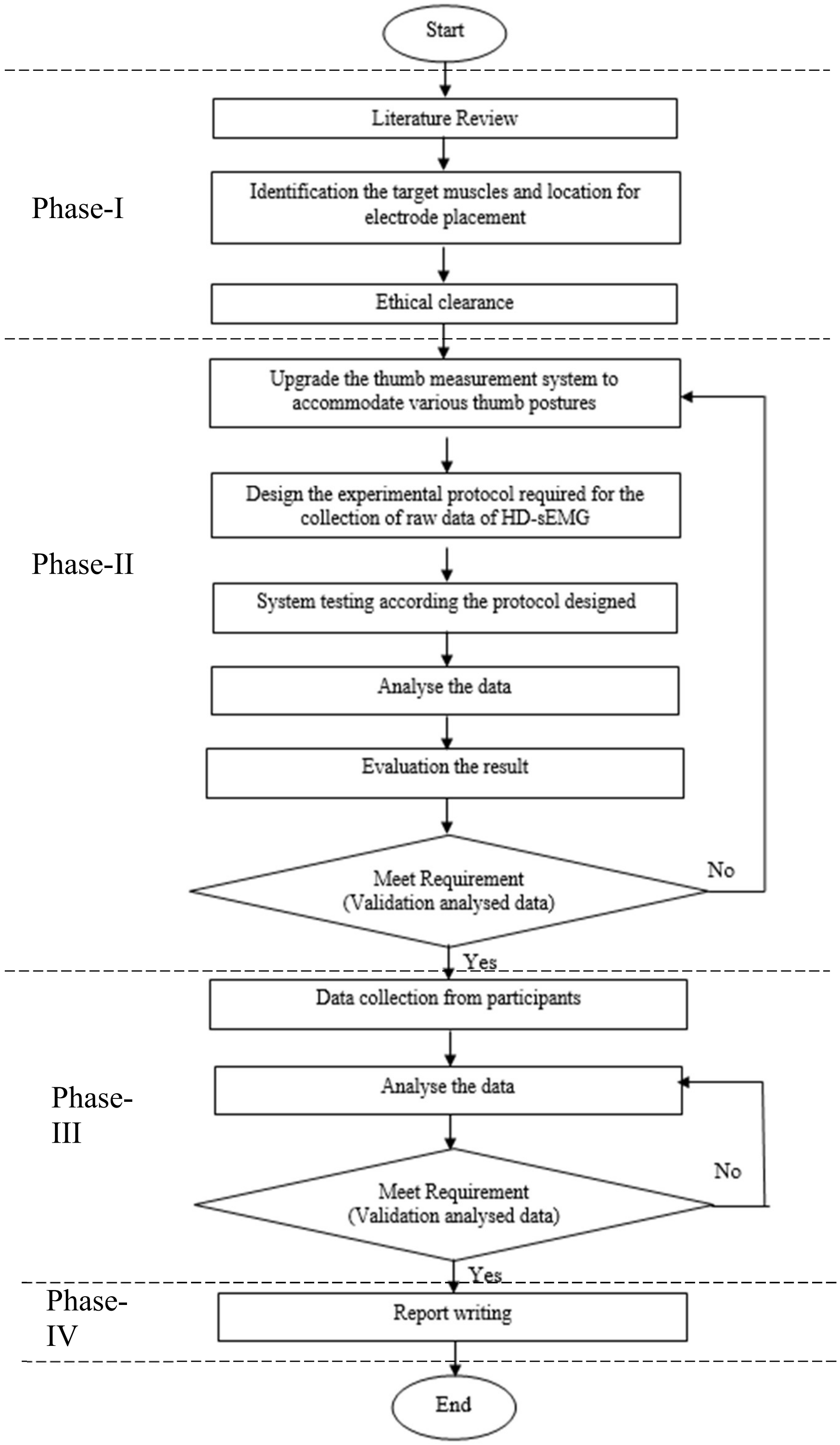

Figure 1.4: Flowchart of the methodology

1.5 SCOPE OF RESEARCH

The scope of the study is as follows:

1. This study to investigate the synergy of EMG signal from forearm with thumb attitude begins with upgrading the portable thumb training system platform to replicate four different thumb attitudes for flexion activities and the methods finalised for HD-sEMG data collection procedures by the forearm of the healthy subject targeting on the right hand.
2. Recruiting 17 subjects from the IIUM students with good health and no accident history and/or diseases on the targeted hand and each participant will be completed the collecting data procedure
3. Examining the features for time domain (TD) and frequency domain (FD) analyses (root mean square (RMS), mean absolute value (MAV), mean frequency (MNF) and median frequency (MDF)) and evaluating the results based on selected classifiers only (linear discriminant analysis (LDA), support vector machine (SVM), k-Nearest Neighbour (KNN), and TREE-based classifier). Then the collected data are analysed with classifying different thumb attitudes using machine and deep learning, and classification learner app in Matlab R2020.

1.6 THESIS ORGANISATION

The thesis is divided into five chapters:

Chapter 1: Describes the overview of the research by discussing the problem statements, research objective, methodology, and scope of the research.