# EMG BASED MOTION INTENTION DETECTION FOR CONTROL OF A ROBOT-ASSISTED TRAINING PLATFORM

BY

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# ABSTRACT

In order to improve the effectiveness of therapeutic training as well as to reduce the labour-intensive job of physiotherapist, robot-assisted training platforms have been developed as tools to assist the affected subjects in performing prescribed training tasks. It has been suggested that active participation from the subject in training session has a positive impact on the therapeutic training outcomes. As a response, past researchers have developed various assist-as-needed (AAN) control strategies for different robotic platforms to assist the subject in the case he was unable to complete the training task. Although the implementation of the AAN control strategy could promote the required assistance when needed, the implementation of the control strategy alone was found to be insufficient. In particular, the main problem with the current AAN control approaches was due to the absence of an important parameter that is a reliable triggering source from the subject in the form of intention to move the impaired limb. The 'intention' is paramount in improving the efficacy of interaction between the subject and the robotic-assisted training platform, as well as to ensure the subject safety. Therefore, the proposed study was attempted to address the issue, by developing an algorithm to predict the intention from electromyography (EMG) signal as well as to develop the adaptive assist-as-needed (AAAN) control strategy. It is worth noting that the study is novel as it evaluates the intention signal from the EMG signals within the range of 40 milliseconds to 100 milliseconds. The signal was acquired from a group of muscles (biceps) located at the upper arm when subjected to a flexion range of motion around the elbow joint along the sagittal plane. From the collected signal, time-domain analyses were implemented to extract the salient features of the signal. These features were then used to develop motion intention model in the form of k-Nearest Neighbour (k-NN) classifier. By leveraging the output of the classifier, a dedicated hybrid automata (HA) control framework was designed by integrating suitable impedance control scheme for different mode of motions namely passive, active and semi-active motions. A total of 30 able-bodied subjects have been recruited for the experiment to collect the signals upon attaining ethical clearance. It was demonstrated from the investigation that the coarse k-NN classifier was able to provide good classification of both the motion intention and pre-intention, preamble to the actual motion with the average training and test classification accuracy of 82.1% and 79.6%, respectively. From the hardware implementation, it was demonstrated that the proposed control strategy was able to provide the required assistance and resistance torques according to the different class of motion abilities that were categorized earlier. Based on the findings, it was evident that the proposed control strategy could provide intuitive and natural assist-as-needed torque input to the system based on one's motion intention and ability.

# خلاصة البحث


من أجل تحسين فعالية التدريب العلاجي وتقليص كثافة العمل لأخصائي العلاج الطبيعي، تم تطوير منصات التدريب بمساعدة الروبوتات كأدوات لدعم الأشخاص المتضررين في أداء مهام التدريب المحددة. لطالما تم اقتراح أن المشاركة النشطة من المتضرر المعني في الفترة التدريبية، لها تأثيرها الإيجابي على مردودات التدريب العلاجي. كرد فعل، قام الباحثون السابقون بتطوير استراتيجيات تحكم متعددة كدعم عند الحاجة (AAN) لمنصات روبوتية مختلفة لدعم المتضرر المعني في حالة عدم قدرته على إكمال المهمة التدريبية. على الرغم من أن تنفيذ استراتيجيات التحكم المتعدد كدعم عند الحاجة (AAN) قد يعزز الدعم المطلوب عند الحاجة، ال أنه قد وجد أن هذا التنفيذ وحده ليس كافيا. بشكل محدد، المشكلة الرئيسية في أساليب التحكم كدعم عند الحاجة (AAN) الحالية كانت بسبب غياب عامل مهم وهم مصدر التفعيل الموثوق من المتضرر المعني على شكل نية تحريك الطرف المصاب. النية هي العامل ذو الأهمية القصوى لتحسين فاعلية التعامل بين المتضرر المعني والمنصة التدريبية المدعومة بروبوت، كما تضمن سلامة المتضرر المعين. لذلك الدراسة المقدمة هي محاولة للتركيز على هذه المشكلة، عن طريق تطوير خوارزمية لتوقع النية من إشارة التخطيط الكهربائي للعضلات (EMG) لتطوير استراتيجية التحكم المتكيفة كدعم عند الحاجة (AAAN). من الجدير ذكره أن هذه الدراسة مبتكرة لأنها تقيّم إشارة النية من إشارات (EMG) خلال نطاق 40 جزء من الألف في الثانية إلى 100 جزء من الألف في الثانية. يتم الحصول على الإشارة من مجموعة عضلات ذات رأسين موجودة في الطرف الأعلى من الذراع عند تعرضها لنطاق حركة انثنائي حول مفصل المرفق على طول المستوى السهمي. من الإشارات المجمَّعة، تم إدخال تحليلات نطاق الوقت لاستخراج الميزات البارزة من الإشارة. هذه الميزات استخدمت لاحقا لتطوير نموذج نية الحركة على شكل مصنف (*k*-NN). عن طريق الاستفادة من مستخرجات المصنف، تم تصميم إطار تحكم آلي هجين (HA) مخصص عن طريق دمج مخطط تحكم معاوقة مناسب لحالات حركة مختلفة مجهولة التسمية، حركات فعالة وشبه فعالة. وظِّف ما مجموعه 30 متضرر معني كعينة للتجربة لجمع الإشارات بعد الحصول على تخليص أخلاقي. من التحقيق تم توضيح أن مجال المصنف (*k*-NN) يستطيع إمداد تصنيفات لكل من نية الحركة وما قبل نية الحركة بشكل جيد، ممهداً للحركة الفعلية مع التدريب المعادل ودقة اختبار مصنفة تبلغ 82.1 % و79.6 % على التوالي. عن طريق المعدات المنفذة، تم التوضيح أن استراتيجية التحكم المقدمة تستطيع إمداد الدعم المطلوب ومقاومة العزم حسب التصنيفات المختلفة لقدرات الحركة والتي صنفت مبكراً. من خلال النتائج، من الواضح أن استراتيجية التحكم المقدمة قد تستطيع إمداد مدخلات عزم عن طريق دعم بديهي وطبيعي عند الحاجة للنظام على أساس نية الحركة والقدرة.




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# APPROVAL PAGE

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# DECLARATION

I hereby declare that this thesis is the result of my own 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.

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| | |
|---|---|
| $M_d$ | Inertia of the robot |
| $B_d$ | Damping of the robot |
| $K_d$ | Stiffness of the robot |
| $\ddot{q}$ | Angular acceleration |
| $\dot{q}$ | Angular velocity |
| $q$ | Trajectory position |
| $\ddot{q}_d$ | Desired angular acceleration |
| $\dot{q}_d$ | Desired angular velocity |
| $q_d$ | Desired trajectory position |
| $r_i$ | Control symbol of HA |
| $s_i$ | State symbol of HA |
| $x_i$ | Condition guard of HA |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| NMD | Neuromuscular Disability |
| TBI | Traumatic Brain Injury |
| SCI | Spinal Cord Injury |
| ADL | Activities Daily Living |
| AAN | Assist-as-Needed |
| AAAN | Adaptive Assist-as-Needed |
| EMG | Electromyography |
| ROM | Range of Motion |
| IIUM | International Islamic University Malaysia |
| IREC | IIUM Research Ethics Community |
| *k*-NN | K-Nearest Neighbour |
| SVM | Support Vector Machine |
| LDA | Linear Discriminant Analysis |
| DT | Decision Tree |
| LR | Logistic Regression |
| HA | Hybrid Automata |
| EEG | Electroencephalography |
| DOF | Degree of freedom |
| TD | Time domain |
| DAQ | Data Acquisition |
| CAD | Computer Aided Design |
| MAX | Maximum |
| MIN | Minimum |
| SD | Standard Deviation |
| VAR | Variance |
| RMS | Root Mean Square |
| MAV | Mean Absolute Value |
| TP | True Positive |
| TN | True Negative |
| FP | False Positive |
| FN | False Negative |
| RMSE | Root Mean Square Error |

# CHAPTER 1

# INTRODUCTION

## 1.1 RESEARCH BACKGROUND

Neuromuscular disability (NMD) can be described as the central nervous system's dysfunction that causes the individual experiencing it, unable to control their affected limbs. In general, there are four types of significant disabilities that fall under NMD, namely stroke, spinal cord injury (SCI), cerebral palsy and traumatic brain injury (TBI). Typically, for individuals diagnosed with such disabilities, rehabilitation or therapeutic training is required to recover their skills to execute activities of daily living (ADL), and it is often carried out with the assistance of a physiotherapist. This process is commonly accomplished whereby the physiotherapist would induce some physical force onto the patient's limb whilst performing a prescribed training task. In general, the rehabilitation process would require a specific duration and can entail single or multiple interventions delivered by an individual or a team of physiotherapists. It can be executed from the acute or initial phase after the impairment forthwith the recognition of a particular health condition to post-acute phases.

In Malaysia, the percentage of the Malaysian population suffering from NMD was at the rate of 71.8 %, as reported in the Malaysian Ministry of Health's annual report in 2017 (Husin et al., 2018). In addition, the report also highlighted that stroke was the predominating cause of NMD, with 62%. The statistics further suggested that rehabilitation services were in high demand, owing to this trend. As the rehabilitation process requires close monitoring and continuous efforts by the physiotherapist, and as the ratio between affected subjects to physiotherapist increases, it is evident that the trend has become an unsustainable burden to the profession. Hence, in order to overcome the aforementioned problem, the initiative to utilize a robotic-assisted training platform to aid the affected subjects in the training session during the rehabilitation process could significantly reduce the workload of the physiotherapists. The involvement of robotic-assisted training platforms in healthcare is advantageous as robots could provide repetitive and structured motion without enduring fatigue. As the robotic-assisted training platform is under the physiotherapist's supervision, the primary requirement is to integrate the physiotherapist's expertise and skills into the robotic platform using existing technologies. The platform is intended to not only be able to provide effective assistance but should also offer other information for better treatment.

In has been reported that the best rehabilitation training strategy in a post-acute phase of the subject is when his effort is somewhat maximized during the training activity, whereby the assistance from the robot would only be actuated when the subject is unable to complete the task. In order words, the assistive force or torque would only be provided by the robotic platform when needed by adopting the assist-as-needed control strategy. As the name implies, the assist-as-needed (AAN) control strategy is a control scheme that provides an assistive force or torque when the subject is unable to complete a specific, pre-defined task. AAN is a widely adopted control strategy adapted from the experiences of the therapists. The robotic platform would complement the physiotherapists from manually assisting the subjects, and it has shown to provide encouraging results, comparable to those achieved through conventional manual therapy. At the same time, the approach allows compliance and systematic monitoring of the subject's performance. In order for the rehabilitation session to be effective, the robotic platform needs to interact with the subject in a gentle but decisive manner.

Another essential aspect that needs to be considered is safety during the interaction between the robot and the subject. In order to ensure a safe physical interaction, there is a need to detect the patient's motion intention so that the robot reacts to the intentions naturally while preserving the safety of the subject. In general, the intention can be defined as the desire to perform any activity, either specific or definite. In general, specific intention involves deliberate delivery of information, whereas definite intention involves  involuntary transmission of information about contextual states and emotions, such as facial expression (Sadri, 2012). Conversely, for definite intention, the signal triggered by the subject is not mainly intended to interact with the robot; nevertheless, the robot can utilize the signal to conclude the intention of the human. The main objective of the intention-prognosis based robotic platform is to give it some degree of intelligence, thus allowing it to recognize human emotion or action. Therefore, the platform can essentially interact with its human partner to modify its action and concurrently adapt to human action (Xing, Wang & Wang, 2017), (Sciutti, Ansuini, Becchio, & Sandini, 2015), (Pérez-Rodríguez et al., 2014), (Lenzi et al., 2012). The significance of detecting subject motion intention is to ensure that the subject's rehabilitation training would be effective, as the controller would regulate only when the subject requires some sort of motion assistance. This feature dramatically drives the necessity to detect the motion intention and adaptability to robot intervention and interaction forces in a smooth and natural manner with motion compliance.

Therefore, the study attempts to develop the assist-as-needed control strategy of a robotic platform for rehabilitation of upper extremities by utilizing the information on motion intention measured from the subject's bio-electrical signals, the electromyogram signal (EMG) in particular. This is to ensure that the assistance provided by the platform is accessible to the subject requiring it, apart from making the training session more intuitive and natural.

## 1.2 PROBLEM STATEMENT

It is suggested from previous studies that active participation from the subjects in the training task during rehabilitation session has significant impact on the rehabilitation outcomes, especially in terms of muscle spasticity. Muscle spasticity is a type of motor disorder characterized by velocity-dependent increase in tonic stretch reflexes with exaggerated tendon jerks, resulting from hyperexcitability of the stretch reflex, as one component of the upper motor neuron syndrome. However, the capacity to maintain active force during the training may hinder the subject from continuously participate in the training task (Huang, Naghdy, Naghdy, Du, & Todd, 2016). In order to overcome this issue, past researchers have developed various AAN control strategies in assisting the training via robotic systems, especially when the subject is unable to accomplish the task. Although the implementation of the AAN control strategy may promote assistance when needed, the implementation of the control scheme alone is insufficient. The main problem with the current AAN control strategies as reported in the literature is fundamentally due to the absence of an important parameter from the subject, i.e., the intention to move their limb, in which without it, it would be deemed as forced motion that is seemed to be unnatural (Proietti, Crocher, Roby-Brami, & Jarrasse, 2016). Therefore, to circumvent the problem, the proposed study would attempt to address the core issue in limb motion by analyzing the EMG signal burst, which occurs in between 40 to 100 msecs before actual limb motion and developing a dedicated algorithm to predict the intention and leveraging the information to develop a dedicated adaptive assist-as-needed (AAAN) control strategy.

## 1.3 RESEARCH QUESTIONS

The following research questions are posed in formulating the objectives of the present investigation;

1. What are the significant EMG based time-domain features that are important for identifying motion intention?
2. Which machine learning model is capable of classifying the motion intention of the subject based on the identified features with the highest efficacy?
3. How does the proposed AAAN control strategy is able to provide the required assistance to the subject undergoing the rehabilitation?

## 1.4 RESEARCH OBJECTIVES

The main objective of the study is to develop an adaptive assist-as-needed (AAAN) control strategy based on the measured motion intention from the subject. The following specific objectives are therefore required to be addressed to achieve the main objective of the study;

1. To identify significant EMG time-domain features that are capable of indicating unique patterns of motion intention from the subject.
2. To develop and implement different machine learning models that are capable of classifying the motion intention from the EMG signal.
3. To evaluate and validate the effectiveness of the adaptive assist-as-needed control strategy on the actual experimental setup.

## 1.5 RESEARCH HYPOTHESIS

The ability to detect motion intention initiated in the therapeutic training could give a significant upper hand in designing the control strategy for a robot-assisted training system. This could allow a more natural training to be deployed by the system in mimicking the expert human therapists. The goal is to make the operation of the system to be synchronized and in compliance with the supposed motion of the impaired limb. On top of that, the ability to record the recovery process in a quantitative manner would allow a more effective rehabilitation regimen and optimize the monitoring of the motor recovery process.

## 1.6 RESEARCH SCOPE

The following scopes were outlined for this research:

3. The experiments were carried out on 30 healthy subjects within the age range between 20 and 30 years old.
3. The developed robot-assisted training platform to induce motion has a single degree of freedom when regulating the flexion and extension of the elbow joint functional range of motion (ROM).
3. The investigation focused on the time-domain analysis of EMG signals.
3. The box-plot analysis was used to identify the significant features extracted.
3. Different machine learning models were investigated towards their ability in classifying the motion intention.
3. The actual implementation of the hybrid automata system was performed on healthy subjects.

## 1.7 RESEARCH METHODOLOGY

In order to achieve the objective of the study, the following research methodology has been adopted. The flowchart of the research is illustrated in Figure 1.1. The research was conducted by applying laboratory experiment design technique that is quantitative in nature. In essence, the study was segregated into five phases, with each phase briefly described as follows.

***First Phase***

For the first phase of this study, a comprehensive literature review was carried out on assist-as-needed (AAN) control strategy and the motion intention of the subject. In this phase, the background and scope of the study will be adequately defined as well as identifying the required variables and data in order to fulfil the objective of the study. Ethical approval from the International Islamic University Malaysia (IIUM) Research Ethics Committee (IREC) was applied since the study involved human subjects.

***Second Phase***

In this phase, the design aspect of the study was established based on the quantitative research design method. The study was divided into two stages; where the first stage of the study was focused on developing the model of motion intention recognition via bio-signals from the subject. In this phase, an assisted-robotic system and g.USBamp as EMG data acquisition system was used for detecting the motion intention from the subject. Subsequently, the data from motion intention were analyzed and extracted using a time-domain technique. From the feature extraction, a statistical method called box-plot analysis was applied in order to determine the significant features of the signals. Several classifiers such as *k*-Nearest Neighbour, Support Vector Machine

(SVM), Linear Discriminant Analysis (LDA), Decision Tree (DT) and Logistic Regression (LR) was utilized in order to develop the optimum model for classifying the motion intention.

***Third Phase***

The third phase of the study was the development of the proposed controller that was used for the system. The main control architecture for the AAN strategy was developed based on the impedance position-based controller. MATLAB/Simulink software was employed to interpret the coding for the controller.

***Fourth Phase***

In the fourth phase, a higher-level controller based on hybrid automata (HA) framework was developed to integrate motion intention with the AAN strategy. The simulation study and hardware realization were also carried out in this phase.

***Fifth Phase***

As for the fifth and the final phase, the research findings were compiled and written for thesis requirement.

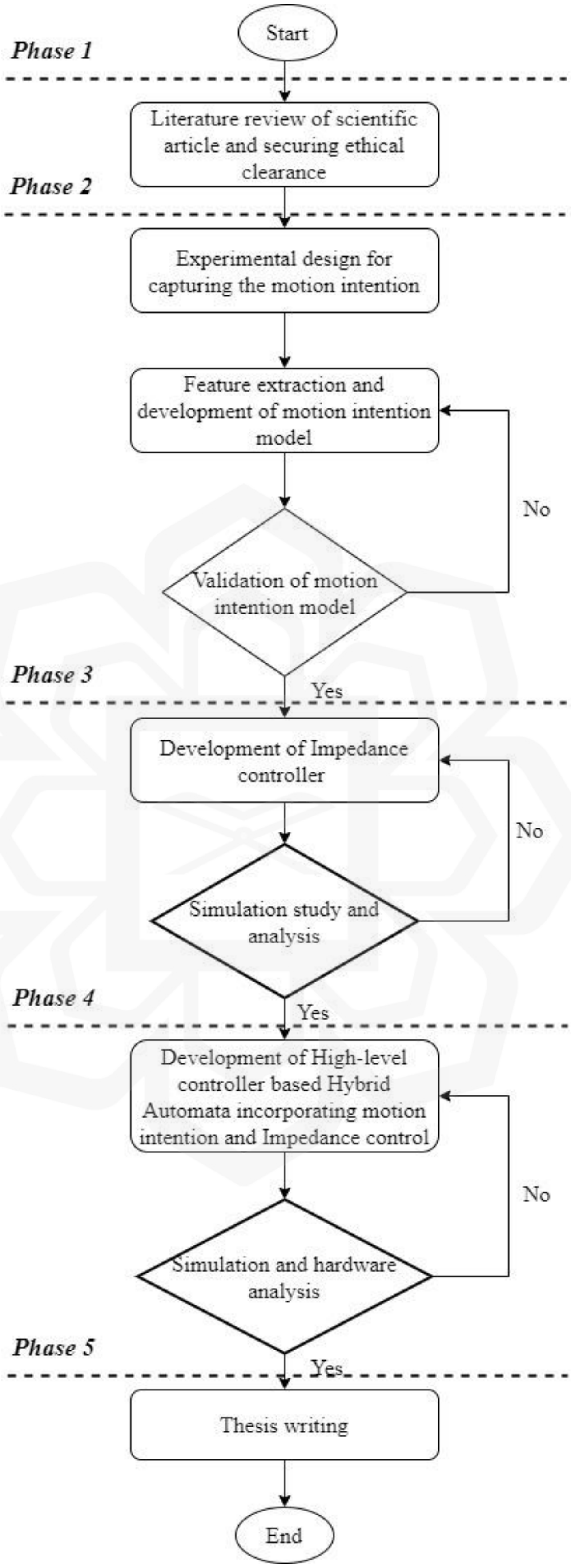


Figure 1.1 Flowchart of the Study