Faculty of Manufacturing Engineering

IMPLEMENTATION OF EEG CONTROLLED TECHNOLOGY TO MODULAR SELF-RECONFIGURABLE ROBOT WITH MULTIPLE CONFIGURATIONS

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IMPLEMENTATION OF EEG CONTROLLED TECHNOLOGY TO MODULAR SELF-RECONFIGURABLE ROBOT WITH MULTIPLE CONFIGURATIONS

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A thesis submitted
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DECLARATION

I declare that this thesis entitled "Implementation of EEG Controlled Technology to Modular Self-Reconfigurable Robot With Multiple Configurations" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name :

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Manufacturing Engineering.

Signature : ……………………………………...

Supervisor Name :

Date :

DEDICATION

This thesis is dedicated to:

The sake of Allah, my Creator and my Master,

My great teacher and messenger, Muhammad (May Allah bless and grant him), who taught us the purpose of life,

My homeland Malaysia

and

Universiti Teknikal Malaysia Melaka (UTeM)

I dedicate my dissertation work to my family and many friends. A special feeling of gratitude to my loving parents, Hasbulah and Norhayati whose words of encouragement and push for tenacity ring in my ears together with my siblings.

I also dedicate this dissertation to my many friends who have supported me throughout the process. I will always appreciate everything they have done, especially for helping me develop my technology skills, for the many hours of proofreading, and for helping me master the leader dots.

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ABSTRACT

The electroencephalogram (EEG) implementation has reached a new level in terms of application that is for the Brain Computer Interfaces (BCI) system and not restricted for medical instrumentation only. The concept of Modular self- Reconfigurable (MSR) robot control can be identified in most of science fictional movies. The implementations of both technologies to each other will act as a frontier for new alternatives that improve self-reconfigurable modular robots in terms of the control strategy. The main problem is that the EEG-based BCI system is always implemented for mobile robots, robot manipulators, and sometimes on humanoid robots. However, it is not implemented to MSR robots, which perform their tasks cooperatively by more than one robot module. Hence, the EEG-based BCI system implementation to MSR robot is needed to ensure the high accuracy of the MSR robot controlled with the BCI system to assess multiple configuration propagations by the MSR robots regardless of external stimulation. Therefore, it is important to analyse society perspective on BCI controlled robot technologies, to establish control, and to assess multiple configurations propagate by the Dtto MSR robot based on the EEG-based BCI system. Finally, the system established needs to be analyzed in terms of versatility for the availability of training, gender, and robot state. The method proposed in our study is utilizing Lab Streaming Layer (LSL) and Python script as mediators. The system developed in our study was done by using OpenViBE software where a Motor Imagery BCI was created to receive and process the EEG data in real time. The main idea for the developed system is to associate a direction (Left, Right, Up, and Down) based on Hand and Feet Motor Imagery as a command for the Dtto MSR robot control. Based on the findings, the SVM classifier produces a better result for Motor Imagery system control accuracy. The study also shows that the EEG acquisition headset with multiple electrodes is necessary for achieving a better control accuracy for the Motor Imagery system. A deeper analysis of the versatility of the MSR robot controlled by the BCI system is based on the three factors that were decided. Highest success rate for Simulation based on Left imagery which is 27.5% and the highest success rate for Young Trained subjects which is 30%. Highest success rate for Real Robot based on Left and Right Imagery which is 37.5% and the highest success rate for Young Trained subjects which is 38.33%. The analysis result shows that “Aged” and “Robot State” are significant for the control success rate of MSR robots by the BCI system. As for the “Training Availability” factor in our study, it is not considered a significant factor on its own but it has an interaction with the other factors and influences the control success rate. Overall, it is something achievable as the BCI system was integrated to the MSR robot to control multiple robot modules in real time and produced positive result as intended even though it was not as high as expected. P300 or SSVEP brain signal can be implemented in the future for more degree of freedom control and more efficient way can be implemented for communication for BCI system to MSR robot.

PELAKSANAAN TEKNOLOGI DIKAWAL EEG TERHADAP ROBOT MAMPU DIKONFIGURASI KENDIRI BERMODUL DENGAN KONFIGURASI PELBAGAI

ABSTRAK

Aplikasi '*Electroencephalogram'* (*EEG*) telah berkembang luas untuk digunakan selain daripada instrumentasi perubatan dan akhirnya membawa kepada satu sistem yang dikenali sebagai sistem '*Brain-Computer Interface'* (*BCI*). Sistem BCI yang diaplikasikan dalam bidang robotik boleh di implementasi kepada salah satu jenis robot yang dikenali sebagai robot *'Modular Self-Reconfigurable'* (*MSR*). Idea konsep untuk robot *MSR* yang dikawal oleh otak boleh dilihat dalam filem fiksyen sains. Masalahnya ialah sistem *BCI* berasaskan *EEG* sentiasa dilaksanakan kepada robot mudah alih (*mobile*), robot *manipulator* dan kadangkala dalam robot berbentuk manusia. Walaubagaimanapun, pelaksanaannya tidak kepada robot *MSR* yang melaksanakan tugas dengan memerlukan lebih daripada satu modul robot. Oleh itu, untuk pelaksanaan sistem *BCI* berasaskan kepada robot *MSR*, harus dipastikan ketepatan yang tinggi robot *MSR* yang dikawal dengan sistem *BCI* untuk menilai pelbagai konfigurasi terbina oleh robot *MSR* tanpa mengira rangsangan luar. Oleh itu, penganalisisan perspektif masyarakat terhadap teknologi robot terkawal *BCI* adalah diperlukan. Akhir sekali, sistem yang dibina perlu dianalisis dari segi fleksibiliti untuk latihan, jantina dan keadaan robot. Kaedah yang dicadangkan dalam kajian ini ialah penggunaan '*Lab Streaming Layer*' (*LSL*) dan skrip *Python* sebagai pengantara. Sistem yang sedang dibangunkan dalam kajian kami dilakukan dengan menggunakan perisian *OpenViBE* di mana imejan Motor *BCI* menerima dan memproses data *EEG* dalam masa nyata. Sistem yang dibangunkan untuk mengaitkan arah (kiri, kanan, atas dan bawah) berdasarkan imejan tangan dan kaki sebagai arahan bagi kawalan robot *Dtto MSR*. Dalam kajian ini, sistem mengklasifikasikan *SVM* menghasilkan hasil yang lebih baik untuk ketepatan kawalan sistem imejan motor. Analisis yang lebih mendalam mengenai versatility yang dikawal oleh sistem *BCI* adalah berdasarkan kepada tiga faktor. Kadar kejayaan tinggin untuk Simulasi berdasarkan Imagineri tangan Kiri ialah sebanyak 27.5% dan kadar kejayaan paling tinggi daripada Subjek muda terlatih sebanyak 30%. Kadar kejayaan tinggin untuk Robot Sebenar berdasarkan Imagineri tangan Kiri dan Kanan ialah sebanyak 37.5% dan kadar kejayaan paling tinggi daripada Subjek muda terlatih sebanyak 38.33%. Hasil analisis menunjukkan bahawa keadaan robot dan umur adalah penting bagi kadar kejayaan kawalan robot *MSR* oleh sistem *BCI*. Bagi faktor ketersediaan latihan, hasil kajian mendapati bahawa faktor ini tidak begitu ketara secara sendiri tetapi ia mempunyai interaksi dengan faktor lain dan mempengaruhi kadar kejayaan kawalan robot. Secara keseluruhan, sistem ini adalah sesuatu yang boleh dicapai sebagai sistem *BCI* bersepadu dengan robot *MSR* untuk mengawal pelbagai modul robot dalam masa nyata dan menghasilkan hasil yang positif seperti yang diinginkan walaupun tidak setinggi yang diharapkan. Isyarat otak *P300* atau *SSVEP* boleh diaplikasikan pada masa hadapan untuk lebih banyak kebebasan kawalan dan cara yang lebih efisyen juga boleh diaplikasikan untuk komunikasi antara system *BCI* dengan robot *MSR*.

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LIST OF ABBREVIATIONS/SYMBOLS

Av	-	Amplitude Value
BCI	-	Brain-Computer Interface
BOLD	-	Blood-Oxygen-Level-Dependent
DOF	-	Degree Of Freedom
EEG	-	Electroencephalogram
ERD	-	Event Related Desynchronization
ERP	-	Evoked Related Potential
ERS	-	Event Related Synchronization
ICA	-	Independent Component Analysis
LDA	-	Linear Discriminant Analysis
MEG	-	Magnetoencephalogram
MI	-	Motor Imagery
MLP	-	Multi-Layer Perceptron
MSR	-	Modular Self-Reconfigurable
Pv	-	Phase Value
s	-	Phase Time in Seconds
SCP	-	Slow Corticol Potential
SSVEP	-	Steady State Visual Evoked Potential
SVM	-	Support Vector Machine
t	-	Real Time Simulation
v	-	Velocity
VEP	-	Visual Evoked Potential
vMMN	-	Visual Mismatch Negativity
V-REP	-	Virtual Experimentation Platform

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CHAPTER 1

INTRODUCTION

1.1 Background

Over several years earlier, the research and development of Modular Self-Reconfigurable (MSR) robot have accelerated to the extent that the controllable complexity of the multiple robot modules of the MSR robot is starting to become available. It is well-known that most types of robots are operated with devices including a keyboard, a mouse, or a joystick, which are regular input devices for robot control. It is limited to the usage of conventional input that requires the user to provide some input before it can be operated.

Brain Computer Interfaces (BCIs) are an exciting manner for device control. However, we are a long way from having an implementation of the BCI system applications for most of the time. This system is specifically implemented for clinical purposes and in the research field. In terms of the robotics field, the BCI system is mainly implemented for assistive robots such as mobile robots (Wheelchair control) or brain-controlled manipulators (Robot arm). This is because the BCI system has been developed to be addressed as alternative interfaces that is used by people with severe disabilities who are unable to deliver their intentions with conventional inputs. Generally, healthy users are able to operate the robot using the input devices as mentioned before. However, it is not suitable to be used by the elderly and especially disabled people with severe neuromuscular disorders. This is where the BCI performs a crucial role in robotic discipline. The fewer usage of real-life BCI application task is due to low efficiency, which is lower than the conventional input devices such as based on touch or contact, gesture-perception, button-based, or voice-perception interfaces. The BCI system has one advantage as opposed to those conventional inputs after all, which is the only system of human-device interfaces that has been acknowledged to be used without the movement of muscles. Hence, as mentioned before, the BCI system is favorable, mostly to the people who are severely disabled that had lost over their muscle control. Besides that, the BCI system provides an opportunity for communication with their surroundings and specifically an assistive device that improves its independence. Otherwise, it could have been used as a means of communication.

An effective attempt to achieve communication that is based on the analysis of electrical brain signals has already begun by which it focuses on helping people who are suffering from severe neuromuscular disorders by providing an alternative communication that bypasses the conventional communication. Jacques Vidal in the 1970s (1973) had established a BCI framework, which is a means of interaction that is established between the human brain and an external device. The BCI system involves the processing of raw data extracted from the human brain, which will be converted into a type of data vectors to be exploited. There are two ways for brain activity signal recording that is used by the BCI system, which is either invasive or noninvasive. As the invasive signal recording for the BCI system calls for electrode implant to the brain that involves surgery, the non-invasive BCIs have been focused on its application. As mentioned before, the primary objective of the BCI system study is to facilitate the disabled and aged people who are unable to deliver their intentions or actions as they are suffering from severe neuromuscular disorders including Myopathy or Muscular Dystrophy. Typically, the electroencephalogram (EEG) is highly involved with the implementation of the BCI system. The measurement of electrical brain signals known as EEG is measured using electrodes placed on the head (which acts as small antennas) (Cohen, 2017). It is also be defined as the electrical potentials generated by the user by which the information is needed for the BCI system that is independent of any muscular activities (Keirn and Aunon, 1990). The EEG has been used to develop the majority of the BCI systems as it is low cost and practical compared to the Magnetoencephalograms (MEG), Blood-oxygen-dependent (BOLD), or the concentrations of (de) oxyhaemoglobin (Nijholt et al., 2008).

Nowadays, the BCI system has been extended in terms of its applications to healthy users or non-disabled individuals such as for 3D virtual environments that lead to gaming entertainment and even for robotics fields. The BCI technology has been extended to commercialization for everyone else who would like to use the BCI system. Some commercialized EEG devices are affordable and allow the users to build a BCI system themselves. It is called EEG-headsets. It is used for brain signal activity recording for a computer to receive the data to be exploited from a user's brain. They were usually used for simple games and research purposes. As mentioned before, the relation of a robot and the BCI system can be seen from an assistive robot for the disabled people, which can provide support to their daily life. Brain-controlled manipulators (robot arm) and mobile robots are the two main classes of robots that are implemented with the EEG-based BCI system to support disabled people (Bi et al., 2013). However, in line with the advancement of technology, there are other classes of brain-controlled robots, which are the humanoid robots (Kawato, 2008; Li et al., 2015). One of the examples of the brain-controlled manipulators is the one developed by Graser et al., which is used within the FRIEND system (Cecotti and Gräser, 2011; Grigorescu et al., 2012).

Besides those two types of robots, it is in our understanding that the EEG-based BCI system can be implemented for a different robot category, and the Modular robots or the MSR robots have a potential for the BCI system implementation. The MSR robot type is one of the robot categories by which the robot is capable of changing its configuration as it is connected from several similar modules to carry out specific tasks. Each module has to be