DESIGN AND DEVELOPMENT OF A MOTOR IMAGERY BASED INTERFACES OF WHEELCHAIR IN A SIMULATED VIRTUAL ENVIRONMENT

by

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LIST OF ABBREVIATIONS

ALS	Amyotrophic Lateral Sclerosis
ANOVA	Analysis of Variance
BCI	Brain Computer Interface
DAQ	Data Acquisition
DFT	Descrete Fourier Transform
DE	Differentially Enabled
ECG	Electrocardiogram
ECoG	Electrocorticography
EEG	Electroencephalograph
ERNN	Elman Recurrent Neural Network
EBP	Error Back-propagation
FFT	Fast Fourier Transform
FT	Fourier Transform
ICA	Independent Component Analysis
IOT	Internet of Things
KMI	Kinesthetic Motor Imagery
LM	Levenberg-Marquadt
MRI	Magnetic Resonance Image
MSE	Mean Squared Error
MND	Motor Neuron Disease
MLP	Multi-layered Perceptron
NARX	Non-liner Autoregressive Exogenous Network Model
NN	Neural Network
PSD	Power Spectral Density

PCA	Principle Component Analysis
RNN	Recurrent Neural Network
STFT	Short-time Fourier Transform
SNR	Signal to Noise Ratio
VMI	Visual Motor Imagery
WT	Wavelet Transform

LIST OF SYMBOLS

δ	Delta band
θ	Theta band
α	Alpha band
β	Beta band
γ	Gamma band
µ	Micro volt
T	Temporal Lobe
p	poles
z	zeros
H	Hertz
d	decibel
Ω	Ohm
N	Data length

Rekabentuk dan Pembangunan Antaramuka Berasaskan Motor Imagery untuk Kerusi Roda dalam Persekitaran Maya

ABSTRAK

Para pesakit yang menderita akibat penyakit seperti penyakit neuron motor (MND), atau trauma seperti kecederaan saraf tunjang (spinal cord injury, SCI) dan juga amputasi ada kemungkinan tidak dapat bergerak. Di sini dibentangkan hasil menggabungkan kerusi roda berkuasa yang direkabentuk untuk membantu dalam pergerakan pesakit ini dan antaramuka Otak-Komputer boleh menggantikan kayu ria konvensional supaya ia boleh dikawal tanpa menggunakan tangan. Isyarat otak terpancar semasa tugasan motor-imejan (MI) boleh ditukarkan kepada isyarat kawalan untuk mengawal kerusi roda berkuasa. Dalam projek ini, lima subjek telah diminta untuk melakukan enam tugasan motor-imejan kinestetik dengan satu tugasan rehat dan isyarat Elektroensefalografi (EEG) telah direkodkan. Penapis elliptic telah digunakan untuk mengasingkan hingar talian kuasa. Ciri yang dicadangkan, ciri gabungan Fraktal Dimensi dengan pekali frekuensi Cepstral Mel telah menghasilkan prestasi yang lebih baik daripada ciri-ciri lain yang digunakan. Ia dapat meningkatkan prestasi pengelasan kepada tahap yang memuaskan terutamanya subjek 3 yang menghasilkan keputusan yang kurang baik dengan penggunaan empat kaedah pengekstrakan ciri-ciri lain. Parameter rangkaian pengelas telah dipilih secara eksperimen dan algoritma Levenberg-Marquardt digunakan untuk latihan rangkaian. Jaringan Syaraf Tiruan Berlapisan Perceptron (MLPNN) berprestasi lebih baik daripada Jaringan Syaraf Tiruan Berulang Elman dan Jaringan Syaraf Tiruan Nonlinear Autoregressive Exogenous (NARX) dengan nilai purata peratus ketepatan 91.7% Model yang terhasil telah diuji dan dinilai di dalam dua persekitaran maya menggunakan antaramuka pengguna grafik (GUI) MATLAB. Keputusan simulasi membayangkan bahawa kawalan langkah demi langkah adalah lebih baik daripada kawalan berterusan untuk kerusi roda dan juga ciri yang dicadangkan, ciri gabungan FD dengan MFCCs dan MLPNN boleh digunakan untuk mengklasifikasikan isyarat motor-imejan bagi kawalan pergerakan kerusi roda berkuasa.

Design and Development of A Motor Imagery Based Interfaces of Wheelchair In A Simulated Virtual Environment

ABSTRACT

Patients suffering from diseases like motor neuron diseases (MND), or trauma such as spinal cord injury (SCI), and amputation are not able to move. Presented is a work on combining the power wheelchair designed to aid the movement of disabled patient and a Brain Computer Interface (BCI) can be used to replace conventional joystick so that it can be controlled without using hands. By using the BCI, the brain signal emanated during Motor Imagery (MI) tasks can be converted into control signal for power wheelchair maneuvering. In this research, five subjects are requested to perform six Kinesthetic Motor Imagery tasks plus one relax task and the Electroencephalography (EEG) signals are recorded. Elliptic filter was used to remove power line noise. The proposed feature, combined feature of Fractal Dimension with Mel-frequency Cepstral Coefficients has outperformed the others. It was able to improve the classification performance to a satisfactory level especially for the subject 3 which yielded relatively poor result by using four other feature extraction methods. The classifiers network parameters were experimentally selected and the Levenberg-Marquardt training algorithm was used to train the networks. The Multilayer Perceptron Neural Network (MLPNN) outperformed Elman Recurrent Neural Network and Nonlinear Autoregressive Exogenous model (NARX) with average accuracy of 91.7%. The developed network models was further tested and evaluated with two simulated virtual environment created by using MATLAB graphical user interface (GUI). The simulation results suggested that step by step control is better than continuous control of wheelchair, and also the proposed feature, combined feature of FD with MFCCs and MLPNN can be used to classify Motor Imagery signal for directional control of powered wheelchair.

CHAPTER 1 : INTRODUCTION

1.1 Research Background

Differentially enabled (DE) communities suffering from diseases like stroke, cerebral palsy, motor neuron diseases (MND) including amyotrophic lateral sclerosis (ALS), or trauma such as spinal cord injury (SCI) and amputation are facing movement impairment issues.

To aid the movement of disabled patients, wheelchair was invented and gone through development for many centuries. A manual wheelchair consists of a seat, two foot rests, two small front wheels and two large rear wheels. It can be moved by turning the rear wheels with handrims by the occupant, or by pushing the handles by a second person. Long duration of wheel turning can be very tiring, especially for certain places with complex landscape.

Electric-powered wheelchair was then invented to assist injured veterans during World War II. The electric-powered wheelchair consists of basic components similar with a manual wheelchair, but with additional components like electric motor, joystick controller and battery. It is driven by electricity from the battery and the direction of wheelchair can be controlled by the joystick. Henceforth, the DE communities can easily travel for longer distance without the need of aid from the others.

However, the severe motor disabilities of the DE communities prevent them from using conventional augmentative methods, including power wheelchair that requires voluntary muscle movement of the patients to move the joystick (Wolpaw, 2002). It was reported by the clinician that managing of steering and maneuvering tasks by using the existing joystick-based power wheelchair interface is extremely difficult or impossible for approximately 40 percent of patients who receive power wheelchair training (Fehr et al., 2000).

To overcome this issue, a Brain Computer Interface (BCI) can be used to replace the joystick for controlling a power wheelchair. BCI is a communication system where it connects a functional human brain and a device to be controlled (Kewate et al., 2014). It provides an alternative pathway where the brain's normal output channels of peripheral nerves and muscles are bypassed (Wolpaw et al., 2002).

By translating the brain signal into equivalent control signal, BCI allows its user to gain control over the connected device without performing any muscular action. Thus, it can be an anticipated solution for the DE communities to overcome their physical limitations and interact with the external environment (Anupama et al., 2012).

1.2 Motivation

The motivation of this research work is to enable the disabled patients to be more independent. There are about 110 million (2.2%) to 190 million (3.8%) of the world's population who have significant difficulties in motor functioning (Hanke-Herrero et al., 2013). As mentioned earlier, there are approximately 40% of the patients find that the power wheelchair currently available in the market is too difficult to be managed. The joystick interface for controlling power wheelchair is not suitable for all type of disabled patients, especially those without functional upper limb.

The rate of cure for these disabled patients is very low that most of them will remain disability and hence an alternative option such as an external communication pathway between human mind and device is required. Researchers had been dedicated to develop a hands-free interface so that power wheelchair is applicable for a broader range of DE communities since last few decades. Various approaches are being considered and experimented to replace joystick for directional control of power wheelchair. The most feasible approaches are voice command, image processing on facial expression or eye blinking, biosignal reading such as Electronystagmography (ENG) (for eye movement), Electromyography (EMG) (for muscle activity) and Electroencephalogram (EEG) (for brain activity) (Arai et al., 2011; Mittal et al., 2012; Nunes et al., 2002; Hwang et al., 2009)

Each of the approaches has their limitation such as low degree of control, or requires muscle activities that may not suits all types of DE patients. Meanwhile, non-invasive BCI system can be used by any patient as long as his brain is functioning properly. The BCI measures the scalp's potential generated by the user's brain activities, and convert it into useable control signal. Hence, by implementing a BCI system with ability of interpreting user's intention, the DE communities would be able to maneuver a power wheelchair independently.

1.3 Problem Statement

The main problem persists among DE communities is their motor impairment which limits them from using a joystick controlled power wheelchair. Other approaches for replacing joystick such as voice command, image processing on facial expression or eye blinking may not be adequate for all types of disabled patients. Each of these control method has their own advantages, but none of them are suitable for all types of disabled patients, either limited to involvement of particular physical body parts or low degree of freedom for control actions. For example, voice command cannot be used by a dumb or naturally deaf patients; facial expression, eye blinking or eyeball location detection have limited degree of freedom, since there are only a few simple gestures that can be performed by face or eyes.

Meanwhile, a thought-controlled interface that converts brain signal into control signal would be an ideal solution for any type of disabled patients to maneuver a powered wheelchair, as long as they have a functional brain. However, a functional brain-actuated power wheelchair is not yet available in the market currently, where the prototypes of BCI powered wheelchair only works in laboratory environment.

Most of the BCI managed to perform well in classifying two directions, but their performance gradually decrease when the number of target classes increase. Therefore, a working BCI with multi-tasks classification system is required for replacing the joystick, in order to allow any DE patient to maneuver a powered wheelchair without the need of voluntary movement. Furthermore, a reliable system should come with on/off flag, so that the user can do their daily basis without triggering wheelchair's movement.

In this research, a protocol consisted of seven (7) tasks that involved four (4) maneuvering directions and three (3) control flags (stop, on and off) has been proposed. The four maneuvering directions and three control flags are associated to different Motor Imagery tasks where movement imagination of different body parts are being performed. The EEG signal emanated while performing Motor Imagery tasks is recorded from the brain area responsible for motor pre-processing and activations.

After the elimination of noise and artifacts using digital filters, time and frequency domain features are extracted and analyzed. The extracted features of the seven tasks are classified into appropriate class using artificial neural network. Finally, the classification of different Motor Imagery tasks into control classes and wheelchair maneuvering are simulated virtually by using MATLAB Graphical User Interface.

1.4 Objectives

In this research work, a framework for the development of a Motor Imagery based BCI has been formulated. The framework focused on the study of Motor Imagery signal preprocessing, feature extraction and classification in order to design a BCI for directional control of power wheelchairs. The main objective of this thesis comprised the following three sub-objectives.

Main Objective: To design and develop a Brain Computer Interfa-ce of a power wheelchair for disabled patient using EEG signal.

The main objective of this research is to design and develop a Brain Computer Interface to convert user's brain signal into appropriate control signal for controlling power wheelchair's direction.

Sub-Objective 1: To develop suitable preprocessing and feature extraction algorithm for the EEG signal.

Power line noise and artifacts that might affect the classification result need to be removed through preprocessing stage and useful information or patterns need to be extracted from the clean Motor Imagery signal. Five different feature extraction algorithms, namely power spectral density (PSD), Fractal Dimension (FD), Mel-frequency Cepstral coefficients (MFCCs), Mel-frequency band structure based features (MFB) and a combination of FD with MFCCs features will be compared and evaluated by classification result.

Sub-Objective 2: To develop suitable classifier for classification of directional status into appropriate class.

Different Motor Imagery tasks need to be classified into corresponding classes. Three different neural network models, namely multi-layered perceptron (MLPNN), Elman and Nonlinear Autoregressive Exogenous (NARX) neural network will be developed and classification accuracies will be evaluated by using the developed feature sets database.

Sub-Objective 3: To test and analyze the developed model in a simulated virtual environment.

The performance of developed BCI needs to be tested and evaluated in a simulated virtual environment with different pathway design. By feeding associated input to the developed network, the accuracy of the classification can be directly visualize through correctness of the route taken.

1.5 Scope

The scope of this research is confined to the design and development of a Motor Imagery based BCI for power wheelchair's directional control in a virtual environment. Therefore, the discussions in this thesis will be focused on the digital processing procedures for converting Motor Imagery signal into appropriate control signal.

Mindset 24 amplifier and a 19 channels EEG cap with unipolar electrode setup will be used for data acquisition. However, the focus for the project will be the location belongs to motor and sensory areas. This is translated into signals emanated from scalp location C3, C4 and Cz based on the 10-20 International System of Electrode Placement.

To develop the BCI system, EEG signals are collected through five (5) healthy subjects. The subjects are selected from volunteers in the laboratory of the school in which the research was conducted. They are young campus students aged between 20-30 years old.

Kinesthetic Motor Imagery tasks will be performed by the subjects and their EEG signal will be recorded. Each Kinesthetic Motor Imagery task represents different control action for the wheelchair. A subject-dependent classifier will be developed for each subject, since a general model for the whole population is tend to have poor classification accuracies.

To evaluate the performance of the developed BCI, the system is implemented in MATLAB environment using MATLAB GUI. The research work would delivers an individual-dependent BCI system with developed neural network models from each subject.

1.6 Thesis Arrangements

This thesis explores the topic of Motor Imagery based interface for continuous control of a wheelchair in a simulated virtual environment. The research work carried out are presented in five chapters in this thesis.

Chapter 1 introduces the research background of differentially enabled communities and the travel difficulties that they face. The problem statement, motivation, research objectives, and scope are included in this chapter.

Chapter 2 discusses about the literature review on BCI, feature extraction methods and classification algorithm. The previous works on BCI for wheelchair are studied and discussed.