BRAIN MACHINE INTERFACE CONTROLLED ROBOT CHAIR

by

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LIST OF ABBREVIATIONS

ABMI	Asynchronous Brain Machine Interface
AAR	Adaptive Auto-Regressive
ALN	Adaptive Logic Network
ALS	Amyotrophic Lateral Sclerosis
ALSA	Amyotrophic Lateral Sclerosis Association
AOR	Artifacts Occurrence Rate
AR	Autoregressive Model
ARMA	Autoregressive-Moving-Average Model
BCI	Brain Computer Interface
BLRNN	Bayesian Logistic Regression Neural Network
BMI	Brain Machine Interface
BP	Back Propagation
CSP	Common Spatial Patterns
CWT	Continuous Wavelet Transforms
DERNN	Dynamic Elman Recurrent Neural Network
DFT	Discrete Fourier Transform
DWT	Discrete Wavelet Transform
ECG	Electrocardiogram
ECoG	Electrocorticography
EEG	Electroencephalography
EMG	ElectroMyoGram
EOG	ElectroOcculoGram
ERD	Event Related Desynchronization
ERP	Event Related Potential
ERS	Event Related Synchronization
ESD	Energy Spectral Density
FFT	Fast Fourier Transform
FIR	Finite Impulse Response
FIRNN	Finite Impulse Response Neural Network
fMRI	Functional Magnetic Response Imaging
FN	False Negative
FP	False Positive
GDNN	Gamma Dynamic Neural Network
GMM	Gaussian Mixture Models
HMM	Hidden Makrov Models
IC	Intentional-Control
ICA	Independent Component Analysis
IIR	Infinite Impulse Response
kNN	K-Nearest Neighbors
LDA	Linear Discriminant Analysis
LRP	Lateralised Readiness Potential

LVQ	Learning Vector Quantization
MA	Moving Average Model
MEG	Magnetoencephalography
MEIG	Modified Eigen Vector Features
MI	Motor Imagery
MND	Motor Neuron Disorders
MS	Multiple Sclerosis
MSE	Mean Square Error
NC	Non-Control
NIND	National Institute of Neurological Disorders and Stroke
NIR	Near Infrared
NIRS	Near Infrared Spectroscopy
NN	Neural Network
NREM	Nonrapid Eye Movements
P300	Potential Detected At 3000 Milliseconds
PCA	Principal Component Analysis
PD	Parkinson's Disease
PET	Positron Emission Topography
PMA	Pre-Motor Area
PMC	Primary Motor Cortex
PSD	Power Spectral Density
PSO	Particle Swarm Optimization
RBF	Radial Basis Function
REM	Rapid Eye Movements
RFLDA	Regularized Fisher's Linear Discriminant Analysis
RP	Readiness Potential
SCP	Slow Cortical Potentials
SCP	Slow Cortical Potential
SFFNN	Static Feed Forward Neural Network
SFFNN	Static Feed Forward Neural Network
SMA	Supplementary Motor Area
SSVEP	Steady-State Visual Evoked Potentials
STFT	Short Time Fourier Transform
SVD	Singular Value Decomposition
SVM	Support Vector Machines
TDNN	Time-Delay Neural Network
TN	True Negative
TP	True Positive
TTD	Thought Translation Device
TTD	Thought Translation Device
WHO	World Health Organization

LIST OF SYMBOLS

β	Beta
μ	Mu
μc	Mean of each class c
μV	Micro volt
Σ	$m \times n$ diagonal matrix
Ω	Frequency of a waveform
c	class
C	Central Lobe
C3	Central Lobe electrode position for left hand
C4	Central Lobe electrode position for right hand
cm	Centimeters
Cz	Central Lobe electrode position for legs
E_x	Total Energy of a finite continuous time signal
F	Frontal Lobe
Hz	Hertz
k	Gain Factor of a filter
K	Kernel function
M	$m \times n$ matrix
Mc	Covariance matrix of class c
mV	Milli volt
N	Data length
n	No. of mental activities (tasks)
O	Occipital Lobe
P	Parietal Lobe
p	poles
p_a	Mean recognition accuracy
T	Temporal Lobe
T_{act}	EEG signal action period
U	$m \times m$ unitary matrix
V	$n \times n$ unitary matrix
x	Feature vector
$X_a(j\Omega)$	Discrete Fourier Transform of $x_a(t)$
$x_a(t)$	Finite continuous time signal
z	zeros

MESIN OTAK ANTARA MUKA MENGAWAL KERUSI ROBOT

ABSTRAK

Mesin Otak Antara Muka Mengawal Kerusi Robot: Mesin otak antara muka adalah sebuah alat hubungan otak manusia secara langsung untuk alat-alat seperti komputer, kerusi roda dan lengan palsu. Antara muka tersebut menyediakan satu saluran digit untuk komunikasi dan kawalan dalam ketiadaan saluran-saluran biologi dan oleh itu membantu dalam pemulihan mobiliti dan individu-individu hilang upaya bercakap. Dalam tesis ini, sebuah novel empat-kelas mesin otak antara muka direka bentuk untuk sebuah kerusi robot menggunakan jaringan saraf. Mudah dan protokol-protokol novel untuk memperolehi isyarat otak EEG daripada dua elektrod kulit kepala tidak invasif dibentangkan. Empat kerja berdasarkan imejan penggerak oleh pergerakan tangan kiri dan kanan adalah dicadangkan untuk mengawal arah bagi kerusi robot. Satu algoritma novel untuk pemerolehan isyarat-isyarat imejan penggerak menggunakan pergerakan tangan adalah dicadangkan. Prapemprosesan algoritma mudah diperkenalkan untuk membuang hinggar daripada isyarat-isyarat mentah. Jalur-jalur frekuensi Mu, beta dan Gamma yang berkaitan dengan tindakan-tindakan penggerak adalah disari menggunakan penapis yang ditempa. Ciri-ciri baru berdasarkan bahagian-bahagian masa dan frekuensi isyarat-isyarat EEG adalah dicadangkan dan diuji dengan pengelas. Pengelasan isyarat-isyarat imejan empat tangan penggerak dibentangkan menggunakan jaringan saraf statik dan dinamik. Algoritma berasaskan pengoptimum kumpulan zarah dicadangkan bagi melatih jaringan saraf. Gabungan cadangan ciri-ciri dan pengelas statik dan dinamik dianalisis. Isyarat-isyarat dihimpun dari 10 subjek terlatih untuk digunakan dalam menganalisis reka bentuk BMI segerak dan tak segerak. Satu maxone algoritma untuk penterjemahan bagi isyarat-isyarat imejan penggerak tangan kepada pergerakan kerusi robot dibentangkan. Sebuah kerusi robot prototaip direka dan diantaramukan dengan tak segerak maju BMI. Ciri-ciri keselamatan disepadukan melalui satu sistem pengelakan pelanggaran untuk meningkatkan prestasi bagi kerusi robot. BMI mengawal kayu ria bagi kerusi robot menggunakan satu algoritma kawalan kongsi. Eksperimen-eksperimen masa-nyata adalah juga dipersembahkan menggunakan 10 terlatih dan 5 tak terlatik subjek untuk mensahihkan kebolehgunaan bagi mesin otak antara muka. Eksperimen-eksperimen dijalankan pada dua penjelasan (luar dari persekitaran makmal) dengan 25 subjek tak terlatih bagi menilai kemungkinannya dalam persekitaran kehidupan sebenar.

BRAIN MACHINE INTERFACE CONTROLLED ROBOT CHAIR

ABSTRACT

Brain Machine Interface Controlled Robot Chair*: Brain Machine Interface is a device that links the human brain directly to devices such as computer, wheelchairs and prosthetic arms. Such interfaces provide a digital channel for communication and control in the absence of the biological channels and thus help in the rehabilitation of mobility and speech impaired individuals. In this thesis, a novel four-class brain machine interface (BMI) is designed for a robot chair using neural networks. Simple and novel protocols for acquiring brain EEG signals from two non-invasive scalp electrodes are presented. Four tasks based on motor imagery of left and right hand movements are proposed to control the directions of the robot chair. A novel algorithm for acquisition of motor imagery signals using only hand movements is proposed. Simple preprocessing algorithms are presented to remove noise from the raw signals. Mu, Beta and Gamma frequency bands related to the motor actions are extracted using customised filters. New features based on time and frequency components of the EEG signals are proposed and tested with classifiers. Classification of the four hand motor imagery signals is presented using static and dynamic neural networks. A particle swarm optimization based algorithm is proposed to train the neural networks. Combinations of the features proposed and the static and dynamic classifiers are analysed. Signals collected from 10 trained subjects are used in the analysis of synchronous and asynchronous BMI designs. A max-one algorithm for translation of the hand motor imagery signals into robot chair movements is presented. A prototype robot chair is designed and interfaced with the developed asynchronous BMI. Safety features are integrated through a collision avoidance system to enhance the performance of the robot chair. The BMI controls the joystick of the robot chair using a shared control algorithm. Real-time experiments are also presented using 10 trained and 5 untrained subjects to validate the applicability of the brain machine interface. Experiments were carried out at two expositions (out-of-lab environments) with 25 untrained subjects to assess its feasibility in real life environments.*

CHAPTER 1

INTRODUCTION

1.1 Introduction

Controlling objects or machines by thought is a dream which is currently moving from science fiction to science and technology. The prospect of humans interfacing the mechanical world through brain-coupled devices and thereby controlling everyday machines through the process of mere thought is certainly appealing. The technology that can make this to happen is known as a Brain Machine Interface (BMI). Hans Berger in 1929 through his experiments on human Electroencephalography (EEG) introduced the idea that brain activity could be decoded and used as a communication channel. EEG is a technique which makes it possible to measure, on the scalp, micro currents that reflect the brain activity.

A promising class of applications of BMI are those concerning assistive devices for people with serious motor impairments. The classical interfaces, that disabled people commonly use to control or manipulate an assistive device, typically require the patient to have adequate control over one or more physical components of his or her body. Typically that would be one of the limbs: an arm, hand or finger. Bioprosthetic systems that are directly controlled through brain signals on the other hand could provide for a more natural extension of human capabilities. Especially in the case where the patient is completely paralysed, this technology may provide the only possible way for the patient to gain control over basic aspects of their daily life.

Amongst these the ability to control the personal mobility is generally considered as an important one. The reduction in mobility that many people experience, due to various impairments or simply due to the effects of ageing, often has a profound impact on the person's independence, social activity and self esteem. For many people suffering from a diverse range of impairments, the primary device that could provide for that mobility is the electrical wheelchair. It is worth noting however, that in case of locked-in patients their highest priority is not mobility. Still, learning to drive complex devices such as a wheelchair will also lead to better communication and domotic tools. BMIs are also becoming more popular in the gaming and virtual reality sector for normal users. This thesis focuses on the development of a BMI system to control a robot chair as an assistive device for the mobility impaired people.

1.2 Goal of a BMI System

BMI research goes back to the early 1970s. At that time Jacques Vidal designed a brain-computer interface by a computer-based system that produced detailed information on brain functions and built the first brain computer interfaces based on visual evoked potentials (Vidal, 1973). During the last decade the definition and the goal of a BMI has been refined and specialized. Definition of a BMI given by Wolpaw (Wolpaw et al, 2002) states that 'a BMI is a system for controlling a device (e.g., wheelchair, neuroprosthesis or computer) by human intentions without using activity of muscles or peripheral nerves'. Previous systems were mainly developed for patients suffering from several disabilities, especially for ALS and spinal cord injuries.

When the cognitive abilities are still intact a BMI might be the last opportunity for them to communicate with other people. A BMI could also help patients like amputees to lead a more comfortable life. Recently, many groups have suggested using a BMI system for healthy people as a further communication path for gaming or in real life. However, the functionality of a BMI is so far very limited as current BMI systems are not convenient for workplace applications. Nevertheless, recent results have given reasons to hope that the system can be improved to be useful for healthy users too (Washington University, 2006).

1.3 Brain Machine Interface Design

The BMI for a robot chair is designed in two phases, (1) an offline training phase which calibrates the system and (2) an online phase which uses the BMI to recognize mental states and translates them into commands for the robot chair. An online BMI follows a closed-loop process, usually comprising of six steps: brain activity measurement, pre-processing, feature extraction, classification, translation into a command and feedback (Mason & Birch, 2003). These are briefly explained as:

(a) **Brain activity measurement:** This step consists of using various types of sensors in order to obtain signals reflecting the user's brain activity. This thesis focuses on EEG motor imagery as the measurement technology.

(b) **Pre-processing:** This step is used to denoise the input data in order to enhance the relevant information embedded in the signals.

(c) **Feature Extraction:** Feature extraction aims at describing the signals by a few relevant values called 'features'.

(d) **Classification:** The classification step assigns a class to a set of features extracted from the signals. This class corresponds to the kind of mental state identified. This step can also be denoted as 'feature translation' (Mason & Birch, 2003).

(e) **Translation into a Command:** Once the mental state is identified, a command is associated to this mental state in order to control a given machine such as a robot, a wheelchair or a prosthetic device (Kubler, Mushahwar, Hochberg & Donoghue, 2006).

(f) **Feedback:** Finally, this step provides the user with a feedback about the identified mental state. This aims at helping the user controlling his brain activity and as such the BMI. The overall objective is to increase the user's performances.

The architecture of a BMI to control a robot chair is schematised in Figure 1.1; it should be noted that before operating such a BMI, considerable calibration work is necessary; this work is generally done offline and aims at calibrating the classification algorithm.

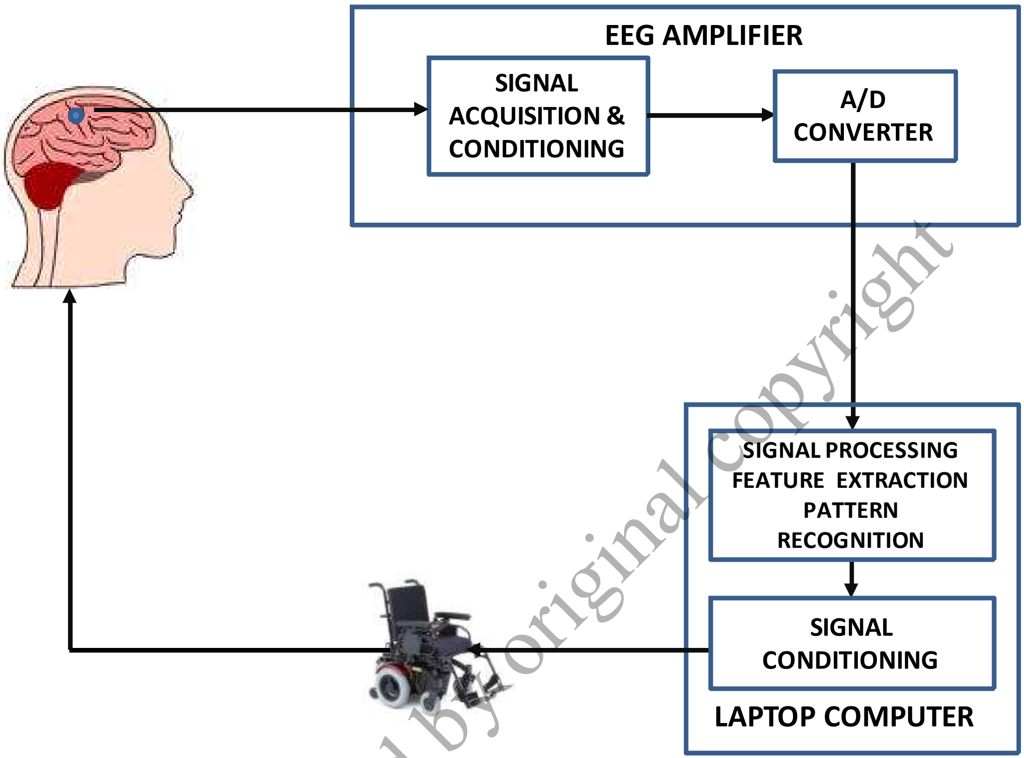

Figure 1.1
Architecture of a Brain Machine Interface for Robot Chair Control.

In order to do so, a training data set must have been recorded previously from the user. Since EEG signals are highly subject-specific, the BMI systems must be calibrated and adapted to each user. This training data set contains EEG signals recorded, when the subject performs each mental task of interest several times according to given instructions. The recorded EEG signals are then used as mental state samples in order to find the best calibration parameters for the user.

1.4 Thesis Objectives

The work presented in this thesis belongs to the framework of BMI research. More precisely, it focuses on the study of EEG signal processing and classification techniques in order to design and use BMI for controlling and navigating a robot chair. Despite the valuable and promising achievements already obtained in the literature to interface the brain and computers (BCI), brain machine interfacing is still a relatively young research field and there is still much to do in order to make BMI become a mature technology. Among the numerous possible improvements, three main points are addressed in this thesis; that is, designing a four-class control BMI using hand Motor Imagery (MI); designing an asynchronous BMI to control a robot chair and real-time robot chair navigation studies in indoor environments using the four-class BMI. The BMI community has highlighted these points as being important and necessary research topics for the further development of BMI technology for real life situations (Wolpaw, Birbaumer, McFarland, Pfurtscheller & Vaughan, 2002; Millán, Renkens, Mourino & Gerstner, 2004; Leeb et al, 2007). The aspects of the three improvements are illustrated as below:

(i) Designing a four-class control BMI using hand MI

Most current BMI systems focus on left hand, right hand, feet, cheek and tongue movements to design a four-class BMI which require more electrodes to record these signals. Designing a four-class BMI using only hand movements with only two electrodes reduces the processing time and thus increases the transfer rate of the BMI for real–time control of a robot chair. A practical four-class BMI for a robot chair can be achieved through effective acquisition protocols and good classification accuracy.

a. **Designing protocols using only hand motor imagery for a four-class BMI:** The number of classes used is generally very small for BMI. Most current control BMI propose only 2 classes (two kinds of mental states) using hand MI. Designing algorithms that can efficiently recognize a larger number of mental states would enable the subject to use more commands and thus benefit from a higher information transfer rate (Kronegg, Chanel, Voloshynovskiy & Pun 2007; Dornhege, Blankertz, Curio & Muller, 2004). However, to really increase the information transfer rate, the classifier