STUDY OF NON-INVASIVE COGNITIVE TASKS AND FEATURE EXTRACTION TECHNIQUES FOR BRAIN-COMPUTER INTERFACE (BCI) APPLICATIONS

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SUPERVISOR'S DECLARATION

We hereby declare that We have checked this thesis and, in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Antara muka otak-komputer (BCI) menyediakan alternatif penting bagi orang kurang upaya yang membolehkan mereka berkomunikasi antara pemikiran individu dan menggunakan alat bantu yang berbeza. Teknologi BCI pada dasarnya terdiri daripada pemerolehan data, pra-pemprosesan, pengekstrakan ciri, klasifikasi dan perintah peranti. Walaupun pencapaian penting dan hebat telah diperolehi dalam setiap komponen BCI, bidang BCI masih merupakan bidang penyelidikan yang masih baru dan masih banyak yang perlu dilakukan untuk menjadikan BCI menjadi teknologi yang bermanfaat. Untuk menjadikan teknologi ini lebih berkesan, kajian tugas kognitif menggunakan ciri EEG dan kerangka klasifikasi telah diselidiki. Di sini, terdapat empat eksperimen berbeza yang telah dilakukan untuk menentukan penyelesaian maksima bagi masalah-masalah di dalam bidang teknologi ini. Dalam eksperimen pertama, tiga tugas kognitif iaitu penyelesaian matematik cepat, permainan santai dan bermain telah disiasat. Ciri-ciri tersebut telah diekstrak menggunakan kepadatan spektrum daya (PSD), entropi log-tenaga, dan sentroid spektrum dan ciri yang diekstrak telah diklasifikasikan melalui mesin vektor sokongan (SVM), jiran terdekat-K (K-NN), dan diskriminasi linear analisis (LDA). Dalam eksperimen ini, ketepatan klasifikasi terbaik untuk set data dari saluran tunggal peranti EEG dan dari lima saluran peranti EEG masing-masing adalah 86% dan 91.66% telah diperolehi dengan menggunakan pendekatan PSD-SVM. Ekspresi wajah berdasarkan kenyitan mata iaitu kenyitan mata kiri, kenyitan mata kanan dan tidak ada kedipan mata telah dikaji melalui teknik cepat transformasi Fourier (FFT) dan ciri julat sampel dan kemudian ciri-ciri yang diekstrak telah diklasifikasikan menggunakan SVM, K-NN, dan LDA. Ketepatan terbaik (98.6%) telah dicapai dengan pendekatan berasaskan julat-SVM. Ekspresi wajah berdasarkan mata berkelip telah diselidiki menggunakan metodologi yang sama dengan kajian ekspresi wajah berdasarkan kenyitan mata. Selain itu, pendekatan pengesanan puncak PSD juga telah digunakan untuk menghitung jumlah kedipan mata. Ketepatan optimum 99% telah dicapai dengan menggunakan pendekatan pengesanan puncak PSD. Selain itu, pergerakan tangan citra motor dua kelas telah diklasifikasikan menggunakan SVM, K-NN, dan LDA di mana ciri tersebut telah diekstrak melalui PSD, centroid spektrum dan transformasi gelombang berterusan (CWT). Ketepatan optimum 74.7% telah dicapai dengan menggunakan pendekatan PSD-SVM. Akhirnya, dua prototaip arahan peranti telah direka untuk menterjemahkan output pengkelasan klasifikasi. Satu prototaip dapat menerjemahkan empat jenis tugas kognitif dari segi 5 Watt empat mentol berwarna yang berbeza, manakala, prototaip lain dapat mengendalikan motor DC yang menggunakan tugas kognitif. Kajian ini telah menggambarkan penerapan setiap komponen BCI untuk memudahkan penggunaan alat bantu gelombang otak. Akhirnya, tesis ini berakhir dengan meramal arah masa depan mengenai isu-isu semasa teknologi BCI dan petunjuk ini dapat meningkatkan kebergunaan untuk pelaksanaan aplikasi komersial bukan sahaja untuk orang kurang upaya tetapi juga untuk sebilangan besar pengguna yang sihat.

ABSTRACT

A brain-computer interface (BCI) provides an important alternative for disabled people that enables the non-muscular communication pathway among individual thoughts and different assistive appliances. A BCI technology essentially consists of data acquisition, pre-processing, feature extraction, classification and device command. Indeed, despite the valuable and promising achievements already obtained in every component of BCI, the BCI field is still a relatively young research field and there is still much to do in order to make BCI become a mature technology. To mitigate the impediments concerning BCI, the study of cognitive task together with the EEG feature and classification framework have been investigated. There are four distinct experiments have been conducted to determine the optimum solution to those specific issues. In the first experiment, three cognitive tasks namely quick math solving, relaxed and playing games have been investigated. The features have been extracted using power spectral density (PSD), log-energy entropy, and spectral centroid and the extracted feature has been classified through the support vector machine (SVM), K-nearest neighbor (K-NN), and linear discriminant analysis (LDA). In this experiment, the best classification accuracy for single channel and five channel datasets were 86% and 91.66% respectively that have been obtained by the PSD-SVM approach. The wink based facial expressions namely left wink, right wink and no wink have been studied through fast Fourier transform (FFT) and sample range feature and then the extracted features have been classified using SVM, K-NN, and LDA. The best accuracy (98.6%) has been achieved by the sample range-SVM based approach. The eye blinking based facial expression has been investigated following the same methodology as the study of wink based facial expression. Moreover, the peak detection approach has also been employed to compute the number of blinks. The optimum accuracy of 99% has been achieved using the peak detection approach. Additionally, two-class motor imagery hand movement has been classified using SVM, K-NN, and LDA where the feature has been extracted through PSD, spectral centroid and continuous wavelet transform (CWT). The optimum 74.7% accuracy has been achieved by the PSD-SVM approach. Finally, two device command prototypes have been designed to translate the classifier output. One prototype can translate four types of cognitive tasks in terms of 5 watts four different colored bulbs, whereas, another prototype may able to control DC motor utilizing cognitive tasks. This study has delineated the implementation of every BCI component to facilitate the application of brainwave assisted assistive appliances. Finally, this thesis comes to the end by drawing the future direction regarding the current issues of BCI technology and these directions may significantly enhance usability for the implementation of commercial applications not only for the disabled but also for a significant number of healthy users.

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LIST OF SYMBOLS

δ	Delta
θ	Theta
α	Alpha
β	Beta
Γ	Gamma
$\boldsymbol{\mu}$V	Micro-Volt
Hz	Hartz
F	Frontal lobe
P	Parietal lobe
T	Temporal lobe
O	Occipital lobe
p(x)	Probability distribution function
c_t	Cell state
h_t	Hidden state
f_t	Forget gate
i_t	Input gate
g_t	Cell candidate
O_t	Output gate

LIST OF ABBREVIATIONS

AEP	Auditory evoked potential
AUC	Area under the Curve
ALS	Amyotrophic lateral sclerosis
AP	Action potential
AR	Autoregressive model
AFA	Amplitude frequency analysis
AIMF	Analytic intrinsic mode functions
BCI	Brain–Computer Interface
BP	Band Power
BMI	Brain–Machine Interface
BOLD	Blood oxygenation level dependent
BSS	Blind source separation
CLIS	Completely locked-in state
CAR	Common average referencing
CNS	Central nervous system
CSP	Common spatial patterns
CNN	Convolutional neural networks
CBP	Checkerboard paradigm
CSSSP	Common sparse spatio-spectral patterns
CWT	Continuous wavelet transforms
CCA	Canonical Correlation Analysis
DBI	Direct brain interface
DBN	Deep belief networks
DFT	Discrete Fourier transform
DTW	Dynamic time warping
DWT	Discrete wavelet transforms
DM	Density matrix
ErrP	Error-related potential
ECG	Electrocardiogram, Electrocardiography
ECoG	Electrocorticogram, Electrocorticography
EEG	Electroencephalogram, Electroencephalography

EMG	Electromyogram, Electromyography
EMD	Empirical mode decomposition
EOG	Electrooculogram
EP	Evoked potential
EPSP	Excitatory postsynaptic potential
ERD	Event-related desynchronization
ERP	Event-related potential
ERS	Event-related synchronization
FES	Functional electrical stimulation
FN	False negative
FNR	False negative rate
FP	False positive
fMRI	Functional magnetic resonance imaging
fNIR	Functional near infrared
FFT	Fast Fourier Transformation
GAN	Generative adversarial network
GDI	Gini Diversity Index
HCI	Human–computer interface
IFSECN	International Federation of Societies for Electroencephalography and Clinical Neurophysiology
ICA	Independent component analysis
IPSP	Inhibitory postsynaptic potential
ITR	Information transfer rate
K-NN	K-nearest neighbor
LDA	Linear discriminant analysis
LFP	Local field potential
LogEE	Log Energy Entropy
LIS	Locked-in state
MEG	Magnetoencephalogram, magentoencephalography
MEP	Movement-evoked potential
MRCP	Movement-related cortical potential
MI	Motor imagery
MND	Motor neuron disease

MRI	Magnetic resonance imaging
NMD	Nonlinear mode decomposition
MSD	Multi-scale Shape Description
NIRS	Near-infrared spectroscopy
NN	Neural Network
PCA	Principal component analysis
PSD	Power spectral density
PET	Positron emission tomography
PSF	Phase space feature
ROC	Receiver Operating Characteristic
RCP	Row column paradigm
RSVP	Rapid serial visual presentation
RBM	Restricted Boltzmann machines
RNN	Recurrent neural networks
SuBAR	Surrogate-based artifact removal
SCP	Slow cortical potential
SMA	Supplementary motor area
SMR	Sensorimotor rhythm
SOBI	Second-order blind identification
SNR	Signal-to-noise ratio
SVM	Support vector machine
SSVEP	Steady-state visual-evoked potential
SSAEP	Steady-state auditory evoked potential
SSSEP	Steady-state somatosensory evoked potential
SWCS	Sliding window cropping strategy
SAE	Stacked autoencoder
TP	True positive
TPR	True positive rate
TN	True negative
VEP	Visual evoked potential
VR	Virtual reality
WHO	World health organization
WT	Wavelet Transforms

WPA	Wavelet packet analysis
WPS	Wavelet Packet Statistics
WPES	Wavelet Packet Energy Statistics

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