DISCRIMINATION OF HEALTHY CONTROLS AND SELECTED VISUALLY IMPAIRED THROUGH VISUALLY EVOKED POTENTIALS

By

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LIST OF ABBREVIATIONS

Acc	Overall accuracy
ACNS	American Clinical Neurophysiology Society
AIRS	Artificial Immune Recognition System
ANOVA	Analysis of Variance
ANFIS	Adaptive Network-Based Fuzzy Inference System
ANN	Artificial Neural Network
BCI	Brain Computer Interface
CF	Colour Fusioned
DFT	Discrete Fourier Transform
DR	Dimensional Reduction
DSP	Digital Signal Processing
DWT	Discrete wavelet transforms
EEG	Electroencephalogram
ELM	Extreme Learning Machine
ERP	Event Related Potentials
FFT	Fast Fourier Transform
FN	False Negative
FmA	Frequency-Maximum Amplitude

FP	False Positive
FPI	Fusion of Principle Component Analysis and Independent Component Analysis
GDA	Generalized Discriminate Analysis
GUI	Graphical User Interface
HC	Healthy Control
ICA	Independent Components Analysis
ISCEV	International Society for Clinical Electrophysiology of Vision
LCD	Liquid Crystal Display
LDA	Linear Discriminant Analysis
LM	Levenberg Marquart
LS-SVM	Least Square Support Vector Machine
mfVEP	Multifocal Visual Evoked Potential
ms	Milliseconds
MS	Multiple Sclerosis
MSR	Mean of Square Root of Standard Deviation
mPSC	Modified Particle Swarm Clustering
Np	Negative predictivity
OH	Ocular Hypertension

PCA	Principal Component Analysis
PERG	Patterned Electroretinogram
PNN	Probabilistic Neural Network
PRVEP	Pattern Reversal VEP's
PSC	Particle Swarm Clustering
Pp	Positive Predictivity
RCE	Rapid Centroid Estimation
Se	Sensitivity
ST	Stockwell Transform
Std	Standard Deviation
STDfmax	Standard Deviation Of Maximum Amplitude
Sp	Specificity
SVM	Support Vector Machine
TN	True Negative
TP	True Positive
VEP	Visually Evoked Potentials
VI	Vision Impaired
WHO	World Health Organization

Diskriminasi Subjeck Kawalan dan Kecacatan Penglihatan Terpilih Melalui Potensi Elektrik Rangsangan Visual

ABSTRAK

Tesis ini membentangkan pendekatan melalui teknik pemprosesan isyarat mengunakan potensi elektrik rangsangan visual (VEP) bagi menyiasat kecacatan penglihatan. Kecacatan penglihatan merupakan istilah yang digunakan untuk menggambarkan sebarang bentuk kehilangan penglihatan. Antara teknik konvensional yang sering digunakan untuk menyiasat kecacatan penglihatan ialah pengimejan fundoscopy, pengimejan ultrasound, dan pemeriksaan manual retina. Teknik-teknik ini mempunyai beberapa kelemahan seperti kualiti imej yang rendah dihasilkan oleh pengimejan ultrabunyi, memerlukan pakar, dan terdedah kepada kesilapan dalam pemeriksaan manual. VEP menawarkan kaedah objektif untuk mendiagnostik kecacatan penglihatan pada pesakit. VEP adalah isyarat elektrik yang dihasilkan oleh otak (Occipital Cortex) sebagai tindak balas terhadap rangsangan visual. Dengan menganalisis tindak balas ini, keabnormalan dalam laluan visual seseorang boleh dikesan. Pembangunan algoritma pengekstrakan ciri dan pengelasan untuk penyiasatan kecacatan penglihatan melalui VEP masih di peringkat awal. Oleh itu, ciri ciri isyarat VEP tunggal dalam konteks masa, frekuensi, dan skala –masa/frekuensi dikaji dan algoritma pengekstrakan ciri dan klasifikasi yang berkesan dicadangkan untuk membezakan kecacatan penglihatan. Empat kaedah pengekstrakan ciri yang berbeza berdasarkan masa, frekuensi, 'wavelet', dan 'Stockwell transform' telah diteroka dan ciri-ciri statistik telah dicadangkan untuk analisis VEP. Satu teknik penambahbaikan ciri baru telah dicadangkan untuk meningkatkan variasi dalam data sebelum analisis. Tiga teknik pengurangan ciri yang berbeza digunakan untuk mengurangkan ruang dimensi ciri-ciri. 'Extreme learning machine', 'least square support vector machine' dan 'probabilistic neural networks' telah digunakan untuk menilai prestasi ciri-ciri dalam mendiskriminasi kecacatan penglihatan. Analisis statistik telah digunakan untuk menunjukkan kepentingan pemprocesan awal ciri-ciri, manakala ukuran penilaian prestasi seperti sensitiviti, kekhususan, predictivity positif, predictivity negatif, dan ketepatan keseluruhan digunakan untuk menilai keberkesanan teknik pengelasaan. Data dari dua tetapan eksperimen yang berbeza telah digunakan dalam analisis ini. Eksperimen pertama dijalankan untuk mengkaji kesan saiz petak rangsangan visual papan main dam terhadap potensi rangsangan manakala eksperimen kedua dikendalikan untuk menyiasat prestasi rangsangan visual bergabung warna dalam menghasilkan potensi rangsangan VEP yang berguna. Hasil kajian ekperimen ini menunjukan bahawa ciri-ciri yang diekstrak dari VEP yang dirangsang oleh rangsangan visual gabungan warna yang dicadangkan berguna dalam mengklasifikasi kacacatan penglihatan. Ketepatan 100% telah dicapai megunakan kombinasi rangsangan visual baru dan kaedah pengekstrakan ciri-ciri yang dicadangkan.

Discrimination of Healthy Controls and Selected Visually Impaired through Visually Evoked Potentials

ABSTRACT

This thesis presents a digital signal processing based detection of healthy controls and selected visually impaired through visually evoked potentials (VEP). Visual impairment is a term used by ophthalmologist to describe any kind of vision loss, whether it's partial or total vision loss. Some of the conventionally used techniques for the investigation of vision impairments include fundoscopy imaging, ultrasound imaging, and manual inspection of retina. These techniques have several disadvantages such as poor quality of images produced by the ultrasound imaging, require experts, and are prone to error in manual inspection. The VEP provides an objective method for the diagnostics of vision impairments in patients. VEP is an electrical signal generated by the brain (Occipital Cortex) in response to a visual stimulus. By analyzing these responses, the abnormalities in the visual pathways of a person can be detected. The development of feature extraction and classification algorithms for investigation of vision impairments through VEPs however is still at an infancy level. Therefore, this study was carried out to investigate the time, frequency, and time-scale/frequency characteristics of the single trial transient VEPs, and propose an efficient feature extraction and classification algorithm for distinguishing the vision impairments. Four different feature extraction methods based on time, frequency, wavelet, and Stockwell transform were explored and statistical features were proposed for the VEP analysis. A new feature augmentation technique was proposed to enhance the variation of the data prior to the analysis. Three different feature reduction techniques were used to reduce the dimensional space of the features. Extreme learning machine, least square support vector machine and probabilistic neural networks were employed to evaluate the performance of the features in discriminating the vision impairments. Statistical analysis were used to demonstrate the significance of the preprocessed features, while performance measures such as sensitivity, specificity, positive predictivity, negative predictivity, and overall accuracy was considered for the evaluation of the classifiers. The dataset from two different experimental settings were used in the analysis. The first experiment was conducted to investigate the effect of different sizes of checkerboard stimulus to the resulting evoked responses while the second experiment was perpetrated to investigate the performance of the new colour fusioned checkerboard stimulus in elicitating reliable VEP responses. The experimental investigation elucidate that features derived from the VEP elicited by the proposed stimulus performed well in classifying the vision impairments. Promising 100% accuracy was achieved using the combinations of the proposed stimulus and feature extraction methods.

CHAPTER 1

INTRODUCTION

This chapter presents an introduction to vision impairments, discussion on conventional methods used for the diagnosis of vision impairments, drawbacks of the existing methods and the advantages of using visually evoked potentials based analysis. The main objectives of the proposed research and the organization of the thesis are also discussed in this section.

1.1 Research Overview

Vision is undoubtedly one of our greatest sensory systems. It influences the way humans perceive the environments. Visual sensory systems enable us to differentiate the light from dark, perceive colours, and coordinate limb movements. Loss of vision can severely affect the functional ability of a human in performing daily activities or safely navigating through the environment (Freeman, K.F., Cole, R.G., Faye, E.E., Freeman, P.B., Goodrich, G.L., & Stelmack, J.A., 1997). Some of the specific problems include difficulty in carrying out work related tasks or leisure activities, inability to recognize faces and loss of ability in driving. When these inabilities limit the personal or socio-economic independence of a person, a visual handicap occurs (Freeman, K.F. et al., 1997).

A visual impairment can medically be defined as a functional limitation of the visual system and can manifest as reduced visual acuity, visual perceptual difficulties, visual field loss, visual distortion, diplopia, photophobia or any of these combinations

(Freeman, K.F. et al., 1997). It can be a result of congenital abnormalities (e.g., pre or post-natal trauma, genetic or developmental abnormalities), hereditary or acquired condition later in life (eg., age related changes, ocular infections or trauma). According to the survey on vision impairment conducted by Malaysian Association for the Blind, an estimated 1 million people are visually impaired out of 28.27 million people in Malaysia (Oviam Solutions, 2010). Some might have difficulties in focusing objects that are far away while others have problems reading small prints. These types of disorders can often be treated with eye glasses or contact lenses. But when one or more parts of the eye or brain that are needed to process images become diseased or damaged, severe or total loss of vision can occur. In these cases, vision cannot be fully restored with medical treatment, surgery, or corrective lenses like glasses or contacts.

Often, patients neglect consulting medical experts at the early stages of the diseases and only seek medical attentions when their vision is partially diminished. By the time their visual abnormality is diagnosed, the damage might be irreversible. An early diagnosis can prove to be useful in preventing serious damages to the vision. The commonly used techniques for the diagnosis of vision impairments in medical facilities include fundoscopy imaging, ultrasound imaging, and manual inspection of retina. These methods however, heavily rely on the expertise of the medical practitioner, subjective and can take long hours for complete diagnosis. The misdiagnosis by human errors can also severely affect the recovery rate of the patient's vision.

Therefore, a new method of analysis using Visually Evoked Potentials (VEP) has been proposed in the literature (Sokol, S., 1976). Researchers have tried to analyze the different components of peaks that were present in the transient VEP responses by averaging a minimum of 64 single trial responses (Holder, G., 2004; Odom, J., Bach, M., Brigell, M., Holder, G., McCulloch, D., & Tormene, A., 2009; Sivakumar, R. &

Ravindran , G., 2006). The commonly examined peaks were the N75, P100, and N125 peaks in which N denotes the negative peaks; P denotes the positive peaks while the numbers indicate the time in milliseconds (ms). By determining the amplitude and the latency of the peaks, the researchers categorized the evoked responses.

These types of analysis were subjective and found to be nonspecific to a common disease. Although humanity have gone great lengths in developing various tools for analyzing discrete signals, the development of signal processing algorithms for characterizing the VEP signal is still in progress. Therefore, this research work was intended to utilize the Digital Signal Processing (DSP) tools to study the unchartered region of VEP responses.

1.2 Problem Statement and Significance of the study

According to the survey on vision impairments by World Health Organization (WHO), 285 million people were estimated visually impaired worldwide (World Health Organization [WHO], 2011). An earlier detection and treatment of the vision impairment can avoid or cure 80% of the vision loses. Nowadays, ophthalmologists widely use fundoscopy imaging, ultrasound imaging, and manual inspection of retina for the investigation of ocular diseases (Atta, H., 1999; Freeman, K.F. et al., 1997). These practices however are subject to drawbacks such as poor quality of images produced by the ultrasound imaging, requires experts, and is prone to error in visual inspection (Abdel-Dayem, A.R. & El-Sakka, M.R., 2007). This will cause difficulties in the treatment of the patients. VEPs have been commonly used in developed nations as an alternative diagnosis method to circumvent the drawbacks in conventional methods. It is widely accepted among ophthalmologists and neurologists that the VEP is always abnormal in patients with ocular diseases (Frederiksen, J.L. & Petrera, J., 1999). The VEP based method is an objective, reproducible, sensitive and continuous measure of the function of the visual pathways (Frederiksen, J.L. & Petrera, J., 1999).

The amplitude and latency values were commonly used parameters for the investigation of VEP's. The amplitudes examined were N75, P100, and N125. The latency value was referred as time taken for a visual stimulation to travel from the eye to the occipital cortex and was determined by identifying the positive P100 peak (Diem, R., Tschirne, A., & Bähr, M., 2003; Holder, G., 2004; Odom, J. et al., 2009; Sivakumar, R. & Ravindran , G., 2006). This method of analysis however, was prone to error. Ensemble averaging used to separate the VEP responses from the accompanying electroencephalogram (EEG) signals results in information related to variation between the single trials to be lost that might be crucial in determining the nature of a disease (Odom, J. et al., 2009; Quian Quiroga, R., 2000; Quian Quiroga, R., Rosso, O., Ba ar, E., & Schürmann, M., 2001). The averaging process also assumes that the reaction of the subject to the visual stimulus was stationary. Since larger numbers of trials were required to perform the averaging, the patients have to endure longer testing hours. This could affect the concentration of the patients, and ultimately affect the diagnosis accuracy.

Therefore, this study was undertaken to explore the various possibilities of using DSP tools to analyze the VEP responses. The best stimulus for inducing reliable VEP responses was investigated. The characteristics of the VEP signal in time, frequency, and time-scale/frequency domains were studied and the best combination of features and classification methods were reported.

1.3 Research Objectives

This research aims to investigate selected vision impairments using visually evoked potentials, DSP algorithms and artificial intelligence techniques. Despite the presence of various studies in literature, this work focuses on some of the problems that have yet to be addressed such as the best checker sizes for inducing VEPs, the ability of colour based stimulus in inducing variation between the healthy controls and visually impaired as well as identification of potential new parameters to capture the minute and hidden information from the VEP data for the detection of vision impairments. The objectives formulated for the successful implementation of the study were as follows.

1) To investigate the effect of different checker sizes and the performance of colour fused checkerboard stimulus in inducing reliable VEP responses for discrimination of selected vision impairments.

2) To extract salient features from the VEP responses of healthy controls and selected vision impaired using selected digital signal processing (DSP) techniques.

3) To enhance and classify the extracted features using the selected feature enhancement method and classifiers.

4) To evaluate the proposed methods in differentiating healthy controls and vision impaired.

1.4 Scope of the thesis

This thesis presents a systematic approach to the investigation of vision impairment through VEPs. Since there were number of downsides to the conventional method of analysis, a more objective approach through DSP tools was investigated in this research work. The VEP data used for the study was limited to the use of pattern reversal visual stimulus. Although there are multiple possibilities for the improvement in diagnostic accuracy of vision impairment, this thesis is limited to the use of selected signal processing techniques to analyze the single trial VEP responses. This research work concentrates on improving the classification accuracy of the predictive algorithms in classifying the HC and VI groups, and therefore does not consider the diagnosis of different types of vision impairments.

Thus, this thesis is limited to the use of time, frequency, time-scale/frequency based feature extraction methods to analyze the VEP responses for classification of vision impairments. The performance of the classifiers in distinguishing the HC and VI is only evaluated through performance measure such as accuracy, specificity, sensitivity, positive predictivity and negative predictivity. Since there is a difficulty in obtaining higher number of VI subjects, this research centers on VEP dataset collected from 16 subjects with the use of g.Bsamp EEG bioamplifier. All the stimulations performed are limited to the MATLAB 7.0 environment.

1.5 Thesis Organization

The research works carried out are presented in seven chapters in this thesis. Chapter 1 (current chapter) provides an introduction to the vision impairments and a