A DUAL-CHANNEL OPTICAL BRAIN-COMPUTER INTERFACE IN A GAMING ENVIRONMENT

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ABSTRACT

This paper explores the viability of using a novel optical Brain-Computer Interface within a gaming environment. We describe a system that incorporates a 3D gaming engine and an optical BCI. This made it possible to classify activation in the motor cortex within a synchronous experimental paradigm. Detected activations were used to control the arm movement of a human model in the graphical engine.

1. INTRODUCTION

We demonstrate the use of an Optical Brain-Computer Interface (OBCI) within a gaming environment. A possible application for this new technology, outside the usual biomedical realm, is investigated in this paper. To date no practical application has been developed for the novel OBCI used in these experiments.

BCIs have been developed using a number of different physiological signal measurement techniques such as functional Magnetic Resonance Imaging (fMRI) [1] and electroencephalography (EEG) [2]. The BCI we will discuss is based on Near-Infrared Spectroscopy (NIRS). This system uses near-infrared light to measure the subtle and correlated changes in oxy-haemoglobin and deoxy-haemoglobin due to activation of parts of the cerebral cortex.

Potential applications of NIRS including neuroprosthesis and Human Computer Interaction (HCI) have been proposed, predominantly for the severely disabled [3]. However, applications of brain imaging BCIs for gaming have been developed using EEG [4], and fMRI [5]. In these previous studies the objective was to navigate a virtual cave or maze using thought processes alone. The subject evokes a haemodynamic response simply by carrying out a predetermined mental task such as mental arithmetic (Frontal Cortex) or mental visualization of limb movement (motor imagery in the Primary Motor Cortex / Supplementary Motor Area) [6]. The elicited signals are quite reproducible, and highly localized within specific regions of the cerebral cortex.

A single channel NIRS-BCI [3] was used for the initial experiments. The responses were passed into a graphical 3D front-end and experiments were conducted to test whether responses elicited from the system were sufficient to control a human avatar. Dual-channel motor imagery trials have been conducted, and preliminary results are presented below.

2. BACKGROUND

2.1. Near-Infrared Spectroscopy

With the advent of optical measurement of tissue oxygenation by Jobsis [7] came the possibility of cerebral haemodynamic monitoring through non-invasive means, namely Near-Infrared Spectroscopy (NIRS). A simple description of spectroscopy is that it is the study of matter using electromagnetic (EM) radiation. In the Near-Infrared region of the EM spectrum there is an optical window (600–950 nm) for light to penetrate the skull and brain tissue. Within this EM region water is largely transparent, and haemoglobin's absorption properties vary slightly depending on its oxygenation level. Light in this EM region can penetrate 2–4 cm below the scalp. Due to the similar refractive index of skull and brain tissue in the NIR region, a portion of the light not absorbed is reflected, exits the skull, and is collected by a detector.

The two main chromophores in brain tissue that are not constant absorbers and that indicate tissue oxygenation are oxy-haemoglobin (HbO) and deoxy-haemoglobin (Hb). These chromophores have different absorption coefficients depending on the wavelength of light used. Based on the analysis of the light detected after absorption and scattering in brain tissue, HbO and Hb concentrations can be determined. These concentrations are then used to assess tissue oxygenation in the region of the cerebral cortex directly below the source and detector.

With an elicited activation, e.g., movement or visualization of movement of a limb, a neurovascular process ensues resulting in changes in Cerebral Blood Flow (CBF), Cerebral Blood Volume (CBV) and Metabolic Rate of Oxygen Consumption ($CMRO_2$). The collective result is an increase in oxy-haemoglobin and decrease in deoxy-haemoglobin within the activated period. When activation ceases these levels the baseline. By monitoring these concentrations the detected activations can then be translated into commands to a device or a prosthetic limb.

2.2. Brain-Computer Interfacing.

A Brain-Computer Interface is a device which can give the user an output channel other that the normal output pathways of the brain. Physiological signals are detected from the brain and translated into commands to control an external device. A BCI can be utilized to write letters as a word processor, control a cursor or move a prosthetic limb. Implanted electrodes or surface EEG have been used within a BCI [8]. Physiological signals include visual evoked potentials, differential modulation of the α-rhythms, P300 evoked potentials (oddball response used in brain fingerprinting of convicts [9]), μ- and β-rhythms, and slow cortical potentials.

Some of these systems require a extensive user training to obtain a reasonable success rates. This can lead to frustration and even abandonment of the device. Other systems use motor imagery as the control signal [4]. However, an Optical Brain-Computer Interface [10] is less invasive, less cumbersome, and more user friendly than other functional brain imaging modalities. To date, insofar as the authors are aware, no application of an OBCI has been previously developed.

2.3. NIRS-BCI

The feasibility of the exploitation of NIRS for a BCI was explored recently with a novel OBCI [10]. This was implemented by visualization of hand movement as the control signal. As well as being non-invasive, advantages of an OBCI include high temporal resolution (100 ms), portability, no ionizing or otherwise potentially dangerous radiation, and suitability for long-term use rendering it safe even for chronic use in a neonatal monitoring [11]. In addition, it requires little or no training (first person kinesthetic imagery has been mooted to require training) [12]. The system also has the potential for use with neuroprosthesis [3] and it has been suggested in literature that a non-invasive BCI may be a more prudent approach for subjects with disabilities such as cortical atrophy [13].

Disadvantages include a lengthy time constant due to the inherent slow haemodynamic response, which limits the baud rate of the device to about 5–6 bits/minute/channel. Development of a multi-channel OBCI device, along with more advanced signal processing and source-detector configurations should all help to increase the system bandwidth. Altering the source detector geometry has been shown to improve spatial resolution [14]. A direct neural correlate, or Fast Event-Related Optical Response (EROS), with a temporal resolution comparable to EEG, has been discussed in the literature; however although its origins and even its existence are still highly contested [15].

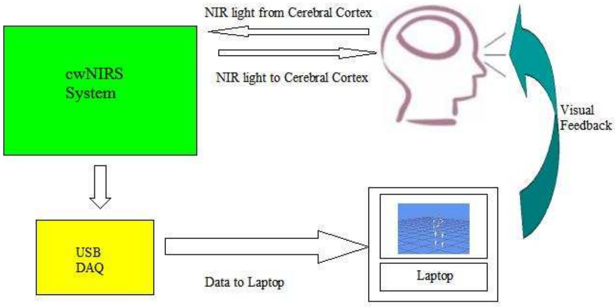

Fig. 1. Hardware Flow Diagram

3. METHODS

3.1. Hardware

The Continuous Wave NIRS (cwNIRS) system (see Figure 1) is composed of two lock-in amplifiers (Ametec 5210), an LED driver, two Avalanche Photodiodes (APD) (Hamamatsu C5460-01), function generators, and LEDs at 760 nm and 880 nm for determination of Hb and HbO, respectively. A dual-channel system was used to monitor the cerebral cortex at C3 and C4 on the primary motor cortex of the International 10-20 electrode placement system. Light from the two sources (each with a 760 nm and 880 nm LED) are driven with carrier waves ranging from 3.4–12 kHz. Infrared light penetrating the subject's head is collected by the highly sensitive APDs after being modulated by the brain, and sent to the lock-in amplifiers for demodulation, filtering, etc.

A new data collection system was introduced for these experiments. The system required more robust data acquisition as well as a simpler interface that would function under the Microsoft .NET Framework. A National Instruments USB-6009 Multi-function DAQ was used to digitize the output of the analogue filters. Commands generated by analysis of detected signals described below control the avatar. Real-time feedback is displayed for the subject. Such feedback has been shown to increase the performance of the response as the user learns to control the asymmetry of their cerebral hemispheres [16].

Initially, simple moving-average filters were used as an online low-pass filter with a cutoff of 1 Hz. During offline experiments the data was preprocessed with different algorithms to attempt to derive the best system to implement online. (Further methods designed specifically for NIRS like the pulse regression algorithm [17] and those developed by Coyle et al. [18] will be implemented in later iterations of the software.)

3.2. Subjects and Experiments

Three subjects (all healthy, two right-handed and one left-handed, two male and one female, all 23–24 years old) participated in the experiments after giving informed consent. All subjects had normal or corrected-to-normal vision, and no pertinent medical history. Two of the subjects had no previous experience with NIRS experiments.

Each subject was placed in a supine position in a dimly lit room. The supine position is known to reduce the effect of the Mayer Wave: inherent slow oscillation thought to be due to blood pressure fluctuations and usually with a period of 10–15 sec [19]. These phenomena are a significant cause of frustration in the NIRS field, as they are the main source of physiological noise within the bandwidth of the haemodynamic response. Each subject remained still with eyes fixed on the laptop screen for commands and avatar feedback. Monitoring cortical regions C3 and C4 on the homunculus measured responses to overt motor movement or motor imagery. (Electrode positions C3 and C4 are widely accepted as being related to right and left hand movement, respectively.) Each subject was instructed to observe commands from the screen to perform or visualize performing a non-sequential finger opposition task of either the left or right hand, at a rate of 2 Hz (thumb opposing each finger in a random fashion). The user then observed the reactions of the avatar on the screen.

3.3. Gaming Engine

This system used a graphics engine originally designed for a motion tracking system [20], which presents an upright human model. This subsystem is written in C#, and allows easy real-time control of a simple human skeleton, or other geometric model. These models are laid out in a Biovision BVH file which deals with the recording and playback of motion tracking. The skeleton is drawn using the DirectX 9c libraries. Using this engine, it was straightforward to use both off- and online data to test the system.

Offline data was fed into the system initially to classify and analyze activation periods and set response intensities. In this way, it was possible to model the effect of real-time data on the system. Using different data sets that varied in quality, the system's response to both poorly- and well-defined activations could be measured and understood.

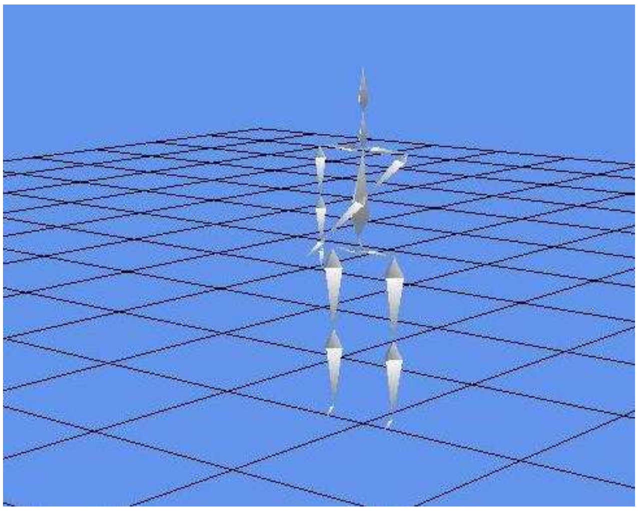

Fig. 2. Graphics Engine in Action

The first implementation of the interface within this engine induced arm movement that followed the trends of the Hb and HbO data. The left arm followed the Hb, while the right followed HbO. During online experiments the subject was encouraged to attempt to move the arms of the avatar to given positions using an overt or visualized stimulus. The software gave commands to the subject to begin activation. The model's arms would then begin to move up and down according to the haemodynamic response. During these experiments the software calculated, in real time, the concentrations of Hb and HbO from the raw light intensities using the modified Beer-Lambert law. The high frequencies were then filtered out, and the resulting trends were stored for processing within the graphical engine, and used to control the direction and intensity of the arm movement.

In a further implementation, classification of true activation was demonstrated by comparing Hb and HbO trends. The inverted correlation between these concentrations properly defined brain activation. A single-channel system would cause an arm to rise as long as a genuine activation was detected.

To implement a second channel, an optode was placed over the C4 region of the user's primary motor cortex. The data from this channel was analyzed to control the avatar's second arm in a similar fashion.

4. RESULTS

4.1. Data

The protocol for these experiments were 15 seconds rest followed by 25 seconds of stimulus, repeated 5 times. The initial 10 seconds of data was discarded. All experiments presented here are single-trial results, with no multi-trial av-

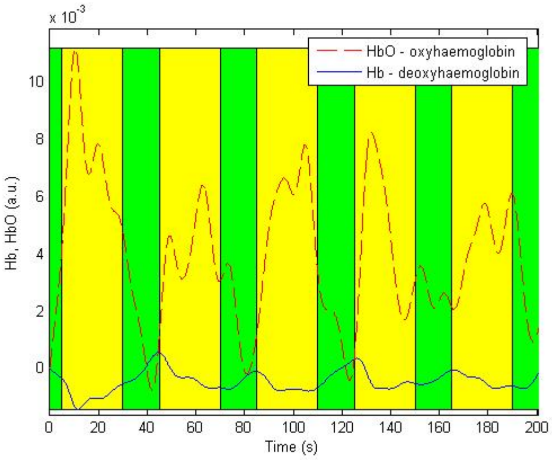

Fig. 3. Motor stimulus data from activations detected in the area under C4 during Overt Tasks

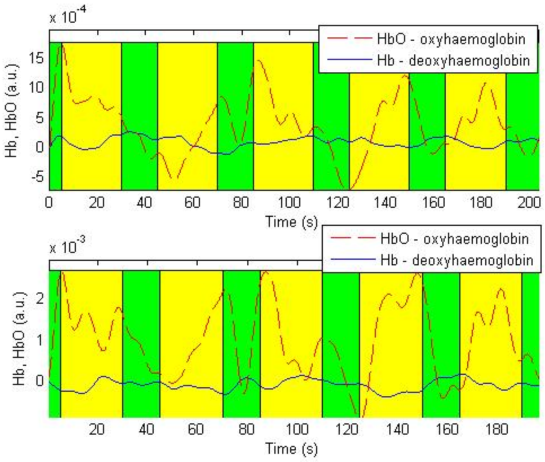

Fig. 4. Stimulus data from a dual-channel motor imagery experiment

eraging.

This system was able to classify activation in the motor cortex in a synchronous paradigm. Figure 3 shows the results from a single experiment in which data was recorded from the C4 area while the subject performed a finger opposition task. Activations can be seen as the inverse correlation of the Hb and HbO trends during stimulus periods.

Figure 4 is the result of data recorded from a dual-channel motor imagery experiment. In both channels it is apparent that the user failed to successfully visualize the task during two of the trials. This may possibly be improved by more user training and increased visual feedback.

4.2. Gameplay

The final system challenges the user to raise the arms of the avatar to a particular point. Using the dual channel setup to detect separate lateralized activation has yet to be investigated. Better classification of the response will maximize the potential for independent activation detection in an asynchronous paradigm.

The gaming system represents a significant advance in the application of OBCIs. Insofar as the authors are aware, it is the first time an OBCI has been used outside of the biomedical area. It would be possible to use the system, as it stands, in other gaming environments. The next stage of our plan is to implement the avatar negotiating a maze using motor imagery alone. At each intersection the user will be given a choice of direction. These choices will be highlighted in sequence, and the user will be instructed to visualize movement while the direction they wish to turn or proceed in is highlighted.

5. CONCLUSION

This above data would seem to indicate that an Optical Brain-Computer Interface based on near-infrared spectroscopy shows promise for simple gaming. A single-channel system can exert control in the gaming environment with similar accuracy to that of previous testing applications [3]. The limitations of a single-channel implementation, such as the low bit rate, restricts the possible complexity of the applications. We have demonstrated that imagined arm movement on the part of the subject can be translated into arm movement of a model in a game. Although the dual-channel experiments are still in their infancy, results have shown that with better signal processing and classification techniques it should be possible to integrate the system into a gaming experience.

Acknowledgments

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