Investigation into a Mixed Hybrid Using SSVEP and Eye Gaze for Optimising User Interaction within a Virtual Environment

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Abstract. Brain Computer Interface (BCI) technology has been used successfully in neurophysiological research laboratories, but has had less success when used outside the laboratory and particularly for people with disability. The hybrid BCI approach offers the potential for a more robust solution, with potential better usability to promote greater acceptance. The emphasis on improving human computer interaction may facilitate more widespread deployment, particularly where BCI alone has proved unsuccessful. This paper adapts an existing modular BCI architecture to support a 'mixed hybrid', by combining a BCI with a commercial eye tracker, and suggests graphical user interfaces to facilitate operation and control of a virtual environment.

Keywords: Hybrid, Brain, Computer, Interface, Eye-gaze.

1 Introduction

The Brain-Computer Interface (BCI) has successfully provided both communication and control of environments, by modifying attributes of the electroencephalogram (EEG) [1]. Consequently, this has facilitated the possibility of augmenting human interaction for a range of application domains, including assisted living and leisure activities.

Scalp recorded EEG is a noisy signal that represents a summation of sensory, motor and cognitive activity associated with neuronal and muscle structures in the head and brain. As a consequence, it provides a challenge for the implementation of reliable and robust BCI that can be used over long periods of time, ironically by the people who are in most need of the technology. Conversely, implanted electrodes have been shown to provide better signal quality, with some studies demonstrating successful long-term use [2]. Furthermore, a number of strategies have been employed in order to provide successful non-invasive BCI; the most common being the use of intended movement potentials, such as Event Related De-synchronization (ERD) and Event Related Synchronization (ERS), the evoked response to a 'target' stimulus (known as the P300 potential), and the recording of the Steady State Visual Evoked Potential (SSVEP), activated in response to a visual stimulus typically consisting of predefined

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frequencies of flickering light. Regardless of the success of individual strategies, it is important to facilitate a range of BCI paradigms, as one paradigm may be successful for an individual, whereas another may fail. By combining strategies, it is possible to produce a hybrid BCI (hBCI) that can increase the classification accuracy, hence further promote acceptance and adoption of the technology. Indeed, such a hybrid approach has been promoted in the BCI Roadmap [3].

An hBCI may also be devised that combines EEG with some other modality, such as eye-gaze interaction. This can potentially allow the two modalities to work sympathetically, providing respite for the user from focused concentration during either EEG recording or eye tracking based interaction. The modalities of the hybrid system could be used either sequentially or collaboratively, with each responsible for different functionality or combined for the same command classification. However, the latter could potentially lead to disagreement in the outcomes of the classification, and issues may also arise with regard to the technologies working within the same time frame. Furthermore, an alternate reason for incorporating a second modality could be to use one modality as a switch to turn on/off the hBCI system and the other modality for control [4].

This paper extends an architecture developed within the BRAIN project [14] to facilitate an hBCI. Software tools were previously developed for interface development, testing and SSVEP and ERD/ERS recording. The paradigms were used successfully on healthy volunteers outside the laboratory setting. However neither approach was sufficient by itself to facilitate usage with a target brain-injured cohort. Interfaces are proposed to support an hBCI, combining EEG with a commercial eye tracker system.

2 Background

Within the literature, a generally accepted definition of a BCI, is a system that provides a communication channel for users, which does not rely on physical movement [3], [5], [9-10]. From a system's point of view, a non-invasive BCI system provides software applications with real-time access to the cognitive state of the user based on EEG obtained during mental tasks. Regardless of the paradigm employed, a traditional BCI comprises a signal acquisition component that records brain signals, along with a signal-processing pipeline, which performs real-time signal preprocessing, feature extraction and control classification. Additionally, a BCI also contains one or more applications or devices, which provide the focus for both user control and feedback, and an application interface that determines interactions between components of the BCI [3], [7]. The majority of BCI systems focus on intentionally modulated brain signals, in which the outputs originate from brain activity that is directly controlled by the user, known as *Active BCI*. However, BCI systems may also utilize indirectly modulated brain signals and arbitrary brain signals, known as *Reactive BCI* and *Passive BCI* respectively [5], [9]. Furthermore, BCI systems are typically designed to operate in either a synchronous or asynchronous manner, with synchronous systems controlling the periods of user interaction with prompts, and asynchronous BCI permitting users to interact without such explicit cues [6], [11]. The primary applications of BCI systems include communication and control, motor substitution and recovery, and entertainment [9]. While the benefits of BCI systems are often focused on improving the lives of users suffering from conditions such as amyotrophic lateral sclerosis, BCI may also provide beneficial enhancements and insights for a wide range of users within the context of HCI [5-6].

By taking a user-centered design approach involving target user cohorts during the design process, and incorporating fundamental HCI design principles, more appropriate BCI systems may be realized [3], [18]. Moreover, extending the BCI paradigm by combining such systems with existing devices and assistive technologies, thus leading to the development of hybrid architectures, may help to overcome some of the challenges of using BCI as a single communication channel [1], [3-4], [6].

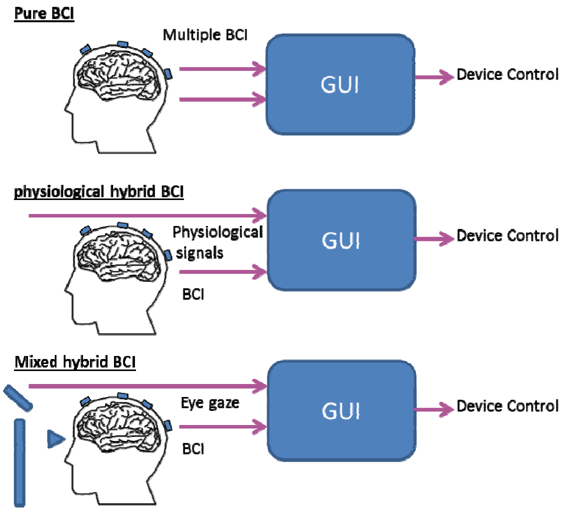


Fig. 1. Hybrid BCIs: pure, physiological and mixed

Such hybrid BCI (hBCI) systems are emerging that promote an innovative approach to the design of BCI, which permits users to utilize a broader range of communication strategies [6]. Indeed, hBCI is commonly defined as a system comprising at least one BCI communication channel that is utilized in conjunction with another assistive technology or input device [1], [3], [6], [10]. For example, an hBCI may derive input signals from a BCI and secondary BCI, known as a *pure hybrid*, or a BCI and signals from a secondary device based on either physiological sensors or communications, known as a *physiological hybrid* and *mixed hybrid* respectively [6], see Figure 1.Consequently, the two input devices are collaboratively employed, with signal processing being performed either sequentially or simultaneously [3], [6], [8], [10]. Subsequently, hBCI opens up the possibility of generating multimodal user interfaces, which facilitate augmented interaction that is more intuitive and natural for users [3]. However, due to the challenges associated with the complementary integration of multiple input mechanisms, the development of hBCI systems is considered to be more difficult task than the development of traditional BCI systems [6]. Furthermore, a key challenge for such systems is to increase the period of reliable operation, while reducing adverse impacts on the user [7].

3 EEG and Eye Tracker Hybrid BCI

This paper focuses on hBCI systems that combine BCI with an eye tracking system. Due to the robust, high bitrates associated with the input channel from an eye tracking system, binary command constraints associated with the low bitrate associated with BCI can be circumvented, resulting in a complementary hybrid system [5], [9], [12]. Currently, a number of examples of such hBCI systems exist that are primarily focused on touchless HCI [5-6], [8-9], [11-13]. These include the use of gaze based input with asynchronous ERD-based BCI for *search and select* tasks featuring both easy and difficult selection conditions within a two-dimensional environment [5-6], [9]. SSVEP and ERD/ERS-based BCI have been utilized in combination with eye tracking for search and selection tasks, and interaction with simple puzzle games [12]. Likewise, hBCI featuring asynchronous BCI and eye tracking have also been employed for text-entry applications [11] and three-dimensional search and select tasks [8]. Such research has shown that the use of eye tracking systems are appropriate for search [5], [9], [12], however without an additional communication channel, such as BCI, selection is difficult due to identifying suitable fixation times, known as *dwell time*. Indeed, by combining eye tracking with BCI, the issues associated with dwell times may be successfully addressed [9], [11].

Additionally, it was found that using information from the eye tracker to adaptively update the BCI component of the hybrid system resulted in a substantial reduction in the number of false positives observed [11]. Within the majority of these systems, a multimodal approach has been used, whereby pupil gaze is used to initially perform spatial navigation and either a fixation threshold, or imaginary selection command, forces a switch in input modality, subsequently permitting selection to be achieved using a predetermined mental state [8-9], [11], [13]. Although some degree of success has been observed with these hBCI systems, a number of issues have also been identified, including the need to define appropriate selection commands [5], [9], and the necessity to conduct both calibration and the time-consuming process of user training for the BCI system in order to ensure good overall performance of the hBCI system [8], [12]. Moreover, it was found that hBCI systems based on eye tracking and BCI were potentially suited to applications where rapid changes in the complexity of stimuli occur [8], and, in general, the use of BCI as a 'selection' mechanism in such hybrid systems reduced the overall level of user frustration [9].

In order to support research into hybrid systems, a number of generalized frameworks for hBCI systems have been developed, including the Tools for Brain-Computer Interaction (TOBI) architecture [6] and OpenBCI software framework [10]. A number of BCI-related software solutions exist. For example, TOBI proposed modular architectures, which utilized standardized data acquisition components and interfaces in order to permit researchers to develop hBCI systems. Similarly, the OpenBCI framework comprises a complete, modular software solution that supports a range of EEG-based BCI paradigms and the development of parallel hBCI systems. Subsequently, by making the underlying platforms increasingly accessible, the availability of such generalized platforms can further promote research and development into hBCI systems [1].

Fig. 2. Eye tracker (Tobii) interacting with Graphical User Interafce

Eye tracking is an assistive technology often used for patients with peripheral muscular dysfunction. The commercially available Tobii system [16] uses both reflected light and infra-red signals to detect the subject's pupil, determine his/her gaze trajectory and map this to an on-screen target, see Figure 2 for general set-up. In this figure the stimulus-acquisition unit is located below the monitor. It allows spatial coordinates to be extracted, thereby providing gaze interaction information to other applications. Eye gaze systems have the potential to change the way users interact with computers. It is an intuitive technology that can increase speed of interaction with a computer screen. Alternative systems based on web cam technology may be constructed for less than a hundred Euro. For example a low cost system may use a laptop web cam or alternatively a miniature camera can be attached to traditional spectacle frames; both using image processing techniques to isolate the pupil and hence infer gaze. In all systems a calibration is required for each recording session, to relate eye gaze to screen resolution. Head movement must also be compensated, and tends to be better controlled in the more sophisticated systems.

4 Architecture

Within the architecture developed for BRAIN [13],[19] a set of UDP packets provided input to control the interface. The values allocated to User Datagram Protocol (UDP) packets related to the appropriate BCI classification (from a signal analysis component such as BCI2000). For example, with SSVEP there were 4 flashing Light Emitting Diodes (LEDs) surrounding the computer screen, each relating to a particular navigation arrow and hence facilitating 4 way directional control. These four classifications have been given the (arbitrary) codes 401, 402, 403, and 404. When employing the user interface for ERD/ERS, the navigational structure needed to accommodate 3-way or even just 2-way directional control, as reliable class discrimination proved more difficult. Again the input to the user interface was UDP packets with codes 501, 502, 503, 504 for all possible directional outcomes. This architecture allowed for a version of the same interface to be used for ERD/ERS. The result was a design that could be tailored easily to ERD/ERS or SSVEP, but was not a concurrent hybrid system. There was no inbuilt mechanism to automate the switch between modes. However, the modular architecture does lend itself to further development for a hybrid BCI that can work simultaneously or sequentially. Signals evoked from the user (SSVEP, ERD/ERS, and eye tracker) are attributed meaning and actuate the interface. Thus the eye tracker packets can be allocated 601, 602, 603 and 604.

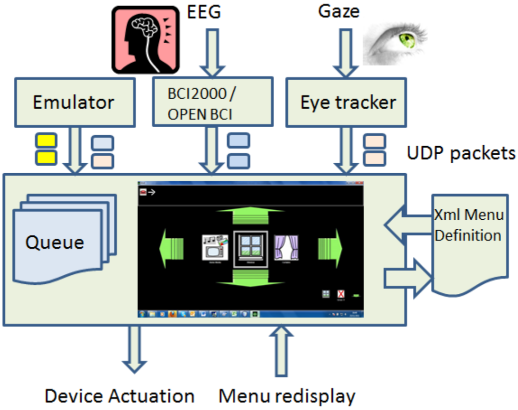


Fig. 3. Architecture of the Graphical User Interface

Command classification data was produced by a BCI2000 processing package [15] and transmitted to the GUI application using the UDP communications protocol, thereby maintaining a clear separation between the functionality of the GUI and the signal processing. The GUI has subsequently been interfaced with the OpenBCI platform [10], which was developed in Python and is freely available under the GNU General Public License. The GUI was developed in Java, thus permitting operating system independent deployment. A menu structure employs a virtual representation of a domestic environment, using images of rooms and appliances. By providing a flexible GUI and modular platform, multiple paradigm support has been facilitated.

Testing the usability of such a multi-modal interface can initially be conducted by using emulator tools which can generate packets to prescribed profiles. Thus it is possible to produce sequences of SSVEP, ERD/ERS and eye tracker packets, without subjects, in an initial experimental phase. Hence an hBCI comprising SSVEP and eye tracker can be emulated. The simulation can extend to both sequential hybrids and collaborative hybrids. Emulation and testing strategies were devised as part of BRAIN [19]. A Catcher utility stimulates the user to follow a set of directional instructions, classifying responses; providing a paced, objective means of assessing accuracy of BCI command classification performance. An accessibility tool generates a user specific estimate of tolerance to inaccuracy when interacting with the interface. This can be contrasted to the results obtained by the Catcher giving a usability indicator.

5 User Interface Design

The difficulty in design is determining the most natural mechanism for control for each application. This is complicated by the fact that some BCI mechanisms work better for some users than others do. A classification of the types of control typically used in an interface and the associated BCI that can handle this might go some way in determining the best-suited combinations. Eye gaze facilitates free cursor control, by providing a high bandwidth, highly responsive channel with good accuracy, assuming appropriate calibration. Discrete cursor control (4-way, 3-way, 2-way) can be achieved using SSVEP (and ERD/ERS). It is suitable for navigating through a hierarchical structure or a grid of icons. Selection of an onscreen icon, toggling a state of a device may be achieved with either modality or a combination. Issues to be considered are: how many packets are required to trigger a command and the latency associated with packet generation and classification. BCI can achieve higher classification accuracy for fewer classes, which makes it suited to hBCI.

Figure 4 provides a simulation of a hBCI GUI configuration that brings together SSVEP with eye gaze technology, using the eye gaze to (quickly) direct the horizontal navigation of the user interface, and SSVEP to trigger a command (reinforcement of eye gaze, downward arrow). This also can act as a safeguard against early ‘exit’ form the interface (reinforcement of eye gaze, upward arrow). Vertical navigation can potentially use ERD/ERS to reinforce selection.

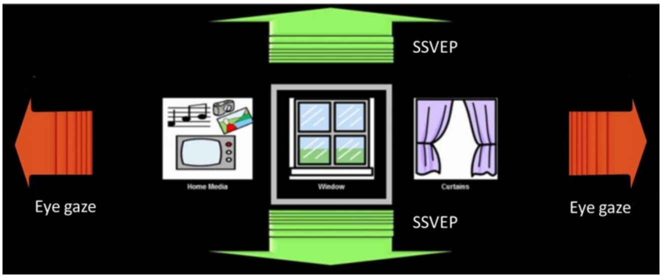
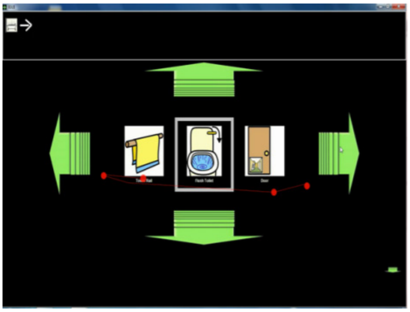
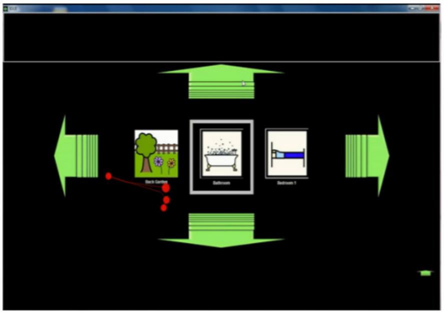


Fig. 4. Simulation of eye tracker with SSVEP for selection

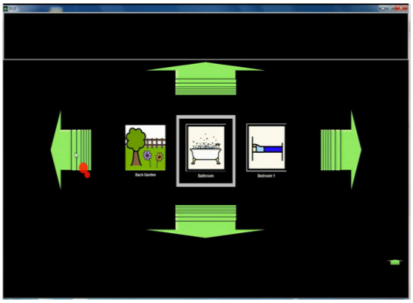
The aim of the eye gaze is to rotate the images in the centre of the interface. At the top level of the hierarchy this is a series of images or icons relating to the user’s home environment. Once the desired location is the centre image then some mechanism is required to select the location and move down to the next level of hierarchy, now displaying the devices within that location. SSVEP rotation of the images was slow and required substantial focus on the appropriate LED. This was mounted on the edge of the screen and made it difficult for the user to see when they had reached their icon of interest. Replacing this control using the eye gaze creates a more natural process. Activating selection can then be achieved using the SSVEP with an LED placed at the bottom edge of the screen. This would signal a more robust intent than eye gaze dwell time alone with the aim of reducing errors. In such a structure errors confound usability by requiring the user to retrace their steps. Movement back up the hierarchy can again be activated using the SSVEP (a second LED). This hybrid architecture requires two distinct stimulus frequencies, which creates a much simpler and robust classification task. Further work could also be investigated into including the eye gaze parameters into the classification process to further ensure that the correct decision is made. For example eye gaze dwell time can be used to assist the EEG classification process. Figure 5 illustrates the concepts menu search, scrolling and command selection and enactment, in the eye tracker. Off-line processing superimposes red dots on the image to indicate the location of gaze and their diameter indicates dwell time.



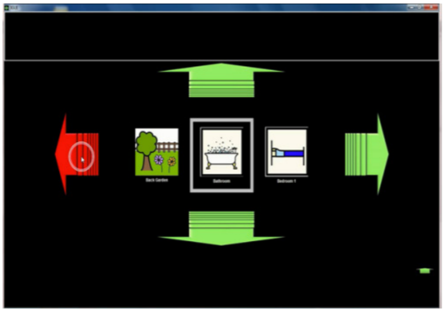
(a) ‘search’ menu structure



(b) ‘scroll’ left to enact menu



(c) ‘select’ to move left



(d) ‘dwell’ left to enact menu

Fig. 5. Eye tracker interaction with Graphical User Interface

6 Discussion

SSVEP operation used 4 LEDs mounted around the outside of a computer screen. In order to navigate a particular direction the user has to make a cognitive link to the LED associated with that direction. The location may mean that the user may no longer have full view of the screen and the changes that they are affecting. Aside from the physical constrains some users found this a cognitive challenge. Within BRAIN two out of 5 target users (i.e. those with some brain dysfunction) were not confident concerning the outcome or consequences of the action of activating an arrow using the flashing LEDs. Only one user was fully confident to navigate to a selected menu item without assistance. Due to the confusion between directional command arrows and the manipulation of menu icons the other users found it difficult when trying to navigate to a specified item. Technically competent users had little difficulty operating the interface. This concurred with other studies in which the use of a computer based system is an immediate hurdle to encounter before even considering the complexity of the BCI itself [17].

While integration between the BCI system and eye tracker is on-going, there are two main drawbacks to the proposed hybrid system. Firstly, the Tobii system is expensive, hence is only applicable to laboratory based testing. Secondly, the API is not open source, therefore has limited value as a research tool. The ideal solution would be to produce a fully open system that utilizes commercial, off-the-shelf webcam technology for eye tracking. Although such a bespoke eye tracker may not meet the performance of the Tobii system, it could offer the potential to enhance the efficacy of the BCI in a hybrid system to the extent that usability is significantly enhanced but the extra cost in terms system complexity is negligible; thereby closing the gap between, the minimum accepted accuracy for system operation, and the achievable accuracy [19]. By making GUI and HCI tools available, it may be possible to facilitate hBCI development, which can be easily deployed outside the research environment. We believe that improved more robust BCIs, such as the hybrid proposed, will be required to engage users with difficulties, i.e. those that can best avail of this technology.

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