

Examining Current and Future BCI Applications for People with Disabilities

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ABSTRACT

Over the past decade Brain Computer Interfaces (BCI) have gone from being a bundle of concepts, to laboratory experiments, to applications that are now being developed by students and researchers. These applications are now being used in the daily lives of many disabled people. The current solutions that have been developed show us the vast potential of BCI applications being capable of effectively supporting, improving and enriching the lives of those diagnosed with neuromuscular disorders such as amyotrophic lateral sclerosis (ALS).

This article will present several proven BCI applications that aim to solve problems in the areas of communication, computer management, Internet browsing and entertainment. Along with this, current limitations of BCI applications and future work and enhancements to BCIs and electroencephalography (EEG) systems are also presented.

Author Keywords

Brain Computer Interface, Disability, Disabled People, Communication, Computer Management, Internet Browsing, Entertainment, ALS, EEG-based BCI, P300 based BCI

INTRODUCTION

Brain computer interfaces (BCI) facilitate the connection between the human brain and an external device. BCI is a communication system that translates brain signals into intelligent commands used to control an external electronic device such as a computer, prosthetic limb or a wheel chair. BCI systems use electroencephalography (EEG) to measure the faint signals generated by the brain when a person thinks. Thinking produces electrical and magnetic activity. By placing electrodes on the scalp of the user we can measure the change in electrical activity over various parts of the brain. This change in electrical activity can then be mapped to a distinct command to control an external device without activating any muscle. Figure 1 illustrates a BCI system.

In the early stages of BCI development, applications were developed for those suffering from quadriplegia or those diagnosed with a neurodegenerative disorder such as amyotrophic lateral sclerosis (ALS) and Parkinson's

disease. These applications were focused on mainly on enhancing the patient's communication by providing a different means of communication through thinking. This was their main focus as those suffering from ALS had an increasing difficulty with speaking, swallowing and breathing.

BCI has developed extensively since and has been proved highly advantages in various other scenarios also such as driving a wheelchair, operating prosthetic devices, selecting letters from a virtual keyboard, navigating in a virtual reality, and providing a disabled woman with no arms the ability to control a robotic arm to feed herself. The rapid developments in this area call for developers of BCI systems to look in to creating advance robust applications to solve the problems of those with physical disabilities and enhance their productivity and quality of life.

This review draws from recent research into BCI applications developed for the disabled and will present research on areas from communication, computer management and entertainment. This article will discuss the various limitations of BCI technologies that need to be overcome before they can successfully go into homes of disabled people. Finally future technologies such as hybrid BCI architectures, better EEG systems and the incorporation of principles in human computer interaction (HCI) will be looked into to improve BCI usability.

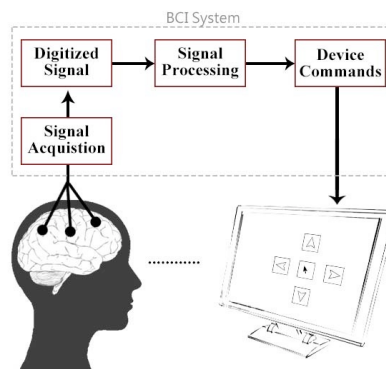


Figure 1: BCI System functionality [7]

BCI APPLICATION AREAS

Communication

Communication has always been one of the primary focuses of BCI applications. Although people with disabilities might have been prevented from communicating via speech or writing, their minds were as healthy as one without any disabilities. Thus the desire to harness this potential led to a large number of BCI researchers to work on various types of communication applications and algorithms to assist the disabled person to voice their ideas, desires and interests.

The P300 based BCI for disabled is an application built to allow the user to create a sentence or a paragraph and have it read out loud [3]. P300 (P3), a component of event related potential (ERP), is a measured brain response signal that is evoked during the process of decision making or as a result of a sensory, cognitive or motor event. An EEG measures P3 signals in the brain. The P3 signals have been used in a wide range of BCI applications such as virtual keyboards that allow users to select alphabetical letters sequentially, to multimedia and virtual reality applications [3]. The user of the P3 based BCI spelling application begins by training to accurately use the application. This is done by “attending” to the target stimulus, whilst ignoring the non-target stimuli that are presented more frequently [3]. By “attending” to the target stimuli, the user creates a P3 response that is reliably sensed by the EEG [3]. Once the training is complete, the user is then presented with a 6 by 6 matrix including 36 characters on a computer screen [3]. The following is an account on how the application works: *“The individual rows and columns flash in rapid succession. The participant’s task is to communicate a specific character by attending to that character and counting the number of times it flashes. The flash of the row and column that contains the desired character elicits a P300 response. By determining which row and which column elicit P300 the BCI can identify the character the participant wants to select. Counting the number of flashes helps to keep the participant’s attention focused on the task”*. Once the sentence or paragraph has been created, the system then allows the user to use the inbuilt text-to-speech (TTS) synthesizer to read the text aloud. Figure 2 presents a user interacting with the P3 based BCI application.

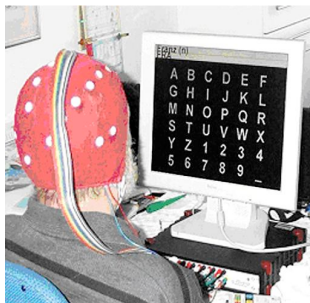


Figure 2: The figure showing the P300 speller matrix displayed on the screen

Another practical study was undertaken where a BCI was developed for a 51-year-old male with ALS who was provided with an electrode cap that connected to a BCI. The aim of this research was to see whether the use of a BCI system for a long-term independent home use for a disabled person was possible. The BCI system that was developed for this project provided a wide range of important features such as word processing, e-mail, environmental control, and speech generation to name a few [6]. Once the electrode cap was placed on the patient and electrode gel applied, the user initially would calibrate the system and then run and use the application [6]. The BCI application provided the patient with a simple matrix-based menu that he used his thought to control and select the desired activity. The study proved to be highly successful with results showing that the BCI accuracy remained at 83% [6] over a period of 2 and half years. The patient’s family had happily concluded that the BCI had brought back his independence and has provided him the ability to run his NIH-funded research lab along with communicating through email with friends and colleagues [6]. Figure 3 shows an email written by the patient, describing the impact BCI has in his life.

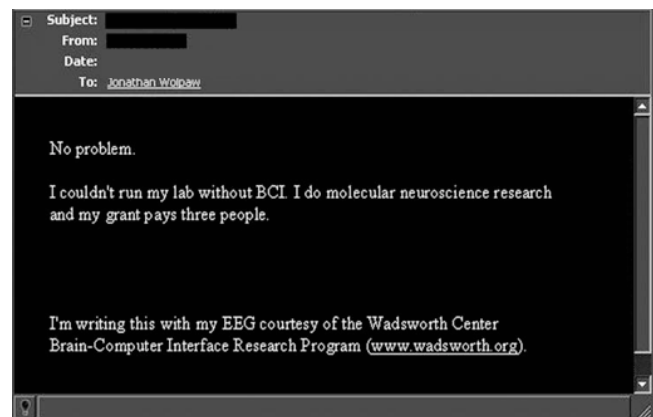


Figure 3: The patient’s description of how BCI has impacted his life

Computer Management

A key area of BCI application development is computer management. Most patients suffering from neuromuscular diseases would have used a computer at home or at work prior to the disability. However due to the disability they are no longer physically able to utilize the peripherals in order to interact with the computer.

To address this issue researchers [1] have looked into using a wireless EEG headset that has the capability of manipulating the mouse on the computer screen based on the user’s thought [1]. The headset connects to the computer via Bluetooth. When the user imagines of the physical movement, neurons in the brain fire in a particular area [3]. This activity is measured and sent wirelessly to the computer application that decreases the noise in the signal after amplification, a process known as preprocessing. This

signal is then compared to previously configured commands, which is known as feature extraction [1]. Once the command is finalized the PC executes these commands to act according to the user's intentions.

The application provides the user the ability to configure and map various mouse actions to mental activity. That is, by the act of a patient closing their eyes or by imagining the movement of either or both fists and feet the user can manipulate the mouse on the screen. "The outcome of this process is a collection of decision rules that can be translated, as required, into PC commands." [1]. Figure 4 shows the control panel illustrating this.

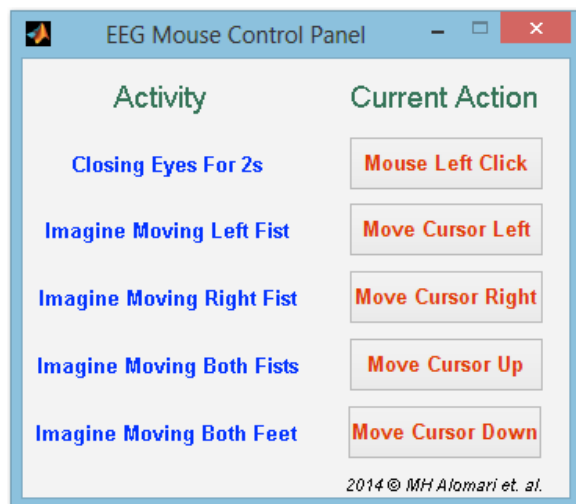


Figure 4: EEG Mouse Application Control Panel

Only the Cz, C4 and C3 channels of the EEG were utilized in this project [1]. This is because "the neural activity that is mostly correlated to the fists movements is almost exclusively contained within these channels"[1]. It is a known fact that EEG signals are noisy by nature thus requiring to be filtered. To filter the Cz, C4 and C3 channels a band-pass filter (0.5-50 Hz) was used [1].

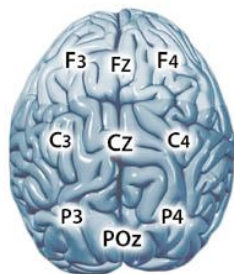


Figure 5: Position of electrodes placed on scalp

The aim of this research was to create an application that used commercially available EEG headsets as a "remote control" for controlling the mouse and other computer applications [1]. The results showed that the system had an accuracy of 74.97% that according to the researchers [1] seemed "very promising" as these results were from imagined movements.

Internet Browsing

The Internet is regarded as the most important technology in the present day. It is used for a variety of reasons ranging from social networking, education, gaming, watching YouTube videos and keeping up with the news, to name a few.

For those with disabilities that hinder the use of a computer, dedicated BCI applications that focus primarily on enhancing the experience of Internet browsing provides enormous benefits for disabled people.

This led a group of researchers [7] to develop and test a BCI that helped severely disabled people such as those diagnosed with ALS to browse the Internet for learning and recreation. The researchers developed a simple interface that consisted of 3 main parts, which were cursor controller, menu and access key. Icons on the interface were linked with a box with a colored bar which acted as a stimuli that was flashing on and off. In order to select an icon the user needs to focus on the stimuli (color) of their choice with the intention to trigger it [7]. This would then fire ERPs in the users' brain that would be measured to carry out the desired intention using the icon. Figure 6 shows the BCI web browser interface with cursor, icons and colored bars.



Figure 6: Web Browser Interface showing icons, cursor and color bars

The major contributions the researchers provided through their project were not only the design and development of a

BCI for a disabled person to browse the Internet using icons and a cursor controller that could be used in a webpage, but they also carried out clinical experiments, analyzed the results to evaluate the accuracy and effectiveness of the system [7]. A valuable finding that surfaced from their research was that the N2P3 component is an important feature of the ERP signals and was more effective in differentiating the target icon from the non-target icons as compared to using just P300 or N200 features. As explained earlier the P300 or P3 is a key component of an ERP signal. P300 stands for a positive wave with 300ms latency in EEG [7] while N200 stands for a negative wave with a latency of 200ms after the occurrence of a stimulus [7]. N2P3 is the difference in potentials between N200 and P300 [7]. As we can see in Figure 7 the 'Target' N2P3 line clearly stands out as compared P3 and N2 non-target lines. Therefore it is used to accurately distinguish target icons from non-target icons.

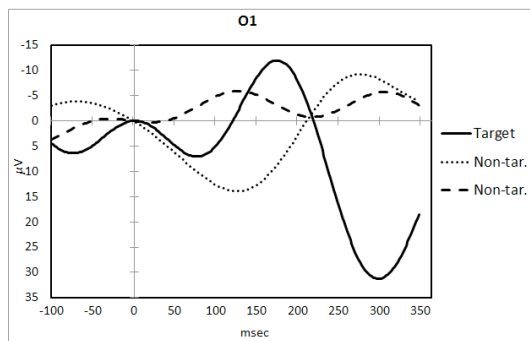


Figure 7: Shows the Target N2P3 line clearly distinct from the two Non-target P3 and N2 lines

Entertainment

Although entertainment was not an area that was given much focus during the early stages of BCI development, it is receiving more attention now as BCI systems are becoming more and more available to the disabled community [5]. BCI applications for gaming, interacting with media collections and music players are now being developed side by side along functional applications such as those for communication and motor control [5].

A BCI is capable of sensing the mood of the user and is capable of providing the user with the genre of music to suit his or her need [5]. Thus BCIs can be more tuned in involuntarily supporting users on the basis of their mood. Such systems allow users to express their desires or emotional state to caregivers directly without and effort to communicate it via text or speech [5].

Gaming was never a focus of BCI but several prototypes were developed to demonstrate the possibility of BCI controlled games [5]. These games were aimed at not only

providing entertainment but to enhance the quality of life of disabled persons. One of the well-developed games was a physical pinball machine with the two strikers controlled via a BCI controller [5]. However user training was mandatory in order to be able to effectively play the game.

Virtual reality plays a big role in BCI applications as it has a number of useful applications. Along with exploring virtual spaces as a form of recreation, more practical uses are presented where a spinal cord injured patient controlled a wheelchair through a virtual street [5] for example. This serves as a means for practicing before applying the BCI system in real life. Although the virtual space does not replicate the real world, it however gives the user a sense of space and ability to test BCI controls. Manipulating virtual objects using BCI systems provides a means to exercise the brain along with providing the potential to learn new things by forming new neural connections known as neuroplasticity.

In the area of music, simple BCI systems for music composition have been developed, although BCI applications for music browsing have not yet been developed. A research into personal photo archiving has shown that there is a “general lack of organization of digital photographs” [5] hence simple exploration techniques were found to be more beneficial than complicated searching techniques. The “berry picking” model of selecting similar images after viewing an image from a large collection is the general behavior of those browsing through a personal collection [5]. This is because a particular image would stimulate memories causing the user to want to see more related photographs [5]. In the field of BCI, a P3 based BCI has been developed to incorporate search techniques that provide related photographs to the one being currently presented. The user has the ability to mentally select individual photographs or categories in their photo archives [5].

CONCLUSION

This review presents a view of existing BCI applications that exist to assist the disabled people to aid, improve and enrich their quality of life. Proven BCI applications and systems are now emerging in various areas from communication, motor recovery to entertainment and computer management to name a few. These systems have convincingly demonstrated to bring immense benefits allowing a disable person to lead a routine independent lifestyle. Effective and tested solutions are evolving and we can surely start to see these BCI systems entering homes of the disabled people in the coming years. As research projects as the ones discussed above are undertaken, new breakthroughs are bound to emerge such as the valuable use of N2P3 component of an ERP signal over just P3 or N2 components. This is the beginning of an array of immensely beneficial and innovative BCI solution systems to come in the near future.

FUTURE WORK

While there have been proven BCI solutions emerging from research projects there is still a large number of problems with the fundamental functioning of a BCI system. One of these problems is the high level of the signal to noise ratio of EEG BCIs [8]. Using the right electrodes goes along way to addressing this issue. Older EEG systems especially require low impedances, as low as 10k Ω or less [8]. To attain such low impedances a bald scalp is required along with conductive gel or pate between the electrode and scalp [8].

A current limitation with BCI is the rate of information transfer from the user through the BCI to the outside world [8]. However this limitation is bound to be resolved, as technology gets better in the years to come.

Another limitation with EEG is that different users exhibit different EEG patterns. This is more the case for those with neurological disorders, psychological issues and those who suffered brain damage [8]. Trying to “establish a universal classification algorithm” that works for all users may not be possible therefore another method such as specialized training that a user can use after a short training session will be highly beneficial [8].

Potential future technologies in BCI include the development of hybrid BCIs (hBCI), better EEG systems, and incorporation of HCI to enhance the usability of BCI applications [5].

Hybrid BCI

An hBCI combines multiple signals with at least one BCI signal. Combining multiple signals from bio signals, assistive technology (AT) signals along with one or two BCI signals creates a hybrid BCI system that can create an effective system that incorporates all channels when carrying out a users intension or decision [5].

Advance EEG Systems

The requirement of EEG based BCIs for commercial use needs to be looked into. To make commercial BCIs concerns such as portability, aesthetically pleasing design, and comfort need to be addressed [5]. For the disabled people, social acceptability is a major concern hence the incorporation of engineering and esthetics must go hand in hand in the design process to achieve the desired result [5].

Integration of HCI principles

Until recently, the focus of BCI systems was on usability and functionality [5] and less on the interface design aspects. Human computer interaction principles incorporated into BCI solutions will bring about more user-friendly interfaces for the users with the main benefit of “speeding up” the interaction and learnability [5]. The virtual keyboard “Hex-O-Spell” showed this [5].

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