A Review on Novel Applications Using Brain Computer Interface

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Abstract— Brain-Computer-Interface is the natural extension to Human Computer Interface. BCI can provide inimitable solutions to currently unsolved problems. Through this review we aim to apprise on the novel technologies using BCI, and also to gauge whether BCI is suitable for mainstream applications. Comparison of existing approaches that solve various problems and how BCI improves upon them, and also the shortcomings of every technology has been discussed, based on which we have proposed some improvements.

I. INTRODUCTION

Conventional means of interacting with software or computer interfaces involves physical movements and muscle power to use buttons, mouse, keyboards and touch screens. Brain Computer Interface (BCI) provides touchless interaction with the software with just a biofeedback from our brains. Human brain is a mesh of neurons that send rapid electric signals in the form of ion flow from one part of the nervous system to the other. This electrical activity is concentrated inside the skull. Minute changes in voltages and signals can be detected using sophisticated instruments, like Electroencephalogram (EEG), functional magnetoresonance imaging (fMRI), functional near-infrared spectography (fNIRS) and magnetoelectroencephalography (MEG). These signals in our brain have been studied for many years and currently classified into 5 categories based on their frequency range viz. alpha, beta, theta, delta and gamma [1]. Each of these category of wave co-relates to the state of our mind. These states can thus be used as triggers for interacting with the computer interface.

The 10-20 system is an international convention for effective placement of electrodes. In this system, F denotes frontal, P denotes parietal, T is temporal, C is central and O is occipital lobe. Even numbers indicate Right Hemisphere and odd indicates Left Hemisphere of the skull.

II. THE NEED FOR BCI

Before the "Brain Computer Interface" (BCI) was recognized as a useful technology in computer systems, applications were mostly designed in the essence of HCI. A human computer interface (HCI) is a realization of communication between a computer system and a human being, through the use of supporting software and input/output (I/O) devices. These I/O devices include touch-sensitive devices and voice-input devices. Ever since their inception, HCIs have been evolving over the years to provide improved features to a wider range of users. Despite this, they fall short in providing the same services to those who are severely disabled; as most HCI revolve around a typical physical necessity, such as the ability to click or touch (touch-based) or the ability to speak for control.

In addition to HCIs inability to assist the disabled; it is also limited by the physical necessity itself. Computers today are capable of performing thousands of computations in the amount of time that it would take for a user to click a button or select a command (In case of touch-sensitive systems). The attempt at finding solutions to these limitations has led to BCI.

The purpose of BCI is to be a means of communication between a computer system and the human brain. In doing so, BCI achieve lower input delays, and utilize the computational resources of modern computer systems more efficiently than current HCI. Additionally, a well-designed BCI system provides much needed functionality and ease-of-access to the severely disabled.

The most obvious use of BCI would be assistive technology for people with physical disabilities. BCI removes the physical restriction of number of keys, fixed input panels, and complexity of designing these input equipment. BCI requires control over the states of mind and also concentration, as a result, BCI applications can also be used for brain training [5], which can be used as a mental exercise to cure certain mental illnesses [4].

III. EXISTING GAMES USING BCI

Studies have shown that mental states can be used as a viable input for playing games [1]. The most prominent wave in our brain is the Alpha wave which relates to relaxed state of mind. Various tests have concluded that the sum of indices of brain waves can be used as a reliable input, rather than the individual indices of each wave [2].

Throw trucks is a commercial game which started as kickstarter project and branched out into Steam and other platforms. Throw truck's commercial success is one of the few prominent examples of BCI being openly adopted by consumers. It shows reliable application of EEG, which was a rare occurrence in products released before it. Prolonged

Distraction testing game provides a novel approach to solve one of the mental illnesses that affects the human brain. The unique aspect of this game is that it uses popular web technologies like HTML5 and ImpactJS with BCI, unlike conventional games that use dedicated game engines. Other games like Pacman, Pinball and World of Warcraft have also been implemented using BCI technologies, but they were not released as a final commercial product.

A. Throw Trucks with your Mind

Throw trucks is a game developed by Crooked Tree Studios which uses Brain Computer Interface and EEG as an input for the action of throwing trucks. It is based on NeuroSky MindWave headset and can take 8 different inputs from users. This game is focused on multi-player first person shooter action where your telekinesis ability increase or decrease based on how calm and focused the player is. The game isn't entirely brain controlled; movement of the character is done using keys. It measures the level of calmness of your mind and thus calibrates the strength of the character.

Tests based on EEG have shown improvements in the conditions of patients suffering from mental diseases like Attention deficit Hyperactivity Disorder (ADHD), Autistic Spectrum Disorder (ASD), Substance Use Disorders (SUD) [2]. Games based on EEG provide neurofeedback from the central and frontal part of the brain, thereby improving the muscle activity in that area, which is linked to spatial control [3]. ADHD and other diseases require daily medication, which is not ideal in case of school going children. ADHD medication leads to poor appetite, reduction in physical growth and non-adherence rate can be high as 25% [5]. Novel approaches like Throw truck help in improving concentration of not only ADHD patients, but also healthy individuals alike.

However, case studies like [6] have provided proof that there is no co-relation between brain training and our cognitive abilities. The increased mental capacity could be placebo effect or our brains just remapping itself to do the repeating tasks of the games more efficiently and not actually improving one's muscle activity.

B. Prolonged Distraction Testing Game

To analyze and improve on the level of distraction while driving a car, a prolonged distraction research-based testing game was developed which considers the audio and visual factors that usually lead to accidents [11]. The motivation for this research came from the fact that while driving a car, a person's level of distraction can be recognized by the change in their Beta brainwaves (12Hz – 38Hz).

Beta waves are involved in logical thinking and reasoning, conscious thought, and tend to have a stimulating effect. Having too much of beta waves usually signifies a person to be experiencing excessive stress and/or anxiety. Higher a person concentrates, higher the Beta waves become. Thus, Beta becomes a comparable and calculative quantity which can be measured to infer the level of distraction a test subject may face due to external factors, viz. audio and visual while already focusing on one task(driving)[12,13].

The method used for this research is electroencephalography (EEG). EEG is a non-invasive technique to measure neural activity when the neurons in brain interact. The NeuroSky MindWave is an equipment which serves as an EEG and is used for acquiring and processing of the electrical activity in the brain. For direct communication and receiving of data from NeuroSky MindWave a programming language, Processing is used as a software interface for the data that is sent to a Bluetooth dongle attached to the computer. ImpactJS is a JavaScript game engine that facilitates the creation of games for all desktop internet browsers with HTML5 capabilities. Along with these materials and a HI-SPEED iC-RWP2000 wired testing wheel, are used for the implementation of this game [14]. After analyzing the data obtained for test subjects who played this game, the researchers came to a conclusion that it actually depends on the person if they chose to focus or relax themselves as they drive past the distractions. Also, there is no necessary contribution to the increase in Beta waves due to the presence of distractions.

Although the particular aim behind this research was not achieved, but the research was successful in signifying the accuracy of the NeuroSky MindWave and the fact that the classification of brain waves can have unlimited society-enhancing applications.

IV. EXISTING SYSTEMS USING BCI

Existing research and review papers elaborate only on applications from specific domains, thus constraining the scope of BCI applicability. This work presents an overview of all the unique applications and tries to show BCI as a mature technology. The following section evaluates various novel approaches used to implement BCI to overcome certain barriers and to solve problems. Both the systems described below use BCI for performing actions that require a functioning body otherwise. Other systems based on BCI such as Brain motic offers home automation using EEG, but implementing this system requires converting every appliance of the house to be controlled by digital system instead of traditional analog.

A. Brain Powered Portable Dialing System

A portable dialing brain computer Interface (BCI) was developed by a team of researchers, with the aim of providing dialing functionality to severely disabled people, such as those suffering from amyotrophic lateral sclerosis (ALS). Users of the interface will be able to spell out characters from a 4x3 matrix of alphanumeric characters on a handheld device. The BCI achieves this by linking an electroencephalograph (EEG) brainwave extraction headset to a portable, off-the-shelf device such as smartphones and tablets to a Neuro headset via Bluetooth. Extraction of brain waves is performed using the "Emotiv EPOC" headset, a 14-channel EEG Neuro headset. The "Microsoft Surface Pro3", serving as the handheld device, was used to implement an online, real-time, highly portable BCI, capable of giving quick results [7].

Their approach was to create BCI which would be based on P300 wave of visual evoked potentials (VEP). Since EEG is non-invasive, it is convenient, safe and quick to build its applications. [8] After the system architecture was built, testing was performed in two locations (With identical equipment and instructions to the subjects). One cycle was performed in a lab environment where distractions were minimal, whereas the other was performed in a metro, where the subjects were prone to unexpected situations and public distraction.

Results from both testing cycles were promising, with the lab testing cycle reporting accuracy of 88.75%±10.57% and the metro testing cycle reporting accuracy of 73.75%±16.9 46% [8]. Therefore, we can safely conclude that, given the moderately high accuracy of the BCI, such applications show potential in improving the lifestyle of patients suffering from disabilities.

The use of the Emotiv EPOC headset over other alternatives is due to the fact that it is praised as the one of the most reliable devices thanks to its low price, excellent resolution, multi-channel facility and wireless connectivity capabilities [9]. It is also portable and easy to wear for any user with little experience with such devices [10].

B. Robot Control using EMOTIV Headset

Disabled individuals have trouble using day-to-day services like transportation. In the following research, the Emotiv headset is used by the patient, in order to control a robot (NXT based robot with a camera in this case). Feedback from the camera based on the robot can be fed back, and monitored by the patient himself. Said robot is controlled by neck movement and eye gestures. Hence, the entire device uses automated gestures, in order to control the robot. Emotiv headset provide 2D-gyro sensor values and Expressive information, so the user is able to effectively control robot with only movement of neck and blinking eye, without hand [15].

Emotiv has built their own SDKs, which can be used by developers, in order to perform signal acquisition (EEG), and its subsequent processing. The headset transmits Radio Frequency, which is then acquired by its receiver software. After this phase, Digital Signal Processing is performed by the SDK. After this phase, the software is able to perform any operation that is necessary.

For the output, given Lego NXT robot is controlled by the person. Neck movements result in vector values that are mapped by the Digital Signal Processor, whilst eye movements are tracked and processed directly as EEG waves [15]. Together, the output from the two is used in order to give a digital output to the NXT robot, which then traverses as per the data it receives. Also, feedback is taken at the same time from the NXT robot.

As a whole, the entire system is based on 14 EEG electrodes, which are then connected to the Emotiv device [15]. Apart from this, the hardware consists of the NXT robot, transmitter, receiver, and a Digital Signal Processor.

V. COMPARISON OF TECHNOLOGIES

The applications of BCI mentioned above try to solve different problems, but they share the same backbone hardware. The following table tries to compare these technologies objectively based on their hardware characteristics as well as software features they provide.

Table I Comparing Applications Based On BCI

Criteria	Applications using Brain Computer Interface				Comments
	Throw Trucks with your mind	*Prolonged distraction testing game*	*Brain powered portable dialing system*	*Robot control using EMOTIV headset*	
Type of electrodes	Dry	Dry	Wet	Wet	Dry electrodes provide more ease of use but wet has more accuracy [16]
Number of electrodes used	6	2	14	14	Higher number relates to more accuracy
Position of electrodes placed	FP1 and earclip	FP1 and earclip	International 10-20 system	International 10-20 system	Standardized position to get comparable results
Waves considered	Alpha	Beta	P300(Delta & theta)	Alpha, Beta	Decides the states of our mind
Frequency of Waves	8Hz-12Hz	12Hz-38Hz	0.5-7Hz	8-38Hz	Range over which dominant waves are measured

No. of channels	12	12	16	16	Decides the resolution of ADC
Number of unique inputs	8	8	12	12	Higher number indicate more functionality
Sensors Interpret	Relaxed brain state	Excited brain state	Brains Reaction to stimulus	Eye blinking, eye raise, winking.	Changes in the brain and body measured
Technology used	NeuroSky	NeuroSky	EMOTIV EPOC	EMOTIV EPOC	Hardware vendor used for application
Software Interface	Steam	Processing	TestBench	None	Software vendor used for application
Peripheral	No	No	Microsoft surface Pro3	Lego Mindstorms NXT	External peripherals required to run the application
SDK	No	No	TestBench	Expressiv, Affectiv, Cognitiv	Software development Kit provided by the system
Mode of working	Single player: offline Multiplayer: online	Offline	Online	Offline	Internet connection required for running the application
Cost	$125	$175	$399	$399	Lower cost makes product more acceptable
Features	First person shooter multiplayer game. Easy installation on steam. Uses Unreal Engine 3 for great gaming experience.	Helps in preventing accidents. Analyses distraction level caused by interferences.	Dialing phone without any physical input. Highly portable and battery powered.	Controlling robot without any physical input. Uses Lego Mindstorms NXT robot.	
Pros	Relatively cheap	Uses web technologies like HTML5, ImpactJS	High accuracy even in noisy environments	Uses eye and neck movements to increase accuracy	
Cons	Slow paced	Some people are in a relaxed state of mind while driving safely	High cost for relatively simple application	Not portable	

Our model will use dry electrodes because they are user-friendly. We will use a minimum of 2 electrodes as they are required for any application to provide at least one "on" and "off" state. The 10-20 system is the most optimal electrode placement system which is used in all the cases. The prominent waves to be considered are based on the type of application and the range of frequencies measured are also dependent on these waves considered. The feedbacks measured are selected such that it is easy for user to operate the system.

VI. CONCLUSION

The practical implementations of BCI and their novel approaches in solving problems have been discussed in this paper. BCI can provide alternative approaches in solving problems especially in the domain of assistive technologies. The medical application of BCI in the case of mental illnesses like ADHD, not only provides an alternative approach but also offers a treatment with no side effects, better suited for children. Current applications have higher prices that dissuade consumers and prosumers alike from investing into such products, as they require both time and money to harvest long-standing results.

It is evident from this review that available implementations of BCI are not only costly but also restrict themselves to just one particular application. Also, EEG is the best approach while making such applications.

We propose to design and implement a system called Braindroid, which uses brain waves as input using EEG acquisition. These inputs are then sampled using a portable microprocessor, which then sends these processed signals to a smart device over Bluetooth. The actions to be performed with these inputs should be completely customizable and under the control of the user. We plan to make both the hardware and software of Braindroid such that it encourages prosumers to develop their own applications.

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