ISSN: 2456-9348
Vol (03) _Issue (03) Impact Factor: 4.520

iJETRM
International Journal of Engineering Technology Research & Management

BRAIN COMPUTER INTERFACE

Omkar Sahasrabudhe
Willingdon College, Sangli.
Shivaji University, Kolhapur.
omkarsahasrabudhe.cs@gmail.com

ABSTRACT

The ability of computers to enhance & augment both mental & physical abilities is no longer the exclusive realm of science fiction writers. It is becoming a reality. Brain Computer Interface technology will help define the potential of the human race. It holds the promise of bringing sight to the blind, hearing to the deaf & the return of normal functionality to the physically impaired. A miracle? Hardly. But perhaps the next closest thing. A brain–computer interface (BCI), sometimes called a mind-machine interface (MMI), direct neural interface (DNI), or brain–machine interface (BMI), is a direct communication pathway between an enhanced or wired brain and an external device. BCIs are often directed at researching, mapping, assisting, augmenting, or repairing human cognitive or sensory-motor functions.

KEYWORDS:
Brain Computer Interfaces, Brain signal acquisition, BCI applications, Mind commands, Brain monitoring.

INTRODUCTION

The ability of computers to enhance & augment both mental & physical abilities is no longer the exclusive realm of science fiction writers. It is becoming a reality. Brain Computer Interface technology will help define the potential of the human race. It holds the promise of bringing sight to the blind, hearing to the deaf & the return of normal functionality to the physically impaired. A miracle? Hardly. But perhaps the next closest thing. A brain–computer interface (BCI), sometimes called a mind-machine interface (MMI), direct neural interface (DNI), or brain–machine interface (BMI), is a direct communication pathway between an enhanced or wired brain and an external device. BCIs are often directed at researching, mapping, assisting, augmenting, or repairing human cognitive or sensory-motor functions. The field of BCI research and development has since focused primarily on neuroprosthetics applications that aim at restoring damaged hearing, sight and movement. Thanks to the remarkable cortical plasticity of the brain, signals from implanted prostheses can, after adaptation, be handled by the brain like natural sensor or effector channels. Following years of animal experimentation, the first neuroprosthetic devices implanted in humans appeared in the mid-1990s.
A Brain Computer Interface (B.C.I.) also called as Mind Machine Interface (M.M.I.) or a Direct Neural Interface is collaboration between a brain & a device that enables signals from the brain to direct some external activity. The interface activates a direct communication pathway between the brain & the object to be controlled such as control of a cursor or a prosthetic limb. Virtually anything that can be controlled by a computer could potentially be controlled by a BCI. It is been examined as a rehabilitation device to help people regain motor skills that are lost from stroke, as well as prosthetic device to replace or compensate for motor skills that will never return. For example : In the case of cursor control the signal is transmitted directly from the brain to the mechanism directing the cursor, rather than taking the normal route through the body's neuromuscular system from the brain to the finger on the mouse.

BCIs can be used for communication, computer access or control of devices such as a wheelchair. They are often directed at researching, mapping, assisting, augmenting, or repairing human cognitive or sensory-motor functions etc. Brain–computer interfaces (BCI's) give their users communication and control channels that do not depend on the brain's normal output channels of peripheral nerves and muscles. Current interest in BCI development comes mainly from the hope that this technology could be a valuable new augmentative communication option for those with severe motor disabilities—disabilities that prevent them from using conventional augmentative technologies, all of which require some voluntary muscle control. In 1995 there were no more than six active BCI research groups, now there are more than 20. They are focusing on brain electrical activity, recorded from the scalp as electroencephalographic activity (EEG) or from within the brain as single-unit activity, as the basis for this new communication and control technology.

In recognition of this recent rapid development and its potential importance for those with motor disabilities, the National Center for Medical Rehabilitation Research of the National Institute of Child Health and Human Development of the National Institutes of Health sponsored a workshop on BCI technology. This workshop, also supported by the Eastern Paralyzed Veterans Association and the Whitaker Foundation and organized by the Wadsworth Center of the New York State Department of Health, took place in June of 1999 at the Rensselaerville Institute near Albany, New York. Fifty scientists and engineers participated. They represented 22 different research groups from the United States, Canada, Great Britain, Germany, Austria, and Italy. Their principal goals were:

1) to review the current state of BCI research;
2) to define the aims of basic and applied BCI research;
3) to identify and address the key technical issues; and
4) to consider development of standard research procedures and assessment methods.

History

The history of brain–computer interfaces (BCIs) starts with Hans Berger's discovery of the electrical activity of the human brain and the development of electroencephalography (EEG). In 1924 Berger was the first to record human brain activity by means of EEG. Berger was able to identify oscillatory activity, such as Berger's wave or the alpha wave (8–13 Hz), by analyzing EEG traces.

Berger's first recording device was very rudimentary. He inserted silver wires under the scalps of his patients. These were later replaced by silver foils attached to the patient's head by rubber bandages. Berger connected these sensors to a Lippmann capillary electrometer, with disappointing results. However, more sophisticated measuring devices, such as the Siemens double-coil recording galvanometer, which displayed electric voltages as small as one ten thousandth of a volt, led to success.

Berger analyzed the interrelation of alternations in his EEG wave diagrams with brain diseases. EEGs permitted completely new possibilities for the research of human brain activities. IN 1970s research on BCIs started at the University of California which led to the emergence of the expression BCI. The focus of BCI research & development continues to be primarily on neuroprosthetic applications that can help restore damaged sight, hearing & movement. The mid 1990s marked the appearance of the first neuroprosthetic devices for humans.

Jacques Vidal coined the term "BCI" and produced the first peer-reviewed publications on this topic. Vidal is widely recognized as the inventor of BCIs in the BCI community, as reflected in numerous peer-reviewed articles reviewing and discussing the field. Vidal's first BCI relied on visual evoked potentials to allow users to control cursor direction, and visual evoked potentials are still widely used in BCIs (Allison et al., 2010, 2012; Bin et al., 2011; Guger et al., 2012; Kaufmann et al., 2012; Jin et al., 2014; Kapeller et al., 2015). After his early contributions, Vidal was not active in BCI research, nor BCI events such as conferences, for many years. In 2011, however, he gave a lecture in Graz, Austria, supported by the Future BNCI project, presenting the first BCI, which earned a standing ovation. Vidal was joined by his wife, Laryce Vidal, who previously worked with him at UCLA on his first BCI project. Prof. Vidal will also present a lecture on his early BCI work at the Sixth Annual BCI Meeting, scheduled for May–June 2016 at Asilomar, California.

Richard Canton's 1875's discovery of electrical signals in animal brains was an inspiration for Berger. As one of the first common use of brain computer interface technology, EEG neurofeedback has been in use for several decades.The year 1998 marked a significant development in the field of brain mapping when researcher Philip Kennedy implanted the first brain computer interface object into a human being. However, the BCI object was of limited function. The only benefit from this development was the use of a wireless di-electrode. John Donoghue and his team of Brown University researchers formed a public traded company, Cyberkinetics, in 2001. The goal was to commercially design a brain computer interface, the so-called BrainGate. The company has come up with NeuroPort its first commercial product. Columbia University Medical Center researchers have successfully monitored and recorded electrical activity in the brain with improved precision. According to researchers, NeuroPort Neural Monitoring System enabled them to identify micro-seizure activity prior to epileptic seizures among patients.June 2004 marked a significant development in the field when Matthew Nagle became the first human to be implanted with a BCI, Cyberkinetics BrainGate. In December

2004, Jonathan Wolpaw and researchers at New York State Department of Health Wadsworth Center came up with a research report that demonstrated the ability to control a computer using a BCI. In the study, patients were asked to wear a cap that contained electrodes to capture EEG signals from the motor cortex – part of the cerebrum governing movement. A number of developments have been taking place in the field. By 2050, it is has been suggested that BCI could become a magic wand, helping men control objects with their mind. The day isn't far off when man may be able to guide an outside object with their thoughts in order to consistently execute both natural and complex motions of everyday life.

OBJECTIVES

Direct Neural Interface is collaboration between a brain & a device that enables signals from the brain to direct some external activity. The interface activates a direct communication pathway between the brain & the object to be controlled such as control of a cursor or a prosthetic limb. Virtually anything that can be controlled by a computer could potentially be controlled by a BCI. It is been examined as a rehabilitation device to help people regain motor skills that are lost from stroke, as well as prosthetic device to replace or compensate for motor skills that will never return.

METHODOLOGY

Types

1. Invasive BCI

Invasive BCI research has targeted repairing damaged sight and providing new functionality for people with paralysis. Invasive BCIs are implanted directly into the grey matter of the brain during neurosurgery. Because they lie in the grey matter, invasive devices produce the highest quality signals of BCI devices but are prone to scar-tissue build-up, causing the signal to become weaker, or even non-existent, as the body reacts to a foreign object in the brain. In vision science, direct brain implants have been used to treat non-congenital (acquired) blindness. One of the first scientists to produce a working brain interface to restore sight was private researcher William Dobelle.

Dobelle's first prototype was implanted into "Jerry", a man blinded in adulthood, in 1978. A single-array BCI containing 68 electrodes was implanted onto Jerry's visual cortex and succeeded in producing phosphenes, the sensation of seeing light. The system included cameras mounted on glasses to send signals to the implant. Initially, the implant allowed Jerry to see shades of grey in a limited field of vision at a low frame-rate. This also required him to be hooked up to a mainframe computer, but shrinking electronics and faster computers made his artificial eye more portable and now enable him to perform simple tasks unassisted.

In 2002, Jens Naumann, also blinded in adulthood, became the first in a series of 16 paying patients to receive Dobelle's second generation implant, marking one of the earliest commercial uses of BCIs. The second generation device used a more sophisticated implant enabling better mapping of phosphenes into coherent vision. Phosphenes are spread out across the visual field in what researchers call "the starry-night effect".

Immediately after his implant, Jens was able to use his imperfectly restored vision to drive an automobile slowly around the parking area of the research institute. Unfortunately, Dobelle died in 2004 before his processes and developments were documented. Subsequently, when Mr. Naumann and the other patients in the program began having problems with their vision, there was no relief and they eventually lost their "sight" again. Naumann wrote about his experience with Dobelle's work in Search for Paradise: A Patient's Account of the Artificial Vision Experiment and has returned to his farm in Southeast Ontario, Canada, to resume his normal activities.

BCIs focusing on motor neuroprosthetics aim to either restore movement in individuals with paralysis or provide devices to assist them, such as interfaces with computers or robot arms. Dummy unit illustrating the design of a BrainGate interface Researchers at Emory University in Atlanta, led by Philip Kennedy and Roy Bakay, were first to install a brain implant in a human that produced signals of high enough quality to simulate movement. Their patient, Johnny Ray (1944–2002), suffered from 'locked-in syndrome' after suffering a brain-stem stroke in 1997. Ray's implant was installed in 1998 and he lived long enough to start working with the implant, eventually learning to control a computer cursor; he died in 2002 of a brain aneurysm. Tetraplegic Matt Nagle became the first person to control an artificial hand using a BCI in 2005 as part of the first nine-month human trial of Cyberkinetics BrainGate chip-implant. Implanted in Nagle's right precentral gyrus (area of the motor cortex for arm movement), the 96- electrode BrainGate implant allowed Nagle to control a robotic arm by thinking about moving his hand as well as a computer cursor, lights and TV. One year later, professor Jonathan Wolpaw received the prize of the Altran Foundation for Innovation to develop a Brain Computer Interface with electrodes located on the surface of the skull, instead of directly in the brain. More recently, research teams led by the Braingate group at Brown University and a group led by University of Pittsburgh Medical Center, both in collaborations with the United States Department of Veterans Affairs, have demonstrated further success in direct control of robotic prosthetic limbs with many degrees of freedom using direct connections to arrays of neurons in the motor cortex of patients with tetraplegia.

2. Partially Invasive BCIs

Partially invasive BCI devices are implanted inside the skull but rest outside the brain rather than within the grey matter. They produce better resolution signals than non invasive BCIs where the bone tissue of the cranium deflects and deforms signals and have a lower risk of forming scar-tissue in the brain than fully invasive BCIs. There has been preclinical demonstration of intracortical BCIs from the stroke perilesional cortex.

Electrocorticography (ECoG) measures the electrical activity of the brain taken from beneath the skull in a similar way to non-invasive electroencephalography (see below), but the electrodes are embedded in a thin plastic pad that is placed above the cortex, beneath the dura mater. ECoG technologies were first trialled in humans in 2004 by Eric Leuthardt and Daniel Moran from Washington University in St Louis. In a later trial, the researchers enabled a teenage boy to play Space Invaders using his ECoG implant.[41] This research indicates that control is rapid, requires minimal training, and may be an ideal trade off with regards to signal fidelity and level of invasiveness. (Note: these electrodes had not been implanted in the patient with the intention of developing a BCI. The patient had been suffering from severe epilepsy and the electrodes were temporarily implanted to help his physicians localize seizure foci; the BCI researchers simply took advantage of this.) Signals can be either subdural or epidural, but are not taken from within the brain parenchyma itself. It has not been studied extensively until recently due to the limited access of subjects. Currently, the only manner to acquire the signal for study is through the use of patients requiring invasive monitoring for localization and resection of an epileptogenic focus.

ECoG is a very promising intermediate BCI modality because it has higher spatial resolution, better signal-to noise ratio, wider frequency range, and less training requirements than scalp-recorded EEG, and at the same time has lower technical difficulty, lower clinical risk, and probably superior long-term stability than intracortical single-neuron recording. This feature profile and recent evidence of the high level of control with minimal training requirements shows potential for real world application for people with motor disabilities.
Light reactive imaging BCI devices are still in the realm of theory. These would involve implanting a laser inside the skull. The laser would be trained on a single neuron and the neuron’s reflectance measured by a separate sensor. When the neuron fires, the laser light pattern and wavelengths it reflects would change slightly.This would allow researchers to monitor single neurons but require less contact with tissue and reduce the risk of scar-tissue build-up. In 2014, a BCI study using near-infrared spectroscopy for “locked-in” patients with amyotrophic lateral sclerosis (ALS) was able to restore some basic ability of the patients to communicate with other people.

3. Non-Invasive BCIs

There have also been experiments in humans using noninvasive neuroimaging technologies as interfaces. The substantial majority of published BCI work involves noninvasive EEG-based BCIs. Non-invasive EEG-based technologies and interfaces have been used for a much broader variety of applications.
Although EEG-based interfaces are easy to wear and do not require surgery, they have relatively poor spatial resolution and cannot effectively use higher-frequency signals because the skull dampens signals, dispersing and blurring the electromagnetic waves created by the neurons. EEG-based interfaces also require some time and effort prior to each usage session, whereas non-EEG-based ones, as well as invasive ones require no prior-usage training. Overall, the best BCI for each user depends on numerous factors.

➢ Non-EEG-based Human-Computer Interface

Pupil-size oscillation In a recent 2016 article, an entirely new communication device and non-EEG-based human-computer interface was developed, requiring no visual fixation or ability to move eyes at all, that is based on covert interest in (i.e. without fixing eyes on) chosen letter on a virtual keyboard with letters each having its own (background) circle that is micro-oscillating in brightness in different time transitions, where the letter selection is based on best fit between, on one hand, unintentional pupil-size oscillation pattern, and, on the other hand, the circle-in-background brightness oscillation pattern. Accuracy is additionally improved by user's mental rehearsing the words 'bright' and 'dark' in synchrony with the brightness transitions of the circle/letter.

➢ Electroencephalography (EEG)-based brain-computer interfaces

Overview Electroencephalography (EEG) is the most studied non-invasive interface, mainly due to its fine temporal resolution, ease of use, portability and low setup cost. The technology is somewhat susceptible to noise however. In the early days of BCI research, another substantial barrier to using EEG as a brain–computer interface was the extensive training required before users can work the technology. For example, in experiments beginning in the mid-1990s, Niels Birbaumer at the University of Tübingen in Germany trained severely paralysed people to self-regulate the slow cortical potentials in their EEG to such an extent that these signals could be used as a binary signal to control a computer cursor. (Birbaumer had earlier trained epileptics to prevent impending fits by controlling this low voltage wave.) The experiment saw ten patients trained to move a computer cursor by controlling their brainwaves. The process was slow, requiring more than an hour for patients to write 100 characters with the cursor, while training often took many months. However, the slow cortical potential approach to BCIs has not been used in several years, since other approaches require little or no training, are faster and more accurate, and work for a greater proportion of users.

Another research parameter is the type of oscillatory activity that is measured. Birbaumer later research with Jonathan Wolpaw at New York State University has focused on developing technology that would allow users to choose the brain signals they found easiest to operate a BCI, including mu and beta rhythms. A further parameter is the method of feedback used and this is shown in studies of P300 signals. Patterns of P300 waves are generated involuntarily (stimulus-feedback) when people see something they recognize and may allow BCIs to decode categories of thoughts without training patients first. By contrast, the biofeedback methods described above require learning to control brain waves so the resulting brain activity can be detected. Lawrence Farwell and Emanuel Donchin developed an EEG-based brain–computer interface in the 1980s. Their "mental prosthesis" used the P300 brainwave response to allow subjects, including one paralyzed Locked-In syndrome patient, to communicate words, letters and simple commands to a computer and thereby to speak through a speech synthesizer driven by the computer. A number of similar devices have been developed since then. In 2000, for example, research by Jessica Bayliss at the University of Rochester showed that volunteers wearing virtual reality helmets could control elements in a virtual world using their P300 EEG readings, including turning lights on and off and bringing a mockup car to a stop.

While an EEG based brain-computer interface has been pursued extensively by a number of research labs, recent advancements made by Bin He and his team at the University of Minnesota suggest the potential of an EEG based brain-computer interface to accomplish tasks close to invasive brain-computer interface. Using advanced functional neuroimaging including BOLD functional MRI and EEG source imaging, Bin He and coworkers identified the co-variation and co-localization of electrophysiological and hemodynamic signals induced by motor imagination. Refined by a neuroimaging approach and by a training protocol, Bin He and coworkers demonstrated the ability of a non-invasive EEG based brain-computer interface to control the flight of a virtual helicopter in 3-dimensional space, based upon motor imagination. In June 2013 it was announced that Bin He had developed the technique to enable a remote-control helicopter to be guided through an obstacle course.

In addition to a brain-computer interface based on brain waves, as recorded from scalp EEG electrodes, Bin He and co-workers explored a virtual EEG signal-based brain-computer interface by first solving the EEG inverse problem and then used the resulting virtual EEG for brain-computer interface tasks. Well-controlled studies suggested the merits of such a source analysis based brain-computer interface. A 2014 study found that severely motor-impaired patients could communicate faster and more reliably with noninvasive EEG BCI, than with any muscle-based communication channel.

➢ Dry active electrode arrays

In the early 1990s Babak Taheri, at University of California, Davis demonstrated the first single and also multichannel dry active electrode arrays using micromachining. The single channel dry EEG electrode construction and results were published in 1994. The arrayed electrode was also demonstrated to perform well compared to silver/silver chloride electrodes. The device consisted of four sites of sensors with integrated electronics to reduce noise by impedance matching. The advantages of such electrodes are:
(1) no electrolyte used,

(2) no skin preparation,
(3) significantly reduced sensor size, and
(4) compatibility with EEG monitoring systems.

The active electrode array is an integrated system made of an array of capacitive sensors with local integrated circuitry housed in a package with batteries to power the circuitry. This level of integration was required to achieve the functional performance obtained by the electrode. The electrode was tested on an electrical test bench and on human subjects in four modalities of EEG activity, namely:

(1) spontaneous EEG,
(2) sensory event-related potentials,
(3) brain stem potentials, and
(4) cognitive event-related potentials.

The performance of the dry electrode compared favorably with that of the standard wet electrodes in terms of skin preparation, no gel requirements (dry), and higher signal-to-noise ratio.

In 1999 researchers at Case Western Reserve University, in Cleveland, Ohio, led by Hunter Peckham, used 64-electrode EEG skullcap to return limited hand movements to quadriplegic Jim Jatich. As Jatich concentrated on simple but opposite concepts like up and down, his beta-rhythm EEG output was analysed using software to identify patterns in the noise. A basic pattern was identified and used to control a switch: Above average activity was set to on, below average off. As well as enabling Jatich to control a computer cursor the signals were also used to drive the nerve controllers embedded in his hands, restoring some movement.

➢ Prosthesis and environment control

Non-invasive BCIs have also been applied to enable brain-control of prosthetic upper and lower extremity devices in people with paralysis. For example, Gert Pfurtscheller of Graz University of Technology and colleagues demonstrated a BCI-controlled functional electrical stimulation system to restore upper extremity movements in a person with tetraplegia due to spinal cord injury. Between 2012 and 2013, researchers at the University of California, Irvine demonstrated for the first time that it is possible to use BCI technology to restore brain-controlled walking after spinal cord injury. In their spinal cord injury research study, a person with paraplegia was able to operate a BCI-robotic gait orthosis to regain basic brain-controlled ambulation. In 2009 Alex Blainey, an independent researcher based in the UK, successfully used the Emotiv EPOC to control a 5 axis robot arm. He then went on to make several demonstration mind controlled wheelchairs and home automation that could be operated by people with limited or no motor control such as those with paraplegia and cerebral palsy.

➢ DIY and open source BCI

In 2001, The OpenEEG Project was initiated by a group of DIY neuroscientists and engineers. The ModularEEG was the primary device created the OpenEEG community; it was a 6-channel signal capture board that cost between $200 and $400 to make at home. The OpenEEG Project marked a significant moment in the emergence of DIY brain-computer interfacing. In 2010, the Frontier Nerds of NYU's ITP program published a thorough tutorial titled How To Hack Toy EGGs. The tutorial, which stirred the minds of many budding DIY BCI enthusiasts, demonstrated how to create a single channel at-home EEG with an Arduino and a Mattel Mindflex at a very reasonable price. This tutorial amplified the DIY BCI movement. In 2013, OpenBCI emerged from a DARPA solicitation and subsequent Kickstarter campaign. They created a high-quality, open-source 8-channel EEG acquisition board, known as the 32bit Board, that retailed for under $500. Two years later they created the first 3D-printed EEG Headset, known as the Ultracortex, as well as, a 4-channel EEG acquisition board, known as the Ganglion Board, that retailed for under $100.

In 2015, NeuroTechX was created with the mission of building an international network for neurotechnology. They bring hackers, researchers and enthusiasts all together in many different cities around the world. According to their rapid growth, the DIY neurotech / BCI community was already waiting for such initiative to see light.

➢ MEG & MRI

Magnetoencephalography and Magnetic resonance imaging Magnetoencephalography (MEG) and functional magnetic resonance imaging (fMRI) have both been used successfully as non-invasive BCIs.[75] In a widely reported experiment, fMRI allowed two users being scanned to play Pong in real-time by altering their haemodynamic response or brain blood flow through biofeedback techniques. fMRI measurements of haemodynamic responses in real time have also been used to control robot arms with a seven-second delay between thought and movement.

In 2008 research developed in the Advanced Telecommunications Research (ATR) Computational Neuroscience Laboratories in Kyoto, Japan, allowed the scientists to reconstruct images directly from the brain and display them on a computer in black and white at a resolution of 10x10 pixels. The article announcing these achievements was the cover story of the journal Neuron of 10 December 2008.

In 2011 researchers from UC Berkeley published a study reporting second-by-second reconstruction of videos watched by the study's subjects, from fMRI data. This was achieved by creating a statistical model relating visual patterns in videos shown to the subjects, to the brain activity caused by watching the videos. This model was then used to look up the 100 one-second video segments, in a database of 18 million seconds of random YouTube videos, whose visual patterns most closely matched the brain activity recorded when subjects watched a new video. These 100 one-second video extracts were then combined into a mashed-up image that resembled the video being watched.

➢ BCI control strategies in neurogaming

Motor imagery :- Motor imagery involves the imagination of the movement of various body parts resulting in sensorimotor cortex activation, which modulates sensorimotor oscillations in the EEG. This can be detected by the BCI to infer a user's intent. Motor imagery typically requires a number of sessions of training before acceptable control of the BCI is acquired. These training sessions may take a number of hours over several days before users can consistently employ the technique with acceptable levels of precision. Regardless of the duration of the training session, users are unable to master the control scheme. This results in very slow pace of the gameplay. Advance machine learning methods were recently developed to compute a subject-specific model for detecting the performance of motor imagery. The top performing algorithm from BCI Competition IV (http://www.bbci.de/competition/iv/) dataset 2 for motor imagery is the Filter Bank Common Spatial Pattern, developed by Ang et al. from A*STAR, Singapore). Bio/neurofeedback for passive BCI designs Biofeedback is used to monitor a subject's mental relaxation. In some cases, biofeedback does not monitor electroencephalography (EEG), but instead bodily parameters such as electromyography(EMG), galvanic skin resistance (GSR), and heart rate variability (HRV). Many biofeedback systems are used to treat certain disorders such as attention deficit hyperactivity disorder (ADHD), sleep problems in children, teeth grinding, and chronic pain. EEG biofeedback systems typically monitor four different bands (theta: 4–7 Hz, alpha:8–12 Hz, SMR: 12–15 Hz, beta: 15–18 Hz) and challenge the subject to control them. Passive BCI involves using BCI to enrich human–machine interaction with implicit information on the actual user's state, for example, simulations to detect when users intend to push brakes during an emergency car stopping procedure. Game developers using passive BCIs need to acknowledge that through repetition of game levels the user's cognitive state will change or adapt. Within the first play of a level, the user will react to things differently from during the second play: for example, the user will be less surprised at an event in the game if he/she is expecting it.

Visual Evoked Potential (VEP) A VEP is an electrical potential recorded after a subject is presented with a type of visual stimuli. There are several types of VEPs. Steady-state visually evoked potentials (SSVEPs) use potentials generated by exciting the retina, using visual stimuli modulated at certain frequencies. SSVEP stimuli are often formed from alternating checkerboard patterns and at times simply use flashing images . The frequency of the phase reversal of the stimulus used can be clearly distinguished in the spectrum of an EEG; this makes detection of SSVEP stimuli relatively easy . SSVEP has proved to be successful within many BCI systems . This is due to several factors, the signal elicited is measurable in as large a population as the transient VEP and blink movement and electrocardiographic artefacts do not affect the frequencies monitored. In addition, the SSVEP signal is exceptionally robust; the topographic organization of the primary visual cortex is such that a broader area obtains afferents from the central or foveal region of the visual field .SSVEP does have several problems however. As SSVEPs use flashing stimuli to infer a user's intent, the user must gaze at one of the flashing or iterating symbols in order to interact with the system. It is, therefore, likely that the symbols could become irritating and uncomfortable to use during longer play sessions, which can often last more than an hour which may not be an ideal gameplay.

Another type of VEP used with applications is the P300 potential. The P300 event-related potential is a positive peak in the EEG that occurs at roughly 300 ms after the appearance of a target stimulus (a stimulus for which the user is waiting or seeking) or oddball stimuli . The P300 amplitude decreases as the target stimuli and the ignored stimuli grow more similar.The P300 is thought to be related to a higher level attention process or an orienting response Using P300 as a control scheme has the advantage of the participant only having to attend limited training sessions. The first application to use the P300 model was the P300 matrix . Within this system, a subject would choose a letter from a grid of 6 by 6 letters and numbers. The rows and columns of the grid flashed sequentially and every time the selected “choice letter” was illuminated the user’s P300 was (potentially)
elicited. However, the communication process, at approximately 17 characters per minute, was quite slow. The P300 is a BCI that offers a discrete selection rather than a continuous control mechanism. The advantage of P300 use within games is that the player does not have to teach himself/herself how to use a completely new control system and so only has to undertake short training instances, to learn the gameplay mechanics and basic use of the BCI paradigm.

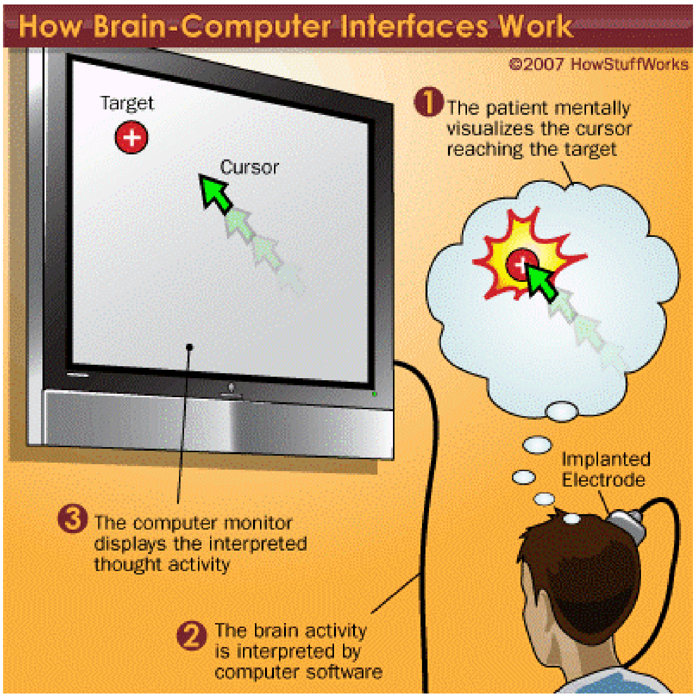
➢ Other research

Electronic neural networks have been deployed which shift the learning phase from the user to the computer. Experiments by scientists at the Fraunhofer Society in 2004 using neural networks led to noticeable improvements within 30 minutes of training. Experiments by Eduardo Miranda, at the University of Plymouth in the UK, has aimed to use EEG recordings of mental activity associated with music to allow the disabled to express themselves musically through an encephalophone. Ramaswamy Palaniappan has pioneered the development of BCI for use in biometrics to identify/authenticate a person. The method has also been suggested for use as PIN generation device (for example in ATM and internet banking transactions. The group which is now at University of Wolverhampton has previously developed analogue cursor control using thoughts. Researchers at the University of Twente in the Netherlands have been conducting research on using BCIs for non-disabled individuals, proposing that BCIs could improve error handling, task performance, and user experience and that they could broaden the user spectrum. They particularly focused on BCI games, suggesting that BCI games could provide challenge, fantasy and sociality to game players and could, thus, improve player experience. The first BCI session with 100% accuracy (based on 80 right-hand and 80 left-hand movement imaginations) was recorded in 1998 by Christoph Guger. The BCI system used 27 electrodes overlaying the sensorimotor cortex, weighted the electrodes with Common Spatial Patterns, calculated the running variance and used a linear discriminant analysis. Research is ongoing into military use of BCIs and since the 1970s DARPA has been funding research on this topic. The current focus of research is user-to-user communication through analysis of neural signals. The project “Silent Talk” aims to detect and analyze the word-specific neural signals, using EEG, which occur before speech is vocalized, and to see if the patterns are generalizable.

Working

Current brain interface devices require deliberate conscious thought, some future applications such as prosthetic controls. By reading signals from an array of neurons & using computer chips & programs to translate the signals into actions, BCI can enable a person suffering from paralysis to write a book or control a motorized wheelchair or prosthetic limb through a thought alone.

At the European research & exhibition held in Paris in June 2006, American scientist Peter Brunner composed a message simply by concentrating on a display. Brunner wore a close-fitting cap fitted with a number
of electrodes. EEG activity from Brunner’s brain was picked up by the cap’s electrodes & the information used, along with software, to identify specific letters or the characters for the message.



The BCI Brunner demonstration is based on a method called The Wadsworth system. Like other EEG based BCI technologies the Wadsworth system uses adaptive algorithms & pattern matching techniques to facilitate communication. Both user & software are accepted to adapt & learn, making the process more efficient with practice.

You should have some questions after getting overview of working of BCI.
o Here we discuss actually how Brain-Computer Interface works?
o What are the parameters?
o What is Algorithm?
o What type of software can used/designed for such system interfaces?

- **Background**

First we need a bit of neurobiology. Neurons (brain cells) communicate to each other using action potentials (also called "spikes"). These are the quanta of neural communication. Action potentials are brief deviations of the cell's membrane potential (voltage inside minus voltage outside) from its resting voltage, and they propagate along neurons' axons, long filaments which reach out to other neurons. There's a lot more to neural signaling, but for implanted electrode BCIs this is all we need.

- **Electrodes**

To eavesdrop on the brain's calculations in the cortex (outer layer, the grey matter of the brain), we typically implant fine electrodes (40 um to 200 um diameters, maybe more, depending on type) into the cortex. For BCI these electrodes come in arrays and are typically 1 mm in length (though some labs go as far as 2.5mm). These electrodes pick up the action potentials which occur near (<50 um typically) their recording site, which is usually the uninsulated tip. Currently popular is the Utah array, which has 96 electrodes on an approximately 4 by 4 mm chip, fabricated out of silicon. For cursor control, we would most likely place the electrode array in the arm and hand regions of M1 (and maybe some other places too).

- **Brain signals**

A BCI records and interprets or decodes brain signals. Brain cells (neurons) communicate with each other, by sending and receiving very small electrical signals. It is possible to ‘listen’ to these signals (generally referred to as ‘brain activity’) with advanced electrical sensors. Healthy people are able to move because the brain sends signals via the central nervous system to the muscles of the body. All interaction of a person (such as speaking or shaking hands) requires precise communication between the brain and muscles. Medical conditions such as stroke or neuromuscular diseases can disrupt or break the communication between the brain and body muscles and lead to paralysis (or the loss of the ability to control one's body, such as cerebral palsy). However, in many cases the brain is still able to generate the activity for intended movements and a BCI can use the brain activity to control assistive devices.

- **Measuring brain signals**

Brain signals can be measure with various techniques that each have pros and cons. A commonly used technique (for example used for neurological testing in hospitals) is electroencephalography (EEG). This technique uses electrical sensors (electrodes) that are places on the scalp. Electrodes can also be placed under the scalp directly on or in the brain tissue. A surgical procedure is necessary to place such electrodes. Electrodes that are placed on the surface of the brain do not damage the brain. The quality of this signal is significantly better that signals recorded from the scalp. It is for this reason that implantable BCIs are now being developed for paralyzed people. Other techniques for measuring brain activity are functional MRI (fMRI), which measures brain activity with a MRI-scanner, and magnetoencephalography (MEG), which measures brain activity with an MEG-scanner. Both of these techniques require large and expensive machines that will not become suitable for home use. An additional technique is near-infrared spectroscopy (NIRS), which measures brain activity by shining near-infrared light through the skull. NIRS can be made portable and does not require any surgery. However, at this time the quality of the brain activity measurement is not sufficient for use with BCIs.

- **Brain function**

In general, each part of the body has its own 'control center' in the brain that is responsible for orchestrating it movements. For example, making a fist with your left hand and wiggling your right big toe are controlled by distinct areas in your brain. The different techniques used to measure brain activity can 'see' when different control centers are active. This allows BCIs to detect the movement of body parts from the brain activity. A special quality of the brain is that these control centers are also active why you simply think about making a movement without actually moving. In general people who suffer from LIS still have fully functioning control centers in the brain. Hence, they are able to activate distinct areas in their brain by thinking about, or attempting to make, movements even if they are no longer able to move the part of the body that that area of the brain normally controls. In addition to movements a number of other brain functions can be detected. For example, there is a small area in the brain that is activated when you do a numeric calculation in your head. Other areas are involved in different aspects of understanding language and speaking. When these areas are active a BCI can detect if a person is adding in their head, or is talking. Hence, there are many distinct areas in the brain that a person can intentionally turn on and off by performing different mental (for example; by counting backwards in steps of 7 in their head) or physical tasks. The fact that a person suffering from paralysis can also intentionally activate specific areas of their brain by performing mental tasks, makes a BCI a realistic and promising assistive device technology.

- **What can a BCI do with the brain signals**

By placing the electrodes exactly on brain areas that someone can control, we obtain signals that respond to that control. When a signal is detected, it can be converted to a command to operate a device or software. A computer can then be programmed to use this information to perform specific tasks. In this way, a person can us a BCI to make a computer mouse 'click' every time they count backwards in their head and select from a menu in a computer program, such as an email program. This type of 'mouse-click' based control is already commonly used by people suffering from paralysis with special 'buttons' that can be activated by whatever type of movement they are still able to make, such as lifting their eyebrows. Thus, a BCI can also be used as a 'button' to control the many types of devices designed for button press control.

- **Signal Production**

For a BCI to be useful, brain signals need to be produced by the subject (i.e. the person using the BCI). There are two ways of producing these brain signals:

1.Actively generating these signals by presenting stimuli to the subject (e.g. flashing lights) or have the subject imagine movements for example.

2.Just reading the brain-waves that are already generated by the subject.

Actively generating signals has the advantage that signal detection is easier, since you have control over the stimuli; you know for example when they are presented. This is harder in the case where you are just reading brain-waves from the subject.

- **Signal Detection**

There are different ways to detect brain signals. The most well known are EEG and fMRI , but there are

others as well (e.g. MEG, ECoG). EEG measures the electrical activity of the brain, fMRI the blood-flow in the brain. Each of these methods have their own (dis)advantages. Some have a better temporal resolution (i.e. they can detect brain-activity as it happens), while others have a better spatial resolution (i.e. they can pinpoint the location of activity). Note that I will assume we are using EEG here. The idea remains largely the same for other types of measuring techniques.

- **Recording**

The signals from the electrodes are typically amplified about 10,000x. This is done in several stages. There is a "head stage" amplifier which is close to the electrode array. This stage amplifies 1-10x and also does high pass filtering. The second stage amplification is much larger, 1000x or more. At this stage, there is also bandpass filtering (something like 400 - 4000 Hz). Then signals are digitized at 30 Khz or 40 Khz temporal resolution. Newer hardware does digitization at the head stage.

- **Spike Sorting**

When measured against a reference electrode (that is far away from the recording electrodes), an action potential appears as a distinctive spike in the voltage versus time graph. Under ideal circumstances, they can be discriminated fairly cleanly using a voltage threshold. Action potentials occurring on different neurons near an electrode recording site will all be picked up by the electrode. Traditionally, these spikes must be sorted, that is, attributed to different neurons. This is done by looking at the shape of the spike. Neurons with different morphology tend to have different spike shapes, and neurons at different distances from the electrode tip will have different spike amplitudes. Spike sorting is typically done using template matching or other classification algorithm, like MAP on a GMM. Once we have done spike sorting, we have timestamps of action potentials from each neuron on each electrode. All of this is typical, some labs use different approaches and research is ongoing.

- **Signal Processing**

One of the problems you will find when dealing with brain-data, is that the data tends to contain a lot of noise. When using EEG, for example, things like grinding of the teeth will show in the data, as well as eye-movements. This noise needs to be filtered out (or at least detected so you could discard the data). The data can now be used for detecting actual signals. When the subject is actively generating signals (case 1 in Signal Production), you are usually aware of the kind of signals you want to detect. One example is the P300 wave, which is a so-called event related potential that will show up when an infrequent, task-relevant stimulus is presented (see Wikipedia for more information). This wave will show up as a large peak in your data and you might try different techniques from machine learning to detect such peaks.

- **Signal Transduction**

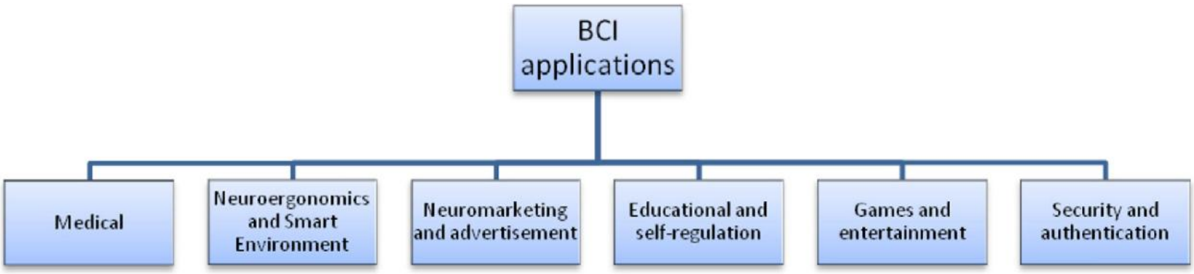
When you have detected the interesting signals in your data, you want to use them in some way that is helpful to the subject. The subject could for example use the BCI to control a mouse by means of imagined movement (e.g. moving my right hand will move the cursor to the right, right feet will move it down, etc.). One problem you will encounter here is that you need to use the data you receive from the subject as efficiently as possible, while at the same time you have keep in mind that BCI's can make mistakes. Current BCI's are relatively slow and make mistakes once in a while (e.g. the computer thinks you imagined right-hand movement, while in fact you imagined left-hand movement).

- **Decoding**

The last step is converting these spike timestamps into BCI outputs. This step is usually called "decoding" because the actions of the neurons "encode" motor commands. The typical approach involves counting the number of spikes which occur in short, non-overlapping time windows (binning) to get an estimate of the instantaneous firing rate. These time windows are 30 ms to 100ms wide, depending on research group. Then, this binned spike count is given to some signal processing algorithm as input. Early work used for linear filters (discrete Wiener filter) to decode the spike counts into cursor velocity. The filter coefficients are fitted using training data (and there are various paradigms of how to get training data). Some groups use algorithms which arose from neurophysiological models of neural encoding (the population vector algorithm), and others have used artificial neural networks. More recently (since about 2007), the dominant algorithm is the Kalman filter, and this algorithm (with some modifications to the models it uses) is still considered the state-of-the art. Other notable algorithms which have been used for cortical BCIs are kernel autoregressive moving average and point-process recursive Bayesian filtering.

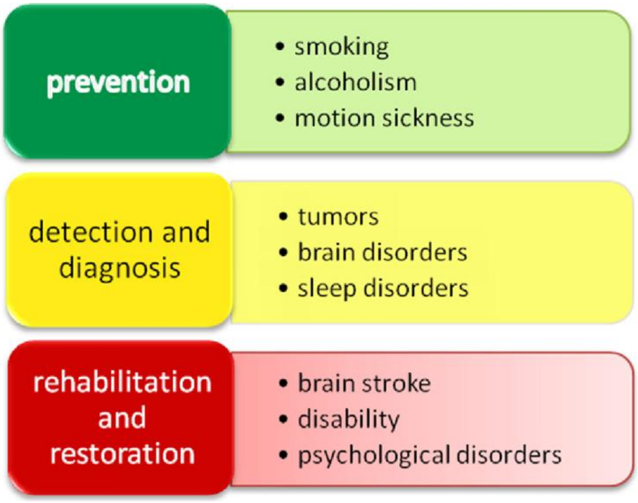
RESULTS AND DISCUSSION

Brain computer interfaces have contributed in various fields of research. As briefed in Fig, they are involved in medical, neuroergonomics and smart environment, neuromarketing and advertising, educational and self-regulation, games and entertainment, and Security and authentication fields.



❖ Medical applications

Healthcare field has a variety of applications that could take advantage of brain signals in all associated phases including prevention, detection, diagnosis, rehabilitation and restoration as shown in Fig.



❖ Prevention

Various consciousness level determination systems along with their brain-related studies have been developed. The attentiveness influences of smoking and alcohol on brain waves have been enlightened in. The importance of such studies for medical prevention lies in the possible loss of function and decrease of alertness level resulting from smoking and/or alcohol drinking, while the authors of have investigated the most responding brain parts to alcoholism. Traffic accidents are considered the main cause for death or some serious injuries as claimed in. Analyzing their causes for later prevention has been a concern for researches in various fields. Thus concentration level for those suffer from motion sickness, especially drivers, has been studied. Motion sickness, which occurs as a result of sending conflicted sensory information generated from body, inner ear and eye to the brain, is usually happening on moving transportation media.

It can cause traffic accidents as it declines in a person's ability to maintain self-control. And according to [26,27], a prediction of motion sickness could contribute in a driver-state monitoring and alertness system using a set of EEG power indicators. Its accompanying EEG signals from different five brain regions have been examined in. The human hearing level, as part of sensory information gathering process, has been measured via auditory evoked potential BCI-based system in. In another study [29], a virtual reality-based motion sickness platform has been designed with a 32-channel EEG system and a joystick which is used to report the motion sickness level (MSL) in real time experiments. Consciousness level monitoring via brain waves has been expanded to include not only drivers but also stayed-alone sick people as suggested in.

Detection and diagnosis Mental state monitoring function of BCI systems has also contributed in forecasting and detecting health issues such as abnormal brain structure (such as brain tumor), Seizure disorder (such as epilepsy), Sleep disorder (such as narcolepsy), and brain swelling (such as encephalitis). Tumor, which is generated from uncontrolled self-dividing of cells, could be discovered using EEG as a cheap secondary alternative for MRI and CT-SCAN. EEG-based Brain tumors detection systems have been the main subject of the researches in, while has been concerned with identifying breast cancer using EEG signals. Sharan Reddy and Kulkarni have proposed a system in that recognizes EEG abnormalities associated with brain tumors and epilepsy seizures. Early detection of epilepsy seizure, one of the most common neurological disorders, and controlling its effects are presented in. Dyslexia, one of the brain disorders, can be diagnosed by measuring brain behavior as described in. It influences the reading and learning ability making its discovery at an early stage saves the children from self-esteem and self-confidence issues and allows them to gain their basic skills and knowledge. Sleep disorders can be detected with BCI assistance as well as claimed in. They demonstrate some methods for deploying EEG signals in noticing Idiopathic rapid eye-movement (REM) sleep behavior disorder (iRBD) as iRBD has been found to be a strong early predictor for Parkinson's disease (PD). Wei et al. have experimentally confirmed the relationship between human gait cycle and EEG signals through the use of plantar pressure measuring system. This relationship helps predicting diseases such as dyskinesia, peripheral neuropathy, and musculoskeletal disease.

❖ Rehabilitation and restoration

Mobility rehabilitation is a form of physical rehabilitation used with patients who have mobility issues, to restore their lost functions and regain previous levels of mobility or at least help them adapt to their acquired disabilities. People suffer from serious injuries or events such as strokes may also be able to fully recover. Stroke is a condition in which the brain cells suddenly die because of the lack of oxygen. It can be caused by an obstruction in the blood flow. The patient may suddenly lose the ability to speak, there may be memory problems, or one side of the body can become paralyzed. Disabilities and brain strokes have been subject for many studies interested in solutions involving brain signals. It has been pointed out in that brain structures associated with stroke injuries could be reorganized and the damaged motor functions could be restored via neuroplasticity.

Mobile robots can be used to help locked-in people completing daily life activities as discussed in. For patients who cannot recover previous levels of mobility or communication, BCI based prosthetic limbs, also called neuroprosthetic devices, can be used to regain normal functionality. Various reality approaches for BCI-based rehabilitation training such as real, virtual, and augmented approaches have been presented. Real rehabilitation approach exploits brain signals generated from healthy people along with the decoded kinematic parameters. It assists stroke patients modifying their thinking behavior to resemble the recorded signals and retraining healthy areas of the brain to take over. Another approach for rehabilitation involves virtual reality through monitoring and controlling avatar movement generated from the outgoing brain waves. Augmented reality represents the third approach in the reality based BCI treatment such as augmented mirror box system which appears as a development for Mirror Box Therapy (MBT). MBT uses brain signals generated from symmetrical movements that incorporate injured and healthy limbs. Motor imagery signals also contribute in neurofeedback systems for post stroke motor therapy. Classification of and Comparing the results of motor imageries and actions are shown in.

❖ Neuroergonomics and smart environment

As previously mentioned, deploying brain signals is not exclusive to the medical field. Smart environments such as smart houses, workplaces or transportations could also exploit brain computer interfaces in offering further safety, luxury and physiological control to humans' daily life. They are also expected to witness cooperation between Internet Of Things (IOT) and BCI technologies as stated in Lin et al. have proposed a cognitive controller system called Brain computer interface-based Smart Living Environmental Auto-adjustment Control System. It monitors user's mental state and adapts the surrounding components accordingly. It has extended its functionality with the involvement of universal plug and play (UPnP) home networking. On the other hand, the surrounding environmental contribution in enhancing BCI based home applications via context awareness has been considered. Navarro et al. have developed such an application that automatically changes the available options accessible by the user according to the current context. Also, integration of both health care and smart house in gaining on-intrusive mental health care has been an existing approach in brain computer applications as shown in. Brain signals also assist in improving workplace conditions by assessment of an operator's cognitive state. They also analyze the impact of workload mental fatigue and task time on EEG features. Operating room as well represents a candidate place for smart workplace BCI-based application as in. The system measures the stress level of a surgeon and alert according to the response type. The field of intelligent transportation has also been benefited from the cognitive state monitoring BCI function. Driver's behavior has been studied in numerous studies. It has been found that distraction and fatigue are two main sources for driver's inattention, which is considered as a strong cause for most traffic accidents.

Various types of measures have contributed in determining the driver's cognitive state. Uses of EEG signals for fatigue detection have been widely studied in, while has discussed the utilization of workload index to assess the driver's mental state. Several models for distinguishing distracted drivers have been examined in. Kim et al. have presented multimodal context recognition for smart driving system to predict concentration and stress by analyzing both ECG and EEG signals and controlling car speed by concentration value of brain signals.

Alcoholic drivers, as a contributor to road accidents, could also be characterized through the use of EEG signals as mentioned in. has developed an audio-visual virtual environment in order to evaluate and analyze the driving responses along with the associated brain signals. has suggested some driving specific tasks to the simulated driving model and explore the neural dynamics generated, while in, kawamura et al. have described the use of multiple stimulation methods when dealing with drowsy drivers to increase their attention level. has investigated the feasibility of using driver's EEG signals to detect emergency conditions such as the sudden appearance of a pedestrian.

❖ Neuromarketing and advertising

Marketing field has also been an interest for BCI researches. The research in has explained the benefits of using EEG evaluation for TV advertisements related to both commercial and political fields. BCI based assessment measures the generated attention accompanying watching activity. On the other hand, the researchers

of have considered the impact of another cognitive function in neuromarketing field. They have been interested in estimating the memorization of TV advertisements thus providing another method for advertising evaluation.

Neurofeedback is a promising approach for enhancing brain performance via targeting human brain activity modulation. It invades the educational systems, which utilizes brain electrical signals to determine the degree of clearness of studied information. Personalized interaction to each learner is established according to the resultant response experienced. Learning to self-regulate through noninvasive BCI has also been studied. It provides a mean for improving cognitive therapeutic approaches. The research in [78] has analyzed the feasibility fMRI for the emotional regulation, while [79] has suggested the use of hybrid rtfMRI–EEG BCI to fight the depression feeling as well as other neuropsychiatric disorders through training sessions. Furthermore, EEG based emotional intelligence has been applied in sport competitions to control the accompanying stress as examined in [80]. In [43], BCI technology has been elaborated in self-regulation and skill learning via functional Magnetic Resonance Imaging (fMRI) neurofeedback.

❖ Games and entertainment

Entertainment and gaming applications have opened the market for nonmedical brain computer interfaces. Various games are presented like in where helicopters are made to fly to any point in either a 2D or 3D virtual world. Combining the features of existing games with brain controlling capabilities have been subject to many researches such as which tend to provide a multi-brain entertainment experience. The video game is called Brain Arena. The players can join a collaborative or competitive football game by means of two BCIs. They can score goals by imagining left or right hand movements. On the other hand, some EEG serious games have been employed for emotional control and/or neuroprosthetic rehabilitation. They are containing either a new game idea or a modified one. In, Tan and Nijholt have described Brain ball game which intends to drop the stress level. The users can only move the ball by relaxing; thus, the calmer player is more likely to be the winner and thus they would learn to control their stress while being amused.

❖ Security and authentication

Security systems involve knowledge based, object based and/or biometrics based authentication. They have shown to be vulnerable to several drawbacks such as simple insecure password, shoulder surfing, theft crime, and cancelable biometrics. Cognitive Biometrics or electrophysiology, where only modalities using bio signal (such as brain signals) are used as sources of identity information, gives a solution for those vulnerabilities. The motivation behind exploring the feasibility of electrophysiology is that bio signals cannot be casually acquired by external observers. They also can be of great value for disabled patients or users missing the associated physical trait. This makes such signals difficult to synthesize and therefore improves the resistance of biometric systems to spoofing attacks. Besides electroencephalogram (EEG), as a biometric modality, could be used to send covert warning when the authorized user is under external forcing conditions, as implemented in. Several researches have considered authenticating the EEG signal generated from driving behavior as part of smart driving systems. In, the authors have used a simplified driving simulator with mental-tasked condition to verify driver's identity on demand. Unconscious driver authentication has taken place in.

REFERENCES

[1] https://en.wikipedia.org/wiki/Brain%E2%80%93computer_interface
[2] Utrecht NeuroProsthesis - About Brain Computer Interface
[3] The Brain Computer Interface Future
[4] Rutgers University Libraries - Health Sciences - Brain-Computer Interfaces
[5] Research Groups - BNCI Horizon
[6] Research - Berlin Brain-Computer Interface (BBCI)
[7] Recordings of brainwaves produced by an electroencephalogram - pdf
[8] Recent Advances in Brain-Computer Interfaces
[9] Nano Brain Entrainment - Recent Advances in Brain Computer Interface Systems
[10] Military Funds Brain-Computer Interfaces to Control Feelings
[11] IJAIEM-2014-03-29-121 BCI algorithm paper
[12] Exploration of Recent Advances in the Field of Brain Computer
[13] Delorme BCITools
[14] Brain-Machine Interface - Brain-Computer Interface Research @ University of Freiburg —
[15] Brain-Machine Interface Research
[16] Brain-Computer Interfaces and Human-Computer Interaction By Desney Tan and Anton Nijholt
[17] Brain-computer interfaces- military, neurosurgical, and ethical perspective. - PubMed - NCBI
[18] Brain-Computer Interfaces in Medicine
[19] Brain computer interfacing_ Applications and challenges