BRAIN COMPUTER INTERFACE AND ITS TYPES - A STUDY

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ABSTRACT

A Brain Computer Interface (BCI) provides a communication path between human brain and the computer system. With the advancement in the areas of information technology and neurosciences, there has been a surge of interest in turning fiction into reality. The major goal of BCI research is to develop a system that allows disabled people to communicate with other persons and helps to interact with the external environments. This area includes components like, comparison of invasive and noninvasive technologies to measure brain activity, evaluation of control signals (i.e. patterns of brain activity that can be used for communication), development of algorithms for translation of brain signals into computer commands, and the development of new BCI applications. This Paper provides an insight into the aspects of BCI, its applications, recent developments and open problems in this area of research.

KEYWORDS: *Brain Computer Interface, Invasive and Non-Invasive, Electroencephalography, Magneto encephalography, functional magnetic resonance imaging*

I. INTRODUCTION

Brain–computer interface (BCIs) started with *Hans Berger's* inventing of electrical activity of the human brain and the development of electroencephalography (EEG). In 1924 Berger recorded an EEG signals from a human brain for the first time. By analyzing EEG signals Berger was able to identify oscillatory activity in the brain, such as the alpha wave (8–12 Hz), also known as Berger's wave. The first recording device used by Berger was very elementary, which was in the early stages of development, and was required to insert silver wires under the scalp of the patients. In later stages, those were replaced by silver foils that were attached to the patients head by rubber bandages later on Berger connected these sensors to a Lippmann capillary electrometer, with disappointing results. 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.

II. OVERVIEW OF BRAIN COMPUTER INTERFACE (BCI)

A Brain–Computer Interface (BCI), often called a Mind-Machine Interface (MMI), or sometimes called a direct neural interface or a Brain–Machine Interface (BMI), is a direct communication channel between the brain and an external device. Brain-computer interface (BCI) is an upcoming technology which aims to convey people's intentions to the outside world directly from their thoughts, enhancing cognitive capabilities [1]. BCIs are often directed at assisting, augmenting, or repairing human cognitive or sensory-motor functions. The BCI can be used for people who are unable to express through speech. Normally these people are "locked in" meaning they can't move their face or any of their appendages. The field of BCI research and development has been focused on neuroprosthetics applications. This aims at restoring damaged hearing, sight and movement.

Neuroprosthetics is an area of neuroscience concerned with neural prostheses. We can use artificial devices to replace the function of nervous system which is not proper and brain related problems as well as sensory organs. The most widely used neuroprosthetic device is the cochlear implant which, as of 2006, had been implanted in approximately 100,000 people worldwide. There are many other neuroprosthetic devices which aim to restore the vision, including retinal implants. The difference between BCI and neuroprosthetics are: neuroprosthetics connect nervous system to a device where as BCI connects the brain to a computer system. However, neuroprosthetics and BCIs are mainly focusing on to achieve the same goal such as restoring sight, hearing, movement, ability to communicate, and even cognitive function. Both use similar experimental methods and surgical techniques.

BCI provides a new communication channel between the human brain and the computer. Mental activity leads to changes of electrophysiological signals like the EEG. The BCI system detects such changes and transforms it into a control signal which can be used in various applications like video game, motion of a wheel chair etc. One of the main goal is to enable completely paralyzed patient to communicate with their environment. The machine should be able to learn to discriminate between different patterns of brain activity as accurate as possible and the user of the BCI should learn to perform different mental tasks in order to produce distinct brain signals [2], [8], [9].

A BCI is a communication and control system that does not depend in any way on the brain's normal neuromuscular output channels. The user's intent is conveyed by brain signals (such as EEG) rather than by peripheral nerves and muscles, and these brain signals do not depend for their generation on neuromuscular activity. Furthermore, as a communication and control system, a BCI establishes a real-time interaction between the user and the outside world. The user receives feedback reflecting the outcome of the BCI's operation, and that feedback can affect the user's subsequent intent and its expression in brain signals as shown in figure1[1]. The first step in developing an effective BCI paradigm is to determine suitable control signals from the EEG. A suitable control signal has the following attributes: (i) it can be precisely characterized for every individual, (ii) it can be readily modulated or translated to express the intention, and (iii) it can be detected and tracked consistently and reliably [3]. The EEG eye blink signals have all the above three attributes and hence can be used as a control signal.

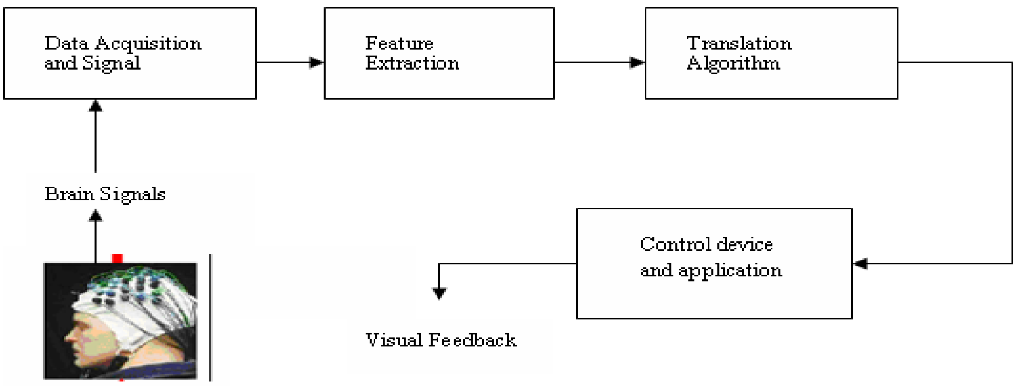

Fig 1: Representation of a BCI

III. TYPES OF BRAIN COMPUTER INTERFACE

There are several types of brain-computer interfaces that are reported. The basic purpose of these devices or types is to intercept the electrical signals that pass between neurons in the brain and translate them to a signal that is sensed by external devices.

3.1 Invasive Brain Computer Interfaces

Invasive Brain Computer Interface devices are those implanted directly into the brain and have the highest quality signals. These devices are used to provide functionality to paralyzed people. Invasive

BCIs are also used to restore vision by connecting the brain with external cameras and to restore the use of limbs by using brain controlled robotic arms and legs. As they rest 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 lost as the body reacts to a foreign object in the brain.

Fig 2: Jens Neumann, a man with acquired blindness, being interviewed about his vision BCI on CBS's The Early Show

In vision science, direct brain implants have been used to treat non-congenital i.e. acquired blindness. One of the first scientists to come up with working brain interface to restore sight as private researcher, William Dobell. He implanted first prototype into Jerry, A man blinded in adulthood, in 1978. He inserted single array BCI containing 68 electrodes into Jerry's visual cortex and succeeded in producing the sensation of seeing light. In 2002, experiment was conducted on Jens Neumann where Dobell used more sophisticated implant enabling better mapping of phosphenes into coherent vision and after the experiment Neumann was interviewed on CBS's show as shown in fig 2.BCIs focusing on motor Neuroprosthetics aim to either restore movement in paralyzed individuals or provide devices to assist them, such as interfaces with computers or robot arms. 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 stimulate movement.

3.2 Partially Invasive Brain Computer Interfaces

Partially invasive BCI devices are implanted inside the skull but rest outside the brain rather than within the grey matter. Signal strength using this type of BCI is bit weaker when it compares to Invasive BCI. They produce better resolution signals than non-invasive BCIs. Partially invasive BCIs have less risk of scar tissue formation when compared to Invasive BCI.

Electrocorticography (ECoG) uses the same technology as non-invasive electroencephalography, but the electrodes are embedded in a thin plastic pad that is placed above the cortex, beneath the dura mater. ECoG technologies were first trade-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. This research indicates that it is difficult to produce kinematics BCI devices with more than one dimension of control using ECoG.

Light Reactive Imaging BCI devices are still in the realm of theory. These would involve implanting laser inside the skull. The laser would be trained on a single neuron and the neuron's reflectance measured by a separate sensor. When 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.

3.3 Non Invasive Brain Computer Interfaces

Non invasive brain computer interface has the least signal clarity when it comes to communicating with the brain (skull distorts signal) but it is considered to be very safest when compared to other types. This type of device has been found to be successful in giving a patient the ability to move muscle implants and restore partial movement. Non-Invasive technique is one in which medical scanning devices or sensors are mounted on caps or headbands read brain signals. This approach is less intrusive but also read signals less effectively because electrodes cannot be placed directly on the desired part of the brain. One of the most popular devices under this category is the EEG or electroencephalography capable of providing a fine temporal resolution. It is easy to use, cheap and portable.

3.4 The Emotiv Education Edition SDK

The EEG headset, to extract a person's brain waves to authenticate him, is EPOC headset manufactured by Emotiv Inc as shown in fig 3. More details about this headset are given below. The Education Edition SDK by Emotiv Systems includes a research headset: a 14 channel (plus CMS/DRL references, P3/P4 locations) high resolution, neuro-signal acquisition and processing wireless neuroheadset as shown in fig 4. Channel names based on the International 10-20 locations are: AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4. [4]

Fig 3: Subject wearing the Emotive Epoc Headset

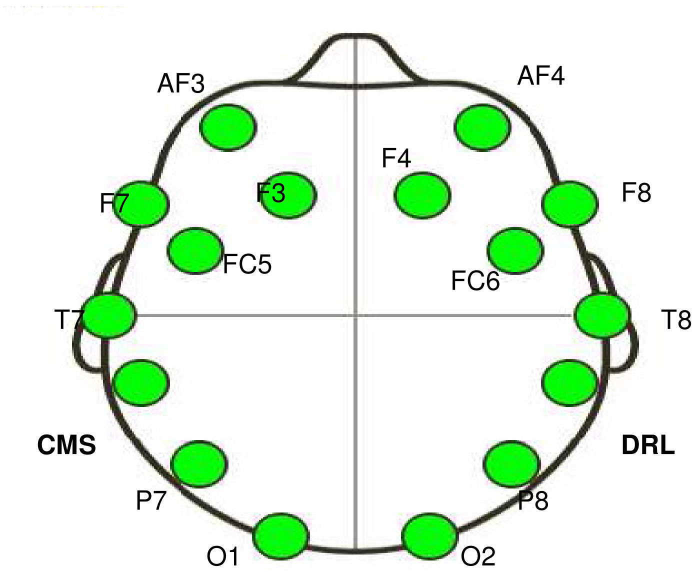

Fig 4: Illustration of location of electrodes on the scalp

The Education Edition SDK also includes a proprietary software toolkit that exposes the APIs and detection libraries. The SDK provides an effective development environment that integrates well with new and existing frameworks.

Other methods of capturing brain signals include electroencephalography (EEG) and magneto encephalography (MEG). The methods that are not in use but are being considered include magnetic resonance imaging (MRI) and near infrared spectrum imaging (NIRS) to provide analysis of brain wave and chemical patterns, but are currently impractical due to their size [5].

i) EEG Based BCI

Electroencephalography (EEG) is a type of non-invasive interface, which has high potential due to its fine temporal resolution, ease of use, portability and low set-up cost. A common method for designing BCI is to use EEG signals extracted during mental tasks [8], [9]. EEG is the recording of electrical activity along the scalp produced by the firing of neurons within the brain. EEG refers to the recording of the brain's spontaneous electrical activity over a short period of time, usually 20–40 minutes, as recorded from multiple electrodes placed on the scalp. The EEG is modified by motor imagery and can be used by patients with severe motor impairments (e.g., late stage of amyotrophic lateral sclerosis) to communicate with their environment and to assist them. Such a direct connection between the brain and the computer is known as an **EEG-based BCI**. EEG-based BCI have become a hot spot in the study of neural engineering, rehabilitation, and brain science [6]. The most commonly used signal that is identified and captured with EEG method is called the P300 wave. The P300 is an event related potential, a measurable electrical charge that is directly related with impulse. Therefore, by capturing the P300, a BCI can directly translate a persons' intent into electrical commands that control artificial devices [7]. A P300 speller is based on this principle, where the detection of P300 waves allows the user to write characters. The P300 speller is composed of two classification problems. The first classification is to detect the presence of a P300 in the electroencephalogram (EEG). The second one corresponds to the combination of differentP300 responses for determining the right character to spell. A new method for the detection of P300 waves is presented. This model is based on a convolution neural network (CNN) [14]. The applications of BCI have extensions into many different fields like Medicine, Military, Manufacturing, Gaming and Communications.

ii) MEG and MRI

Magneto encephalography (MEG) and functional magnetic resonance imaging (fMRI) are another type of non-invasive interface. Both have been used successfully as non-invasive BCIs. 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.[10], [11].

IV. APPLICATIONS OF BCI

BCI is one of the exiting areas of research. This device has been developed to control the thoughts of the different users. Some of the applications of this technology may seem interesting such as the ability to control a video game by thought. If you think a remote control is convenient, channels could be controlled by our mind. This device would allow severely disabled people to work independently without anybodies support and also offers the paralyzed patients to improve the quality of life. BCI is well suited for patients who are paralyzed or locked-in and because of that they have very limited options of communication with other people, such as ALS (Amyotrophic Lateral Sclerosis) patients on a ventilator. BCIs are being developed for a variety of applications ranging from assistive technologies for patients with motor disabilities to entertainment devices [12]. Possible applications of an EEG-based BCI are, e.g., to move a cursor by mental control, which allows the patient to select letters or words and to control a functional electrical stimulation device for patients with spinal cord lesions. These applications can be controlled by at least one binary output signal of the BCI, which is obtained, for example, by classification of EEG patterns during imagination of left and right hand movements [13].

Several laboratories have managed to record signals from monkey and rat cerebral cortices in order to operate BCIs to carry out movement. Monkeys have navigated computer cursors on screen and commanded robotic arms to perform simple tasks simply by thinking about the task and without any motor output. Schmidt, Fetz and Baker in the 1970s established that monkeys could quickly learn to voluntarily control the firing rate of individual neurons in the primary motor cortex. In the 1980s, Apostolos Georgopoulos at Johns Hopkins University found a mathematical relationship between the electrical responses of single motor-cortex neurons in rhesus macaque monkeys and the direction that monkeys moved their arms(based on a cosine function).

V. CONCLUSION AND FUTURE WORK

The use of EEG signals as a vector of communication between man and machines represents one of the current challenges in signal theory research. The principal element of such a communication system is known as "Brain Computer Interface". BCI is the interpretation of the EEG signals related to the characteristic parameters of brain electrical activity. This is the new emerging area which is mainly for the patients in the treatment bed (those have lost their speech due to accident or with any reason). Over the past few years, numerous proof-of-concept experiments have shown that people unable to move can use simple EEG-based BCI systems for point-and-click, robot control, and even spelling at rates as fast as 20 words per minute.

However it has its own drawbacks. EEG measures tiny voltage potentials where signal is weak and prone to interference. Signals have to be recorded from brain in a clinical condition where there are no external (noise free environment), users have to be trained to perform various tasks with full concentration and Handling high dimensional data.

Future work in this regard would be exploring different approaches which can increase the reliability of scalp EEG recordings, exploring some more dimension reduction algorithms which helps in reducing the size of the EEG features. We can also say as detection techniques and experimental designs improve, the BCI will improve as well and would provide wealth alternatives for individuals to interact with their environment.

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