ISSN XXXX XXXX © 2019 IJESC

Research Article Volume 9 Issue No.3

Brain Computer Interface: An Overview

Vrushali .S. Sakharkar[1], Akhilesh A. Tayade[2]
Department of Computer Science and Engineering
P.R.M.I.T.& R. Badnera, India[1]
P.R.Patil C.O.E.T., Amravati, India[2]

Abstract:
The Brain Computer Interfaces (BCI) are devices allowing direct communication between the brain of a user and a machine. This technology can be used by disabled people in order to improve their independence and maximize their capabilities such as finding an object in the environment. A brain-computer interface (BCI) translates brain signals into commands that can be used to control computer applications or external devices. The main purpose of Brain Computer Interface is to enable the paralyzed people to communicate with their environment. The main issue to build applicable Brain-Computer Interfaces is the capability to classify the Electroencephalograms (EEG). The main focus of this review is on the Brain control signals, their types and classifications. In addition, this survey reviews the current BCI technology in terms of hardware and software where the most used BCI devices are described as well as the most utilized software platforms are explained. Finally, BCI challenges and future directions are stated.

Keywords: Brain Computer Interface (BCI), Electrocorticogram (ECoG), Electroencephalogram (EEG), Magnetoencphalogram (MEG), Near Infrared Spectroscopy (NIRS), Functional Magnetic Resonance Imaging (fMRAI).

I. INTRODUCTION

Brain-Computer Interface (BCI) is a developing research field attracting researchers worldwide. BCI provided a new communication channel that allows a person to send commands to an electronic device using his/her brain activities[4]. Electronic devices control by severely handicapped patients with brain diseases, such as epilepsy, dementia and sleeping disorders [2] is the main target of BCI systems. Brain Computer Interface (BCI) technology is a powerful communication tool between users and systems. It does not require any external devices or muscle intervention to issue commands and complete the interaction [1]. The research community has initially developed BCIs with biomedical applications in mind, leading to the generation of assistive devices [2]. They have facilitated restoring the movement ability for physically challenged or locked-in users and replacing lost motor functionality [3]. The promising future predicted for BCI has encouraged research community to study the involvement of BCI in the life of non-paralyzed humans through medical applications. There are some diseases which lead the patient in the locked in syndrome. In this condition, the person is cognitively intact but the body is paralyzed. Amyotrophic lateral sclerosis(ALS) is one example of such types of disease or a person can be paralyzed due to some accident like road accident, radiation accident etc. The main cause of ALS is unknown and this disease does not have any cure. Here the word paralyzed means that person has lost any voluntary control over the muscles, but his or her mind is as active as ours. The patient cannot move the ir legs, arms or faces. They totally depend upon the artificial respirator. In that state the patient can communicate effectively with their environment with the help of device that can read the electrical signals from the brain and can convert them into the corresponding control signals. Such devices are called Brain Computer Interface. The natural form of control or conversation needed nerves and movement of muscles. This mechanism begins with the user's intent. A complex process is prompted by this intent which includes some of the brain areas. As the result of this process, some signal are generated from brain which is used in BCI. A straightforward conversation link between a human or animal brain and an exterior equipment is called Brain-Computer Interface. It is also known as Brain-Machine Interface or Direct Neural interface. Basically, Brain Computer Interface is an artificial system that bypasses the body's normal efferent pathways, which are the neuromuscular output channels. BCI measures brain activity correlated with the user's intent and converts the recorded brain activity into the corresponding control signals [4]. These converted signals are further used for BCI applications. The translation of electrical brain signals into the signals used by the BCI applications is done by the computer which usually involves signal processing and pattern recognition. Since the measured activity or signals emerge directly from the brain and not originates from the muscles or peripheral devices, the system is called a Brain–Computer Interface.

1. BRAIN ARCHITECTURE:

The common concept about the brain is that it is a general purpose computer. This concept is far beyond the truth. In fact, the brain is more complex than a general purpose computer. It is a set of subsystems that cooperate together to control the whole human body and its functionalities. Through external devices such as sight, touch, taste, hearing, and smell, the brain is able to receive information from the external environment. There are also some other information that is received by the brain from the body internal systems. This three-pound organ is able to analyze all of the received information and accurately control the body parts such as hands, legs, eyes, etc. Based on the recent topographical maps of the brain, it was discovered that the brain parts are associated with distinct cognitive functions. The brain could be generally divided into two main parts which are the cerebral cortex and sub-cortical regions. Sub-cortical regions are those the areas that control the basic and vital functions such as heart rates, body temperature respiration, and emotional responses including fear, reflexes, learning, and memory. On the other hand, the cerebral cortex is considered newer in terms of evolutionarily. It is the largest and the most complicated part of the brain. This part is the focus on most of BCI research where it controls the sensory and motor processing and higher level functions such as language processing, pattern recognition, planning, and reasoning. Cerebral cortex is divided into two hemispheres, as shown Fig. 1, in which each hemisphere is portioned to four lobes which are: frontal, partial, occipital and temporal lobes. The partial lobe is responsible for several functions such as spelling, perception, objects manipulating, and spatial awareness. The basic functions of the temporal lobe are the language, recognizing faces, memory, and generating emotions. The third lobe is the Frontal lobe in which it is linked with organizing, planning, social skills, flexible thinking, conscious movement, problem solving, attention, and emotional and behavioral control. The final lobe is the Occipital lobe in which it is related to interpreting visual stimuli.

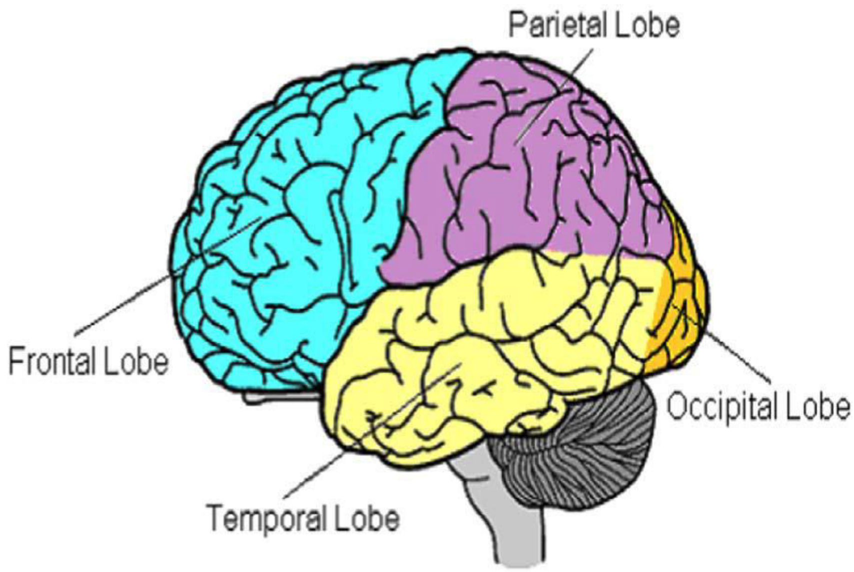

Figure. 1. Lobes of Cerebral Cortex

which are central and peripheral systems. Spinal cord and the brain are the two components of the central nervous system. The peripheral nervous system involves the autonomic nervous system in which it controls functions such as digestion, secretion of hormones, breathing and heart rate.

2. BCI CLASSIFICATIONS:

According to Fabien [5], the BCI could be classified according to dependability, invasiveness, and synchronization as shown in Fig. 2. In terms of dependability, the BCI is categorized as dependent and independent while in terms of invasiveness it could be divided into invasive BCI, non-invasive, and semi-invasive BCI. In the final category, the BCI could be synchronous or asynchronous (self-paced). These three categories are briefed as follows.

3.1. Dependent BCI and independent BCI:

The dependent BCI requires certain level of motor control from the subject while independent BCI does not require any control [6]. Dependent BCI could help the subject to do things more easily such as playing video games and moving wheelchair. On the other hand, subject with severe disabilities would need an independent BCI where no motor control is needed.

3.2. Invasive BCI, non-invasive, and semi-invasive BCI:

BCI is classified to invasive, non-invasive, and semi-invasive according to the way of the brain activity is measured. In invasive BCI, the microelectrodes are implanted in the brain, under the skull, during neurosurgery [7]. In this case, the signal might be produced with high quality but prone to scar tissue build-up over time and the signal might get lost. In addition, once the invasive technologies have been planted, it is not possible to move it to measure other parts of the brain [8]. On the other hand, in non-invasive BCI, the signals are recorded without any penetration in the scalp [19]. The signals in this case could be in low quality; however, non-invasive BCI is still preferable due to avoiding surgery. In the semi-invasive BCI, the electrodes are implanted underneath the skull and the brain signals are recorded using Electrocardiography (ECoG). For instance, Pfurtscheller group in [93] implanted macroelectrodes for epileptic patients over frontal regions. The patient tried to perform imagery tasks for hand, mouth and tongue and the BCI system with able to classify the imagery tasks ECoG through a single session.

3.3. Synchronous and asynchronous (self-paced) BCI :

BCI system is called a synchronous when the user interaction with the system is done at certain period of time. In other words, the system has to impose the subject to interact with it at certain period of time. Otherwise, the system will not be able to receive the subject signals. On the other hand, in asynchronous BCI, also named as “self-paced” , the subject is able to perform its mental tasks at any period of time and the system will react to his/her mental activities. Therefore, the subject is free to have his/her activity at any period of time.

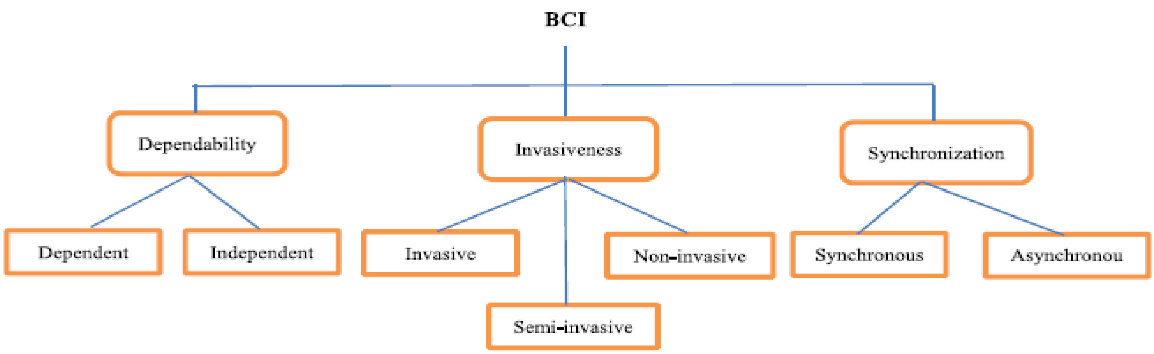

Figure.2. BCI Classifications

3. OTHER NEUROIMAGING APPROACHES IN BRAIN COMPUTER INTERFACE :

The brain computer interface need brain signals to perform any type of task. To get the signals from the brain BCIs rely on recording these electrical signals and then converting them into the corresponding commands. Two types of brain activities may be monitored:

i) Electrophysiological

ii) Hemodynamic.

4.1 ELECTROPHYSIOLOGICAL

Electrophysiological activity is generated by electro-chemical transmitters exchanging information between the neurons. Ionic currents are generated by the neurons which flow across and within neuronal assemblies. With the help of dipole conducting current from a source to a sink through the dendritic trunk the large variety of current pathways can be simplified [5]. Electrophysiological activity can be measured by Electroencephalography (EEG), Magnetoencephalography (MEG), Intracortical recording, Electrocorticography (ECoG) and electrical signal acquisition in single neurons. Electroencephalography, Electrocorticography, Intracortical recording are already discussed above.

4.1.1 Magnetoencephalography(MEG)

It is a non-invasive method that measures magnetic fields produced by electrical currents occurring naturally in the brain. The magnetic signal outside of the head is currently acquired only using the superconducting quantum interference device (SQUID). MEGsignals could interfere with other magnetic signals such as the earth's magnetic field so this recording methodrequires laboratory configuration with shields and specific equipments [18] as shown in Fig.3 . Despite its portability and cost issues, MEG signals are less distorted by the skull layer compared to electric fields. But this advantage does not lead to huge improvement either in performance or in training times over noninvasive electronic acquiring techniques[18].

Figure.3. MEG acquisition

4.2 Hemodynamic

When the blood releases glucose at a greater rate than in the area of inactive neurons to active neurons this process is known as the hemodynamic response. The oxygen and glucose delivered through the blood stream results in a surplus of oxyhemoglobin in the veins of the active area, and there is a distinguishable change of the ratio of oxyhemoglobin to deoxyhemoglobin. Neuroimaging methods are used to quantified these changes such as functional magnetic resonance and near infrared spectroscopy[17]. These methods are categorized as indirect methods, as they measure the hemodynamic response, which is not directly related to neuronal activity.

4.2.1 Functional Magnetic Resonance Imaging (fMRI) :

fMRI detects the changes in blood flow which are related to neural activity in the brain using the device shown in Fig. 4. Thus it helps mapping activities to the corresponding used brain areas which is known as source localization problem. It depends on the fact that any usage of brain part requires the increase of incoming blood flow. It uses bloodoxygen- level-dependent

(BOLD) contrast, which is sensitive to the hemodynamic response [16]. The intensities of BOLD contrast reflect the changes in the deoxyhemoglobin concentration in the brain tissue. Although fMRI temporal resolution is low, it provides a high spatial resolution and captures information from deep parts of the brain that cannot be gathered by electrical or magnetic measuring [18].

Figure. 4. fMRI Acquisition

4.2.2 Functional near-infrared spectroscopy (fNIRS)

fNIRS is a noninvasive technique that measures blood dynamic in the brain in order to detect the neuronal activity. It uses light in the near-infrared range to determine the blood flow . It has the advantage of providing high spatial resolution signals. But regarding the temporal resolution, fNIRS recording is likely to be less effective than that based on electromagnetic signals. Compared to fMRI, fNIRS is portable as shown in fig. 5. and less expensive but provides less imaging capabilities. Its advantages present a viable alternative for clinical studies and possibly for practical use [18].

Figure.5. fNIRS Acquisition

5. Applications Of Brain Computer Interface:

5.1 Military

In an actual fight the experience of the soldier can't be duplicated by machines. In that case soldier, while in simulation using BCI, the voluntary movements and decision of soldier can be used to guide robots/drones while the soldier sits safely playing simulation [15].

5.2 Medical Applications

BCI have variety of application in the medical field which can take advantage of brain signals in its associated phases including detecting, prevention, diagnosis, rehabilitation and restoration. Such as seizure predicting [14].

5.2.1 Prevention

A motion sickness level (MSL) can be reported using a virtual reality-based motion-sickness platform which is designed with 32-chennel EEG system and a joystick. The influence of smoking and alcohol on the brain waves can be detect using Brain Computer Interface [13].

5.2.2 Detection and Diagnosis

BCI system has also contribute in the detecting and forecasting the health issues such as the abnormal Brain Structure(Brain

Tumor), Sleep Disorder(Narcolepsy), Seizure Disorder (Epilepsy) and Brain Swelling(Encephalitis).EEG based BCI can be used to detect Breast Cancer, Dyslexia (a kind of brain disorder).

5.2.3 Rehabilitation and Restoration

When the brain cells are suddenly die because of the lack of oxygen that condition is known as the stroke due to which the patient can lose the ability to speak, or control over the limbs. Stroke may be fully recovered with the help of BCI [12]. Neuroprosthetic devices, which are used to regain the normal functionality for the patients who can not recover the mobility and communication like wheel chair, robotics prosthetic or an exoskeleton.

5.3 Smart Environment

K. K. Ang, C.Guan et al. have proposed a Brain Computer Interface-based Smart Living Environment Auto-Adjustment Control System(BSLEACS), which is a cognitive control system that monitor the users mental state and accordingly adapts the surrounding component. Using audio-video environment the alcoholic drivers, who contributes to a road accident, could be characterized using EEG.

5.4 Neuromarketing and Advertisement

The EEG evaluation is also beneficial for the TV Advertisement, related to the both political fields and commercial fields.G. Vecchiato, F. Babiloni *et al.* have consider the effect of cognitive function in the neuro-marketing field.

5.5 Self-Regulation and Education

In the sports competition an emotional intelligence based on EEG has been applied to control the stress. Functional Magnetic Resonance Imaging (fMRI) neurofeedback has been elaborated in self-regulations and skill learning [11].

5.6 Games and Entertainment

Now a days many researchers have the topic to combining the features of the exiting game with the brain controlling capabilities. Tan and Nijholt describe the brainball game which helps to drop the stress level [11].Halicopters are made to fly in any dimension either 2D or 3D. BCI provide a simplified driving simulator with mental-tasked condition for the verification of drivers identity. Cognitive Biometric or electrophysiology, which only modalities using bio-signals(such as brain signals) can be used to protect highly confidentional information.

6. CHALLENGES OF BRAIN COMPUTER INTERFACE:

The development of the Brain Computer System rely on the accurate selection of the signals then the data should be acquire in the correct manner, feature extraction, translation algorithm, dependent/independent mode, output devices, synchronous/ asynchronous mode, training user group, choice of application and protocols all these have their great effect on working of the BCI system . The main challenges which are faced by BCI system are:

6.1 Information Rate

It depends upon the sensors, the more the sensors are used to acquire the brain signals the more will be the information rate and upon the channels bandwidth which is used to pass these signals to corresponding system/device.

6.2 Error Rate

Error in the BCI is defines as classification error occurred while allocating task to external device. If there is higher the error rate in the BCI system then there will be the more complication while interacting with environment.

6.3 Autonomous

BCI systems cannot be used autonomously by disabled people, the reasons behind it is that BCI systems require assistants to apply electrodes or signal-receiving devices .

6.4 Midas Touch Problem

For the BCI system it is very difficult to distinguish between the voluntary or in-voluntary acts of the person. Midas is such a type of problem in which the system wrongly interprets the fixations which may be caused due to the long processing time. As user can off the BCI system by sending input to it but can not turn it on back again.

6.5 Cognitive load

It is the load on the brain to control the complex task of the hybrid BCI system, which may further depend upon the critical system means the user has to control in how many dimension.

II. CONCLUSION:

The field of BCI is one of the important fields that deals with brain activities. It is expected that BCI applications will have great effect on our daily life. Brain signals reflect the handled activities and controlling behavior of the brain or the influence of the received information from other body parts either sensing or internal organs. Brain Computer Interfacing provides a channeling facility between brain and external equipment. This paper focuses on defining the BCI. It also classifies and compares the brain signals. Moreover, it explains the current challenges of the field.

III. REFERENCES:

[1]. van Erp J, Lotte F, Tangermann M. Brain-computer interfaces: beyond medical applications. Computer 2012; 45 (4):26–34.

[2]. Rao R, Scherer R. Brain-computer interfacing [in the spotlight]. Signal Process Mag, IEEE 2010;27(4), 152-150.

[3]. Bi L, Fan X-A, Liu Y. Eeg-based brain-controlled mobile robots: a survey. Human-Machine Syst, IEEE Trans 2013; 43(2):161–76.

[4].B. Benjamin, D. Guido, "The Berlin Brain–Computer Interface: EEG-Based Communication Without Subject Training", IEEE transactions on neural system and rehabilitation engineering, vol. 14, no. 2, pp. 147-152, 2006.

[5]. F. Lotte, L. Bougrain, M. Clerc, F. Lotte, L. Bougrain, M. Clerc, E. Eeg, F. Lotte, L. Bougrain, and M. Clerc, Interfaces To cite this version: Electroencephalography (EEG) -based Brain-Computer Interfaces. 2015.

[6]. B. Allison, B. Graimann, A. Gräser, Why use a BCI if you are healthy, BRAINPLAY – Brain-Computer Interfaces Games Work. ACE (Advances Computer Entertainment, pp. 1–5, 2007.

[7]. H. Nakasaki, T. Mitomi, T. Noto, K. Ogoshi, H. Hanaue, Y. Tanaka, H. Makuuchi, H. Clausen, S.I. Hakomori, Mosaicism in the expression of tumor-associated carbohydrate antigens in human colonic and gastric cancers, Cancer Res. 49 (13) (1989) 3662–3669.

[8]. D. Tan, A. Nijholt, Brain-Computer Interfaces, (Human-Computer Interaction Series), in: Desney S. Tan, Anton Nijholt (Eds.), Brain-Computer Interfaces_ Applying our Minds to Human-Computer Interaction, Springer-Verlag L.,, 2010.

[9]. P. McCullagh, G. Lightbody, J. Zygierewicz, W.G. Kernohan, Ethical challenges associated with the development and deployment of brain computer interface technology,, Neuroethics 7 (2) (2014) 109–122.

[10]. T. Castermans, M. Duvinage, G. Cheron, T. Dutoit, Towards effective non-invasive brain-computer interfaces dedicated to gait rehabilitation systems, Brain Sci. 4 (1) (2014) 1–48.

[11]. C. Babiloni, V. Pizzella, C. D. Gratta, A. Ferretti, G. L. Romani, "Fundamentals of Electroencefalography, Magnetoence falography, and Functional Magnetic Resonance Imaging", Brain Machine Interfaces for Space Applications,New York, Vol. 86, pp. 67–80, 2009.

[12]. N. Weiskopf, K. Mathiak, S. W. Bock, F. Scharnowski, R. Veit, W. Grodd, R. Goebel, N. Birbaumer, "Principles of a brain-computer interface (BCI) based on real-time functional magnetic resonance imaging (fMRI)", IEEE Trans. Biomed. Eng., vol. 51, pp. 966–970, 2004.

[13]. D. Di, C. Zhihua, F. Ruifang, L. Guangyu, L. Tian, " Study on human brain after consuming alcohol based on eeg signal. In: Computer Science and Information Technology (ICCSIT)", 3rd IEEE International Conference, vol. 5, pp. 406–09, 2010.

[14]. A.P. Z. Mohammad, P. Manoranjan, "Seizure Prediction Using Undulated Global and Local Features", Vol. 64, issue. 1, Pages: 208 – 217, 2017.

[15]. A. N. Sarah, A. Ayman, M. M. Mostafa-Semi, " Brain Computer Interface: Application and Challenges", Egyptian Informatics Journal, Vol. 16, pp. 213-230, July,2015.

[16]. Ayaz H, Shewokis PA, Bunce S, Onaral B. An optical brain computer interface for environmental control. In: Engineering in Medicine and Biology Society, EMBC, 2011 Annual International Conference of the IEEE. IEEE; 2011. p. 6327–330.

[17]. Wei C-S, Chuang S-W, Wang W-R, Ko L-W, Jung T-P, Lin CT. Implementation of a motion sickness evaluation system based on eeg spectrum analysis. In: Circuits and Systems (ISCAS), 2011 IEEE International Symposium on. IEEE; 2011. p. 1081–84.

[18] He B, Gao S, Yuan H, Wolpaw JR. Brain-computer interfaces. Neural Engineering. Springer; 2013.

[19].J.R. Millan, F. Renkens, J. Mourino, W. Gerstner, Noninvasive brain-actuated control of a mobile robot by human EE", IEEE Trans. Biomed. Eng. 51 (6) (2004) 1026–1033.