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Critical Review and Study of Brain wave Acquisition and Applications & Challenges of Brain Machine Interfacing

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ABSTRACT

This paper depicts the generation of different kind of brain waves in different states of brain and applications and challenges in using Brain machine interfacing for the betterment of society. Brain machine interfacing is growing field of study now days with many applications in various fields such as in medical field; it is used for neuronal rehabilitation, helpful for physically disabled person. It can also be used in games, entertainment and security purpose. This paper also shows the major challenges in using brain machine interfacing. First sections of the review comprises of the basic introduction abut BMI, Second section depicts the basic working block diagram of BMI, Third section indicates the important applications of BMI in various fields, fourth section of review indicates the different brain states and the corresponding brain waves produced with different range of frequency, fifth section depicts the different signal acquisition methods and last, sixth section shows the challenges related to the utilization of BCIs.

Keywords: *BMI, BCIs, Brain states, Challenges.*

1. INTRODUCTION

A brain machine interface (BMI), also called Brain Computer interface (BCI) is a kind of communication technique between software and hardware with the help which human beings communicate with the surrounding without utilizing any muscles and nerves, but by using control signals generated by brain in its different states [1]. The main aim of BMI is to provide a mode of communication for people with damaged sensory functions to use their brain to control artificial devices and restore lost ability via the devices [2].

The BMI concept was initially developed for biomedical applications which lead to the generation of assistive devices. [3,4]. They have helped in restoring the movement ability for physically challenged persons but the promising future of BMI has encouraged the researchers to go beyond and device some other applications for healthy users also which can be used in many other applications of security, entertainment etc.[4].The Problem of low information transfer rate (ITR) is one of the major concerns for BMIs. This problem is restricting the BMI application for physically challenged persons as it will not be able to keep up with ways of ordinary communication [5]. BCI could be helpful especially for applications such as Safety, educational, industry, advertising and smart transportation or Applications movements are difficult to perform and the response time is crucial.

2. WORKING STAGES OF BMI

BMI system works like a bridge between human brain and the outer world. BMI system records the brain signals of an individual in different states and sends it to the computer so that the intended task will completed and then the processed data is used to control many devices to express the individuals view [3,6].

A BMI is kind of artificial intelligence system which works with five consecutive stages: signal acquisition, preprocessing or signal enhancement, feature extraction, classification, and the control interface [3]. All these stages are explained with the help of block diagram shown in figure 1.

A. Signal Acquisition: The main function of signal acquisition stage is to recognize signals from the brain and also workout on the reduction of noise and process the artifacts.

B. Preprocessing Stage: The preprocessing stage prepares the signals in a suitable form for further processing.

Volume 7, Issue 1
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C. Feature Extraction Stage: The main function of this stage is to identify discriminative information in the brain signals that have been recorded. One the signals are recorded they are mapped on to a vector which contains discriminated and observed features form the observed signals.

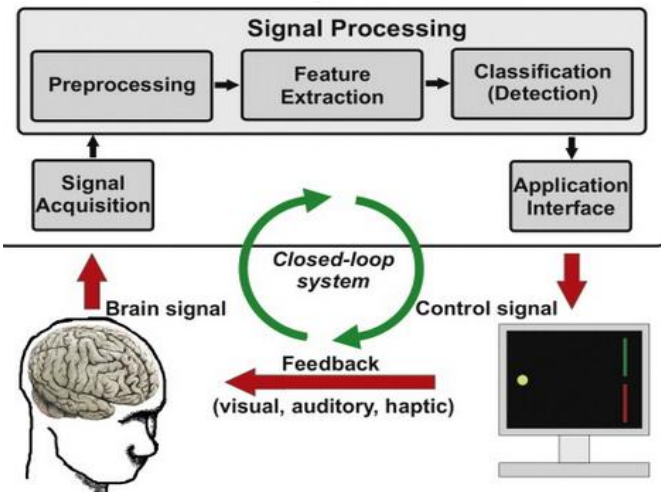

Figure 1 Block Diagram of Working stages of BMI

Brain signals are mixed with other signals coming from a finite set of brain activities that overlap in both time and space. Moreover, the signal is not always perfect because they are affected by artifacts such as electromyography (EMG) or electrooculography (EOG). The feature vector must also be of a low dimension, in order to reduce feature extraction stage complexity, but without relevant information loss.

D. Classification Stage: The classification stage classifies the signals taking the feature vectors into account. The choice of good discriminative features is therefore essential to achieve effective pattern recognition, in order to decipher the user's intentions.

E. Control Interface Stage: The main function of this stage is to perform the translation of classified signals into commands for any connected equipment such as Computer or a wheel chair.

3. APPLICATIONS OF BMIs

A. In Medical field: BMI finds wide application in medical fields which utilizes the brain signals in different states which includes diagnosis, rehabilitation and restoration. As shown figure 2

a) Prevention: The main cause of death and serious injuries are accidents as depicted in [6, 7], analysis of reasons for prevention has been a concern for researchers thus the concentration level for those having a motion sickness has been studied. Motion sickness generally occurs due to sending of conflicted sensory information generated form a body, inner eye and ear to the brain this usually happens in case of moving transportation media.

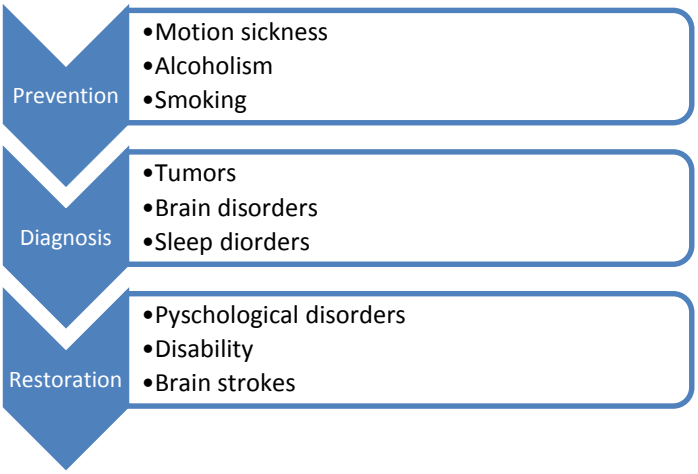

Figure 2 Applications in Medical field

Many researches are done for determination of various consciousness levels which shows the attentiveness influences of alcoholism and smoking on brain depicted in [8,9]. Such studies are helpful in medical prevention lies in the possible loss of function and decay of alertness level resulting from smoking andnor alcohol drinking, while the authors of [10] have investigated the most responding brain parts to alcoholism.

b) Detection and Diagnosis*:* In [11] authors have proposed a design of BCI that recognizes EEG abnormalities of brain tumor and epilepsy seizures. Epilepsy seizures are the most common neurological disorders and controlling its effects are presented in [12]. Dyslexia is also a common brain disorder which affects the reading, writing and learning ability and it can be diagnosed by brain behavior as depicted in [13]. The early diagnosis of can saves an individual form issues such as self esteem and self confidence. Tumor which is generated due to uncontrolled self division of cells could be diagnosed using EEG which is much cheap alternative than MRI and CT SCAN [12]. Authors in [14] also showed a utilization of EEG in detection of breast cancer.

Volume 7, Issue 1
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c) Rehabilitation and Restoration: It is depicted by authors in [15] that with the help of neuroplasticity using BCI the damaged motor function and the damaged portions of brain due to some brain strokes could be easily monitored and restored. Many patients are suffering from mobility issues, to regain lost function and regain significant level of mobility, Mobility rehabilitation is beneficial [16]. For locked in peoples, mobile robot can be used which help them to complete their daily activities [17].

B. Smart Environment: In present scenario the BCI technologies are not only restricted to medical fields. Now days they find utilization in applications such as smart houses or smart workplace and transportation. They are also used to maintain cooperation between Internet of things and BCI as stated in [18]. Integration of medical and smart houses are gaining non-intrusive health care has been an existing approach in BCI application as shown in [19].

C. Games and Entertainment: BMI also finds wide application in gaming. As depicted in [20], a helicopter is made to fly in 2D or 3D virtual world. If brain controlling capabilities are combined with features of the games then it gives multi brain entertainment experience, known as multi brain arena [21]. The players can join collaborative games by means of two BCIs. In [5], Tan and Nijholt have designed a game called brainball game which helps to drop the stress level of person. 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.

D. Neuromarketing and advertisement: In [22] authors has depicted the advantage of using EEG for advertisement related to political as well as commercial fields. The researchers of [23] proposed a design of estimating the memorization of TV advertisement thus providing another method for advertising evaluation.

E. Educational and self-regulation: Neurofeedback is reliable method of improving brain performance via targeting brain activity modulation. This method utilizes brain electrical signals to determine the extent of clearness of studied information. Dedicated interaction is conducted according to the observation obtained [24] . EEG based emotional intelligence has been applied in sport competitions to control the accompanying stress as examined in [25].

3. DIFFERENT STAGES OF BRAIN

Under different brain conditions different signals are generated which are categorized on the basis of its bandwidth. Table 1 shows the classification of different brain states and corresponding waves generated:

Table 1 Types of Brain Waves and Corresponding Brain States

Name of Waves	Frequency Range	Brain States
Delta	0.5 – 3 Hz	Sleep
Theta	4 – Hz	Deeply relaxed, Inward focused
Alpha	8 – 12 Hz	Very Relaxed, Passive attention
SMR Beta	12 – 15 Hz	Relaxed, External attention
Mid Beta	15 – 18 Hz	Active, External attention
High Beta	22 – 35 Hz	High Correlation with Anxiety Dominant
Gamma	>35 Hz	Some evidence of association with peak performance states

a) Delta Waves: Waves of frequency less than 4 Hz which are frontally in adults and prosteriorly in children are delta waves. It is usually present in adult slow wave sleep and in babies. It has also been found during some continuous-attention task. (Shown in figure 3)

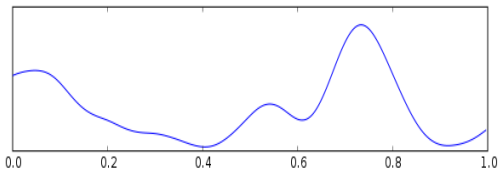

Figure 3 Delta waves

b) Theta Waves: Waves of frequency 4 Hz-7 Hz which is seen normally in young children are theta waves. These may be seen in drowsiness or arousal in older children and adults; it can also be seen in meditation. It can also be seen in generalized distribution in diffuse disorder or metabolic encephalopathy or deep midline disorders or some instances of hydrocephalus. (Shown in figure 4)

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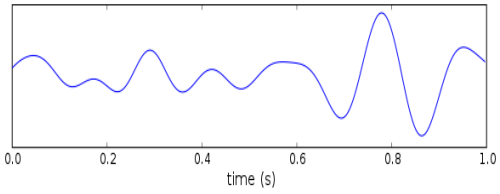

Figure 4 Theta waves

c) Alpha Waves: Waves of frequency 8-15 Hz which are present in the posterior region of the head, in both sides and higher in amplitude on the dominant side are alpha waves. It emerges with closing of the eyes and with relaxation, and attenuates with eye opening or mental exertion. EEG that has diffuse alpha occurring in coma and is not responsive to external stimuli is referred to as "alpha coma" [2]. (Shown in figure 5)

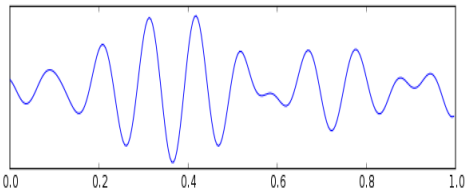

Figure 5 Alpha waves

d) Beta Waves: Waves of frequency from 14 Hz to 20 Hz which is usually seen on both sides in symmetrical distribution are beta waves. This type of wave is dominant in patients who are alert or who have their eyes open. But it is normally during active thinking [2]. (Shown in figure 6)

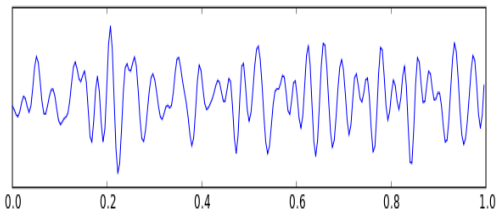

Figure 6 Beta waves

e) Gamma Waves: Waves of frequency from 30 to 100 Hz which is thought to present binding of different population of neurons together into a network of carrying out a certain cognitive or motor function are gamma waves. It is also shown during short term memory matching or recognized objects, sounds or tactile sensations [2]. (Shown in figure 7)

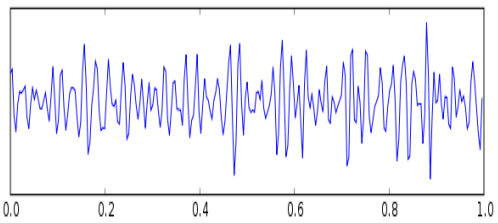

Figure 7 Gamma waves

4. METHODS OF BRAIN SIGNAL ACQUISITION

Acquisition of brain is the primary stage of any BCI system. It basically indicates the neural activities of an individual. The signal acquisition method are categorized on the basis of BCI applications and category of intended users.

A. Invasive techniques

Invasive technique of signal acquisition utilizes the implantation of electrodes under the scalp which is responsible of recognizing the neural activities of human brain. The main merit of using is, it provides high temporal and spatial resolution hence good quality of signal is obtained with low Signal to Noise ratio. However it requires complicated surgery and once implanted cannot be shifted to measure brain activity.

a) Intracortical Technique

This Technique is the most invasive technique of in which the electrodes are implanted under the cortex surface of the brain as shown in figure 8 [25,26]. Single or array of electrodes can be used for acquisition of signals generated by neural activities. Generally the tips of the electrodes are placed closed the signal source and the array of electrodes are expected to be stable for long period of time. In this we get high spatial resolution due to which it is highly recommended for source localization problem but this technique could also encounter long term signal variability. This happens due to neuronal cell death or due to increased tissue resistance. Monkey and rats are generally used as subject for intracortical implantation and the corresponding movements of animals are analyzed. Monkeys have been used to move robotic arm in virtual reality using this technique. Researchers have also succeeded in assisting them to eat with a real robot arm [28].

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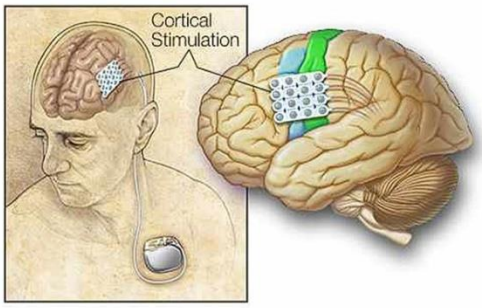

Figure 8 Intracortical Technique

b) Cortical surface

Electrocorticography (ECoG) is method of brain signal acquisition in which the electrode grips or strips are implanted over the cortex surface with the help of surgery as shown in figure 9 [2]. It is a kind recording method which is less invasive also preserves the advantage of invasive approach. It records the neurons activity in electrical form at embracing area. [26] has considered the number of electrodes as invasiveness degree.

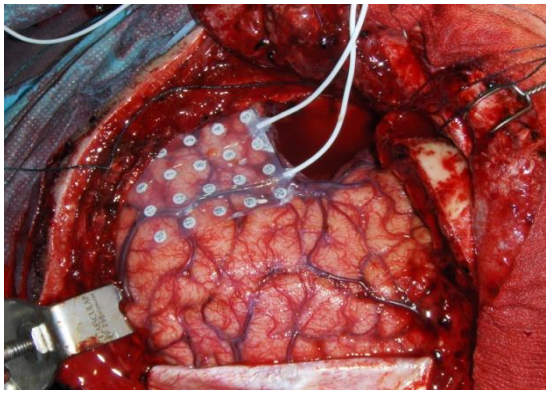

Figure 9 Cortical Technique

B. Noninvasive techniques

These are the recording method which does not require any implantation of electrodes on cortex of surface of the brain but the electrodes are implanted externally on the subject's brain.

a) Magnetoencephalography (MEG)

It works upon the fact of measurement of magnetic field produced by electrical signals of the brain as shown in figure 10. The magnetic signal at the outer part of the brain is acquired by superconducting quantum interface device (SQUID). Magnetic field produced by the electrical signals may interfere with other magnetic field such as earth's magnetic field due to this reason separate lab setup with proper shielding is required. Though it has portability and cost issues but the major advantage is magnetic signals are less distorted by skull layer as compare to electrical signals [26,27]

b) Functional magnetic resonance imaging (fMRI)

fMRI works upon the principle of detection of changes occurring in blood flow due to neural activity in the brain[29]. It uses source localization method of brain activities are mapped it also uses blood oxygen level dependent (BOLD) contrast which is sensitive to hemodynamic response [28].

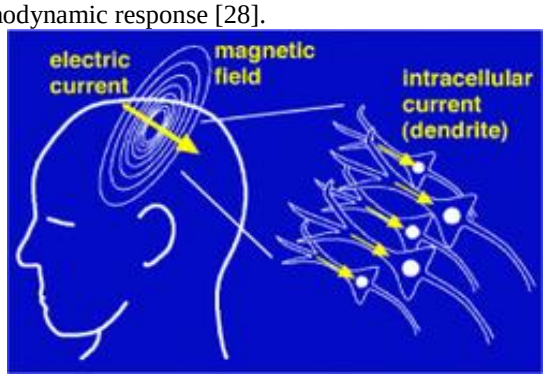

Figure 10 MEG Technique

The change deoxyhemoglobin in brain is reflected by change in the intensities of BOLD as shown in figure 11. This method provides low temporal resolution but high spatial resolution.

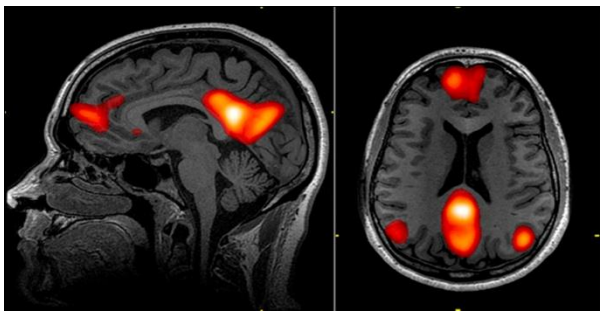

Figure 11 fMRI Technique

c) Functional near-infrared spectroscopy (fNIRS)

This method of signal acquisition is noninvasive technique which utilizes the measurement of blood dynamic in order to recognize blood activity as shown in figure 12. It uses infra red light in order to detect the blood flow. This Method provides high spatial resolution but provide less temporal resolution. This method is less expansive but has less imaging cabalities.

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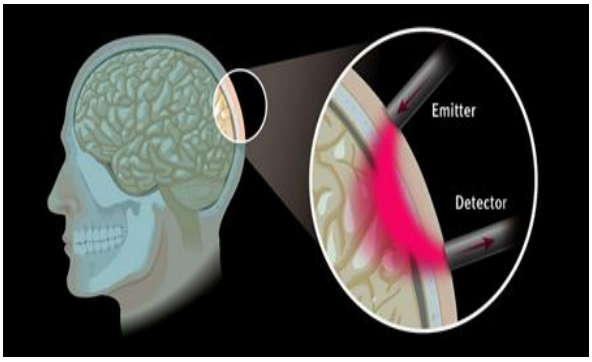

Figure 12 fNRIS Technique

d) Electroencephalogram (EEG)

In this method of acquisition the recording of electrical signals are done along the scalp by measuring the fluctuation of voltage due the neural activities in the human brain. The electrodes are arranged in a form of arrays in a cap fashion. It has major advantages over the other methods: portable, easy to use and less expansive, hence utilized commercially on large scale.EEG recording provides good temporal resolution but has low spatial resolution and poor Signal to noise ration. The international 10-20 electrode system is shown in figure 13.

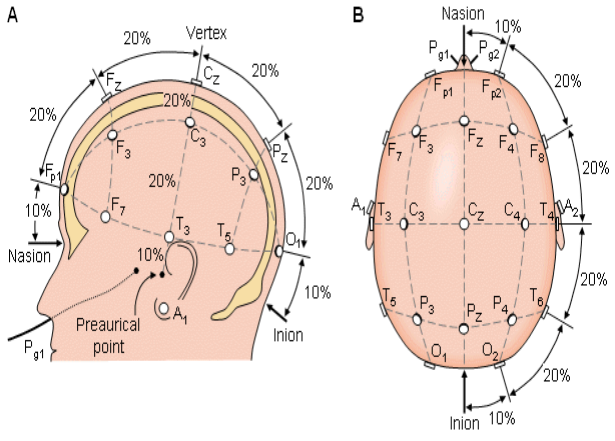

Figure 13 EEG Technique

5. CHALLENGES IN BCIs

BCI has been an exciting platform researchers now days but with number of advantages they also have many challenges which must be of prime importance for researchers:

a) The first important challenge is training the user for adopting BCI and it is a time consuming process either in guiding them in recorded session or through any process. It takes place generally in classifier calibration phase and also in preliminary phase [30].

b) The up gradation of hardware used for signal acquisition is also a great challenge for BCI users. Bio sensors used for signal acquisition must be dry, suitable to use and easy to modify. BCI systems should be favorable to use beyond laboratories and hospitals. Sensors used for BCI application should impart a significant SNR especially for mobile users. BCI can also be used outside hospitals and laboratories but have poorer performance than in laboratories condition. The future work must focus on developing better active electrodes with active shielding.

c) BCI technology have shown poor reliability in many application. BCI system are expected to appropriate for real time execution and must be suitable for any muscular actions. With any further improvement in technology the use of BCIs devices are restricted to for those having severe disorders.

d) Recording of electrophysiological signals is also difficult task as especially for the signals which include non linearity, noise, non stationary and dimensionality curse.

e) Human brain is highly nonlinear system in which chaotic and complex behavior of neurons can be detected. Thus the focus must be on developing nonlinear dynamic methods which provides better characterization than linear methods.

f) In most of the BCI systems the recording of signal takes place to preserve high spatial resolution. If the amount of data required to different signals increases exponentially with dimensionality of the vectors.

6. CONCLUSION

Signals generated from brain shows the controlling behavior of the brain or its influence on the other part of the body. BCI also provides a channel between brain and external environment. Several studies are depicted in this paper showing the different applications of BCI, different brain states and corresponding brain waves. Different methods for signal acquisitions are also depicted in this paper which is mainly classified on the basis of need of surgery, temporal and spatial resolution. At the last the different challenges are posed in front of researchers which have to be taken care of for further advancement and betterment of the BCI usability.

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