Electroencephalogram based Brain Computer Interface System Analysis

Parth Agrawal, Parul Khanna, Beaulah Soundarabai P, Niju P Joseph

Abstract: ***Electroencephalogram is the study of electrical signals of the brain recorded using a mesh like structure containing electrodes that is placed on the scalp. The history of EEG dates more than a century back, when the brains of rabbits and monkeys were studied and almost 50 years later in the year 1924, the first ever brain activity of human was noted by famed psychiatrist and physiologist Hans Berger from Germany. EEG based systems that can communicate with the brain are categorized as Brain Computer Interface i.e. BCI. The electrodes read the brain signals, amplifies them in order to be studied more accurately by the machine send them to machine after converting it into digital form. With the recent changes in technology better electrodes are being used which can catch highly sensitive signals as well.[1][2] EEG based BCI systems can change the world for many people as it holds so much power if thought properly. This paper reviews the EEG functioning and some innovations in BCI and also proposes ideas about potential help for people suffering from hearing and speech impairment.***

Keywords: Brain-Computer Interface, EEG, fMRI, BCI, EEG-fMRI fusion, MEG

I. INTRODUCTION

EEG is the abbreviation of Electroencephalogram and is the recording of the electrical signals produced by the brain. The signals are produced by the neurons that are oriented perpendicular to the surface of the head. This term dates back to 1875 when the brains of rabbits and monkeys were studied for electrical phenomenon. The finding about brain waves came later in the year 1890 when a Polish physiologist Adolf Beck studied brains of rabbits and dogs. Although the first ever EEG study on human brain was accomplished in 1924 by German psychiatrist H. Berger. EEG produces the wave graph of the brain signals and through that we can read and analyze the state of the brain. A hundred years ago, the graphs were plotted on paper but now as technology is constantly growing, it is now recorded in digital form. There are various methods to record brain activity but EEG stands out as it has excellent temporal resolution i.e. it records brain activity as it is happening.

EEG incorporates electrodes, amplifiers, conductive gel (like AgCl), and analog to digital converter. A number of electrodes are positioned on the scalp at particular coordinates to examine the electrical signals of the brain. The electrodes are filled with electrolyte i.e. the conductive gel. The signals produced by the nerve cells are amplified by the electrodes placed on the scalp, which are then read by the computer and interpreted in the waveform. The signals produced by neurons cannot be read accurately by the EEG recording machines therefore electrodes amplifies them and thus ma- chines can understand and analyze the signals. Ever since their discovery, EEG signals have been studied for investigating cerebrum work, for clinical diagnosis and to some extent for therapy. The belief of broadening the usage of EEG signals have been there for quite a while, like to use them as an alternative method to convey the message or thoughts inside the brain to the outside world. This possibility gives birth to systems like Brain-Computer Interfaces (BCIs) which unlike the usual neurological working of the brain, constructs a non-muscular connectivity between a computer and a human mind.[12]

The increased interest in such systems is largely due to the following reasons:

• Applications of such systems in regards to the people suffering from disabilities. Machines like ventilators having life-supporting technology give the chance to people to fight for their life to extended time. Even for people having less or no muscular control, such systems can be used for communication and control.[11]

• Having in-depth knowledge of the animal and human brains and improved technology leads to extensive re-search in this domain.

• The availability of the powerful, inexpensive components required for BCI systems.

II. RELATED WORKS

There are multiple invasive and non-invasive procedures for mapping signals generated by the brain like Electroencephalogram (EEG), functional Magnetic Resonance Imaging (fMRI), Positron Emission Tomography (PET), Near- infrared Spectroscopy (NIRS), Event-related optical signal (EROS), Magneto Encephalography (MEG). Out of all the techniques that are non-invasive in nature applied for analyzing the human mind, an immediate proportion of cortical movement with a worldly goal of not exactly a millisecond is furnished with EEG.[12]

Visualization of human behavior can be done in terms of sensory or motor states of the body like lip movements, eye movements, hand clenching, etc. For better understanding of the complex brain structure, some specific signal frequencies which are related to the mentioned states are observed.[37]. There are various waveforms when it comes to reading the state of the brain, which are discussed briefly:

• Gamma (>30 Hz, typically 40 Hz) : It was not discussed or even considered earlier as it is above 25Hz. But now due to advanced technology and instruments, we can record

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gamma frequencies as well. These waves have the highest frequency of all waves. These waves take over in the state of panic, fear, rapid eye movements.

• Beta (12-30 Hz): The beta waves are a sign of actively engaged state of mind. These waves dominate a general day for a human. They have low amplitude and has a high frequency. An orator or someone debating will have high beta waves productivity.

• Alpha (8-12 Hz): Alpha waves take over the human brain whenever the subject closes their eyes and bring themselves into a calm state. These levels are hiked when the subject enters in a state of relaxed wakeful- ness. A person having done some work and is now resting is in alpha state. Alpha waves are slower but higher in altitude.

• Theta (4-8 Hz): A person day dreaming is said to be in theta state. The theta waves have slower frequency and higher amplitude. An individual taking break during a task may also be in theta state as he/she may begin to day dream or in a state that is out of normal conscious awareness.

• Delta (0.5-4 Hz): These waves are deeply penetrating and have low frequency. Generally they are analyzed to determine the deepness of sleep. Stronger the delta rhythm, deeper the sleep. These waves have regenerating and healing properties therefore deep meditation and a good relaxed sleep is recommended for healing process.[2]

In the process of waking up from a deep sleep, an individual goes through a series of changes in terms of state of his/her brain. Initially the subject will be in delta state then to theta and then to alpha and finally when the alarm rings, the brain shifts into the beta state. If the subject hits the snooze button and falls back into sleep again, the brain might go back to theta or even delta state. In delta state, the subject might recollect the events of the previous day or think about the day lying ahead. This duration of time may produce creative ideas and increase mental activity of the individual.

Table I
Types of Brain Waves

Name	Frequency (Hz)	Brain State
Gamma	>30	In the state of panic or fear.
Beta	12 - 30	Actively engaged mind.
Alpha	8 - 12	Calm state.
Theta	4 - 8	Day dreaming.
Delta	0.5 - 4	Deep Sleep

Structure of a BCI framework requires a multidisciplinary approach of consolidating the following components: PCs, processing of signals, gadgets, psychology and neuroscience. Such a conventional framework comprises of terminals, an- other framework for acquiring signals, a unit for processing the acquired signals, a control interface, gadget, and a feedback unit as demonstrated in Fig. 1. These frameworks have been advanced to produce enormous inventions like mechanical hands/arms i.e. neuroprosthetics, hands free applications reading and translating the contemplations/emotions by distinguishing unmistakable neural patterns.[19]

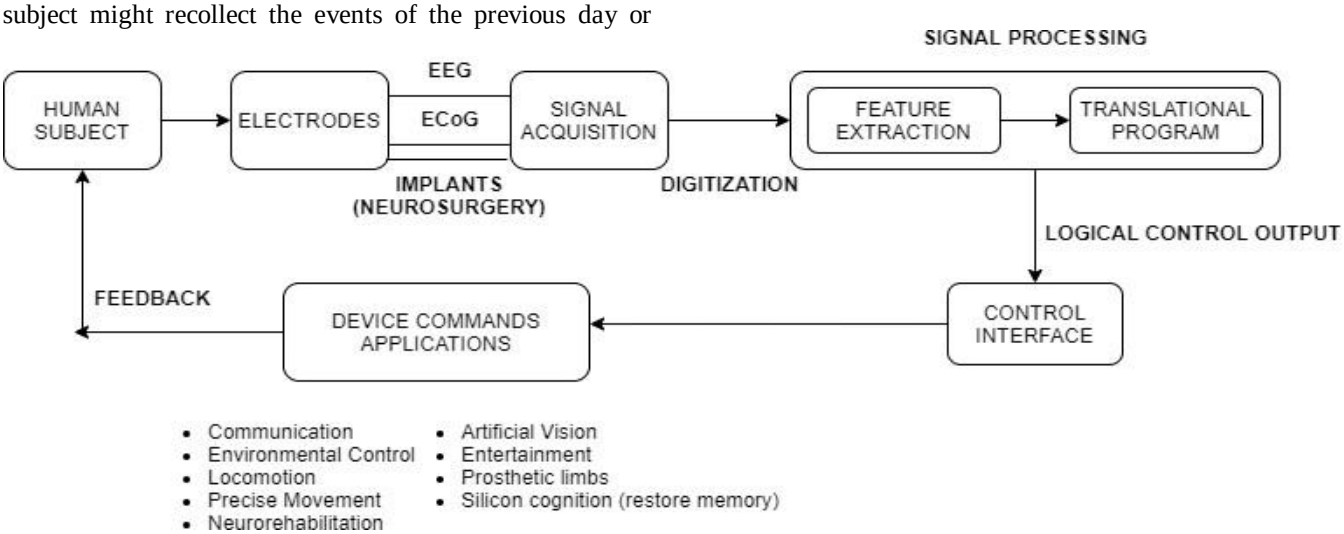

Fig 1. Basic layout of a BCI system

BCI conceivably connects the human psychological neural reactions to the outside world to interpret the subject's goals/considerations into real-time control signals. To accomplish this, a BCI framework has elements including procurement gadget that acquires electrophysiological signals from the subject, an interfaced PC to process the procured signals for feature extraction and their interpretation, thus creating output for operative gadgets commands for the chosen application.

These components and their consequent connections are represented by a successful controlling convention that oversees the comparing activity occasions (onset, offset, and timing of activity), depiction/choice of systems for signal preprocessing as well as post processing, a type of gadget yield commands pursued by parameters to examine the general execution of a planned application. Such BCI have proven to be a productive and one of a kind correspondence

control framework for patients experiencing serious nervous disorders. Fig. 2 outlines the entire design of an EEG-based BCI system.[20]

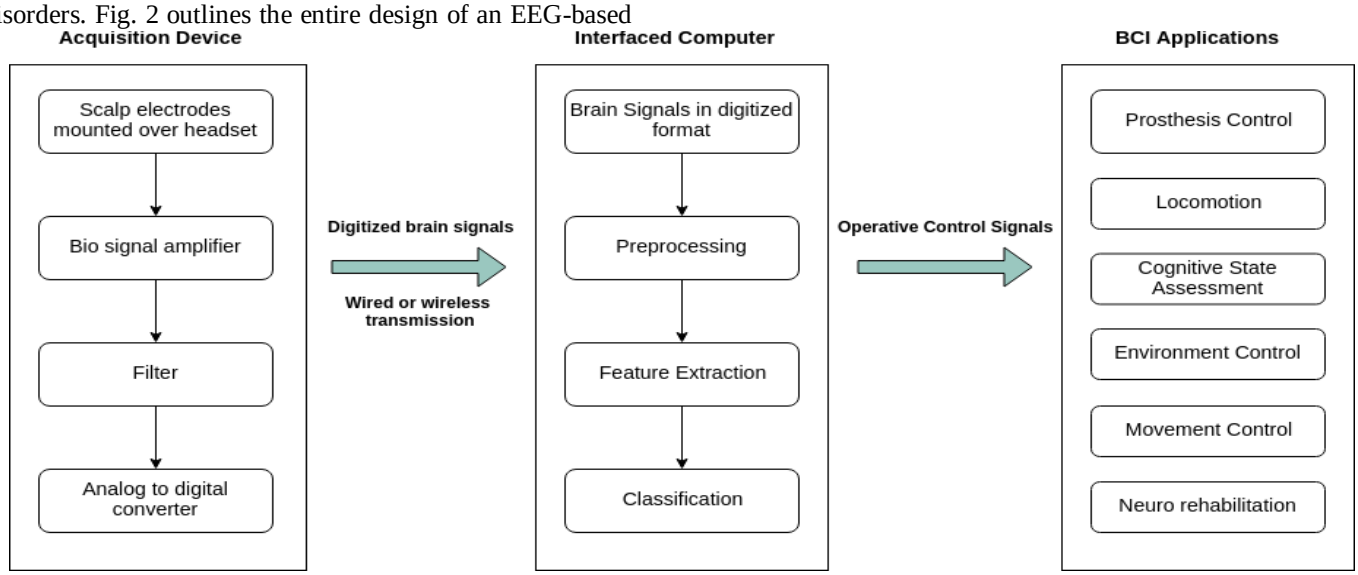

Fig 2. EEG based BCI system

Fundamental steps in an EEG based BCI systems are briefed below:

Signal Acquisition: It consists of recording the hemodynamic or electrophysiological reactions corresponding to action of the subject's mind. The signals are recorded utilizing invasive or noninvasive BCI neuroimaging modalities. We will concentrate on EEG as a chosen neuroimaging methodology in this paper. Various kinds of sensors can be utilized to procure the crude cerebrum signals. The gained cerebrum reactions are amplified to upgrade the signal level and filtered to expel control line impedance and other noises followed by the transition to digital signals using analog to digital converters followed by their transmission to the interfaced PC for further signal preparing.[20]

• Preprocessing: It includes the development of algorithmic methods for standardization, benchmark evacuation, de-noising, and removal of artifacts like electromyography (EMG) electrical movement of engine neurons and electrooculography (EoG) - electric possibilities because of movements of eyes, from recorded signals. The point is to improve data quality in the recorded crude mind signals. It is the progression to separate the necessary information from recorded neural reactions and includes the representation of recorded signals using minimal numerical capacities and mathematical functions. Principle center is around design and development of productive signal accretion and exact signal processing framework to avert loss of any important content. The filtration of procured neural information is frequently utilized pursued by their transmission during preprocessing stage. A definitive expectation of this step is to improve SNR i.e. signal-to-noise ratio of the recorded signals. This pitch in the proficient portrayal of acquired brain signals.[20]

• Feature Extraction: This step develops the most discriminative and useful reduced feature set from preprocessed cerebrum signals. A low-dimensional feature vector containing of direct and nonlinear features is separated to catch and describe the varieties (transient and morphological varieties) in obtained neural reactions relating to explicit neural movement. Each cerebrum signal is depicted/measured by a couple of pertinent qualities termed as "features". These separated features must cut down the intra-class feature fluctuations while escalate the differences among various class features.[13]

• Classification: It includes the usage of removed list of capabilities from preprocessed brain signals and assigning of a class or category to the analyzed cerebrum patterns.[14] This mapping is accomplished by analyzing the distinctions and likenesses in the mind signal features. An allotted class distinguishes the sort of corresponding captured neural action pattern (e.g., single eye blink, twofold eye blink, left-leg movement development, right-leg movement). This stage deciphers the separated list of capabilities into operative gadget control signals.

One of the most salient diagnostic components is ERP (Event related potentials). ERPs show the brain responses to cognitive, sensory and motor events. Amplitude, latency and width helps in characterizing ERPs. If any changes are observed in these parameters it usually means the malfunctioning of the brain. ERPs are short term waves in EEG signals which can only be seen after multiple trials. Hence it is very challenging to accurately detect and separate out ERP waves.[3]

A recent approach to track ERPs is to implement Vibrational Bayes (VB) which is also known as ensemble learning. VB is often referred as an extension of expectation maximization which is used to estimate the most probable value for each parameter. It helps in estimating the value of each parameter using likelihood function.

Even if the previous data of the parameters is not available, increasing the livelihood will lead to increase in KullbackLeibler divergence between the approx. computed posterior and the actual posterior distributions.

An approximate value of posterior distribution can be calculated considering the estimated parameters and latent variables using VB. [4]

Another approach by using spatiotemporal filtering was proposed to calculate the correlation between ERP subcomponents. This algorithm overcome one subcomponent within the spatial domain at the same time as diagnosing the other one within the temporal domain.[5]

If a person wants to move any of his body parts, several changes will be observed in brain. The motor cortex present inside the brain will increase its activity to pass the signal to execute an action. The cortex area will receive more oxygen rich blood as it is highly active. Using fMRI, the change in flow of oxygenated blood can be determined. If more oxygenated blood is observed in any part of the brain then there are high chances of that part being more active. Such a phenomena is known as Blood Oxygenation Level Dependent (BOLD).

Fig 3. Visualization of fMRI

fMRI has low temporal resolutions as reading is limited by computational factors and it takes few seconds for blood to change its flow. Due to this delay the process of collecting the data is slow.

Table 2: shows the difference between EEG and fMRI. Both EEG and fMRI can be used to diagnose the working of brain. As nothing in this world is perfect, even these technologies have their own advantages and limitations. Therefore using amalgamation of fMRI and EEG can over-come the limitations of each method and can produce better results. EEG-fMRI fusion approach can be classified into two major methods i.e. Data driven and Model driven method. Computational biophysical model is used by model driven approach. These strategies are used to model the relation be- tween fMRI and EEG primarily based on some assumptions of neural activities. Model driven approach provides better understanding of neural substrates which in turn helps in interpreting the recorded EEG and fMRI.[6] Whereas in data driven approach focuses on common interactions of EEG and fMRI.

These procedures are further divided in groups:

- Prediction based fusion
- Constraints based fusion.

Prediction based fusion model helps in calculating the correlation between fMRI and brain rhythms. This approach directly uses the neural responses which are recorded by EEG rather than depending on the timing of an event. As this method is not bound by the timing of an event, it can be used for experiments where no information about the time is available like the study of epilepsy. Blind Source Separation (BSS) methods are used to reduce noise from the data and form priors. Initially the recorded data is decomposed into several units and later cross matched. This approach is very useful as it can overcome the problems which are faced by neurovascular transformation function estimation. The relation between hemodynamic and electrophysiology can be elucidated by this approach.[7]

fMRI activation maps which are produced by fMRI analyzer is wield for electromagnetic source localization in constraints based fusion model.[8]

Electromagnetic Source Imaging (ESI) is used to solve the following equation:

$$X = AB + C \qquad (1)$$

Where X is the EEG measurement result, B holds different magnetized poles moments, C denotes noise, and A depict the transfer matrix with multiple columns where each column corresponds to the pattern produced magnetized poles placed on the scalp. Transfer matrix rows define the sensitivity pattern generated by a sensor. EEG sensors are generally less than the sources in the brain in an effort to avoid retroverted problem more constraints are needed to get a stable and reliable solution.

Frameworks like weighted minimum norm and Wiener filter are used to acquire the geometrical information from fMRI that is used to obtain the covariance prior for the reconstruction of source. Locations present in fMRI maps are anticipated to contain more active current sources. Degree of inclination of highlighted areas in the map is controlled by the covariance matrix which contains the weighing factors of fMRI.

It uses distributed source imaging methods which can track data not only from active areas but also from areas which are not active according to fMRI map.

Collaborating EEG with fMRI needs techniques for the statistical evaluation of fMRI generated data. Major techniques used for this purpose is General linear model (GLM) which depends upon the available information about the experiment and another one is data driven methods like BSS which doesn't require any prior data about the events timing.[9]

Magneto encephalography (MEG) can also be used to analyze the brain currents. Brain currents from the beginning of external magnetic measurements are reconstructed for MEG analysis. The advent of SQUIDs i.e. superconductive quantum interference device in early 1970s made MEG more reliable. These sensors can measure immensely low magnetic fields from brain signals with great accuracy. MEG particularly identifies the current which affects the outermost part of the brain. This outermost part is a layer grey tissue which is 2-4mm thick and is folded in the form of highly complex pattern. Brain currents can be categorized in 2 types:

- Primary Currents
- Passive Currents

Primary currents contain ion fluxes induced by chemical concentration gradients and Passive currents are the closing loops of primary fluxes. Volume currents can also be evaluated effectively if ion fluxes and their surrounding conductivity is known which will later help in computing the complete magnetic field everywhere.

As brain currents are reconstructed from magnetic fields which are measured externally, leads to inverse electro-magnetic problems. Due to this MEG suffers from ill-conditioning because of the following reasons:

• If proper care is not taken while choosing the basis for representation.

• Ineffective regularization and an accurate appraisal be-tween the related sources, measurements and fields.

To get better results and avoid these problems EEG and MEG can be merged, so advantages of both the systems can be utilized to analyze such a complex structure. It can even be combined with other diagnostics like MRI.[10].

Table II
Difference between EEG, fMRI and MEG

Factors	EEG	fMRI	MEG
Cost	Low	High	Low
Spacial Resolution	Low	High	Low
Activity Measurement	Direct	Indirect	Indirect
Knowledge	Basic	Extensive	Extensive
Temporal resolution	High	Low	High
Portability	Yes/No	No	No

III. BCI APPLICATIONS& RESULTS

Mental ability is being saddled in incredibly astounding manners and with the upcoming promising patterns in figuring innovations, BCI frameworks accordingly created promising answers for complex needs. Significant commitments in medicine fields ranging from preventive to analytic to rehabilitative for patients experiencing LIS i.e. Locked- In Syndrome, CLIS i.e. Completely Locked-In Syndrome or even for healthy people [15][16]. Other significant applications that help common comprehension between human mind and the neighboring frameworks incorporate neuroergonomics, smart home and environment, neuro-showcasing, commercial uses, training, games, amusement, security, verification, safeguard, and aviation [14][17][18]. Consequently, as is self-evident, the BCI innovation is quickly moving from research facility conditions to regular day to day existence helpful items. Some applications are explored in the ensuing subsections.

A. Clinical Applications

Mind diseases that can influence a person's capability to communicate to the outside world could be a consequence of infections, tumors, or cerebrum wounds like hematomas, clustering of blood, cerebral edema, or maybe strokes. The neurodegenerative diseases like Huntington's, Parkinson's, Alzheimer's, dementia, ALS, or Lou Gehrig's may develop over the age. Even due to hereditary, cerebrum diseases like Tay-Sachs, and behavioral diseases that hampers one's capacity to associate with the outside world like, depression, anxiety, bipolar disorder, or schizophrenia may be developed. Such cerebrum related clutters can be dealt with utilizing distinctive BCI advances which fundamentally rely upon the level of disability and not on the etiology.[18] Some of the clinical applications of BCI are discussed below:

• Assistive Devices for the purpose of communication: Helping mind-damaged subjects to communicate better has always been a prime concern and a great deal of efforts is being put into this field to demonstrate same. An EEG-based BCI system for communication purposes should be basically a closed circle real time framework and essentially relying upon the accompanying cerebrum patterns:

- P300 ERPs
- SCPs
- SMRs

In SCPs patient can control positive and negative thoughts through broad preparing and the associated BCI system deciphers these progressions to move or control things on a PC screen. Along these lines, brain-disabled individuals are encouraged in sharing their thoughts and perspectives by the utilization of spelling gadgets [21], thought interpretation gadgets [22], and for fundamental and verbal correspondence too.[23][24][25][26][27]

• Assistive Devices for Locomotion: Autonomous movement proves to be significant as routine exercises in the world of disabled and differently-abled people. BCI offers a beam of hope to this necessity. Reestablishment of nerve control and brain-controlled wheelchairs are in effect broadly investigated and applications are being worked to address the needful.

Researchers even showed the SMR-based system bolster control of prosthetic gadgets in multidimensions [28]. Researchers have also had the option to give training to tetraplegic patients to oversee hand developments utilizing electric orthosis through EEG inputs.[29]

• Medical Diagnostics: The EEG-based BCI frameworks can possibly foresee the health of mind and aid in preventive consideration to control cerebrum issues like dyslexia, epileptic seizure, mind tumors, sleep disorders, encephalopathy, Parkinson's, cerebrovascular issue, is- sue of cognizance, and even other medical issues like malignant growth, and so on. Researchers found that proper examination of EEG signals can foresee unsettling influences in the brain and help in diagnosing epileptic seizures or tumors[30][31]. Even there has been attempt at creating SoC prosthetic device i.e. system- on-chip to

obtain and examine EEG flag progressively with a target to lessen epileptic attack[32].

B. Non-Clinical Applications

BCI have progressed to such a degree, that it is being offered to improve typical educational encounters. A few nonclinical applications dependent on instinctive human machine cooperation in the discipline of neuroergonomics, brilliant/smart homes, IOT (Internet of Things), amusement, training, music, security, verification, and so on are being investigated.

• BCI in Neuroergonomics: Neuroergonomics, a developing examination region manages the investigation and examination of mind utilizing BCI to help improve the working environment by understanding workman's wishes and needs and comprehend the effect of stress and advance a smart working setup [33][34].

• BCI for Smart Home: Reconciliation of Brain Computer Interface to give brilliant home condition is an energizing examination field that can possibly help clients control electrical appliances, security, etc. and offer achievable home computerization Researchers created self-ruling frameworks utilizing hybrid BCI systems with a goal to make older generation self-subordinate. Innovation that can consequently modify the temperature as per the user's preferring and play tunes and change lighting relying on the user's state of mind are already there to use. [35][36]

• BCI for Marketing: BCI systems can also be used in marketing domain. Vecchiato G et al have delineated the advantages of the using EEG for TV ads for each business and political advertisements[41]. BCI based evaluation measures those produced consideration going with viewing activity[42]. Astolfi L et al have reviewed the impact of different cognitive features in neuromarketing[43]. They intrigued by estimating the remembrance of television commercials consequently giving an alternate strategy for publicizing assessment.

• BCI for Entertainment and Games: Gaming and entertainment applications have unlatched the showcase for non-medical BCI. Various applications are developed for gaming industry like helicopters are programmed to fly from one point to another in 2D or 3D world [40].

• Some BCI application focuses on self-regulation and education domain. Neurofeedback is a guaranteeing approach for enhancing brain performance by focusing on human brain activity modulation. It attacks those instructive systems, which uses mind electrical signs to figure out the level for clearness of the gathered data. Customize connection on each learner may be secured as stated by those resultant reaction encountered[44]. It gives a mean for enhancing cognitive restorative methodologies. The researchers of [45] analyzed the possibility of fMRI for emotional regulation, same time another exploration[46] suggested to use rtfMRIEEG BCI to reduce the melancholy feeling and additionally different neuropsychiatric issue through preparation sessions.

Joining together the features for existing games with mind controlling competencies has been subject to huge number of researches for example, [38] which have a tendency should furnish a multi-brain stimulation experience. This feature game is known as BrainArena. The players might join a squad oriented or challenging foot- ball diversion by using two BCIs. They score goals by imagining alternate hand actions. Diversely, few EEG games are being utilized for neuroprosthetic restoration or emotional control. They would holding whichever another diversion thought or a changed person. Re- searchers of [39], have depicted Brainball game which will help in dropping those stress level. Users could best move the ball if they are relaxed. Therefore, those calm players will be less averse on moving towards victory. This will help other players to be more calm and amused at the same time to win further games.

IV. PROPOSED IDEA

Communication is the base of human existence where interaction with the outside world is what changes the mere existence of a human being to a lively life. While speaking and hearing is an integral part of basic communication, a good percentage of people suffer from speech or hearing difficulty/disability. Our curiosity lead to think of how we could analyze the basic age-old technique such as EEG and use it to help such people overcome the obstacle of basic communication providing them to have a chance at life as normal as it gets. Thus we propose the idea of using EEG signals to build a BCI system that will record the electric signals of the brain, analyze them and convey the correct message to the outside world in the form of text/audio. Such a system will help people having a speech disability or even difficulty to effectively perform basic communication and move ahead of conventional methods such as the usage of voice larynx or sign language.

The same thought extends to build a BCI system for people suffering from hearing difficulty/disability that will convert the sound signals recorded by the device into electrical signals that are understood by the brain. A conventional hearing aid captures the sound signal through a microphone and amplifies it and then passes the amplified signal to the ear through a speaker, so basically, a sound is made louder to make the person hear it. But such methods fail to separate the noise and actual sound signal and also such methods dont serve well for the people having permanent hearing loss or in some cases the absence of the ear.

V. CONCLUSION

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