ISSN 0975-2366
DOI: https://doi.org/10.31838/ijpr/2020.12.01.344

Research Article

Brain Computer Interface (BCI): Mechanism and Challenges - A Survey

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Received: 20.03.20, Revised: 10.04.20, Accepted: 05.05.20

ABSTRACT
The communication between patients and doctors is very common till the time the patient is in complete conscious state. But due to unfortunate incidences there may be a time when the patient gets into unconscious state known as disorders of consciousness (DOC) patients and are not able to communicate their feelings with their doctors. The restoration of communication is one of the prime objectives for DOC patients. In this paper review of several different methods to restore the communication with DOC patients have been discussed in detail. The advantages of using all these different methods and problems occurring due to their usage are explained. There are different methodologies for establishing communication with DOC patients and several challenges faced on their application. Both Electroencephalography (EEG) and Magnetic Resonance Imaging (MRI) signal have been used in different methods. In this paper, a complete discussion of these methods along with their challenges have been reviewed.

Keywords: BCI- Brain Computer Interface, DOC- Disorders of consciousness, HCI- Human Computer Interface, EEG-Electroencephalography, MRI- Magnetic Resonance Imaging

INTRODUCTION

There are different ways in which a human can interact with computer systems. Initially only keyboards were used to access the computer terminals. But with growing technology we started working with mouse and other pointing devices. The transition of a traditional HCI (Human Computer Interface) system to a BCI based HCI system is completely based on delivering thoughts from human brain to computer directly [1]. The BCI systems communicate using only brain signals also termed as communication signals that are acquired from either Electroencephalography (EEG) signal, Magnetic Resonance Imaging (MRI) signal depending on the mode of comfort level [2]. The BCIs use the brain signals as an activity to drive computer interfaces as an external device in order to enable communication without using a single motor response. Before adjusting to any BCI structure for a DOC patient, the preliminary step is to build up conclusions, that they can follow at least minimum orders with satisfactory consistency level. In reality, not all patients are active when it comes to following commands. Henceforth, BCIs in DOC should follow a two-advance approach: the first is set up a communication establishment within patients so that they follow proper commands. The second is attempt to establish safe communication. Preferably, programming and equipment segments utilized as an initial step would be promptly used for the second [3]. The Prolonged conditions in DOC patients result into different states and are categorized as Vegetative State(VS) also called as Unresponsiveness wakefulness syndrome, coma state, minimally conscious state(MCS) basically as (MCS+, MCS-) and Locked in syndrome state(LIS). Mostly LIS patients are not considered as DOC patients since they are completely conscious. The only difference is they can neither speak neither walk and are considered as VS patients. The VS and MCS patients are similar but can be differentiated based on their awareness either externally or internally. This awareness is associated with the interference of brain signals in neural networks of brain areas.
Brain Computer Interface (BCI) technologies were implemented in two different forms. The invasive and non-invasive BCI technology had different advantages and disadvantages. The biggest disadvantage with invasive BCI was due to electrodes being inserted in the skull there were many tissue damages in the brain risking the life of many DOC patients. The non-invasive BCI was a boon to the brain communication technology as it became the cheapest way to communicate the brain signals from brain to the computers. There is a lot of difficulty in analysing the human behaviour that is considered as very much complex in the research world. This human behaviour in terms of human emotions is extracted by recording the

signals from our brain such as EEG signals that has wide variety of different practical applications. The research, computing and medical fields use EEG signals to monitor various brain related activities. Thus the machines extracting these EEG signals are human computer interactive machines with higher degrees of emotional intelligence. Currently, the prime focus is mainly on developing an effective algorithm for processing of an EEG signal. More than fifty algorithms are being developed for measuring the brain activities. In situations of crucial time response, the BCI is extremely helpful for providing applications that is related to accuracy and safety point of view. Thus BCI contributes in fields of industry, transportation, education and advertising. The biggest challenge for BCI is user acceptance to this new developed technology.

BCI technology is used in cases where the patients show lack of muscular movement but are aware of environmental changes and can follow some simple instructions. The Locked-In Syndrome (LIS) patients are able to move only their eyes that too in a vertical movement and can blink with their eyes sometimes. Such patients are completely unable to communicate their day to day needs even when they are aware of their surroundings. The disease termed as Amyotrophic Lateral Sclerosis (ALS) disease is caused due to strokes and it leads to LIS patients [13]. However the life prospect of LIS patients can be improved to certain decades with different kind of medical care. In order to increase the quality of life of such patients the basic criteria is very important that is to restore communication with care takers and family members. Thus different algorithms for BCI's have been developed so as to communicate with the paralysed patients which includes online yes/no communication with ALS patients [14]. In DOC patients basically the visual pursuit assessment is applied to get the behavioural marks leading to a better clinical examination. But this sort of assessment is very challenging as the behavioural responses happen to change with respect to time and situations [15]. Brain Computer interfaces (BCI's) helps to sense brain responses with respect to peripheral stimuli without the need of any behavioural expressions. After the signal acquisition process, the features of these signals get extracted using different methods. The common spatial pattern (CSP) is one of the feature extracting method [16] that is combined with some non-linear classifiers. This method helps to provide a better result in some of the cases. Though CSP is a very noise sensitive method as well as very susceptible to over fitting, the performance of this method solely depends on the frequency band provided by the statistics of the EEG data.

Recently enormous work has been done in medical research fields using machine learning and deep learning. From early 2009, machine learning started developing thereby creating a boom in the industry of academics. In case of data sets, the challenges underlies to analyse the complicated patterns in artificial neural networks. Deep learning is an application that helps enable this analysis [17] and attained prominent benchmarks when the artificial neural network started overtaking other different methods on various image processing applications. From 2019, a lot of efforts are undertaken to apply deep learning to the medical problems. The Brain MRI images are collected in order to predict some parameters like body mass index (BMI), age and memory scores with a very simple 3D architecture of neural network [18]. The main problem that needs to be solved in DOC patients is their accurate diagnosis and predictions. Presently, depending on their behavioural benchmarks , there are some diagnosis available like Wessex Head Injury Matrix (WHIM), Coma Recovery Scale-Revised (CRS-R), Glasgow coma scale (GCS) and Full Outline of Unresponsiveness (FOUR). There are lot of research in the Coma Recovery Scale-Revised (CRS-R) method. Thus with the efforts of the researchers in the medical field, the restoration of communication between patients with unconscious state and family members along with doctors have been possible.

FLOW OF BCI FRAMEWORK

The complete flow of Brain Computer Interconnect (BCI) framework is discussed in this section. There are different blocks that are responsible for performing different functions at each level. In Fig 1, all the blocks and their work has been labelled so as to understand the basic flow of this BCI Framework. The brain signals from the brain are acquired using signal acquisition method. But researchers who have access to DOC patients in real time can collect this data very easily. On the other hand the medical research field is so vast that different kinds of datasets are readily available in which the DOC patients also termed as subject's record their responses. These recorded responses are used for research work since data collection is a difficult step as it involves different permissions to deal with DOC patients.

However the acquired brain signals from brain or dataset is sent to signal recorder (EEG/ MRI) to record the signals. The signals that are recorded certainly have noise that needs to be filtered in the next level. After the noise reduction, the signals that have certain features needs to be extracted. Thus the feature extraction block comes into existence. Depending upon different features,

different researches can be undertaken. The extracted features get classified in the feature classification block. The feature extraction and feature classification is the actual signal processing that happens to the signal after its acquisition. The processed signals are sent to for translation so that the signals get converted and translated to certain commands. These commands then start controlling the device that happens to be called as a BCI application device. This device may be a wheelchair, any remote control device, games that can be easily operated by the DOC patients. Thus due to accidents the patients who lost their voluntary movements including audio and visual communications get their communications restored by brain connect interface. There are many algorithms designed for translating the signals into commands and a lot of research work is also in boom to get as much accuracy as possible using different BCI methods. The biggest disadvantage in BCI is recording the brain responses that remain inconsistent with time and situations. This has a huge impact on the results provided by each methods. Though stability, reliability and flexibility are the prime objectives in BCI but accuracy plays a vital role in the field of medical research.

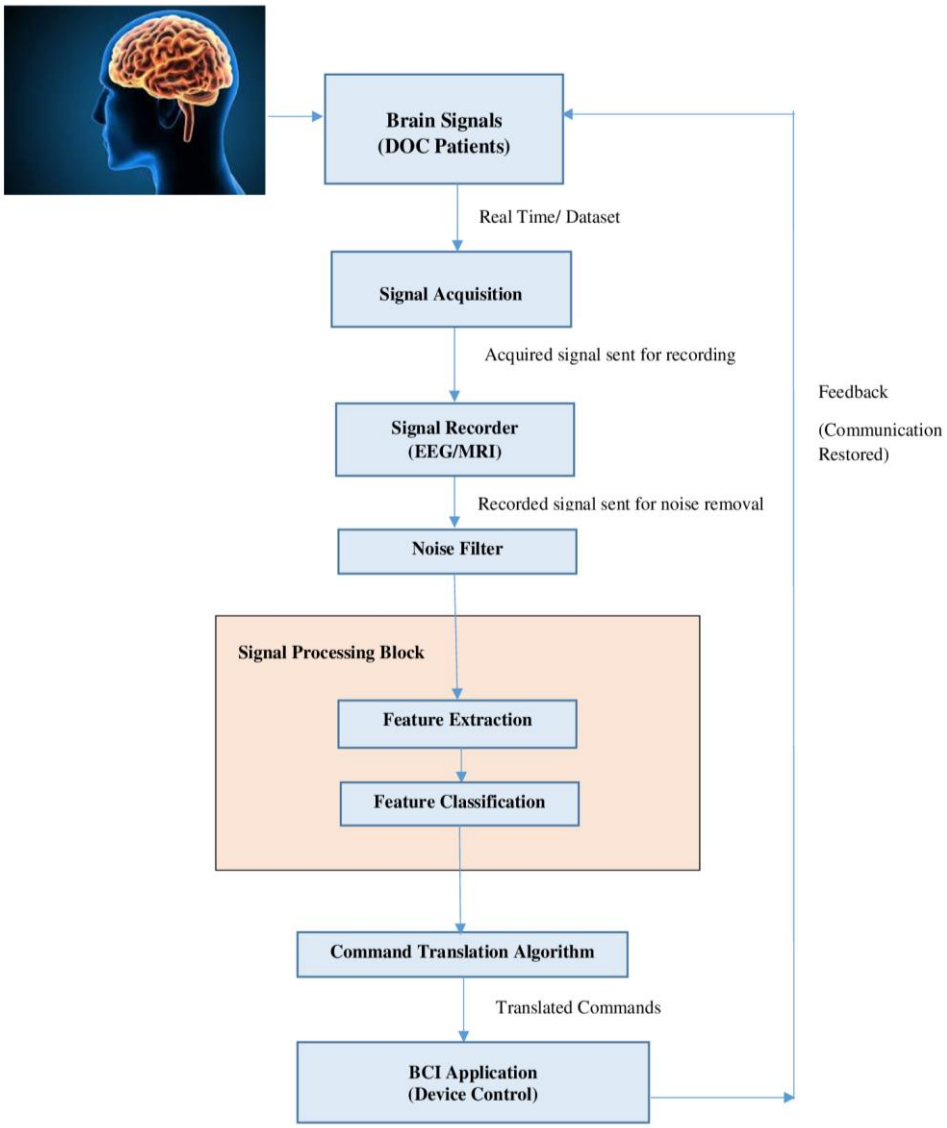

Fig 1: Flow of BCI Framework

LITERATURE SURVEY

The literature review of different papers were studied and below are the different methodologies that are used in different papers. The pros or advantages and the cons or disadvantages have been specified clearly along with the challenges that were faced in each methodology. The future scope helped to identify the real gap in the restoration of communication using BCI.

Methodology	Pros/Advantages	Cons/Disadvantages	Challenges	Future Scope
[1] Brain Connect Interface	The psychological problems are diagnosed, no physical connection is required, its eco- friendly	It is not a consumable technology as it's difficult to read the potential patterns.	The filtering of noise along with clustering of neuron with difficult signal acquisition and user interface design	Making the BCI technology as a consumable technology
[2]Signal Processing	Brain signals are used directly to support the processes of the brain helping to extract more of network source information	The data is large and handling big data sets is a huge concern	Processing of data needs to be channelized effectively	A high-bandwidth and a bidirectional way of communication can be developed in future
[3]Slow cortical potentials , P3 potential, sensorimotor rhythms, steady state oscillations	Less Training required from user point of view	Disabling nonvisual stimulation, modulation effect hard to detect in real time	Getting proper feedback, restrictions of stimulation modality, stability	Addressing the technical and practical challenges by providing consistent application to the patient.
[4]3D CAD modelling	It is a time saving method	It is difficult to classify the EEG signals also the participants experienced fatigue	Difficulty in integrating BCI with speech as well as the gesture modalities	More research in Interface Usability so to integrate BCI modalities
[5]BCI using non-invasive method	No surgery is required, Implementation is safe and easy	Traditional BCI methods have less performance, the capacity is limited when it comes to replacement of the lost bodily functions	User Training, safety issues, ethical and legal problems, process of BCI installation	More research is required regarding the application of non-invasive EEG-based BCIs' clinically for analysis
[6]Functional Imaging	Cost is low, sensitivity to signal is less	It has insufficient cognitive reserve, signal modification is required by brain lesion	The selection of best subjects, improving efficiency with all subjects, portability of the setup	Auditory BCIs are more relevant and needs to be developed.

[7]Backscattering approach	Fast and simple method for conductive patterns generation on a variety of platforms	There is a dearth of implantable technology which can last for a lifetime,	The ability of implantation poses key constraints on the size and power consumption of system	Minimization of test boards is required to remove the possibility of any kind of added connection through them.
[8] (mRMR) feature selection method and machine learning method	Good and accurate detection of emotion information from EEG recorded signals	This methods improves the performance by eliminating some inappropriate feature vectors.	Unknown selection of features to find out the results are reaching the best	Addition of features to system to improve performance. Fusion method needs to be analysed along with channel selection.
[9]EEG processing methods	Simple, less computational cost, data amount required is small	Real time is reduced with increase number of training set, also sensitive for redundant feature.	Usability, information transfer rate, non-linearity and training set is very small, noise.	A development of the methods lead to a new era of BCI applications.
[10]Invasive and non-invasive BCI method	Channelling facility	The information transfer rate (ITR) is very poor, BCI utilization is restricted for LIS patients	Challenges are either technical related to system or usability related that leads to restrict user acceptance.	The feature selection and reduction algorithms leading to more accuracy can be designed
[11]Voxel-based unbiased approach, called as functional connectivity density (CD)	Reliable, accurately address the changes in the functionality of the brain	Less number of participants, homogenous connection of functional characteristics	Creative prediction and therapeutics methods by changing the setting.	Assessment of brain damage that lead to externally induced connectivity
[12]The mindBEAGLE platform	More accuracy and more success rate of patients getting communicated	The test failed for user not trained or those who did not respond well	The waveforms, amplitudes and timing looked different making interpretation very hard.	More awareness needs to be done on the awareness part
[13]Deep learning method using convolutional network	Emoji helps to communicate well with patients, faster communication	Variations from person to person	The signal-to-noise ratio reduction, noisy signals increase recognition difficulty, the density of sensor is low	More research to be done in deep learning to improve efficiency and accuracy

[14]EEG-based BCI model	Successful yes/no communication with patients	There is discriminable features as there are different mental tasks.	Auditory feedback has to be provided	Home appliances using this method can be developed
[15]Visual BCI Method	Visual pursuit detection is better	The DOC patients were not able to undergo long trails	Based on the behavioural markers that are severely lacked due to lack of behavioural responses.	Extensions to system and increasing the number of trails on DOC patients
[16]FB-TRCSP+RF along with common spatial pattern and use of random forest method	Sensitivity to noise reduced , robust, more accurate, reliable	Training sample size is small and most prone to overfitting	The average of the peak classification dropped.	more research work to be done when combining CSP with deep learning
[17]Deep learning method	Extreme accurate predictions, safe, each layer of data is informative	Complicated data of deep neural network	Data collection and discarding some data is challenging as all the collected information seems valuable	Software systems with very high impacts is the need of the future
[18]3D network of neural signals using Brain MRI images	Signal optimization had good overall performance	Not good for prediction parameters for mean values	Extracting medically sound heatmaps	Representing brain to help get better predictions
[19] Method is novel BCI with 3D stereo audio and visual stimuli	Less sensitive while recognition of objects	Motor responses are ambiguous, inconsistent, difficulty to analyse voluntary and reflexive behaviours	Mismatch is BCI accuracy of DOC patients and healthy subjects	BCI system performances to be improved, subjects in assessment need to be increased
[20]Emotion recognition is done by EEG based BCI system	The emotional responses are recorded better	Data collected from less DOC subjects, emotion recognition by subjects is less	Taking more subjects into study and cooperation from patients side to record more emotions	Low amplitude and self-induced emotional signals need to be recorded

[21]Automatic reconstruction of EEG signal with (MEMD) method	Features were separable increasing the overall performance, noise filtering is good, less complex	Preserving long term memory difficult	Long term memory network needs to be designed	Parameters selected needs to be channel specific to increase the performance
[22]2D CNN network with anaesthetic datasets	Helps to provide physicians with reference information	DOA data analysis is not accurate	Reaching quantitative analysis requirements	More accurate and higher levels of classification to increase overall performance and predict depth of anaesthesia
[23] VTP model	Accuracy more than 60%	Limited DOC patients were studied so the straight comparison between UWS as well as MCS patients became difficult	Direct Brain Simulation is challenging	DOC patients data to be collected more by considering more subjects for research
[24]Deep learning framework with multiscale CNN	Tolerates amplitude changes and EEG signal Potential changes	Accurate result with limited training dataset but inaccuracy develops when data set increases	Creating a stable network for small datasets	To work for more training datasets values
[25] EEG wireless medium using TMS and NTSA.	Easy to use, secure, easy communication, no complex devices involved	System size is large and is the biggest drawback in this model	Reducing the size of the system	Efficient way of using deep learning techniques and reducing system size
[26] Hybrid BCI model technology	Reduces users workload, BCI is flexible, reliable, good for patients with low control capabilities and low recognition	Combinations of BCI must be considered carefully	Working on appropriate combinations to decide the hybrid BCI design	Applying h-BCI model to DOC patients
[27] VAD Model	Reduces complexity to make it reliable, accuracy increases by 5%	Collection of dataset recorded values in changes of emotions which can change with situations and responses	Emotions can be recognised using EEG signals and multidisciplinary skills are required for this approach	More research to be done in fields of neuroscience and physiology to recognize emotions using EEG based systems

CONCLUSIONS

This paper mostly focuses on the study of various BCI mechanism and different challenges faced in the process of retrieving the results. The most difficult part as per the review was in recording the behavioural responses of Disorders of Consciousness (DOC) patients. There is a lot of research work undergoing for collecting proper subject responses such that the behavioural changes of these subjects or patients do not impact the overall BCI application system. The biggest advantage according to the discussions in all the reviewed papers are that there is establishment of restoration of communication with the DOC patients thereby helping them to recover with their day to day needs and also support them with their daily tasks. BCI needs to address the technical as well as the practical challenges with reliable implementation. The need to study different filters is also of prime concern owning which it would be easier to control the SNR ratio. A system/process needs to be proposed for noise filter mechanisms for DOC patients using proper BCI system. A flexible model needs to be proposed using data sets already available in the research with proper validation.

CONFLICT OF INTEREST

None

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