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Comparative Analysis to Identify Efficient Technique for InterfacingBCI System

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Abstract. Brain Computer Interfacing (BCI) allows user to control certain devices or objects using human brain. With the availability of various sensors, it is possible to obtain the data from the human brain which controls the physical activities in the brain itself. BCI users can access a system capable of communicating efficiently in a special manner that works based on the brain signals. BCI gives a better platform for physically challenged people to do certain significant functions in their daily routine. The use of brain imaging technologies in BCI helps to enhance the signal quality during the communication among the machines and the human beings. The paper describes some of the research works carried on BCI and its advancements to perform a better communication between the computers and the human brain, by using emerging technologies. This paper also covers the applications, challenges, and future directions of BCI.

Introduction

The technological advancements lead to the development of different kinds of interactive systems that use different parts of the body to acquire the data. Example, Nam et al. [1] presented a paper on how a wheelchair is controlled by the movements of tongue. Liu et al. [2] proposed the human-computer interaction system that makes use of eye- tracking technique. BCI lets users to communicate with computer only through their brain signals. BCI studies mainly focused on people suffering from motor impairments i.e. paralyzed persons. BCI is an emerging field of research been studied since 1970s in various zones like biomedicine, neuroscience, computer science, automation and control engineering, but it is quiet relatively immature. The applications of BCI range from medicine to entertainment. The Human brain comprises a complex network of around hundred billions of neuron cells. Electrical signals generate in the brain when the person moves, feel, remember, or think about something. Sensors are used to detect and record these electrical signals which can be used later to control a device. BCI make use of brain signals captured by specialized equipment to control the devices and it doesn't involve any muscular activity, hence it forms a separate interaction mode between the humans and computer [26].

BCI captures signals directly from human brain. The three possible methods to acquire the brain signals are: (i) non-invasive technique, (ii) partially invasive technique and (iii) invasive technique. The non-invasive type allows the system to capture signals without any implant. Here the electrodes are placed on surface of the scalp. The partially invasive method captures information by means of implants that are placed below the skull. The risk factor is low
to health compared to invasive method. Invasive method of capturing introduces the implants directly into subject's encephalic mass i.e. into the grey matter. This approach provides very good quality of signal recording. This method not only causes major risks to human health but also inconvenience for the user while using it. Non-invasive BCIs are more suitable and easy to use, and the advancements technology provides good quality of signal capturing. BCI forms a non-muscular way to express a user's intentions and it is particularly helpful for people with severe disabilities like amyotrophic lateral sclerosis,

1. Related Previous Work

In the previous research work, researchers in the field have scripted several survey papers to complete their work. In the field of computer science, automation, control engineering neuroscience, and biomedicine research work were carried out during the mid of 1970s [3] as per survey done by Ferreira et al.

Keum-Shik Hong et al. [4], this paper provides significant published articles on BCI in the year from 2009 to 2016 which is shown in Fig. 1. The figure describes the increase in number of articles published in this field. Arafat's [5] survey provides the complete history of Brain Computer Interface work carried out from 1929. The author concluded that this is the most challenging field of research. This BCI approach offers best result for the treatment of lunatic and differently abled. From the survey done by Dhabale et al. in [6] on BCI for controlling robots. The interface controls the robot using different techniques that include pattern classifier and from alpha waves of brain

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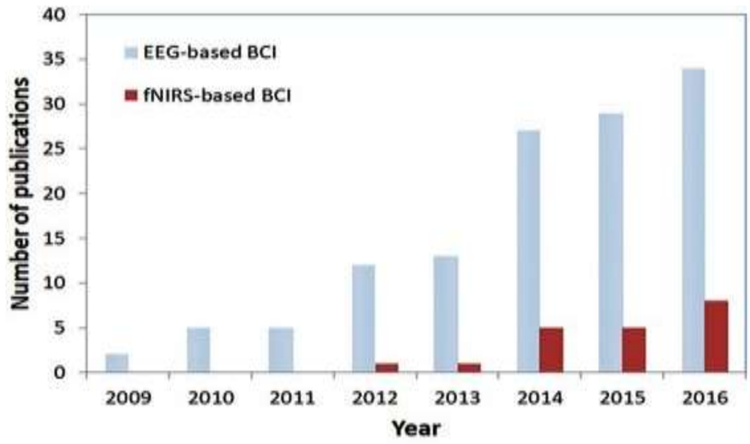

etc.

Figure 1. Published BCI articles from 2009 - 2016 [4].

2. BCI System

BCI system has four different stages, such as Signal acquisition, Signal Pre-Processing, Feature extraction & Classification.

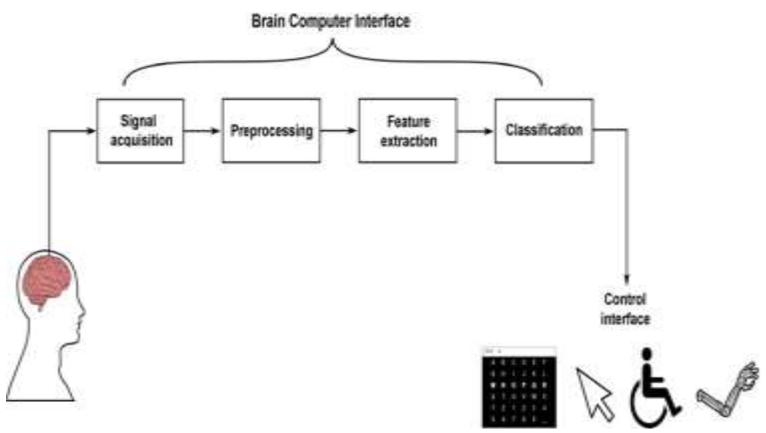

Figure 2. Brain Computer Interface System.

2.1. Signal Acquisition and Signal Pre-Processing

Data collection and filtering are carried out at the primary stage in BCI. Current Approaches concentrate on EEG signals [7], However, there are many other techniques which can record neural activity. Every technique has its own merits and demerits while capturing various parts of brain signals. And here are some common techniques for obtaining brain information.

2.1.1. Functional Magnetic Resonance Imaging (fMRI). This method captures activity of brain via flow of blood and blood oxygenation that increases particular region of mental activity. The method needs the use of large- scale equipment scanner that works on very high magnetic field. This technique involves analyzing the change in blood stream (hemodynamic response) of a subject in a magnetic resonance imaging machine (MRI). The response produced by the active neurons processes is referred as Blood Oxygen Level Dependency-BOLD [8]. But slow system response time becomes the main disadvantage of this method. The delay is related to BOLD response time of brain that can usually be delayed from 3 to 6 seconds. [9]. The drawbacks of this method include the following reasons: expensive, difficulty in understanding the working principle and fMRI can only provide the level of information about the blood flow in the brain

Near-Infrared Spectroscopy (NIRS). This strategy additionally measures mind action through blood oxygenation and stream, however it depends on distinguishing variety of optical behaviors in cerebrum pictures. Near- infrared light passed through subject's forehead and the reflected lights are collected by light detectors. The output of detector is correlated to precise level of oxygen concentrations. The LED emits near infrared light that penetrate into the cerebrum tissue and it is collected by the detectors. The limitation of NIRS method is dependency of light passing via brain; i.e. hair like things can significantly interrupt the signals and gives flawed readings. Example of NIRS method:"On-line BCI spelling machine [10]. Limitation of NIRS method: The technique is unable to distinguish the attenuation level between the signals due to the absorbency of signals that overlap in the NIR range.

2.1.2. Magnetoencephalography (MEG). The method offers more sensors, hence provides more spatial information. To record the signal, user is placed in chair inside the magnetic shielded room equipped with a range of superconducting quantum interference devices (SQUIDs). The disadvantage of this method is the dependency of magnetic shielded room and the enormous brainwave sensor [11]. Limitation: This technique has difficulty in recording the activities of paroxysmal movement confined to the medial temporal lobe.

2.1.3. Electrocorticography (ECoG). Electrocorticography is an invasive type of approach that needs surgery to insert sensors straightforwardly onto the brain surface to acquire the signals. High spatial resolution, less vulnerability, high amplitude and broad bandwidth are some of the advantages of these techniques [12]. Limitations: Partial sampling period, recording is subjected to the stimulus of narcotic, analgesics/ anaesthetics, and the surgery.

2.1.4. EEG. The possible way to capture the activities of the brain neurons is by fixing the electrodes on the surface of the scalp. There is a standard technique that defines the position of electrodes, example: 10/20 positioning [13] standard. While placing the electrodes, a conductive gel is used as a medium that helps to capture the data with more accuracy.

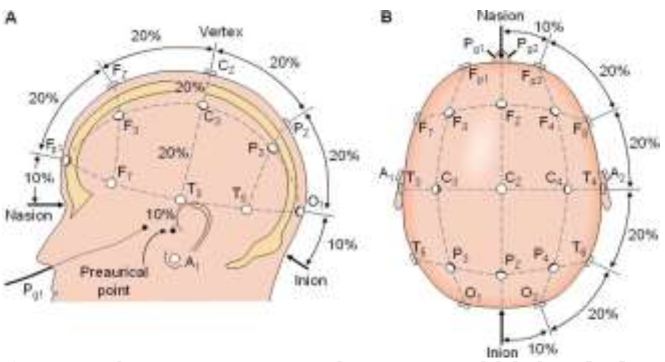

Figure 3. The 10/20-International positions and labeling [14]

EEG based BCI is a most popular method of capturing brain signals is only because of the following factors: standardized electrode placement, plenty of techniques available to acquire brain signals, and the comparatively low cost than other methods.The signal acquired typically much smaller compared to the surrounding signals, and those signals require special filtering methods to identify and extract the required information. The signal generated from the brain neurons is called as event related potential (ERP). Hence the recognition of this evoked response is the major objective of a BCI system. Identification of required signal is very difficult since the occurrence of artifacts in the EEG signal that created from facial muscle movement, eye-blinks or movements. The data related to ERP is normally analyzed in frequency domain; hence the information is transformed to frequency domain from time domain using Fourier transforms. The transformed signals then represent the spectral power of the signal.

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Feature Extraction

A feature represents a unique property. Several linear and non-linear approaches for feature extraction have been described in the literature. Linear methods include Principal Component Analysis (PCA), Fast Fourier Transform (FFT),

Independent Component Analysis (ICA), Wavelet transform (WT), Wavelet Packet Decomposition (WPD), Eigenvector, Autoregressive (AR). Non-linear methods consist of largest Lyapunov exponent (LLE), correlation dimension (CD),

Fractal Dimension (FD), Higher Order Spectra (HOS), recurrence plots and phase space plots.

According to the Heisenberg uncertainty principle, it is hard to compute the signal in both frequency and time domains concurrently, because increasing accuracy in time domain will leads to decrease in accuracy in frequency domain, and vice-versa. A combination of features in both the domains may result in better results, when compared with features in each domain, separately [15]. Bidiagonalization[23] method can also be used for feature extraction of motor imagery EEG, where bidiagonalization is one of unitary (orthogonal) matrix decompositions.

2.2. Signal Classifications

Below table provides the information about commonly used classifiers in BCI [16].

Table 1. Some commonly used classifiers in BCI

Classifiers	Categories	Field of application
Linear Classifiers	Linear Discriminant Analysis (LDA)	A P300-based BMI system developed for remote writing using human brain-actuated robot arm. [17].
	Support Vector Machine (SVM)[24].	A spelling application for paralyzed patients (suffering from focal epilepsy) [18].
Neural Networks	Back Propagation BP network Multilayer Perceptron Learning Vector Quantization (LVQ) Neural Network	A new EEG recognition algorithm for integrating discrete wavelet transform (DWT) with BP neural network[19]
Nonlinear Bayesian classifiers	Bayes quadratic Hidden Markov Model	Virtual Reality BCI Application
Nearest Neighbor	Nearest Neighbors Mahalanobis distance	An application to extract features that the user can control and translate into device commands [20]

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classifiers

3. Types of BCI

This section provides the brief note on BCI types.

3.1. Active BCI

It is a commonly used prototype where the subject actively generates the brain signals that can be used for control applications. One such application is illustrated in [21], the active BCI is directly adopted to control the movement of paddles to left or right in a pinball game. The prototype was developed to distinguish two different types of motor-imagery, like right or left hand movement. Motor imagery is the most commonly used paradigm in the research. The short-lasting attenuation of brain oscillations and localized amplitude decrease of rhythmic activity is termed as event-related desynchronization (ERD).It is often found in the alpha and beta bands of individuals during imagery of movement and observation. It is considered to reflect the action-perception coupling and cortical motor activity.

When the subject visualizes the movement of right hand, the amplitude level of the mu-rhythm in the sensory-motor area of the human brain increases in the right hemisphere and decreases in the left hemisphere. For the left hand motor imagery, the reverse phenomenon occurs. The motor imagery thus results in spatially different patterns for brain activity according to which the hand is used. The use of signal processing and classifiers allow BCI to notice the spatially different patterns which decides the movement direction of the subject. The direction information then used to control left or right paddles, which is similar to conventional interfaces like left or right keyboard arrows. Here the subject initiates activity of brain; therefore, the information embedded in the captured signal is then used to control the paddle movements.

3.2. Reactive BCI

Information regarding the user's intention is embedded in the stimulation response signal. The user can activate their brain signals by simply taking care of certain stimuli or looking at them. The steady state visual evoked potential (SSVEP) signals are natural responses to visual stimulation at specific frequencies. The SSVEP signal is used to control some application like “Mind Balance” game. The 17 and 20 Hz flickering checkerboards are placed on the right and left side of a game icon called avatar. The user maintains balance of the avatar by focusing on either the right or left checkerboard. The brain activity in the occipital region contains the correlated frequency information in response to visual stimulation. The P300 (P3) wave is an event related potential (ERP) component stimulated in the process of decision making. As an example of SSVEP, P300 paradigm is widely used in the development of reactive BCI.

3.3. Passive BCI

The function of the passive BCI system is not to give the user control and no effort on the part of the user is required; instead, it automatically monitors the mental state of the user. It quantifies the attention level or distinguishes emotional conditions to facilitate communication between the system and the user. Example: for attention index quantification, frequency band ratios such as sensory- motor rhythm (12–15 Hz), beta (13–30 Hz) and theta(4–8 Hz) are used; for relaxation level, alpha(8–13 Hz) power is used.

4. Applications of BCI

The BCI technology in different forms have proved by its performance in some extensive applications such as medical, communication, security, marketing, entertainment etc. This technology was initially introduced to support physically challenged people and now expanded enormously in all the fields.

4.1. BCI for Prosthetic Applications

4.1.1. Vision. Invasive technologies were utilized initially for treating blindness. Scientist William Do belle successfully implemented a prototype of a functioning brain interface implanted in a man blinded visual cortex in the year 1978 that enclosed nearly 69 electrodes and produced a light sensation without light affecting the eye. In a 2008 surgery, American scientists used important hardware to insert electro-biological parts and sensors into a volunteer's brain. The person blind from birth voluntarily agreed for this research to fix a camera to electro biological organs to replace the eye. This research worked after a tedious surgery of nearly 48 hours and 7 days after medication. The surgery was successful and the person began to identify, observe everything; even though the camera used was colour her vision was black and white.

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Movement. The BCI is used for people with paralysis so that they can activate their paralyzed body parts.It is usually accomplished by giving them dedicated devices to move their paralyzed muscles. The device provides various kinds of interfaces of computers with knee joints, legs, hands, robot arm, and other parts of the body for control. Till 20th century, the wooden hands/legs were used as a substitute for any injury. Later the advancement in technology helps to develop the metallic arm which can be controlled by user with their brain signals. The invention of robotic arm gave birth to the development of "Mind Controlled Prosthetic Robotic Arm". The prosthetic arm is coupled to sensory cortex and motor cortex using wires; as a result, when user touches object it feels and responds to the stimulus. Signals from motor cortex helps to control the pressure and motion of the robotic arm. Sensory cortex helps to provide the sensation when the arm touching something. Fig. 4 depict the schematic for controlling prosthetic arm using brain signals.

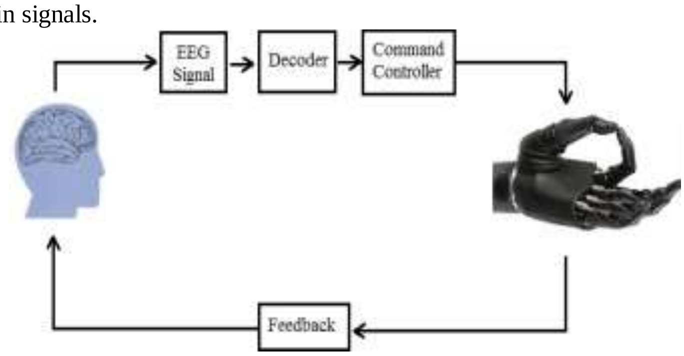

Figure 4. The mind controlled prosthetic robotic arm.

4.2. Entertainment Applications

The connection between the brain and the computer has developed into a cutting- edge technology as neuro-gaming. Some of the neuro-games include, "Mind Balance video game", "NeuroMage", "NeuroRacer" and "Throw trucks with your mind". Brain Computer Interface offers enormous applications with signal acquisition techniques, feature extraction techniques and different classifiers. Some applications in this area are listed in Table 2:

Table 2. Research works carried out in the field of BCI [22]

Sl. No	Topic	Description
1	Driving a wheel chair using BCI	Brain Computer Interface is used to control the movement of an autonomous wheelchair
2	The life of Rats	Controlling Rat's brain using Brain Machine Interface (BMI), Electroencephalography (EEG).
3	Human thought to control robots	brain Communication.
4	EPOC- A neuro headset for gaming.	
5	BCI based Brain to	

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BMI is used to control human thoughts and later used to control ASIMO- Honda's Humanoid Robot.

It detects non-conscious thoughts, expressions and conscious emotions based on electrical signals around the brain. It opens up a plethora of new applications The application can be controlled with our expressions, thoughts, and emotions.
A experiment had a person using BCI headset to send the thoughts, translated as a series of binary values, over the internet to other person whose PC receives the binary digits and sends them to the second user's through flashing an LED light. The ciphered information is then extracted and deciphered to know whether a zero or a one was transmitted.

6 Gesture recognition. Here the person allowed wearing "data gloves" with illuminated LEDs. The information sent through the flashing LEDs are tracked by two pairs of webcams interfaced to a computer working to produce an all-round binocular view. This allows the PC to monitor the person's shoulder or hand movements. This input can then be fed to a program, a game, or simulator, or to control a character, an avatar, in a 3D virtual environment.

In brain-to-brain communication system the data extracted in the form of images from the activities of brain neuron can be transferred from one system to another. Partial image encryption [25] algorithm can be used to secure these data.

5. Challenges Faced by BCI Technology

Each and every success is followed by several challenges. Similarly, researchers faced many challenges, in overcoming uncertainties and creating something extraordinary and new. However, brain- computer interfaces are not new to us, but yet lot of research has to be done.

5.1. Human Brain Activity

For engineers, it is very difficult to understand the functionality of the human brain

The user must first identify the key regions which should be emphasized when working on prosthesis or other BCI devices, to find a solution for challenging job.

5.2. Usefulness

In all cases, person wants the BCI system to be accessible. Developing a system to be user-friendly with such a complexity is challenging and tedious task. The EEG process involves applying a cream to the sensors to measure the accurate signal amplitude values. The recent EEG technology works without the injection of gel into the sensors and also gives 70% accurate results.

5.3. Hardware Problem

The challenging task of hardware implementation is that, the hardware system must be capable of operating outside the labs and in sensitive areas. These BCI systems must be intelligent enough to work outside the appropriate environment especially noisy locations. They must be capable to distinguish between random inputs and actual inputs in such positions.

6. Conclusion

The work gives the information about the most remarkable techniques and examples in the field of brain computer interfacing system. The information here highlights the most common uses. According to the review, a great deal of improvement is needed in order to create a system which can be worked in real conditions. EEG based BCI is a most popular and best suitable method of capturing brain signals is only because of the following factors: standardized electrode placement, plenty of techniques available to acquire brain signals, and the comparatively low cost than other methods.

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