EEG SIGNAL ANALYSIS FOR BCI INTERFACE: A REVIEW

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Abstract— **Brain Computer Interface (BCI) systems are the devices which are proposed to help the disabled; people who are incapable of making motor response to communicate with computer using brain signal. The aim of BCI is to interpret brain activity into digital form which acts as a command for a computer. One key challenge in current BCI research is how to extract features of random time-varying EEG signals and its classification as accurately as possible. Feature extraction techniques are used to extract the features which represent a unique property obtained from pattern of brain signal. Earlier EEG analysis was restricted to visual inspection only. The visual inspection of the signal is very subjective and hardly allows any standardization or statistical analysis. Hence, several different techniques were intended in order to quantify the information of the brain signal. Many linear and non-linear methods for feature extraction exist. The purpose of this paper is to give a brief introduction to the EEG signals and BCI system. The paper also includes a review on the conventional methods that are used for feature extraction of the signal.**

Keywords— Electroencephalogram (EEG); Brain Computer Interface (BCI); Feature Extraction.

I. INTRODUCTION

BCI (Brain-Computer Interface) acts as a channel for human brain to communicate between with a computer system. It allows its users to control external devices which are independent of peripheral nerves and muscles with brain activities. BCI system allows a subject to send commands to an external device by using brain signal. BCI channel can be considered as the only way through which people affected by motor disabilities can communicate their thoughts. It is very helpful to assist patients with impaired motor functions, such as completely paralyzed patients with amyotrophic lateral sclerosis [1, 2]. The aim of BCI is to interpret brain activity into digital form which acts as a command for a computer. One key challenge in current BCI research is how to extract features of random time-varying EEG signals and classify the signals as accurately as possible [1]. The success of this methodology depends on the selection of methods to process the brain signals in each phase.

II. EEG BRAIN PATTERNS

The human brain is a complex system, inter-connection of billions of nerve cells (neurons) which exhibits rich spatiotemporal dynamics. There are several invasive as well as non-invasive techniques for mapping brain signals such as: EEG (Electroencephalogram), fMRI (Functional Magnetic Resonance Imaging), MEG (Magneto Encephalography), NIRS (Near-infrared Spectroscopy), PET (Positron Emission Tomography), EROS (Event-related optical signal). Among all the non-invasive methods for examining human brain, a direct measure of cortical activity with a temporal resolution of less than millisecond is provided with EEG [3]. EEG technique can also be used to extract the features of the brain signal even if the subject is not in a state to attend the stimuli.

Hans Berger in 1929 recorded the first human brain EEG. Previously, its analysis was restricted to visual inspection only. The visual inspection is very subjective and hardly allows any standardization or statistical analysis. The traditional methods are very tedious and time consuming [4]. Hence several techniques were proposed in order to quantify the information of the brain signal.

The nature of EEG signals is highly non-linear, non-Gaussian, random, non-correlated. The injuries in brain, any such disease or symptom can be detected using Electroencephalography (EEG). It is also used in detecting many diseases related to neurology, such as Seizure disorders like epilepsy, sleep disorders like Narcolepsy, tumour, depression and various problems which are related with trauma (stress) [5]. The traces are different for different brain activities. Using signal processing techniques brain activity of a normal and abnormal person can be distinguished easily.

A. Detection of EEG signal

The neurons communicate with each other through electrical impulses. The electrodes are placed on the scalp to measure the amplitude of electric impulse. Frequency range of a normal EG signal is 1 Hz-100 Hz but the 100Hz is very rare and amplitude ranges between 10 µV - 100 µV.

2327-0659/15 $31.00 © 2015 IEEE
DOI 10.1109/ACCT.2015.72

Generally, the signal suffers from poor spatial resolution and low signal-to-noise ratio (SNR) of any evoked response which gets embedded within on-going background activity. While recording a signal, various artifacts and interferences combines with the information signal [6]. Different kinds of artifacts that affect the signal are blinking of eyes during signal acquisition procedure, muscular activities, and activities happening in the background. Therefore, EEG signals are extracted from highly secured, de-noised labs and sophisticated machines which are free from interferences, artifacts and several other forms of noise.

Despite poor spatial resolution, EEGs have excellent temporal resolution of less than a millisecond. The signal when analysed has a very low frequency range in hertz. These signals can be classified based on the frequency bands. The different rhythms of brain are delta, theta alpha, beta and gamma. These rhythms along with their frequency ranges, amplitude and respective state of mind are given in table I. The wave shapes for these rhythms are shown in figure 1.

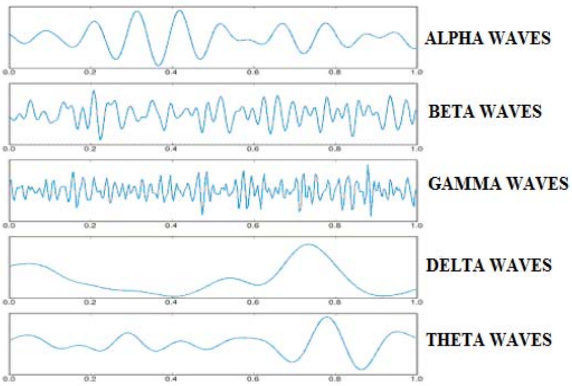

Figure 1: Wave shape for different rhythms

B. Signal Analysis

The nature of EEG signals is very complex, non-correlated and random. The characteristics/ features of EEG depends on several factors such as the individual himself, age and the mental state of subject [5]. Hence, understanding the behaviour and dynamics of brain cells involves many linear as well as nonlinear signal processing methods whose outcome is co-related to the physiological events the subject is going through. Several methods have been suggested in literature to diagnose the hidden dynamical features and abrupt changes that can take place.

The interpretation of the signal implies three important aspects. The spectral analysis of the signal determines the dominant frequencies in the EEG. The temporal analysis of the EEG keeps a record of normal and abnormal wave shapes in the signal and also presence and absence of these rhythms. The spatial analysis estimates the distribution of these rhythms over the different brain regions [4].

III. BCI SYSTEM

A BCI system is composed of four phases. These are Signal Acquisition, Signal Pre-Processing (monitoring and enhancing acquired signals), Feature Extraction & Classification and Computer Interaction.

TABLE I. DIFFERENT BRAIN RHYTHMS

RHYTHYM	FREQUENCY RANGE (Hz)	AMPLITUDE (µv)	STATE OF MIND
DELTA	Up to 4	High amplitude (20-200)	Deep sleep
THETA	4-8	More than 20	Emotional stress, drowsiness and sleep in adults
ALPHA	8-13	30-50	Relaxed awareness
BETA	13-30	5-30	Active thinking, active attention, alert
GAMMA	Above 31	Less than 5	Mechanism of consciousness

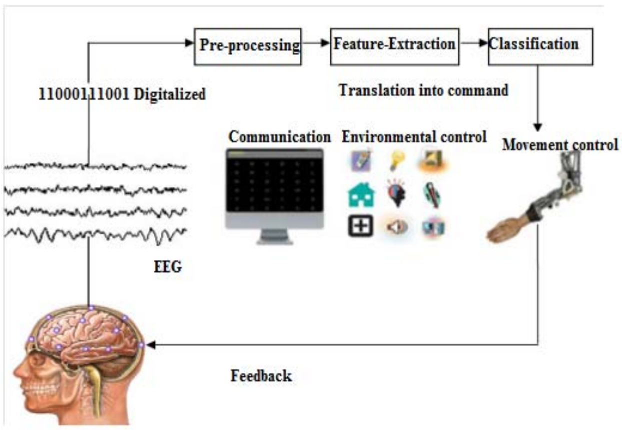

Figure 2: Model of a BCI System

In Brain Computer Interface, the normal cortical-muscular pathway is bypassed and an alternate path is proposed. Neural activity of the brain cells is recorded and these signals are given as drive to applications. It is a difficult task to study he non-Gaussian, non-linear and random nature of EEG signal. Many methods for feature extraction have been studied and the selection of both appropriate features and location of electrode is usually based on neuro-scientific findings [7]. Many linear and non-linear methods for feature extraction exist.

A. *Signal Acquisition and Signal Pre-Processing*

In BCI, data collection and filtering is performed at initial stage. Data is recorded collection (EEG signal) with the help of electrodes placed on the scalp of the subject [5]. Several electrode systems are reported in literature.

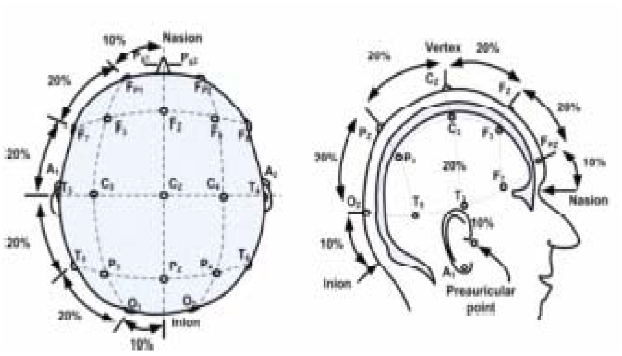

Figure 3: 10-20 International System of Electrodes (IFSE)

Artifacts and noise in the signal requires the efficient detection and removal. The acquired signal then acts as an input to the filter. The filter filters out the noise signal from the signal and prevents the distortion of the signal. Notch filters (null freq. of 50 Hz) are used for rejection of the artifacts and noise. High pass filters having cut-off frequency of less than 0.5 Hz are used to reject components having very low frequency e.g. breathing components. While, high-frequency noise components are removed with the help of low pass filters having 40–70 Hz as cut-off frequency [9]. Different window techniques such as hamming, hanning, spatial filtering can be used for signal windowing. To improve the quality of hand’s motion detection Hamming technique was used by Hoodgar et al. [10], spatial filtering is applied using a Common Average Reference (CAR) filter using a window length of 4s with overlapping of 3.75 s [11].

The next step involves the pre-processing of the signal includes signal filtering, signal cutting, amplitude scaling, and verification of expert marks, artifact detection, averaging techniques and signal segmentation. The acquisition of EEG signal is basically done in time domain. The signal features, its characteristics and the information required from the signal are suppressed by noise. In order to extract the same, signal processing is done to extract the features of the signal as a function of time or/and frequency.

B. *Feature Extraction*

A feature represents a unique property. Emotion recognition from EEG signals allows the direct assessment of the “inner” state of a human, which is considered as an important parameter in Brain-Computer-Interface. Several methods for feature extraction have been studied and the selection of both appropriate features and location of electrode is usually based on neuro-scientific findings. Many linear and non-linear methods for feature extraction have been reported in the literature. Linear methods include Independent Component Analysis (ICA), Fast Fourier Transform (FFT), Eigenvector, Autoregressive (AR), Wavelet transform (WT), Wavelet Packet Decomposition (WPD), Principal Component Analysis (PCA). Non-linear methods include correlation dimension (CD), Hurst exponent (H), largest Lyapunov exponent (LLE), different entropies, Higher Order Spectra (HOS), Fractal Dimension (FD), recurrence plots and phase space plots.

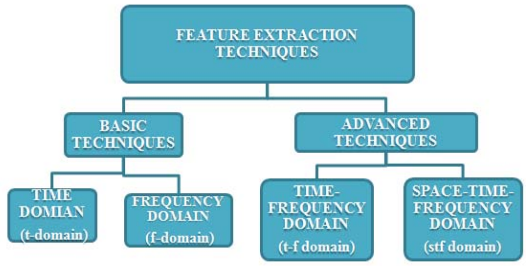

Figure 4: Feature extraction Technique

According to the Heisenberg uncertainty principle, it is difficult to measure the signal in both time and frequency domains simultaneously i.e. increasing accuracy in time domain leads to decrease in accuracy in frequency domain, and vice-versa. A combination of features in time and frequency domains may result in better results, when compared with features in each domain, separately [10]. Figure 4 shows various domains in which analysis can be done.

The Time-Frequency Domain combines the time and frequency domain analyses. They represent the distribution of the signal energy in the Time-Frequency plane (t-f plane). Time frequency analysis is beneficial in clarifying rhythmic information in EEG signals. Coherence techniques can also be used. Spectral covariance or coherence involves measurement of phase regularity between signal pairs in each frequency band. As coherence cannot separate amplitude information and phase information while relating two signals, it measures roundabout phase locking only. Synchrony technique is being used rather than having spectral or coherence analysis. It is quantification of degree of phase locking between different narrowband signals.

No doubts, by using t-f domain analyses accurate results have been found. For multichannel EEGs, in which spatial dimension is calculated by the geometrical positions of the electrodes, Space–Time–Frequency (stf) is considered to be popular [12]. Suleiman et.al [9] used the space-time-frequency method over multiple electrodes. Wide region of the scalp was used to collect the data that discriminated between various tasks. According to the study, space-time-frequency analyses showed better result than time-frequency domain. In table II various features and its extraction techniques in respective domain are summarized.

TABLE II. FEATURES & THE EXTRACTION METHODS

DIFFERENT DOMAIN	FEATURE EXTRACTION METHOD	DIFFERENT FEATURES
TIME DOMAIN *(t-domain)*	1. Linear Prediction (LP) 2. Independent Component Analysis (ICA)	1. Event Related Potentials (ERP) 2. Statistics of signal Power • Mean • Standard deviation • 1st difference • Normalized 1st difference • 2nd difference • Normalized 2nd difference. 3. Hjorth features • Activity • Mobility • Complexity 4. Fractal Dimension (FD) 5. Higher Order Crossings (HOC)
FREQUENCY DOMAIN *(f-domain)*	1. Fast Fourier Transform (FFT) 2. Autoregressive Method (ARM) 3. Eigenvector	1. Band power 2. Higher Order Spectra (HOS)
TIME-FREQUENCY DOMAIN *(t-f domain)*	1. Short-Time Fourier Transform (STFT) 2. Spectrogram 3. Wigner Ville Distribution 4. Scalogram 5. Hilbert-Huang Spectrum 6. Discrete-Wavelet Transform (DWT) 7. Wavelet Packet Decomposition (WPD)	Combination of time and frequency features.
SPACE-TIME-FREQUENCY DOMAIN *(stf domain)*	For multichannel EEGs, in which spatial dimension is calculated by the geometrical positions of the electrodes.	Combination of time and frequency features.

A very informative and in detail survey of EEG signal detection and feature extraction techniques with their merits and de-merits have been reviewed [4-7, 13]. Alexandros et.al analyzed time-frequency method for epilepsy detection and evaluated frequency analysis (FFT), time-frequency analysis (STFT) over multiple electrodes. The classification results were found to be best for STFT [14]. Another paper compared FFT, AR, TF and WT with their limitations and according to the author, WPD method yield a redundant representation of the signal and achieve better accuracy [15]. DWT and SVM based expert model was developed for epileptic seizure detection [16]. The problem of improving feature extraction has been studied in [17]. This paper also reviewed the adaptive feature extraction method i.e. adaptive common spatial patterns (ACSP). The study revealed that the discriminative features related to the brain states can be extracted with the use of multi-class common spatial patterns (CSP) method. To evaluate the performance of classification in lie detection a new approach for EEG feature extraction has been reported [18]. Different features were analyzed according to the requirement and various methods were applied for analysis. Maximum accuracy was achieved with WT method. By using linear WT method for the feature extraction, emotions were classified [19]. The new advanced method such as FS was used for the feature extraction that showed better results. Multivariate feature selection techniques performed slightly better than univariate methods, generally requiring less than 100 features on average. Authors also investigated the various most promising features and which electrodes are most suited for them. Advanced feature extraction methods such as HOC, HOS, and HHS were found to outperform commonly used spectral power bands. It has been suggested to prefer locations over parietal and centro-parietal lobes for better outcomes. A major limitation has also been reported that no systematic comparison of features exists [7].

IV. CHALLENGES

Due to natural limitations like time dependency, large dimensions of feature vector set, doubtfulness; challenge for the engineers is to make fast and correct decisions for EEG signal. To meet this, the system delay time and response time should be reduced so that BCI system is designed to work in real-time systems. EEG being a non-invasive technique i.e. signals are acquired through the electrode placed on the scalp is itself one of the cause that induce noise. Artifacts detection and removal is the major ongoing challenge these days for the engineers. Recognition performance of the signal with large amount of possible features extracted from the signal with minimum computation and avoiding over-specification is still a key problem.

V. CONCLUSION

EEG signals allow us to diagnose the mental states and various neurological diseases. The EEG signals are very subjective, non-Gaussian, non-correlated, random in nature and are considered as a chaotic signal. According to the review, a lot of improvement needs to be done to produce a system that can be operated in real environment. Different signal processing techniques linear and nonlinear, time domain, frequency, time-frequency and space-time-frequency domain techniques have been discussed. Among all the linear techniques the accuracy of Wavelet Packet Decomposition (WPD) in Space-time-frequency domain is reported to yield better performance than the other existing techniques. The nonlinear methods yield better results for the events which cannot be detected by the of visual EEG signal inspection, traditional and linear signal processing methods. The use of non-linear methods helps to understand the complex physiological events like chaotic behavior and sudden transitions that take place in the brain.

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