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Brain Signal Analysis for Brain-Machine Communication

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Abstract

Brain-Machine Communication (BMC) help to the disabled people those are not capable of using their hands or other body organs to communicate with the machine. The main objective of BMC systems is to convert brain signal into a digital signal that can understand by machine. The major problem in BMC research filed is to extract the features of brain signals, which are random time varying in nature and how to classify these features with desirable accurately. Extraction of features can be using various techniques, numbers of linear and non-linear feature extraction methods exist. Earlier brain signal analysis was only being done using visual inspection. Therefore, this manual inspection of brain signal is very limited to standardization or statistical analysis. However, several techniques have developed to quantify the brain signal's information. The motive of this research is to provide a brief detail of brain signals and BMC system. The article is about the methods that are using to extract the feature of the brain signal.

Keywords: *Brain-Machine Communication, Brain Signal, EEG, Feature Extraction, random time-varying signal.*

1 Introduction

Brain-Machine Communication (BMC) systems is also popular as Brain-Computer Interface (BCI). BCI acts as a medium for communication between the brain and a computer system. It gives users the ability to control those devices that are not controllable with nerves and muscles. BCI system makes a human to send a command signal to a device by using EEG signals. BCI medium is one of the important paths through which motor disabilities patients can deliver the thoughts to outer world. BCI medium is most useful to assist people with motor disabilities, like a patient suffering from paralyzing [1, 2]. The main objective of BMC systems is to convert brain signal into a digital signal that can be understand by the machine. The major problem in BMC research filed is to extract the features of brain signals, which are random and time varying in nature. In addition, how to classify these features with desirable accurately [1]. The accuracy of BCI depends on the processing of brain signals, such as methods of feature extraction and classification.

The way, in which a computer operates show a replica of the human brain's working. The human brain is a system, which comes under the category of complex systems. It has billions of neurons that exhibit rich spatiotemporal dynamics. Many techniques are existing for mapping of brain signals like fMRI (Functional Magnetic Resonance Imaging), EEG (Electroencephalogram), NIRS (Near-infrared Spectroscopy), MEG (Magneto Encephalography), EROS (Event-related optical signal), PET (Positron Emission Tomography). EEG is one, that provides a direct measure

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of less than a millisecond for cortical activity with a temporal resolution [3]. Features of brain signal can also be extracted using EEG technique even if the human is not able to attend the stimuli.

The first EEG signal recorded by Hans Berger in 1929. In those days, EEG analysis was only being done using visual inspection. Therefore, this visual examination of brain signal is limited to standardization or statistical analysis. The conventional algorithms consume more time and very irksome [4]. However, various algorithms have proposed to collect the useful data from the brain signal.

EEG signals are extremely non-linear, non-Gaussian, and random in nature. Any kind of damages in the brain, any kind of disease can be observed from analysis of Electroencephalography (EEG). This analysis helps to identify many diseases associated with neurology, seizure disorders, sleep disorders, tumors, depression are few of those diseases [5]. A human can be classified as a normal or abnormal using brain signal processing.

As human brain has a complex structure of billions of neurons, these neurons send electrical impulses to each other to communicate. The amplitude of the electric impulse can measured by placing the electrodes on the scalp. A normal EEG signal ranges from (1 – 100) Hz. However, the highest frequencies of this range are uncommon and amplitude ranges from (10 – 100) micro volts.

Mostly, the brain signal suffers from low signal to noise ratio (SNR) and any poor spatial resolution of evoked response due to ongoing activities in the background. While signal recording, several artifacts like blinking of eyes, muscular activities, and any background activities, and also interferences mix in the brain signal [6]. Hence, EEG signals is recording in highly secured and de-noised labs using that machines which have fewer interferences, and other forms of noise.

Table 1. The specification of brain rhythms.

Rhythm	**Frequency Band(Hz)**	**Amplitude Range(μV)**	**State of Mind**
Gamma	Greater than 31	Up to 5	Consciousness, Complex activity
Beta	13 to 30	05 to 30	Active Thinking, alert
Alpha	08 to 13	30 to 50	Relaxed awareness
Theta	04 to 08	Above 20	Emotional Stress, sleep in adults
Delta	Less than 04	20 to 200	Deep Sleep

EEGs have the highest quality of temporal resolution, even less than a millisecond though it has a poor spatial resolution. The EEG signal has a low-frequency band. The classification of these signals is possible on the bases of frequencies. Brain signal has different rhythms as gamma, beta, alpha, theta, and delta. Table I shows the specification of these rhythms, and figure 1 shows the wave shapes of these rhythms.

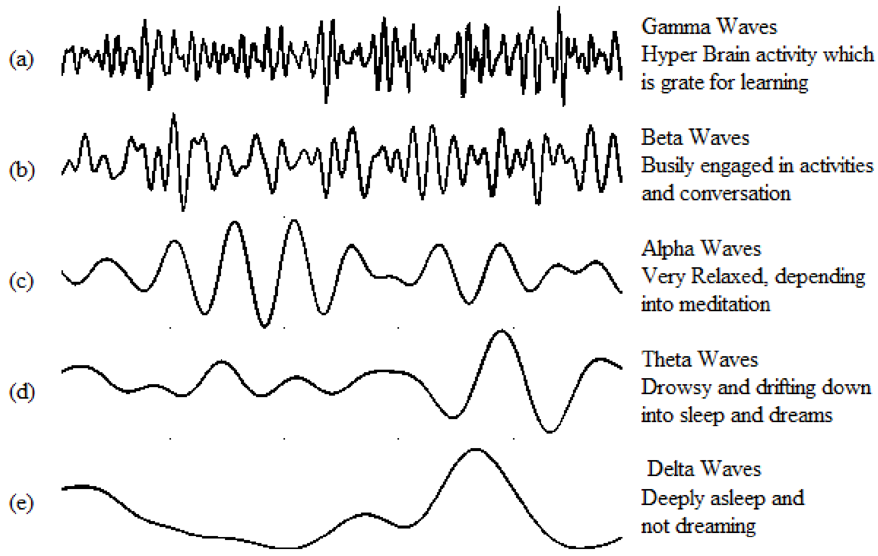

Fig. 1. Wave Shapes for Brain Rhythms. (a) Gamma Wave, (b) Beta Wave, (c) Alpha Wave, (d) Theta Wave, and (e) Delta Wave.

2 Literature Review

The characteristics of brain signals are composite, uncorrelated and random. There are various factors on which changes the EEG signal like, it changes from subject to subject, and it changes with a change in mental state and/or age of human [5]. Therefore, to realize the analogy of brain cells requires various models of brain signal processing, these models are based on linear methods or non-linear methods. Theses method helps to co-relate the present physiological stage of human brain with the outcomes of model. Many state-of-the-art methods are available to extract the hidden features of EEG signal.

Any signal can interpret as three different and important aspects such as spectral analysis, temporal analysis, and spatial analysis. Spectral analysis is use to determine the highest energy carrying frequencies of the brain signal. Temporal analysis helps to record the rhythms of the EEG signal for normal or abnormal activities. To analyze the distribution of brain waves over the various regions of the brain, the researcher uses the spatial analysis [4].

A BCI/BMC system is a combination of four stages such as Signal Acquisition, Pre-Processing of Signal, Feature Extraction followed by Classification, and Computer Interaction. In BCI/BMC, a recording of the neural activity as EEG signal is the first step. The recorded signal then converted into a control signal and uses to drive the applications. Various methods for feature extraction of brain signals have reviewed and the choice of suitable features and appropriate arrangement of the electrode is commonly depending on neuro-scientific decisions [7]. Numbers of spectral and temporal domain techniques for feature extraction are available.

In BCI/BMC, filtering is the initial stage of sample collection. Samples are recorded using electrodes adjusting to the scalp [5]. Various electrode systems had discovered in literature.

Efficient method to detect the artifacts and noise while recording the brain signal needs. Efficient detection can help to remove artifacts and noise properly. The recorded signal passed through the desired filter. This filter prevents the recorded signal from distortion and removes the

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unwanted frequency components. Mostly notch filters are the suitable choice to reject the artifacts from the signal. High pass filters with 0.5 Hz of cut-off frequency is a desired filter that helps to remove the low frequency components like breathing. Whereas, components having high-frequency can be filtered by the use of low-pass filters with cut-off frequency ranges between 40 Hz to 70 Hz [9]. Various window preferred for signal windowing like hamming, hanning, and spatial filtering. Hoodgar et al. [10] suggested Hamming window detect the hand's motion. Common Average Reference (CAR) filtering can used to apply the spatial filtering with 4 seconds of window length and overlapping of 3.75 seconds [11].

An ideal feature shows a distinctive property of signal. Recognition of human emotions from the EEG signals helps to understand the "inner" state of mind, which is one of the important factors in BCI/BMC. Heisenberg uncertainty principle says that to get a good time resolution and a good frequency resolution simultaneously is not easy i.e. good time resolution makes the poor frequency resolution, and vice-versa. A hybrid feature vector of time and frequency domains may lead to better resolution, rather than a feature vector of time domain or frequency domain, separately [10].

The Time-Frequency Domain requires the analysis of time and frequency domain. Time-frequency analysis shows the energy distribution of the signal in Time-Frequency domain. Time-frequency analysis is useful to clarify rhythmic information of EEG signals. Coherence techniques are one another solution. Coherence fails to create a barrier between amplitude information and phase information of different signals during comparing, it identifies the phase locking of different signals. Hence the shortcoming of spectral or coherence analysis can be overcome using synchrony technique. With the use of time-frequency analyses results have improved, still for multichannel EEG signal, where positions of electrodes help to find the spatial dimension. Another Space-Time-Frequency analysis found useful [12].

A very useful and a deep study of brain signal sensing and extraction of the feature with their shortcomings and overcomes have been summarized [4, 13]. Epilepsy detection using spectral analysis and short time Fourier transfer(STFT) analysis for multiple electrodes shows and best results has shown for STFT [14]. A comparison of fast Fourier transform, Auto-Regressive, and wavelet transform with their shortcoming is summarize in [15]. Epileptic seizure detection based on Discrete Wavelet Transform and Support Vector Machine had proposed in [16]. The analysis of improvement for extraction of feature has explained in [17]. A BCI has developed for Detection of arm movements based on Functional Near-Infrared Spectroscopy (fNIRS) using Phase-Space Analysis in [18]. A novel methodology has proposed to Identification of emotions in the real-time movie from EEG signals in [19], the method found very useful with the accuracy of 86.63 % for the positive emotions and 65.09% for negative emotions.

3 Conclusion

Brain signal processing helps us to analyze the mental states of human and different diseases in the field of neurological study. The brain signals are extremely immanent, non-Gaussian, and of random type, can be classified as a chaotic signal. Many improvements are need to develop a BCI system that gives desirable results in real time. Various signal processing methods based on linear model analysis and nonlinear model analysis, time, spectral, short time Fourier transform, wavelet transform and space-time-frequency domain analysis has reviewed. From all the linear method based analysis, the accuracy of the space-time-frequency domain using Wavelet Packet Decomposition (WPD) is shown the better results than the other existing methods. The nonlinear techniques give even better results than the visual inspection of EEG signal, traditional techniques, and linear techniques. The complex physiological events can be understand using non-linear methods. Brain signal processing has many applications like arm movement detection, emotion detection.

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