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ScienceDirect
Procedia Computer Science 84 (2016) 192 – 197
Procedia Computer Science

7th International conference on Intelligent Human Computer Interaction, IHCI 2015

Multiple Feature Extraction of Electroencephalograph Signal for Motor Imagery Classification through Bispectral Analysis

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Abstract

Electroencephalograph (EEG) signals associated with motor imagery (MI) are highly non-Gaussian, non-stationary and have non-linear characteristics. Bispectral analysis is an advanced signal processing technique that quantifies quadratic non-linearities (phase-coupling) among the components of a signal and holds promise for characterizing MI-related EEG. Studies have been reported on the applicability of bispectrum for MI classification; often with different choice of high order spectra features. Question remains as to which of the different features of non-linear interactions over frequency components are best suited for MI classification. In this paper, an analysis based on bispectrum is reported to extract multiple high order spectra features of EEG for MI classification. MI signals from C3 and C4 channels for two tasks are used in the analysis. Based on bispectrum analysis, four high order spectra features are extracted. The classification results indicate that the extracted features could differentiate the two MI tasks with an accuracy of 90±4.71%.

Peer-review under responsibility of the Organizing Committee of IHCI 2015
Keywords: Brain-Computer Interface, Electroencephalogram, Motor Imagery, Bispectrum.

1. Introduction

Brain Computer Interface (BCI) is part of physiological computing wherein signals from the brain is made to control external devices. Chapin et al[1] was the first to demonstrate the control of a robotic manipulator by electrical activity generated through ensembles of cortical neurons. Starting thereof, research on BCI has been witness to a rapid growth. BCI holds promise for assisting, augmenting, and rehabilitating sensorimotor functions in clinical populations. Out of a range of invasive or noninvasive neurophysiological recording techniques used by these systems, electroencephalograph (EEG) is the most preferred. EEG-based BCI are driven through detection of event-related desynchronization/synchronization (ERD/ERS) in sensorimotor oscillatory rhythms associated with motor imagery (MI). EEG signals associated with MI are highly non-Gaussian, non-stationary and have non-linear characteristics. Bispectral analysis is an advanced signal processing technique that quantifies quadratic non-linearities (phase-coupling) among the components of a signal and holds promise for characterizing MI-related EEG.

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1877-0509
Peer-review under responsibility of the Organizing Committee of IHCI 2015
doi:10.1016/j.procs.2016.04.086

Bispectrum analysis of EEG was first reported by Huber et al[2]. Bispectrum analysis has been shown to provide a way to evaluate mental representation during observation and imagination of hand movement[3]. Studies have been reported on the applicability of bispectrum for MI classification[4,5,6,7]; often with different choice / combination of high order spectra features. For MI-related EEG signals, Zhou et al[4] was among the first to introduce higher order statistics (HOS) along with the traditional techniques. Zhou et al identified 12 features - 8 features extracted through traditional signal processing methods and 4 features by HOS. Such a combination could not overcome optimally the problems due to non-Gaussian and nonlinear EEG signal characteristics. A more effective way was proposed by Shahid and Prasad[5] with feature extraction comprising of selectively extracted bispectrum features. The sum of absolute log-bispectrum over all bifrequencies in the non-redundant region[8] was computed from a bandpass filtered EEG signal. Bordoloi et al[6] used hybrid features of bispectrum for MI classification. Four different MI is classified based on two hybrid features of bispectrum. As a demonstration of the applicability of bispectrum for a non-invasive BCI, Bordoloi et al[9] designed and developed a BCI maze game, where a player plays the game in real time using his brain signals. Question remains as to which of the different features of non-linear interactions over frequency components are best suited for MI classification.

In this paper, an analysis based on bispectrum is reported to extract multiple high order spectra features of EEG for MI classification. MI signals (from the C3 and C4 channels) provided in the BCI-competition IV Dataset - IIb[10] for two MI tasks is used. Based on bispectrum analysis, four high order spectra features are extracted; extracted features could differentiate the two MI tasks with an accuracy of 90±4.71

2. Proposed Feature Extraction Technique

ERD/ERS based neurophysiological phenomenon[11] is the basis of the feature extraction technique. Left or right hand MI generate desynchronizing oscillations in the contralateral EEG along with simultaneous synchronizing oscillations in the ipsilateral EEG signal[12]. EEG signals from channels C3 and C4 (as per the 10:20 system of electrode placement) located in sensorimotor regions of left and right brain hemispheres are used. Band pass filter of different frequency range is implemented. A second-order Butterworth filter is used in different range of targeted brain rhythms - α (8-12 Hz), β (12-36 Hz) and μ (8-13 Hz). We conduct an initial experiment to identify the required band-pass filter. Thereafter, the bispectrum-based features are extracted from the corresponding filtered signals.

2.1. Bispectrum-based Feature Extraction

A bispectrum of a signal is the expectation of three frequency components: two direct frequency components and the third is the conjugate frequency of the sum of these two frequencies[13]. From the Fourier frequency components, $X(f)$, of the signal $X(n)$, the bispectrum, $B(f1, f2)$, can be estimated using the Fourier-Stieltjes representation.

$$B(f_1, f_2) = E < X(f1)X(f_2)X^*(f_1 + f_2) > \tag{1}$$

Where $X^*(f)$ the complex is conjugate of $X(f)$ and $E <>$is the statistical expectation operator. $X^*(f_1 + f_2)$ represents the correlation among different frequency in $(f_1 + f_2)$ plane. The bispectrum is complex quantity and therefore it has magnitude and phase. For each $(f_1 + f_2)$, bispectrum value can be represented as a point in a complex space, Real $[B(f_1, f_2)]$ versus Imaginary $[B(f_1, f_2)]$, thus defining a vector. Phase is determined by the angle between the vector and the positive real axis. Unlike the power spectrum, which suppress the phase information, bispectrum exclusively measures the correlation of phases between the frequency components f_1, f_2 and $(f_1 + f_2)$. In fact, bispectrum is the only spectral method that can provide the phase information of signal. In EEG signal analysis, frequencies that are contributed by quadratic phase coupling generated due to quadratic phase is indicated by a peak in the bispectrum at the bifrequencies $B(f_1, f_2)$.

High Order Spectra Features. : Bispectral entropies were derived to characterize the regularity or irregularity of the signals. Mean magnitude of the bispectrum is formulated. Features related to moments of the bispectral plot and the weighted center of bispectrum is computed. Ω is the non-redundant region (principal domain)[8]. The normalization in the equations ensures that entropy is calculated for a parameter that lies between 0 and 1 (as required of a probability) and hence the entropies (BE1 and BE2) computed are also between 0 and 1[14].