ANALYSIS AND CLASSIFICATION OF EEG SIGNALS USING NOVEL FEATURES BASED ON NON-STATIONARY SIGNAL DECOMPOSITIONS

A THESIS

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requirements for the award of the degree
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VARUN BAJAJ

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **ANALYSIS AND CLASSIFICATION OF EEG SIGNALS USING NOVEL FEATURES BASED ON NON-STATIONRY SIGNAL DECOMPOSITIONS** in the partial fulfillment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY** and submitted in the **DISCIPLINE OF ELECTRICAL ENGINEERING, Indian Institute of Technology Indore**, is an authentic record of my own work carried out during the time period from July 2010 to August 2013 under the supervision of Dr. Ram Bilas Pachori, Assistant Professor, Indian Institute of Technology Indore, India.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other institute.

21-08-2013 VARUN BAJAJ
Signature of the student with date
(NAME OF THE PhD STUDENT)

This is to certify that the above statement made by the candidate is correct to the best of my/our knowledge.

21-08-2013
Dr. RAM BILAS PACHORI
Signature of Thesis Supervisor with date
(NAME OF THESIS SUPERVISOR)

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has successfully given his/her Ph.D. Oral Examination held on

Signature(s) of Thesis Supervisor(s)
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Convener, DPGC
Date: 10/02/2014

Signature of PSPC Member #1
Date: 10/02/2014

Signature of PSPC Member #2
Date: 10/02/2014

Signature of External Examiner
Date: 10/2/2014

Abstract

Electroencephalogram (EEG) is a highly complex signal, contains information relating to the different physiological states of the brain. Hence, the EEG signal is an invaluable measurement for the purpose of assessing brain activities. The main aim of this thesis is to develop novel features based on non-stationary signal decompositions of EEG signals for analysis and classification with special emphasis on pathological state changes in epilepsy and physiological state changes in sleep stages and emotions. The details of developed features for different applications are as follows:

- Epilepsy is one of the most common neurological disorders characterized by transient and unexpected electrical disturbance of the brain. The EEG signal contains a lot of information about the human brain function and neurological disorders like epilepsy. The empirical mode decomposition (EMD) decomposes an EEG signal into a finite set of band-limited signals known as intrinsic mode functions (IMFs). The Hilbert transformation of IMFs provides analytic signal representation of IMFs of EEG signals. The area measured from the trace of the analytic IMFs, which have circular form in the complex plane, has been proposed as a feature in order to discriminate the epileptic seizure EEG signals from the normal EEG signals. The modified central tendency measures (CTM) has been proposed to compute the radius for measuring the area of analytic IMFs in the complex plane. It has been shown that the area measure of the IMFs has given statistically significant discrimination between epileptic seizure and normal EEG signals. Experimental results on the published dataset have been included in order to show the effectiveness of the proposed area feature for discriminating epileptic seizure EEG signals from the normal EEG signals.

- The IMFs generated by EMD method can be considered as a set of amplitude and frequency modulated (AM-FM) signals. The two bandwidths, namely amplitude modulation bandwidth (B_{AM}) and frequency modulation bandwidth (B_{FM}), computed from the analytic IMFs, have been proposed for classification of seizure and non-seizure EEG

signals. These bandwidth features have been proposed as an input to least squares support vector machine (LS-SVM) together with the radial basis function (RBF), Mexican hat wavelet, and Morlet wavelet kernel functions for classification of seizure and non-seizure EEG signals. The experimental results with the recorded EEG signals from a published dataset are included to show the effectiveness of the proposed bandwidth features for classification of seizure and non-seizure EEG signals. The proposed classification method has been compared to the existing methods for classification of seizure and non-seizure EEG signals. The best classification accuracy among the ten classification results for seizure and non-seizure EEG signals obtained by proposed method is 100% for second IMFs with Morlet wavelet kernel function of the LS-SVM classifier.

- The intracranial EEG signals have been used to detect focal temporal lobe epilepsy. The instantaneous area measured from the trace of the windowed analytic IMFs of EEG signals has been proposed for rules-based detection of focal temporal lobe epilepsy. The experiment results on intracranial EEG signals are presented to show the effectiveness of the proposed method for detection of focal temporal lobe epilepsy. The performance evaluation of the proposed method for epileptic seizure detection has performed by computing the sensitivity (SEN), specificity (SPE), positive predictive value (PPV), negative predictive value (NPV) and error rate detection (ERD). The proposed method has been compared to the existing methods for detecting focal temporal lobe epilepsy from intracranial EEG signals. The proposed method has provided detection of focal temporal lobe epilepsy with increased accuracy.

- The proposed histogram based features namely maximum count of pixel intensity in the histogram of gray sub-images, spread in the histogram of gray sub-images, and aspect ratio in the histogram of binary sub-images, have been computed from the sub-images obtained from the time-frequency image (TFI) using frequency-bands of rhythms of EEG signals. The smoothed pseudo Wigner-Ville distribution (SPWVD) based time-frequency representation (TFR) of EEG signal has been used to obtain the

TFI. The segmentation of TFI has been performed based on the frequency-bands of the rhythms of EEG signals. These proposed features have been used as an input feature set to multiclass least squares support vector machines (MC-LS-SVM) together with the radial basis function (RBF), Mexican hat wavelet, and Morlet wavelet kernel functions for automatic classification of sleep stages from EEG signals. The experimental results are presented to show the effectiveness of the proposed method for classification of sleep stages from EEG signals. The proposed method has been compared to the existing methods in the literature for sleep stage classification using EEG signals which have been studied on the same EEG dataset according to Rechtschaffen and Kales (R&K) and American Academy of Sleep Medicine (AASM) standards respectively. The classification accuracy for sleep stage classification obtained by proposed method is 92.93%.

- The statistical features namely mean of Euclidean distance (MED) and standard deviation of Euclidean distance (SED) extracted from third level decomposed sub-signals obtained by using multiwavelet transform are proposed for emotion classification from EEG signals. The sub-signals obtained by multiwavelet decomposition of EEG signals are plotted in a 3-D phase space diagram using phase space reconstruction (PSR) method. The statistical features based on Euclidean distance are computed from 3-D phase space diagram. These features have been proposed as an input feature set for MC-LS-SVM for classification of emotions using EEG signals. The classification accuracy for classification of emotions obtained by proposed method is 91.04%.