journal homepage: www.intl.elsevierhealth.com/journals/cmpb

Classification of normal and epileptic seizure EEG signals using wavelet transform, phase-space reconstruction, and Euclidean distance

Sang-Hong Lee [a], Joon S. Lim [b], Jae-Kwon Kim [c], Junggi Yang [b], Youngho Lee [b,*]

[a] Department of Computer Science & Engineering, Anyang University, Anyang-si, Republic of Korea
[b] IT College, Gachon University, Seongnam-si, Republic of Korea
[c] Department of Computer Science & Engineering, Inha University, Inchon-si, Republic of Korea

ARTICLE INFO

Article history:
Received 21 August 2012
Received in revised form
18 April 2014
Accepted 21 April 2014

Keywords:
Epileptic seizure
Feature selection
Phase space reconstruction
Euclidean distance
ROC curve

ABSTRACT

This paper proposes new combined methods to classify normal and epileptic seizure EEG signals using wavelet transform (WT), phase-space reconstruction (PSR), and Euclidean distance (ED) based on a neural network with weighted fuzzy membership functions (NEWFM). WT, PSR, ED, and statistical methods that include frequency distributions and variation, were implemented to extract 24 initial features to use as inputs. Of the 24 initial features, 4 minimum features with the highest accuracy were selected using a non-overlap area distribution measurement method supported by the NEWFM. These 4 minimum features were used as inputs for the NEWFM and this resulted in performance sensitivity, specificity, and accuracy of 96.33%, 100%, and 98.17%, respectively. In addition, the area under Receiver Operating Characteristic (ROC) curve was used to measure the performances of NEWFM both without and with feature selections.

1. Introduction

Human brain disorders are responsible for many physiopathological diseases, especially epilepsy. Epilepsy is a chronic neurological disorder that is generally characterized by sudden and recurrent seizures [10,13,20]. Until recently, the occurrence of an epileptic seizure was unpredictable and its mode of action was little understood [9].

The electroencephalogram (EEG) is a highly complex signal and it provides one of the most commonly used information sources for studying brain function and neurological disorders [2]. Study of the brain's electrical activity, using electroencephalographic records, is one of the most important steps in the diagnosis of neurological diseases [1,14,31,32,41].

EEG signal processing uses nonlinear methods, such as the Lyapunov exponent, and the correlation dimension is used to measure the complexity or degree of the EEG signal disorder [8,13,23]. Apart from EEG, Empirical mode decomposition (EMD) was developed specifically for nonlinear and nonstationary signal analysis [36]. Time and frequency domains are commonly used in feature extraction methods for the EEG

* *Corresponding author*. Tel.: +82 328204100.
E-mail addresses: shleedosa@gmail.com, shleedosa@anyang.ac.kr (S.-H. Lee), jslim@gachon.ac.kr (J.S. Lim), jaekwonkorea@naver.com (J.-K. Kim), yjunggi@gmail.com (J. Yang), lyh@gachon.ac.kr (Y. Lee).
http://dx.doi.org/10.1016/j.cmpb.2014.04.012
0169-2607/

signals and cross-correlations of EEG time series have been used for high performance classification of the time domain features [7,12,15,45,51]. Past research shows that, to analyze the frequency domain features, discrete Fourier transform (DFT) was applied first followed by the calculation of power spectral density (PSD) of the EEG signals [15,34]. Grammatical evolution (GE) [35,44], eigenvector methods [12,49,50], and the Fourier transform [39] are also other reported approaches for extracting features when classifying epileptic signals from the EEG recordings.

EEG signals have been decomposed into time–frequency representations using discrete wavelet transform (DWT) [5,11]. First, EEG signals are decomposed into several sub-signals by DWT, and then wavelet coefficients of the several sub-signals are produced. The wavelet coefficients were used as inputs of Adaptive neuro-fuzzy inference system (ANFIS) [11]. Genetic programming is applied to extract new features, which are nonlinearly transformation from the wavelet coefficients [9]. Wavelet entropy was obtained from the wavelet coefficients on the several sub-signals, and then the wavelet entropy was used as features [20]. Statistical methods were also used to extract features from the wavelet coefficients [46]. Certain features based on DWT were obtained and applied as different classifiers during epileptic EEG classification, including methods, such as adaptive neuro-fuzzy inference [11], relative wavelet energy (RWE) with artificial neural network (ANN) method [26], multistage approach for clustering [16], new phase space-based approach to automatically classify sleep-wake cycle [4], mixture of expert model [46] and support vector machine (SVM) [7].

In the current study, a neural network with weighted fuzzy membership functions (NEWFM) [21,22,24] that is known to deliver excellent performance in prediction and classification was used to classify the normal and the epileptic seizure signals from the EEG signals and 3 preprocessing steps were implemented for this purpose. The 3 preprocessing steps, applied sequentially, comprised of wavelet transform (WT), phase-space reconstruction (PSR), and Euclidean distance (ED). NEWFM and non-overlap area distribution measurement method were used for classification and feature selection. In this regard, the area under the Receiver Operating Characteristic (ROC) curve (AUC) was used to compare the performances of NEWFM without feature selection and NEWFM with feature selection.

The remainder of this paper is organized as follows. Section 2 describes the related works. Section 3 describes EEG datasets used in this paper. Section 4 describes feature extraction and selection method. Section 5 provides experimental result. Discussion and conclusion have been included in Section 6.

2. Related works

Until now, several techniques have been proposed for the classification of normal and epileptic seizure EEG signals in the literature and EEG classification accuracy have been reported. A description of the previous research follows.

Güler and Übeyli [11] proposed the ANFIS to classify EEG signals using wavelet coefficients. The presented ANFIS model combined the neural network adaptive capabilities and the fuzzy logic qualitative approach. Guo et al. [9] applied genetic programming (GP) to perform automatic feature extraction since GP can improve the discrimination performance of K-nearest neighbor (KNN) classifier and decrease the input feature dimension. Kumar et al. [20] reported entropy based detection of neurological disorders, where three entropies, called as wavelets, were used as feature selection parameters and the neurological disorders were classified using two neural network models, viz. recurrent Elman network and radial basis network. Subasi [46] proposed an ANN based expert model, with a double-loop Expectation-Maximization (EM) algorithm, for the detection of epileptic seizures. This study employed DWT for feature extraction on the same two sets of the epileptic EEG signals.

Ling et al. [26] proposed DWT, RWE along with ANN to classify the EEG signals. The EEG signals were first decomposed into different frequency bands with DWT. The RWE provided information about the relative energies associated with the different frequency bands of the EEG signals. A feed-forward ANN was finally used for classification. Abawajy et al. [16] proposed a novel multistage approach for classifying large and highly dimensional dataset. The multistage approach combined dimensionality reduction algorithms, multiple unsupervised clustering algorithms and several supervised classification algorithms. Arnaud et al. [4] proposed a new phase space-based approach to automatically classify sleep–wake cycles in humans, using only two EEG electrode positions. However, this study did not classify each sleep stage using phase space analysis (mainly on Poincare plot), which is generally applied in non-linear and relatively short time series analysis. Chandaka et al. [7] utilized a cross-correlation aided SVM classifier for classifying EEG signals of healthy subjects with eyes open and epileptic patients during seizure with the epileptic EEG signals. This study involved least square support vector machine (LS-SVM) and feature extraction using a clustering technique.

In the literature, numerous techniques have been used to obtain representations and extract features of interest for the classification purposes. Until now, there is no study that is related to the phase-space reconstruction and ED approach for feature extraction of the EEG signals. In this paper, we propose a new approach that combines the wavelet transform, phase-space reconstruction, and ED comprising of feature selection based neural network, with weighted fuzzy membership function (NEWFM), to classify the normal and the epileptic seizure EEG signals.

3. Electroencephalogram (EEG) datasets

This study used EEG signal datasets (http://epileptologie-bonn.de/cms/front_content.php?idcat=193&lang=3&changelang=3) to classify normal and epileptic seizure signals [3,46]. The experimental dataset was first divided into five sets denoted as A, B, C, D, and E, each containing 100 single-channel EEG signals and each signal is of 23.6 s in duration [3,46]. These segments were selected and cut out from continuous multichannel EEG recordings after visual inspection for artifacts, e.g., due to muscle activity or eye movements. Sets A and B consisted of segments taken from surface EEG recordings