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Original Research Article

Automatic epilepsy detection using wavelet-based nonlinear analysis and optimized SVM

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ABSTRACT

Aiming at the problems of low accuracy, poor universality and functional singleness for seizure detection, an effective approach using wavelet-based non-linear analysis and genetic algorithm optimized support vector machine (GA-SVM) is proposed to deal with five challenging classification problems in this study. Instead of the traditional discrete wavelet transform (DWT), we attempt to explore the ability of double-density discrete wavelet transform (DD-DWT) to decompose the original EEG into specific sub-bands. The Hurst exponent (HE) and fuzzy entropy (FuzzyEn) are extracted as input features and then fed into two classifiers. On using these ranking non-linear features, the GA-SVM configured with fewer features is found to achieve the prominent classification performance for various combinations such as AB-CD-E, A-D-E, ABCD-E, C-E and D-E, achieving accuracies of 99.36%, 99.60%, 99.40%, 100% and 100%, respectively. The results have indicated that our scheme is not only appropriate in solving problems with multiple classes but also of lower complexity and better expansibility. These characteristics would make this method become an attractive alternative for actual clinical diagnosis.

1. Introduction

Epilepsy is a common chronic neurological disorder that is characterized by recurrent unprovoked seizures [1]. According to a report by the World Health Organization (WHO) [2], approximately 50 million people worldwide have epilepsy, making it one of the most common neurological diseases globally. People who suffer from epilepsy are two or three times more likely to die prematurely when compared to a normal person [3]. Also people with epilepsy and their families suffer from stigma and discrimination. So it is venerable to develop effective and reliable epilepsy detection techniques and anti-epileptic drugs, which would provide patients better care while helping the clinician to give the proper diagnosis and possible treatment plan of epilepsy.

Electroencephalogram (EEG) signal is commonly used by clinicians in diagnosis of neurological disorders including epileptic seizures [4]. Nowadays, the traditional epilepsy diagnosing is based on visual inspection which is quite tedious and time consuming. Thus, developing automatic tools for classification of the EEG signals is of great significance. Some related methodologies have been proposed to deal with

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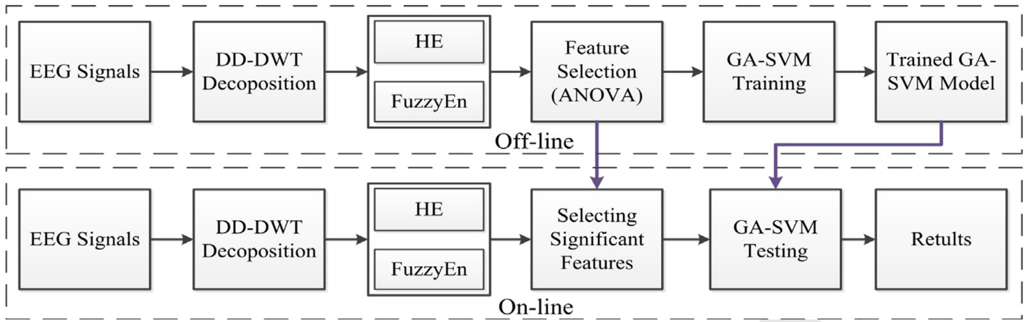

Fig. 1 – Block diagram for proposed method.

epileptic signals. Research works in recent studies can be fallen under four categories namely time-domain, frequency-domain, time-frequency domain and nonlinear methods of analysis. Since the EEG signals are complex, nonlinear and non-stationary in general, time-frequency domain and non-linear analysis methods are most widely used in epilepsy detection.

Among time-frequency analysis methods, the discrete wavelet transform (DWT) stands out in terms of algorithmic elegance and efficiency [5]. From the variety of approaches available [6–9], DWT is extensively adopted for epilepsy detection as feature extractor. However, the major short-comings of DWT are the sensitivity to translation and lack of shift invariance, by which small shift in EEG signals will lead to major variation in the distribution of the energy between wavelet coefficients at different scales. Therefore, a novel method named double-density discrete wavelet transform (DD-DWT) is introduced in this paper as a better time–frequency representation of signals as compared to the traditionally used DWT. Based on the particular structure with dual wavelets, DD-DWT is able to describe the detail information of signals precisely. Although DD-DWT has been successfully deployed in the fields of image processing [11] and signal de-noising [10], research report on the use of DD-DWT for EEG signals processing is rather limited. Thus, the application of DD-DWT in EEG identification is explored in this work.

Nonlinear analysis [12–17,22,23,35,37,39,43,46] is another popular research method which could better reflect the characteristics of the EEG signals. The use of Hurst exponent (HE) has been proven to achieve good accuracy in detecting seizures [12]. Moreover, entropies like approximate entropy (ApEn) and sample entropy (SampEn) are extensively applied to unearth the hidden complexities existing in the EEG time series [13–17]. Recently, several studies [18] have evaluated that a new entropy measure named Fuzzy entropy (FuzzyEn) was more accurate than ApEn and SampEn. In this paper, the FuzzyEn combined with HE is introduced to characterize the EEG signals in terms of the stronger relative consistency and less dependence on data length.

With the development in medical industry, it is necessary to develop an automated, simple, objective, functional, and efficient diagnostic method that can help the physicians make a definite diagnosis in practice. For this purpose, a novel methodology based on DD-DWT and non-linear analysis is present for EEG classification in our paper. The data is divided into two groups, one is for model building and the other is for model testing. Fig. 1 has illustrated the main work of proposed technique. The signals are decomposed into 5 levels using DD-DWT and then nonlinear features such as HE and FuzzyEn are computed on each of these sub-bands. In addition, highly discriminating features selected by the analysis of variance (ANOVA) test are fed to genetic-based support vector machine (GA-SVM). Finally, the model in on-line stage is built according to the guidance from the off-line stage. This paper is organized as follows: In Section 2, the EEG signal used in our study is described. Section 3 discusses the proposed methodology. In Section 4, the evaluation procedure and the obtained experimental results are presented. And the conclusions of the whole paper have been included in Section 5.

2. Data

The EEG data used in this study, which is publicly available, is taken from University of Bonn, Germany [19]. The complete database was composed by five sets denoted as A-E, each containing 100 samples of 23.6 s duration. The description of five data sets is shown in Table 1. The signals were recorded with the same 128-channel amplifier system and digitized at 173.61 samples per second using 12 bit resolution. Sets C and D denoted as interictal data are recorded during the patients in pre-ictal. Set E, which is called ictal data, contains signals recorded during the epileptic seizure. In this study, five cases involving all of the data sets would be presented. The exemplary EEG from five data sets is depicted in Fig. 2.

3. Methods

3.1. *Double-density discrete wavelet transform*

Double-density discrete wavelet transform (DD-DWT), proposed by Salasnick [20], is a new wavelet analysis method which is quite powerful for signal processing. Owing to the prominent properties of approximate shift invariance and anti-aliasing, DD-DWT is able to provide a more flexible way of time-frequency representation for signals. Different from traditional DWT, the frame of DD-DWT is based on a single scaling function $\varphi(t)$ and two distinct wavelet functions $\psi_1(t)$ and $\psi_2(t)$. And the two wavelet functions are particularly

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