BBE 262 1–16

ARTICLE IN PRESS

BIOCYBERNETICS AND BIOMEDICAL ENGINEERING XXX (2018) XXX–XXX

Available online at www.sciencedirect.com

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journal homepage: www.elsevier.com/locate/bbe

Original Research Article

Generalized Stockwell transform and SVD-based epileptic seizure detection in EEG using random forest

Tao Zhang, Wanzhong Chen, Mingyang Li*

College of Communication Engineering, Jilin University, Changchun 130025, China

ARTICLE INFO

Article history:
Received 24 July 2017
Received in revised form
5 March 2018
Accepted 28 March 2018
Available online xxx

Keywords:
Electroencephalogram (EEG)
Automatic seizure detection
Generalized Stockwell transform (GST)
Singular value decomposition (SVD)
Random forest

ABSTRACT

Purpose: Visual inspection of electroencephalogram (EEG) records by neurologist is the main diagnostic method of epilepsy but it is particularly time-consuming and expensive. Hence, it is of great significance to develop automatic seizure detection technique.
Methods: In this work, a seizure detection approach, synthesizing generalized Stockwell transform (GST), singular value decomposition (SVD) and random forest, was proposed. Utilizing GST, the raw EEG was transformed into a time–frequency matrix, then the global and local singular values were extracted by SVD from the holistic and partitioned matrices of GST, respectively. Subsequently, four local parameters were calculated from each vector of local singular values. Finally, the global singular value vectors and local parameters were respectively fed into two random forest classifiers for classification, and the final category of a testing EEG was voted based on sub-labels obtained from the trained classifiers.
Results: Four most common but challenging classification tasks of Bonn EEG database were investigated. The highest accuracies of 99.12%, 99.63%, 99.03% and 98.62% were achieved using our presented technique, respectively.
Conclusions: Our proposed technique is comparable or superior to other up-to-date methods. The presented method is promising and able to handle with kinds of epileptic seizure detection tasks with satisfactory accuracy.
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1. Introduction

Epilepsy is a spontaneously- and periodically-occurring brain disorder that is prevalent in people of all ages, regions and races. It is characterized by the so-called "epileptic seizure" which is caused by synchronous, unprovoked and excessive abnormal electrical discharges of brain neurons [1]. Being the second-most common neurological disease inferiors to stroke, epilepsy affects approximately one percent of world's population and the quantity maintains rapid growing at 5% per year; nearly 80% of epilepsy patients are coming from the non-developed and developing countries such as China, India, etc., as reported by World Health Organization (WHO) [2]. Many

* *Corresponding author at*: College of Communication Engineering, Jilin University, Changchun 130025, China.
E-mail addresses: zhangtao14@mails.jlu.edu.cn (T. Zhang), chenwz@jlu.edu.cn (W. Chen), mingyang15@mails.jlu.edu.cn (M. Li).
https://doi.org/10.1016/j.bbe.2018.03.007
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Please cite this article in press as: Zhang T, et al. Generalized Stockwell transform and SVD-based epileptic seizure detection in EEG using random forest. Biocybern Biomed Eng (2018), https://doi.org/10.1016/j.bbe.2018.03.007

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predisposing factors, for instance, brain tumor, brain infection, severe head injury and so on can lead to epilepsy. Although many epilepsy patients can be successfully cured by anti-epileptic drugs or surgery, the mechanism of epilepsy, especially the idiopathic epilepsy, is still outstanding and mysterious.

Electroencephalogram (EEG), a graphic description of brain's electrical activity, is regarded as the most popular and prominent diagnostic instrument for epilepsy [3]. An EEG is recorded with the help of the non-invasive electrodes of an electroencephalograph placing on patient's scalp. By monitoring EEG records visually, neurologists are able to detect epileptic seizures and to take proper measures to minimize any risk to epilepsy patients. However, visual interpretation of EEG records for the diagnosis of epilepsy is expensive and time-consuming. What's more, the diagnosis results of the same record from different doctors may also be discrepant from others', due to the fact of lacking consistent reference standard and prone to personal experience [4]. By contrast, those computer-aided epileptic diagnosis techniques are of low artificial workload, unified processing procedures and evaluation indexes as well as low financial burden. Therefore, it is essential to develop automated seizure detection technologies.

Multitudinous encouraging and remarkable accomplishments have been reached in epileptic seizure detection since Gotman [5] published the first automated seizure detection approach in EEG. Essential procedures of the overwhelming majority of seizure detection methods can be sum up as: (1) feature extraction via signal processing technologies and (2) classification employing various kinds of machine learning algorithms. These two procedures are auxiliary to each other. An outstanding feature extraction approach will greatly enhance the final classification performance while a preeminent classification algorithm is capable of mining more discriminating information from extracted features. At the infancy, time-domain or frequency-domain parameters such as mean, variance, skewness, kurtosis, discrete cosine transform, discrete Fourier transform (DFT), autoregressive (AR) model, power spectral density were used in feature extraction procedure [6]. Nevertheless, EEG subsequently has been proven to be a nonstationary and nonlinear signal in nature [5], these aforementioned parameters may be insufficient in revealing the hidden characters of EEG. Time–frequency representation and nonlinear analysis are adept at managing nonstationary and nonlinear signals like EEG, electromyogram, electrocardiogram, and they are thus introduced for EEG quantitative analysis extensively. As examples, Şengür et al. [7] carried out an investigation of short time Fourier transform (STFT)-based texture descriptors for seizure detection. Authors in literature [8] presented a new seizure detection technique based on smoothed pseudo Wigner-Ville distribution. Hyvärinen et al. [9] proposed a spontaneous EEG/magnetoencephalography analysis technique uniting independent component analysis (ICA) and STFT. Though remarkable results have been achieved, these algorithms described above, however, encounter several difficulties. STFT is able to present the time–frequency representation of EEG, but the fixed time window leads to a lack of flexible time–frequency concentration. By contrast, WVD is a more-refined analysis tool than STFT, but the cross-term interference of this quadratic time–frequency scheme is inherent and inevitable. Compared with STFT and WVD, CWT does not meet with issues STFT and WVD encounter, nonetheless, the computation complexity of CWT is indeed high and prevents the further exploration of CWT for EEG analysis. In addition to aforementioned methods, other time frequency analysis algorithms including rational discrete short-time Fourier transform [10], empirical mode decomposition [11–13], local mean decomposition [14], variational mode decomposition [2] as well as their modified versions [15] have been introduced for EEG characterization.

With the advancement of wavelet technology, the discretization of CWT-discrete wavelet transform (DWT) is able to provide a clear time–frequency representation in a short computational time, commendably takes into account both efficiency and representational capacity. Being one research hotspot, a series of seizure detection techniques involving DWT and its extended versions have sprung up. To name a few, Murugavel et al. [16] tried to extract DWT-based nonlinear and statistical features in feature extraction procedure and followed by classification using SVM with ELM kernel. A fusion method of DWT and fuzzy approximate entropy was presented by Kumar et al. [17] to characterize different EEGs, then support vector machine (SVM) was exploited to classify seizure and non-seizure EEGs and their method achieved accuracies above 97.38% in seven binary-class tasks. Authors in [18] had extracted mahalanobis-similarity-based and sample-entropy-based features from coefficients of DWT, extreme learning machine (ELM) was used to classify interictal and ictal EEG segments, and the classification accuracy is 97.53%. A comparative study was carried out by Upadhyay et al. [19] to investigate the best wavelet basis, exploiting criterion of maximum energy to permutation entropy ratio. Three kinds of feature ranking techniques were studied and the presented study can achieve an accuracy of 100% in differentiating normal, pre-ictal and ictal EEGs. Besides DWT, wavelet packet decomposition (WPT) is also a frequently used time–frequency analysis tool for seizure detection. In [20], WPT in conjunction with modified AdaBoost was developed to distinguish non-seizure and seizure EEGs, a sensitivity of 96.11% and a specificity of 99.51% were reached. In [21], a new entropy named fuzzy distribution entropy (fDistEn) was proposed, a hybrid approach of WPT, fDistEn, Kruskal–Wallis nonparametric one-way analysis of variance was put forward for feature extraction and selection, then the K-nearest neighbors (KNN) was used to classify kinds of EEG combinations. Their approach can handle ten types of classification cases with a least accuracy of 98.758%. Conventional wavelet transforms are sensitive to noise and lack of shift invariant [22]. In comparison, dual-tree complex wavelet transform (DTCWT) is of approximate shift invariant and translation invariant, it has become a popular tool to characterize EEG in recent years. For example, Chen [23] presented the first seizure detection method utilizing DTCWT and Fourier transform. After that, numerous DTCWT-based schemes appear one after another. Combining DTCWT with normal inverse Gaussian, authors of [24] proposed a feature extraction technique of EEG and the SVM classifier yielded accuracies of 100% in all classification tasks except the case of classifying normal, interictal and ictal

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