Seizure 26 (2015) 56–64

Contents lists available at ScienceDirect

Seizure

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

Review

Wavelet-based EEG processing for computer-aided seizure detection and epilepsy diagnosis

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ARTICLE INFO

Article history:
Received 25 October 2014
Received in revised form 15 January 2015
Accepted 18 January 2015

Keywords:
Continuous Wavelet Transform
Discrete Wavelet Transform
Electroencephalogram
Epilepsy

ABSTRACT

Electroencephalography (EEG) is an important tool for studying the human brain activity and epileptic processes in particular. EEG signals provide important information about epileptogenic networks that must be analyzed and understood before the initiation of therapeutic procedures. Very small variations in EEG signals depict a definite type of brain abnormality. The challenge is to design and develop signal processing algorithms which extract this subtle information and use it for diagnosis, monitoring and treatment of patients with epilepsy. This paper presents a review of wavelet techniques for computer-aided seizure detection and epilepsy diagnosis with an emphasis on research reported during the past decade. A multiparadigm approach based on the integration of wavelets, nonlinear dynamics and chaos theory, and neural networks advanced by Adeli and associates is the most effective method for automated EEG-based diagnosis of epilepsy.

1. Introduction

Scientific work on mechanizing the detection of epileptic seizures began around 1970 [1]. However, it took about 30 years to develop the algorithms to turn these ideas into physical problem solutions [2]. Various Electroencephalography (EEG) analysis and classification methods use the fact that the information processing in the brain is reflected in the EEG as dynamical changes of the electrical activity in time, frequency, and space. Various frequency and nonlinear methods have been used to understand the mechanisms behind the information processing [3,4]. Among time–frequency analysis methods the Wavelet Transform (WT) stands out in terms of algorithmic elegance and efficiency. WT captures the subtle changes in the EEG signal well. These minute variations are difficult to spot using the naked eye in the EEG signal. Therefore, this review is dedicated to WT-based EEG processing and computer-aided seizure detection and epilepsy diagnosis.

Fig. 1 shows sample normal, interictal and ictal (epileptic) EEG signals from a database hosted by the University of Bonn [5]. The signals in the database were obtained from five normal subjects and five epileptic patients. The EEG data is classified into three categories: control, interictal, and ictal/epileptic. The interictal EEG signals were obtained from the hippocampal formations during seizure free intervals. The ictal signals were recorded from the lateral and basal regions of the neocortex. The EEG signals were recorded using a 128-channel amplifier system digitized with a sampling frequency of 173.61 Hz, and filtered using a band pass filter of 0.53–40 Hz.

2. Computer aided seizure detection

A trend in healthcare is shifting from clinician-centric care to patient-centric care where the patient becomes an active participant in her care management. Automated Computer-Aided Diagnosis of epilepsy which is significantly more challenging than computer-aided seizure detection was advanced with the seminal work of Adeli et al. [6] for diagnosis of the absence seizure more than a decade ago. This review aim to summarize the research reported since then. A CAD system can help neurologists make the

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http://dx.doi.org/10.1016/j.seizure.2015.01.012
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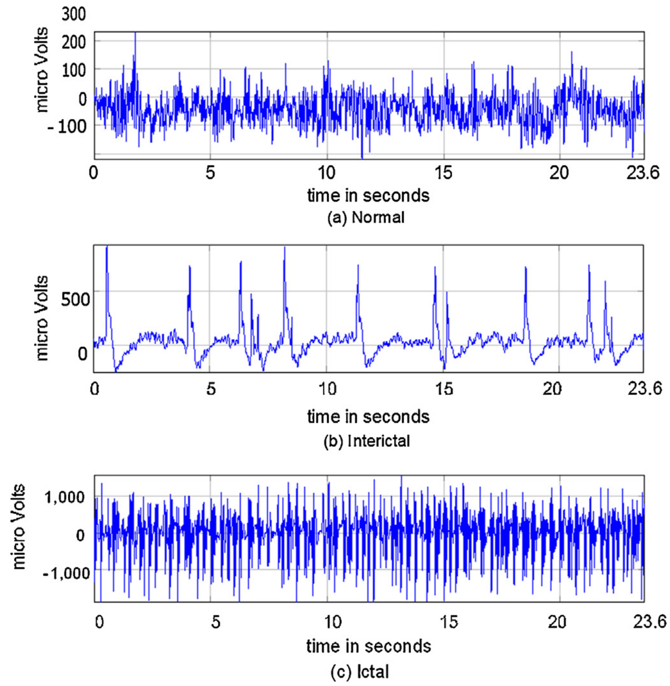

Fig. 1. Sample EEG signals.

diagnosis more efficiently and accurately. Fig. 2 presents a block diagram for a computer-aided seizure detection and epilepsy diagnosis system. It consists of an offline and an online system. The offline system consists of the design steps necessary to create and test the CAD algorithm structure. This algorithm is then used in the online system by the neurologist as a decision support system.

WT is used for signal preprocessing/denoising and for feature extraction. WT was developed in the 1980s as a powerful signal processing technique to overcome the shortcomings of other methods such as the Fourier transform [11]. Since then it has been used in a variety of signal processing applications [8,9]. WT provides a smooth representation, unlike windowed representation in the short time Fourier transform. Hence, one can capture very minute details, sudden changes and similarities in the EEG signals. WT acts like a mathematical microscope, because it has the capability to analyze EEG signals at different scales [12]. Researchers have proposed unique wavelets. Fig. 3 shows examples of mother wavelets used for EEG processing: (a) Daubechies (db), (b) Morlet, (c) Biorthog-onal (bior), (d) Orthogonal Cubic Spline (ocs), (e) Mexican Hat (MH), (f) Haar, (g) Complex Gaussian (CG), and (h) Coiflet (coif) wavelet. The following two sections introduce the application of WT in computer aided seizure detection.

3. Signal preprocessing/denoising

Raw EEG signals suffer from poor spatial resolution, low signal-to-noise ratio and artifacts [7]. Preprocessing is the denoising step which aims to improve the signal-to-noise ratio of the EEG.

The WT is now a well-known tool for removing noise from the signal. Multi-resolution analysis provides information about the signal in different frequency bands. The wavelet decomposition of a noisy signal concentrates intrinsic signal information in a few wavelet coefficients having large absolute values without modifying the random distribution of noise. Therefore, denoising can be achieved by thresholding the wavelet coefficients. The WT gives a time-variant decomposition, an advantage over techniques such as Wiener filtering. With a time-variant decomposition it is possible to choose different filtering settings (i.e. wavelet coefficients) for different time ranges. Hence, it is possible to create event-related filter responses. With time-invariant approaches, such as Wiener filtering, it is not possible to find a unique implementation that is suitable for all event related potentials [10].

4. Wavelet analysis for signal feature extraction

In addition to denoising, wavelets can be used for feature extraction. The mother wavelet is shifted by a small interval in the x-axis and correlation coefficients are computed. This procedure is repeated for various scaling factors (dilations) in the y-axis.

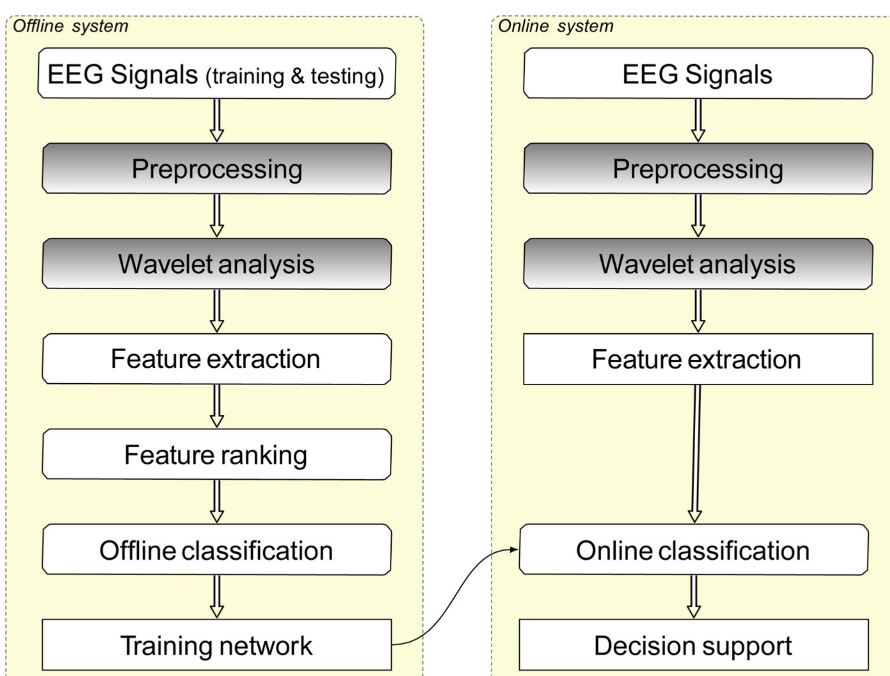

Fig. 2. Block diagram for a computer-aided seizure detection and epilepsy diagnosis system.