Computer Methods and Programs in Biomedicine (2005) **78**, 87—99

ELSEVIER

Computer Methods and Programs in Biomedicine

www.intl.elsevierhealth.com/journals/cmpb

Classification of EEG signals using neural network and logistic regression

Abdulhamit Subasi [a,*], **Ergun Erçelebi** [b]

[a] *Department of Electrical and Electronics Engineering, Kahramanmaras Sutcu Imam University, 46601 Kahramanmaraş, Turkey*
[b] *Department of Electrical and Electronics Engineering, University of Gaziantep, 27310 Gaziantep, Turkey*

Received 26 May 2004; received in revised form 12 October 2004; accepted 26 October 2004

KEYWORDS
EEG;
Epileptic seizure;
Lifting-based discrete wavelet transform (LBDWT);
Logistic regression (LR);
Multilayer perceptron neural network (MLPNN)

Summary Epileptic seizures are manifestations of epilepsy. Careful analyses of the electroencephalograph (EEG) records can provide valuable insight and improved understanding of the mechanisms causing epileptic disorders. The detection of epileptiform discharges in the EEG is an important component in the diagnosis of epilepsy. As EEG signals are non-stationary, the conventional method of frequency analysis is not highly successful in diagnostic classification. This paper deals with a novel method of analysis of EEG signals using wavelet transform and classification using artificial neural network (ANN) and logistic regression (LR). Wavelet transform is particularly effective for representing various aspects of non-stationary signals such as trends, discontinuities and repeated patterns where other signal processing approaches fail or are not as effective. Through wavelet decomposition of the EEG records, transient features are accurately captured and localized in both time and frequency context. In epileptic seizure classification we used lifting-based discrete wavelet transform (LBDWT) as a preprocessing method to increase the computational speed. The proposed algorithm reduces the computational load of those algorithms that were based on classical wavelet transform (CWT). In this study, we introduce two fundamentally different approaches for designing classification models (classifiers) the traditional statistical method based on logistic regression and the emerging computationally powerful techniques based on ANN. Logistic regression as well as multilayer perceptron neural network (MLPNN) based classifiers were developed and compared in relation to their accuracy in classification of EEG signals. In these methods we used LBDWT coefficients of EEG signals as an input to classification system with two discrete outputs: epileptic seizure or non-epileptic seizure. By identifying features in the signal we want to provide an automatic system that will support a physician in the diagnosing process. By applying LBDWT in connection with MLPNN, we obtained novel and reliable classifier architecture. The comparisons between the developed classifiers were primarily based on analysis of the receiver operating characteristic (ROC) curves as well as a number of scalar performance

* Corresponding author.
E-mail addresses: asubasi@ksu.edu.tr (A. Subasi), ercelebi@gantep.edu.tr (E. Erçelebi).

0169-2607/$ — see front matter
doi:10.1016/j.cmpb.2004.10.009

measures pertaining to the classification. The MLPNN based classifier outperformed the LR based counterpart. Within the same group, the MLPNN based classifier was more accurate than the LR based classifier.

1. Introduction

The human brain is obviously a complex system and exhibits rich spatiotemporal dynamics. Among the noninvasive techniques for probing human brain dynamics, electroencephalography (EEG) provides a direct measure of cortical activity with millisecond temporal resolution. EEG is a record of the electrical potentials generated by the cerebral cortex nerve cells. There are two different types of EEG depending on where the signal is taken in the head: scalp or intracranial. For scalp EEG, the focus of this research, small metal discs, also known as electrodes, are placed on the scalp with good mechanical and electrical contact. Intracranial EEG is obtained by special electrodes implanted in the brain during a surgery. In order to provide an accurate detection of the voltage of the brain neuron current, the electrodes are of low impedance (<5 kΩ). The changes in the voltage difference between electrodes are sensed and amplified before being transmitted to a computer program to display the tracing of the voltage potential recordings. The recorded EEG provides a continuous graphic exhibition of the spatial distribution of the changing voltage fields over time.

Epileptic seizure is an abnormality in EEG recordings and is characterized by brief and episodic neuronal synchronous discharges with dramatically increased amplitude. This anomalous synchrony may occur in the brain locally (partial seizures), which is seen only in a few channels of the EEG signal, or involving the whole brain (generalized seizures), which is seen in every channel of the EEG signal.

EEG signals involve a great deal of information about the function of the brain. But classification and evaluation of these signals are limited. Since there is no definite criterion evaluated by the experts, visual analysis of EEG signals in time domain may be insufficient. Routine clinical diagnosis needs to analysis of EEG signals. Therefore, some automation and computer techniques have been used for this aim. Since the early days of automatic EEG processing, representations based on a Fourier transform have been most commonly applied. This approach is based on earlier observations that the EEG spectrum contains some characteristic waveforms that fall primarily within four frequency bands—delta (<4 Hz), theta (4—8 Hz), alpha (8—13 Hz) and beta (13—30 Hz). Such methods have proved beneficial for various EEG characterizations, but fast Fourier transform (FFT), suffer from large noise sensitivity. Parametric power spectrum estimation methods such as autoregressive (AR), reduces the spectral loss problems and gives better frequency resolution. But, since the EEG signals are non-stationary, the parametric methods are not suitable for frequency decomposition of these signals [1,2].

A powerful method was proposed in the late 1980s to perform time-scale analysis of signals: the wavelet transforms (WT). This method provides a unified framework for different techniques that have been developed for various applications [2—18]. Since the WT is appropriate for analysis of non-stationary signals and this represents a major advantage over spectral analysis, it is well suited to locating transient events, which may occur during epileptic seizures.

Wavelet's feature extraction and representation properties can be used to analyze various transient events in biological signals. Adeli et al. [2] gave an overview of the discrete wavelet transform (DWT) developed for recognizing and quantifying spikes, sharp waves and spike-waves. They used wavelet transform to analyze and characterize epileptiform discharges in the form of 3-Hz spike and wave complex in patients with absence seizure. Through wavelet decomposition of the EEG records, transient features are accurately captured and localized in both time and frequency context. The capability of this mathematical microscope to analyze different scales of neural rhythms is shown to be a powerful tool for investigating small-scale oscillations of the brain signals. A better understanding of the dynamics of the human brain through EEG analysis can be obtained through further analysis of such EEG records.

Numerous other techniques from the theory of signal analysis have been used to obtain representations and extract the features of interest for classification purposes. Neural networks and statistical pattern recognition methods have been applied to EEG analysis. Neural network detection systems have been proposed by a number of researchers [19—29]. Pradhan et al. [19] used the raw EEG as an input to a neural network while Weng and Khorasani [20] used the features proposed by Got-