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EEG signal classification using wavelet feature extraction and a mixture of expert model

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Abstract

Mixture of experts (ME) is modular neural network architecture for supervised learning. A double-loop Expectation-Maximization (EM) algorithm has been introduced to the ME network structure for detection of epileptic seizure. The detection of epileptiform discharges in the EEG is an important component in the diagnosis of epilepsy. EEG signals were decomposed into the frequency sub-bands using discrete wavelet transform (DWT). Then these sub-band frequencies were used as an input to a ME network with two discrete outputs: normal and epileptic. In order to improve accuracy, the outputs of expert networks were combined according to a set of local weights called the "gating function". The invariant transformations of the ME probability density functions include the permutations of the expert labels and the translations of the parameters in the gating functions. The performance of the proposed model was evaluated in terms of classification accuracies and the results confirmed that the proposed ME network structure has some potential in detecting epileptic seizures. The ME network structure achieved accuracy rates which were higher than that of the stand-alone neural network model.

Keywords: Electroencephalogram (EEG); Epileptic seizure; Discrete wavelet transform (DWT); Mixture of experts; Expectation-Maximization (EM) algorithm

1. Introduction

Temporary electrical disturbance of the brain causes epileptic seizures. Sometimes seizures may go unnoticed, depending on their presentation, and sometimes may be confused with other events, such as a stroke, which can also cause falls or migraines. Approximately one in every 100 persons will experience a seizure at some time in their life (Adeli, Zhou, & Dadmehr, 2003). Unfortunately, the occurrence of an epileptic seizure seems unpredictable and its course of action is very little understood. Research is needed for better understanding of the mechanisms causing epileptic disorders. Careful analysis of the electroencephalograph (EEG) records can provide valuable insight into this widespread brain disorder. The detection of epileptiform discharges occurring in the EEG between seizures is an important component in the diagnosis of epilepsy. (Adeli et al., 2003; Subasi, 2005a).

Spectral analysis of the EEG signals produces information about the brain activities. However, artificial neural networks (ANNs) may offer a potentially superior method of EEG signal analysis to the spectral analysis methods. In contrast to the conventional spectral analysis methods, ANNs not only model the signal, but also make a decision as to the class of signal (Subasi, 2005a; Subasi & Ercelebi, 2005). Neural networks have been successfully used in a various medical applications (Baxt, 1990; Miller, Blott, & Hames, 1992). Recent advances in the field of neural networks have made them attractive for analyzing signals. The application of neural networks has opened a new area for solving problems not resolvable by other signal processing techniques (Basheer & Hajmeer, 2000; Chaudhuri & Bhattacharya,

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2000; Guler & Ubeyli, 2005). In recent times there have been widespread interests in the use of multiple models for pattern classification and regression in statistics and neural network communities. The crucial idea underlying these methods is the application of a so-called divide-and-conquer principle that is frequently used to deal with a complex problem by dividing it into simpler problems whose solutions can be combined to yield a final solution. Utilizing this principle, Jacobs, Jordan, Nowlan, and Hinton (1991) proposed a modular neural network architecture called mixture of experts (ME). The ME network contains a population of simple linear classifiers (the "experts") whose outputs are mixed by a "gating" network. During learning, the experts compete to classify each input training pattern, and the gating network directs more error information (feedback) to the expert that performs best. Eventually, the gating network learns to partition the input space such that expert 1 "specializes" in one area of the space, expert 2 specializes in another area of the space, and so on. As pointed out by Jordan and Jacobs (1994), the gating network performs a typical multi-class classification task. Moreover, Expectation–Maximization (EM) algorithm have been applied to the ME architecture so that the learning process is decoupled in a manner that fits well with the modular structure (Dempster, Laird, & Rubin, 1977; Jordan & Jacobs, 1994). The favorable properties of the EM algorithm have been shown by theoretical analyses (Chen, Xu, & Chi, 1999; Jordan & Xu, 1995; Xu & Jordan, 1996).

The EM algorithm can be extended to provide an effective training mechanism for the MEs based on a Gaussian probability assumption. Although originally the model structure is predetermined and the training algorithm is based on the Gaussian probability assumption for each expert model output, the ME framework is a powerful concept that can be extended to a wide variety of applications including medical diagnostic decision support system applications due to numerous inherent advantages (Chen et al., 1999; Guler & Ubeyli, 2005; Hong & Harris, 2002; Jordan & Jacobs, 1994; Mangiameli & West, 1999).

Until now, there is no study in the literature related to the estimation of ME accuracy in analysis of EEG signals. In this study, a new approach based on ME was presented for epileptic seizure detection. The ME network was used to detect epileptic seizure when statistical features of discrete wavelet transform (DWT) sub-band frequencies were used as inputs. In the configuration of ME for the detection of epileptic seizure, we used two local experts and a gating network, which were in the form of multi-layer perceptron neural networks (MLPNNs), since there were two possible outcomes of the detection of epileptic seizure (epileptic or not). We were able to achieve considerable enhancement in accuracy by applying ME with EM algorithm compared to the stand-alone neural networks. Finally, some conclusions were drawn regarding the impacts of features on epileptic seizure detection.

2. Materials and method

2.1. Data selection and recording

We used the publicly available data described in Andrzejak et al. (2001). In this section, we restrict ourselves to only a short description and refer to Andrzejak et al. (2001) for further details. The complete data set consists of five sets (denoted A–E) each containing 100 single-channel EEG segments. These segments were selected and cut out from continuous multi-channel 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 that were carried out on five healthy volunteers using a standardized electrode placement scheme (Fig. 1). Volunteers were relaxed in an awake state with eyes open (A) and eyes closed (B), respectively. Sets C, D, and E originated from EEG archive of presurgical diagnosis. EEGs from five patients were selected, all of whom had achieved complete seizure control after resection of one of the hippocampal formations, which was therefore correctly diagnosed to be the epileptogenic zone. Segments in set D were recorded from within the epileptogenic zone, and those in set C from the hippocampal formation of the opposite hemisphere of the brain. While sets C and D contained only activity measured during seizure free intervals, set E only contained seizure activity. Here segments were selected from all recording sites exhibiting ictal activity. All EEG signals were recorded with the same 128-channel amplifier system, using an average common reference. The data were digitized at 173.61 samples per second using 12 bit resolution. Band-pass filter settings were 0.53–40 Hz (12 dB/oct). In this study, we used two dataset (A and E) of the complete dataset. Typical EEGs are depicted in Fig. 2.

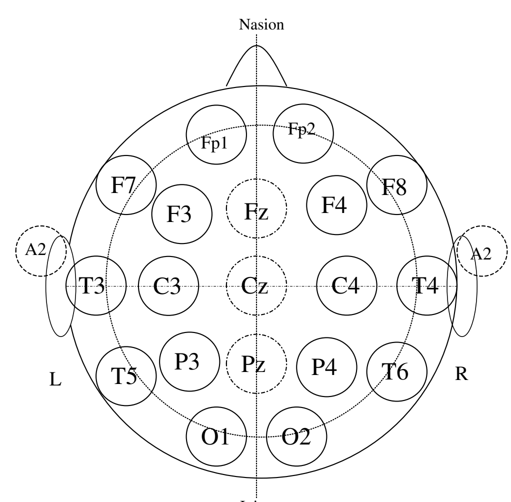

Fig. 1. The 10–20 international system of electrode placement.