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Original Research Article

Electroencephalography (EEG) signal processing for epilepsy and autism spectrum disorder diagnosis

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ABSTRACT

Quantification of abnormality in brain signals may reveal brain conditions and pathologies. In this study, we investigate different electroencephalography (EEG) feature extraction and classification techniques to assist in the diagnosis of both epilepsy and autism spectrum disorder (ASD). First, the EEG signal is pre-processed to remove major artifacts before being decomposed into several EEG sub-bands using a discrete-wavelet-transform (DWT). Two nonlinear methods were studied, namely, Shannon entropy and largest Lyapunov exponent, which measure complexity and chaoticity in the EEG recording, in addition to the two conventional methods (namely, standard deviation and band power). We also study the use of a cross-correlation approach to measure synchronization between EEG channels, which may reveal abnormality in communication between brain regions. The extracted features are then classified using several classification methods. Different EEG datasets are used to verify the proposed design exploration techniques: the University of Bonn dataset, the MIT dataset, the King Abdulaziz University dataset, and our own EEG recordings (46 subjects). The combination of DWT, Shannon entropy, and *k*-nearest neighbor (KNN) techniques produces the most promising classification result, with an overall accuracy of up to 94.6% for the three-class (multi-channel) classification problem. The proposed method obtained better classification accuracy compared to the existing methods and tested using larger and more comprehensive EEG dataset.

The proposed method could potentially be used to assist epilepsy and ASD diagnosis therefore improving the speed and the accuracy.

1. Introduction

Computer-based systems have many applications in the medical field, such as for electronic health records (EHR) systems, hospital information systems (HISs), and computer-aided diagnosis (CAD) systems. Computer system can be used by medical doctors to diagnose certain disorders by automatically analyzing medical images [1] or physiological signals recorded from patients, such electroencephalography (EEG) signals [2]. Medical diagnosis is often a challenging task that requires deliberate effort and expertise from medical experts.

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With advances and developments in signal processing and machine learning methods, computer-based systems have become able to perform more sophisticated tasks, including EEG signal analysis. These automatic mechanisms would ultimately save time and improve global diagnosis accuracy.

Analyzing abnormality in brain signals may provide a clue to brain conditions and pathologies. EEG, which captures signals from the human brain, has great potential to be used for brain activity and condition analysis. EEG recordings have been used for a long time as a diagnostic tool for epilepsy [3]; recently, researchers have utilized EEG for autism spectrum disorder (ASD) diagnosis purposes [4]. Alzheimer's [5] and other neurological disorders are among targets of EEG-based analysis applications. Despite their low spatial resolution, EEG recordings have several advantages such as high temporal resolution, simplicity, lower costs, and wider availability.

In this paper, we investigate different feature extraction and EEG classification techniques for assisting epilepsy and autism spectrum disorder (ASD) diagnosis. After applying the pre-processing step, the discrete wavelet transform (DWT) and cross correlation approaches are used to extract features from the EEG signals. We combine DWT with several functions, including standard deviation (SD), band power (BP), Shannon entropy (SE), and largest Lyapunov exponent (LLE). We also compare different classification methods including artificial neural networks (ANNs), *k*-nearest neighbor (KNN), support vector machine (SVM), and linear discriminant analysis (LDA). The remainder of this paper is organized as follows. Section 2 describes the proposed methods, including feature extraction and classification techniques. Section 3 provides a description of the EEG data used during our experiments, the classification problem formulation, and the performance evaluation. Results and discussion are presented in Section 4. Section 5 provides our main conclusions and highlights of future research directions.

2. Methods

To build a CAD system for medical pathology diagnosis, we follow the four main steps depicted in Fig. 1, namely, acquisition of brain activities, pre-processing of EEG recordings, feature extraction, and classification. The acquired EEG signal is treated using a pre-processing block to remove any noise in brain patterns. An elliptic band-pass filter is used to efficiently limit the signals to a frequency between 0.5 and 60 Hz. We also investigated the different feature extraction and classification methods shown in the figure. We used the DWT and cross-correlation (measuring synchronization between EEG channels) to extract features from the EEG segment. For classification, we implemented ANN, KNN, SVM, and LDA.

Table 1 – Frequency bands for each wavelet coefficients.

Wavelet coefficients	Frequency (Hz)	EEG bands
D_3	32–64	Gamma
D_4	16–32	Beta
D_5	8–16	Alpha
D_6	4–8	Theta
A_6	0–4	Delta

DWT is able to capture small changes in the EEG signal by representing the signal in multi-scale time-frequency domains in terms of approximate (A_x) and detail (D_x) coefficients. In this work, we used six-level decomposition based on the Daubechies 4 (Db4) wavelet, which is commonly used for EEG analysis [6]. Only the D_3, D_4, D_5, D_6, and A_6 coefficients are used for feature extraction to represent the EEG sub-bands in the 0- to 32-Hz spectrum range. As shown in Table 1, these wavelet coefficients correspond to several EEG sub-bands, namely, delta (1–4 Hz), theta (4–8 Hz), alpha (8–15 Hz), beta (15–30 Hz), and gamma (30–60 Hz). More details regarding DWT and brain pattern rhythms are presented in [7]. Fig. 2 shows an example of the EEG signal and its DWT outputs (different labeled EEG sub-bands). EEG sub-bands with higher frequency, i.e., beta and gamma, have lower magnitude or power than lower frequency sub-bands, i.e., delta, theta and alpha.

We propose combining the discrete wavelet transform (DWT) with several statistical functions to build more efficient feature vectors. In fact, DWT can be associated with SD, BP, SE, and LLE. For a discrete time series of data $S[n]=[s_1\, s_2 \ldots s_N]$ with a length N, the standard deviation is calculated as follows:

$$SD = \sqrt{\frac{1}{N}\sum_{n=1}^{N}(s_n-\mu)^2} \qquad (1)$$

where μ is the mean of the discrete data.

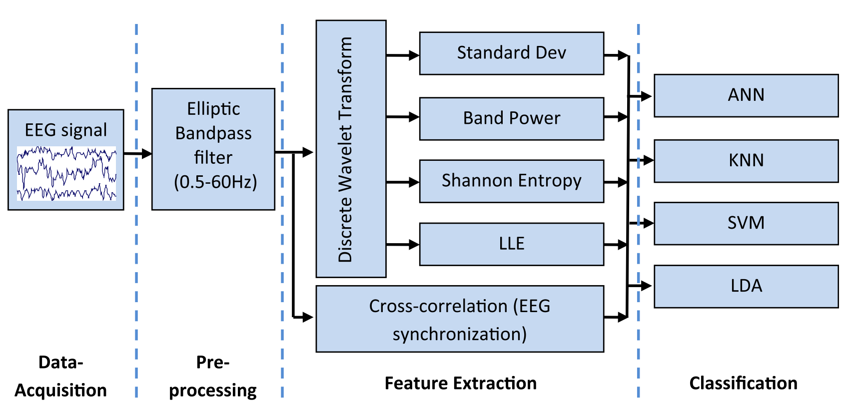

Fig. 1 – Generic block diagram of CAD system for medical pathology diagnosis.