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A decision support system for automated diagnosis of Parkinson's disease from EEG using FAWT and entropy features

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Highlights

- Proposed methodology is based on flexible analytic wavelet transform (FAWT) for detection of Parkinson’s disease where EEG data is collected from two different centers.
- The ninteen entropy-based features are extracted from sub-bands obtained after FAWT.
- Relevant features are ranked using analysis of variance (ANOVA) to achieve accurate classification of Parkinson’s disease using k-nearest neighbor classifier.
- The effectiveness of proposed approach is evaluated accurately in real-time with optimum computation time.

Abstract

Parkinson's disease (PD), a neurodegenerative disorder characterized by rest tremors, muscular rigidity, and bradykinesia, has become a global health concern. Currently, a neurologist determines the diagnosis of Parkinson's disease by taking into account several factors. An automated decision-making system would enhance patient care and improve the outcomes for the patient. Biomarkers, such as electroencephalograms (EEGs), can aid in the diagnosis process as they have proven useful in detecting abnormalities in the brain. This study presents a novel algorithm for the automated diagnosis of Parkinson's disease from EEG signals using a flexible analytic wavelet transform (FAWT). First, these acquired EEG signals are preprocessed before decomposition into five frequency sub-bands based on the FAWT method. Several entropy parameters are computed from the decomposed sub-bands and ranked based on their significance level in detecting PD through analysis of variance (ANOVA). Various classifiers are used to identify appropriate feature sets, including support vector machines (SVM), logistics, random forests (RF), radial basis functions (RBF), and k-nearest neighbors (KNN). The proposed approach is evaluated using data collected from two centers in Malaysia (Dataset-I) and the United States (Dataset-II). In dataset-I, the KNN classifier produces accuracy, specificity, sensitivity, and area under the curve of 99%, 99.45%, 99.12%, and 0.991, respectively, while in dataset-II, these values are 95.85%, 95.88%, 96.14%, and 0.959. The proposed system would be extremely useful for neurologists during their diagnostic process, as well as for current clinical practices.

Introduction

Parkinson's disease (PD) is a devastating neurological disorder which arises due to the low level of a chemical neurotransmitter called dopamine resulting from the loss of dopaminergic neurons [1], [2]. It is estimated that there exist more than 10 million people with PD around the world and in India, its prevalence is approximately 10% of the global burden [3], [4]. The cardinal signs of PD are bradykinesia, muscle stiffness, speech alteration, tremor, and loss of balance. In addition to these motor symptoms, there are also non-motor symptoms associated with this disease [5], [6], [7], [8]. In current clinical settings, there is no specific medical approach exists for diagnosing Parkinson's disease. A neurologist usually performs multiple tests (e.g. dopamine transporter scan, computerized tomography, and magnetic resonance imaging) before deciding on the diagnosis. However, the diagnosis becomes more difficult when patients exhibit no significant motor or non-motor signs.

Researchers utilized various physiological signals such as speech, gestures (gait), and accelerometer (tremor) to detect PD [9]. Tuncer et al. [10] extracted 122 acoustic parameters using singular value decomposition technique with minimum average maximum tree concept. They achieved an accuracy of 92.46% using KNN classifier with vowels. Similarly, to characterize Parkinson's speech, an intrinsic mode function cepstral coefficient feature was used by Karan et al. [11] to classify healthy controls (HC) from PD patients. In addition, Sigcha et al. [12] used recurrent neural network (RNN) with a single waist-worn triaxial accelerometer approach to detect freezing of gait in PD patients. For the diagnosis of PD patients using handwritten tasks, Adams et al. [13] analyzed characteristics of hand and finger movement using keystroke timing information with ensemble machine learning classifiers.

Recently, EEG has been used as a potential diagnostic tool for different types of neurological disorders. Among all these above-mentioned candidates i.e., EEG, speech, gait, and handwritten, EEG is considered as suitable method due to its excellent temporal resolution, ease to use, and direct link to neurotransmission. On the other hand, the neurodegenerative disease decreases the connectivity of the brain network which directly influences the electrical potentials that are collected by the EEG electrodes [3]. PD lowers the dopamine level inside the brain, which in turn affects the synapse potentials of the neurons. The EEG signal recorded via scalp electrodes is the combination of the electrical potential of large clusters of neurons which makes it appropriate as a biomarker for PD diagnosis.

Many research studies have been conducted to propose an automated PD diagnosis method based on EEG signals [14], [15]. In this context, the research community has started utilizing wavelet transform and a deep learning approach using EEG signals to diagnose the disease. The dyadic wavelet transforms (DyWT) [16], [17] and its various improved methods [18], [19] were proposed for the detection of PD patients. In [18], automated tunable Q wavelet transform (TQWT) was used to classify PD patients from HC with ON medication and OFF medication, respectively. Another approach using the wavelet packet entropy and AR Burg method to investigate EEG signal abnormalities in PD patients in the frequency domain was studied by Han et al. [19]. Furthermore, Yuvaraj et al. [3] demonstrated a technique to diagnose PD using higher-order spectral analysis (HOSA) with PD diagnosis index values. In the approach of moving towards deep learning, Oh et al. [20] proposed thirteen-layer convolutional neural network for PD detection among healthy individuals. Moreover, Ruffini et al. [21] evaluated spectrograms acquired using fast Fourier transform and classified with five layers deep convolutional neural network.

However, these wavelet transforms (DyWT, TQWT) suffer from poor frequency resolution and shift-invariance at high-frequency characteristics with constant time–frequency coverage at all scales. In addition, to preserve consistency in extracted features, the optimum selection of mother wavelet is required in these transforms [22], [23]. So, there exists an imperative need for a technique that overcomes these limitations by studying significant descriptive features for HC and PD patients. Moreover, the acquired EEG signals are non-stationary, complex, and non-linear in nature, thus entropy measures are considered as effective features to quantify the dynamical changes in these signals [24], [25]. Therefore, this present work investigates the use of flexible analytic wavelet transform (FAWT), which provides a flexible time–frequency windowing base with valuable shift-invariance properties for identifying Parkinson's disease patients using multichannel EEG signals. Due to these characteristics, FAWT provides an accurate way of detecting transient intervals and obtaining information content contained within the signals, which facilitates the analysis of non-stationary EEG signals efficiently [23], [26], [27]. FAWT has been successfully used in signal processing for the analysis of biomedical signals such as driver fatigue [27], epilepsy [23], [28], atrial fibrillation [29], diabetic retinopathy, and diabetic macular edema [30], etc.

Therefore, a major contribution of the current framework is to provide accurate identification of PD patients among healthy controls using time–frequency analysis of EEG signals through FAWT and entropy-based features. In addition, the contributions of the present work are summarized as follows:

- This work proposes the method for automated PD diagnosis system using FAWT technique with optimum selection of input parameters to accurately handle non-stationary nature of EEG signals.

- It analyzes the dynamic variations of EEG signals using nineteen distinct entropy features to provide robust and computationally efficient framework.
- Afterwards, to obtain accurate and prompt classification with high diagnosis rate for PD, significant features are selected using ANOVA from the extracted entropy features of FAWT based sub-bands.
- Finally, it concludes the appropriateness of proposed KNN classifier fed with FAWT and entropy-based features which emerge as an efficient approach with optimal computational time to ensure its suitability for real-time usage.

The structure of the rest of this paper is framed into different sections. We describe the clinical scalp EEG datasets in Section 2.1 and then followed by methodology including preprocessing, signal decomposition, feature extraction methods, feature ranking, and classifiers in Section 2.2. In Section 3, experimental results are presented, while the interpretation of results is discussed in Section 4. The conclusions and ideas for future study are described in Section 5.

Section snippets

Material and methods

This section discusses the various steps which are performed for analysis and detection of Parkinson's patients among healthy controls using multichannel EEG signals. Fig. 1 illustrates the methodology followed in the present study. This flow chart illustrates a collection of clinical raw multichannel EEG signal datasets, preprocessing of the signal using filtering and segmentation, signal decomposition, feature extraction, feature ranking, and classification for the identification of PD.

Experimental results

The present study takes into consideration of two distinctive datasets for the diagnosis of PD patients among healthy controls for execution of the desired task. Implementations related to signal processing and feature extraction are carried out using MATLAB software on a personal computer (PC) with an Intel *i5* processor and Windows 10 operating system.

This system is clocked at 2.60 GHz and has 3GB of RAM. The classifiers are implemented using the Waikato environment for knowledge analysis

Discussion

In this study, a decision support system for automated diagnosis of Parkinson's disease is proposed using FAWT and entropy features from EEG signals. The novelty of the current analysis is in the fact that flexible analytic wavelet transform in integration with different entropy features is employed for detection of PD patients among healthy controls. There are numerous neuroimaging modalities used for detection of PD disease but these techniques are examined under the guidance of experienced

Conclusion

The current study proposes a novel FAWT and entropy features-based approach for the automated diagnosis of Parkinson's disease patients among healthy controls using multichannel EEG signals. Using Database-I, we found a maximum mean accuracy of 99%, a specificity of 99.45%, and a sensitivity of 99.12%. Additionally, for dataset-II based on a uniform sampling rate, an average accuracy of 95.85% was achieved with a sensitivity of 96.14% and a specificity of 95.88%. A computational time of

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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