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Eigenvalue Distribution-Based Approach for EEG Signal Analysis: Noise Removal and Epileptic Seizure Discrimination

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Abstract

This paper presents a novel approach for the analysis of electroencephalography (EEG) signals based on the distribution of eigenvalues of a scaled Hankel matrix. The proposed approach enables the determination of the number of eigenvalues required for noise removal and signal extraction in singular spectrum analysis. It explores the applicability of the approach in discriminating between epileptic seizure and normal EEG signals, extracting attractive patterns, filtering EEG signals, and eliminating noise. Various criteria are utilized as features to distinguish between epileptic and normal EEG segments. The experimental results demonstrate the capability of the approach for effective noise removal in EEG signals and successful discrimination between epileptic and normal segments. This approach offers a promising solution for enhanced EEG signal analysis and has potential applications in neurological disorder diagnosis and treatment.

Keywords: electroencephalography (EEG), singular spectrum analysis (SSA), eigenvalue distribution, noise removal, epileptic seizure discrimination.

I. Introduction

The electroencephalography (EEG) signal is a valuable tool for studying brain function and investigating neurological disorders. It provides insights into the state of various body systems [1] and plays a significant role in the detection and treatment of brain diseases such as epilepsy and brain tumors. Accurate analysis of EEG signals is crucial; however, they are often contaminated by diverse types of noises and artifacts, making noise removal essential for proper analysis [2]. Various methods, such as independent component analysis (ICA), principal component analysis (PCA), and wavelet transform (WT), have been employed for denoising EEG signals [3-9].

EEG signals, particularly during epileptic seizures, exhibit nonlinear and chaotic behavior [10-12]. Differentiating strange attractors in brain signals and detecting epileptic activity are important for diagnosis and treatment [12]. Non-stationarity is a major challenge in EEG analysis, especially during abnormal events [13]. Many existing methods rely on restrictive assumptions of normality and linearity, highlighting the need for robust techniques to analyze non-stationary time series accurately. Singular spectrum analysis (SSA) is a promising technique that does not depend on these assumptions and has been applied successfully in various biomedical applications [14-21].SSA involves analyzing the main series and reconstructing a noise-free series for further analysis. The choice of window length (L) and the number of required eigenvalues (r) for reconstruction are critical. Optimal selection of L and r leads to accurate analysis and separability between time series components. However, there is no universal rule for obtaining optimal values [22]. Previous work proposed an approach based on the distribution of eigenvalues of a scaled Hankel matrix for selecting the value of r in noise reduction, filtering, and signal extraction [23]. This paper extends the approach to discriminate between epileptic seizure and normal EEG signals, filter EEG segments, and eliminate noise.

The remainder of the paper is organized as follows: Section 2 provides a brief description of the proposed approach and its algorithm. Section 3 demonstrates the approach's ability to decompose synthetic data into distinct subspaces. Section 4 presents the implementation of the approach in filtering EEG signals, extracting attractive patterns, and discriminating

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