On Application of Rational Discrete Short Time Fourier Transform in Epileptic Seizure Classification*

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Overview

The so-called electroencephalography (EEG) is the electric potential generated by the neurons that can be measured via electrodes along the human scalp. Due to its high spatial resolution, EEG signals are widely used in diagnosis of neurological disorders such as epilepsy which is characterized by epileptic seizures.

We propose a new time–frequency distribution based on rational functions [1]. It can be considered as a generalization of the short time Fourier transform (STFT). The optimization of the free parameters (i.e. poles) of the rational functions results in compact power spectrum density. It leads to a significant improvement for reconstruction error. The method can successfully be applied for localization of seizures.

Rational Functions

To define rational function systems let us consider a sequence of poles $\mathbf{a} = a_0, \ldots, a_{n-1} \in \mathbb{D}$ and multiplicities $m_0, \ldots, m_n \in \mathbb{N}$ where $\mathbb{D}$ denotes the open unit disk of the complex plane. The corresponding rational function system is:

$$\varphi_{k,i}(z) = \frac{z^{i-1}}{(1-\overline{a}_k z)^i} \qquad (k = 0, \ldots, n-1)\,,$$

where $i = 1, \ldots, m_k$. By orthogonalization we obtain the system Φ_k. Let $\Psi_{k,i}$ stand for the system biorthogonal to $\varphi_{k,i}$. Projections with respect to these systems can be used to approximate functions in the Hardy space $H^2(\mathbb{D})$. The mean square error (MSE) can be minimized by using optimal poles adapted for the individual signal.

Generalized STFT

The nature of epileptic EEG signals is non-stationary and multicomponent. Paper [3] addresses this problem by applying several time-frequency decompositions of the form

$$\mathcal{F}_g f[n,k] = \sum_{m=0}^{M-1} f[n-m]g[m]\epsilon_k[m]\,,$$

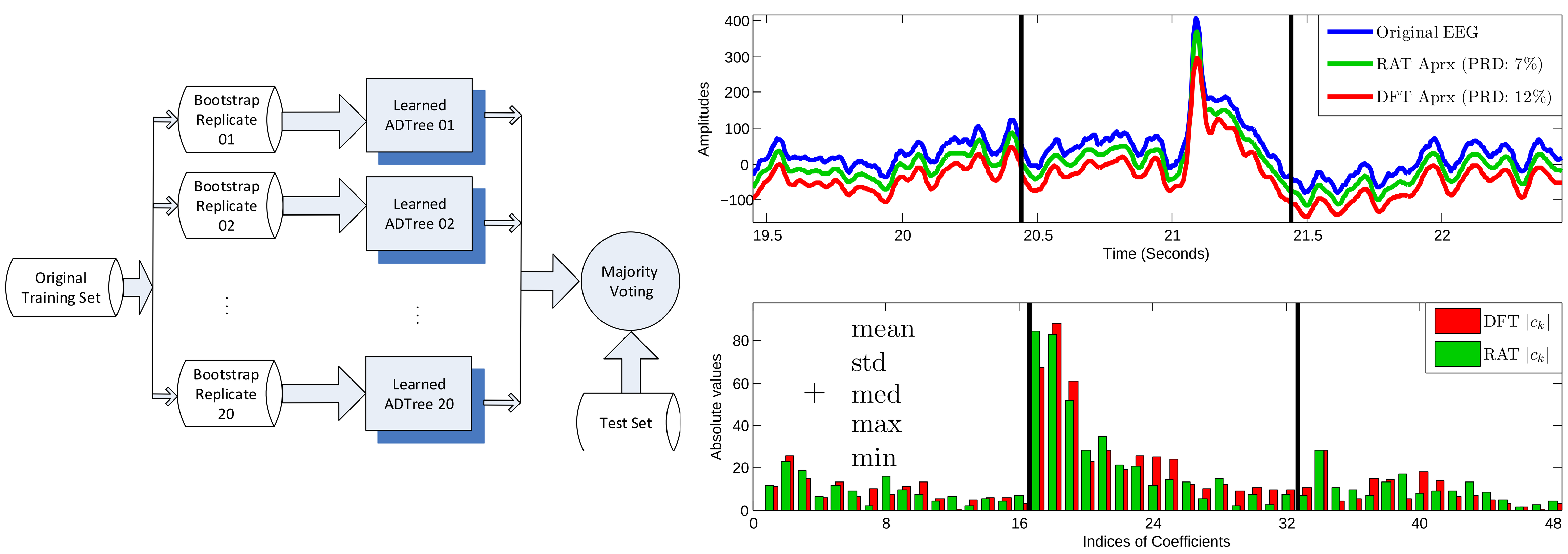
where $\epsilon_k[m] = e^{-2\pi i k \frac{m}{M}}$, M is the window length of g. One can define a similar representation by replacing ϵ_k with Φ_k or $\Psi_{k,i}$. Especially, a single pole a_0 with multiplicity $m_0 = M$, and an $f \in H^2(\mathbb{D}))$ uniformly sampled function are considered. Then the generalized rational STFT can be written as

$$\mathcal{R}_\phi \mathcal{F}_g f[n,k] = \sum_{m=0}^{M-1} f[n-m]g[m]\phi_k[m]\,,$$

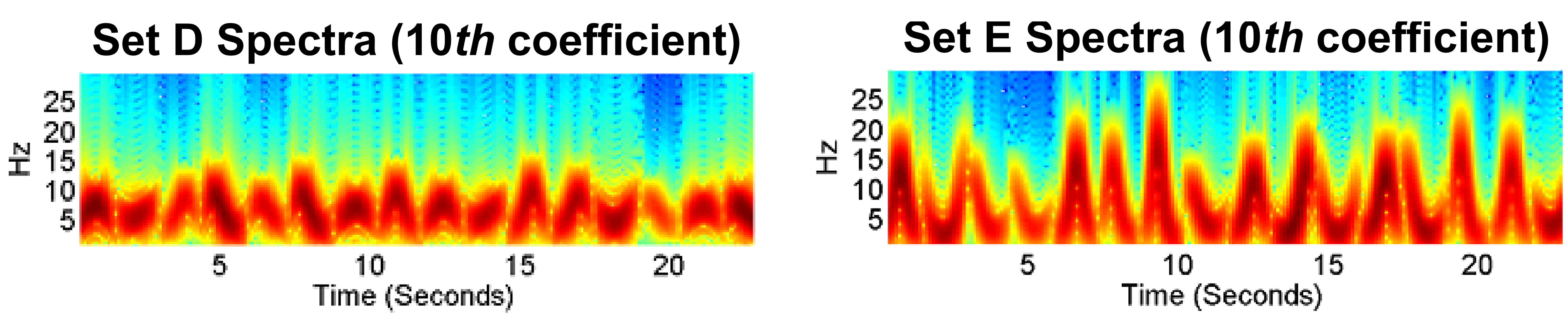
where $\phi_k[m] = \Phi_k(e^{-2\pi i \frac{m}{M}})$. We note $\psi_k[m] = \Psi_{0,k+1}(e^{-2\pi i \frac{m}{M}})$ or $\varphi_k[m] = \varphi_{0,k+1}(e^{-2\pi i \frac{m}{M}})$ can also be used.

Feature Extraction and Optimization

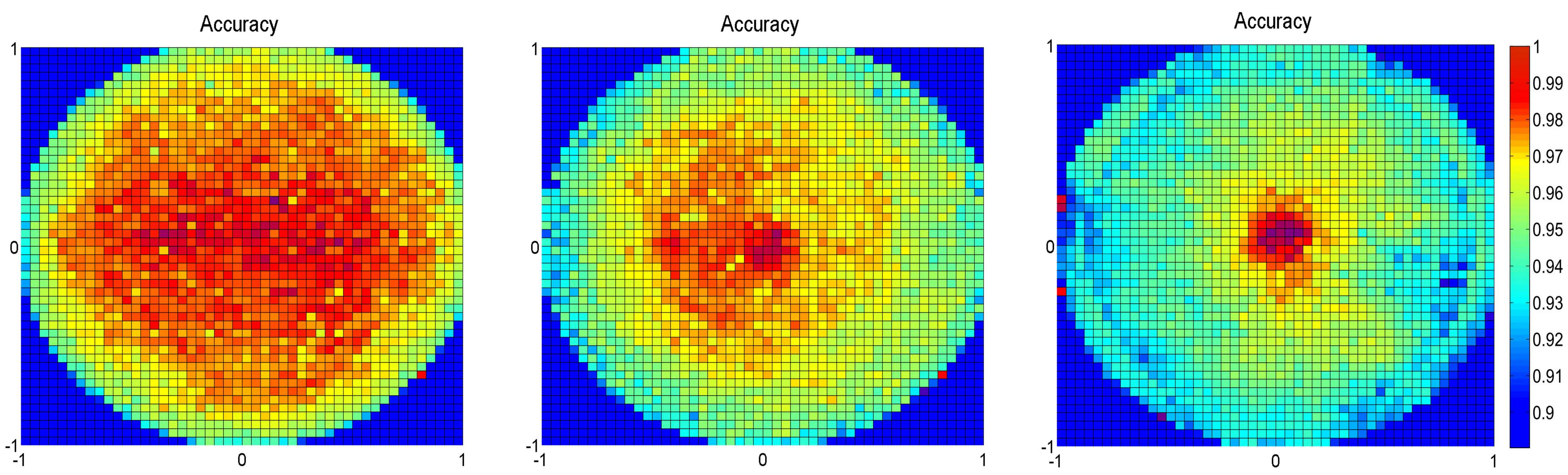
Feature extraction works with one pole specified via hyperbolic optimization [2] for each 1 second long EEG segment. 16 coefficients of the rational STFT and their statistical values are taken. Finally, these 21 features are classified as seizure or non-seizure using bagged ADTrees.



Extracting features for a 3 seconds long segment of the record *D003*.



Spectrograms of sets E and D using the 10*th* coefficient of the rational function Φ .



Classification results obtained by rational systems Φ, φ, Ψ for each pole.

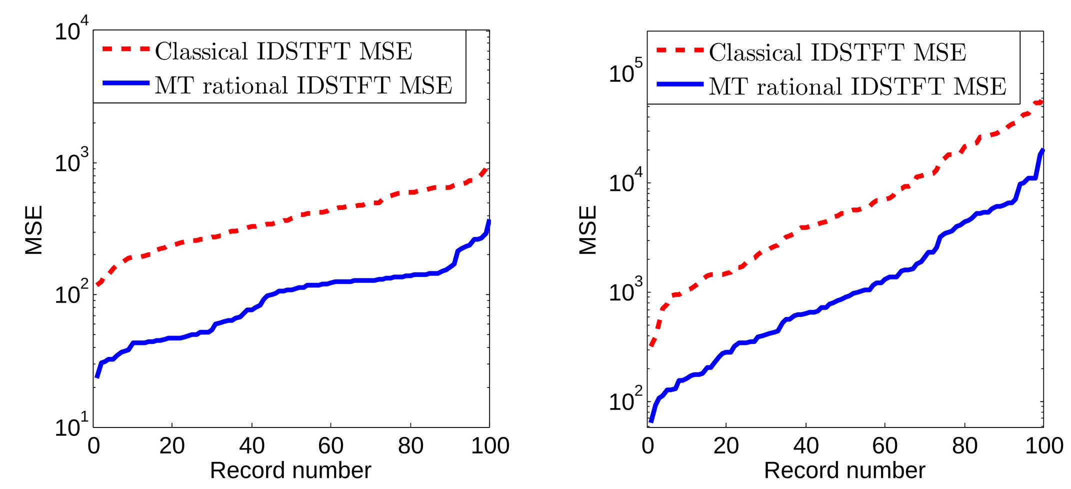
Classification

Our method was tested on the Bonn dataset which contains five sets (A-E) with 100 single channel EEG records. Sets (A) and (B) represent healthy signals with open and closed eyes. In sets (C) and (D), segments contain inter-ictal intervals while seizure activities occur only in set (E). The focus of this work was seizure classification in the presence of seizure-free segments.

Classification results with optimization.

System	Classification Problem (%)		
	E-A	E-A, C	E-A, B, C, D
ϵ	**99.7**	98.2	95.6
Φ	**99.7**	**98.6**	**96.7**
Ψ	97.6	94.8	93.1
φ	99.1	97.3	96.3

Mean Square Errors for sets (B) and (E).



References

[1] S. Fridli, L. Lócsi, and F. Schipp, "Rational function system in ECG processing," in *Computer Aided Systems Theory, LNCS*, 2011.

[2] P. Kovács, S. Kiranyaz, and M. Gabbouj, "Hyperbolic particle swarm optimization with application in rational identification," in *Proceedings of the 21st EUSIPCO*, 2013.

[3] A. T. Tzallas et al., "Epileptic seizure detection in EEG using time-frequency analysis," *IEEE Trans. Inform. Technol. Biomed.*, 2009.

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