EEG Signal Description with Spectral-Envelope-Based Speech Recognition Features for Detection of Neonatal Seizures

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Abstract

- Study of different types of signal features in application for seizure detection
- Feature ranking/selection using SVM and Recursive Feature Elimination
- Spectral envelope-based features used in ASR can provide almost the performance of the original EEG spectral features

Outline

1. EEG data set of 17 patients
2. SVM-based seizure detection system
3. Standard EEG spectral features
4. Spectral envelope-based features
5. Feature performance evaluation and analysis

EEG data set of 17 patients

The dataset

- Composed of EEG recordings from 17 newborns obtained from the neonatal intensive care unit
- All seizures were annotated independently by 2 neonatal electro-encephalographers with the assistance of simultaneous video recordings
- Contains a wide variety of seizure types including both electrographic-only and electro-clinical seizures of focal, multifocal, and generalized types

The dataset

- Multichannel EEG at 256 Hz using 10–20 electrodes

- Combined length of the recordings = 267.9 h
- Contains 705 seizures

- EEG recordings were not edited to remove the large variety of artifacts and poorly conditioned signals (commonly encountered in EEG)

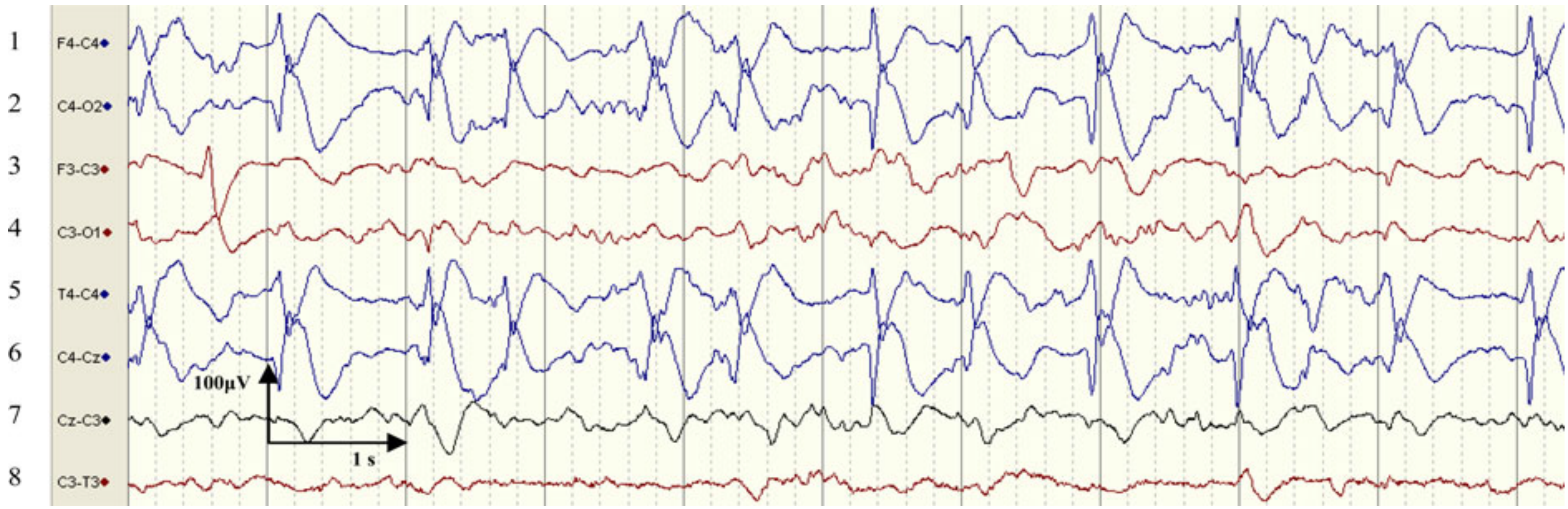
SVM-based seizure detection system

Neonatal Seizure Detection System

- Will talk about the features later on
- On average 4 channels are involved in a seizure
- Data annotated in per-channel basis using 2 min windows

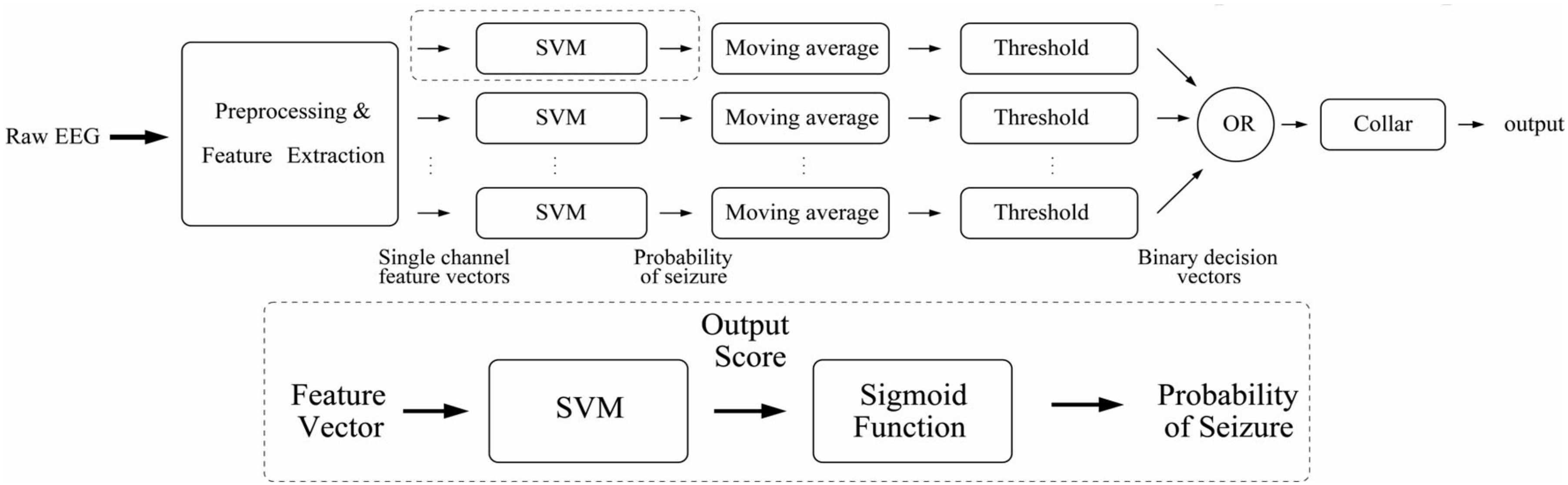
Example of a neonatal seizure

a focal seizure localized in the channels 1, 2, 5, 6



Neonatal Seizure Detection System

- Epoch length of 8 s with an overlap of 4 s
- The normalized features extracted from each epoch were used to train a single SVM classifier (with Gaussian kernel) per a channel



Standard EEG spectral features

Features extracted for each epoch

- A set of 55 features (baseline) extracted from the frequency and time domains

- Types of features:

1. Frequency
2. Energetic
3. Structural information (information theory)

Features extracted for each epoch

1. Frequency

   - Total power (0-12Hz), - Peak frequency of spectrum, - Spectral edge frequency (SEF80%, SEF90%, SEF95%), - Power in 2Hz width subbands (0-2Hz, 1-3Hz, ...10-12Hz), - Normalised power in same subbands, - Wavelet energy (Db4 wavelet coefficient corresponding to 1-2Hz)

2. Energetic

   Baseline (55)

   - Curve length, - Number of maxima and minima, - Root mean square amplitude, - Hjorth parameters (activity, mobility and complexity), - Zero Crossing Rate (ZCR), - ZCR of the Δ and the ΔΔ, - Variance of Δ and ΔΔ, - Autoregressive modelling error (AR model order 1-9), - Skewness, - Kurtosis, - Nonlinear energy

3. Structural information (information theory)

   - Shannon entropy, - Spectral entropy, - Singular Value Decomposition entropy, - Fisher information

Spectral envelope-based features

6 spectral envelope feature sets

linFBE	15 subband energies (0-2Hz, 1-3Hz, …)
relFBE	15 subband energies normalised by total energy
logFBE	15 logarithmically scaled subband energies
CC	15 cepstral coefficients
FF	15 second order frequency filtered bank energies
RSD	15 relative spectral difference

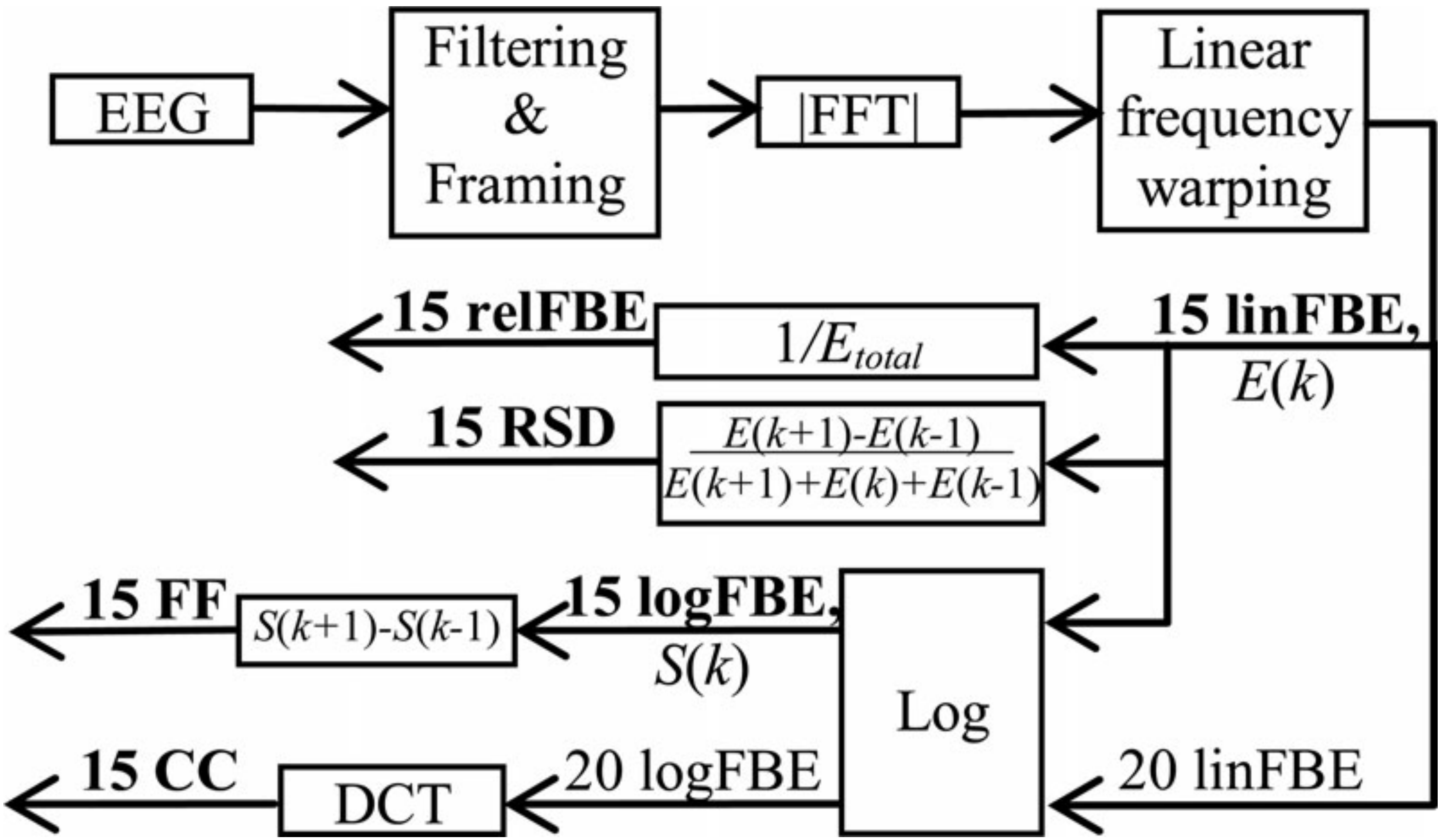
Filter-bank energies (FBE)

- linFBE:
  - The spectrum is linearly smoothed using 15 triangular windows, with an overlap of 50%
  - Linear non-normalized powers are computed

- relFBE:
  - These are linFBE energies normalized by the total power

- logFBE:
  - Log of linFBE
  - The basic features considered in speech and speaker recognition

Calculation of spectral envelope features



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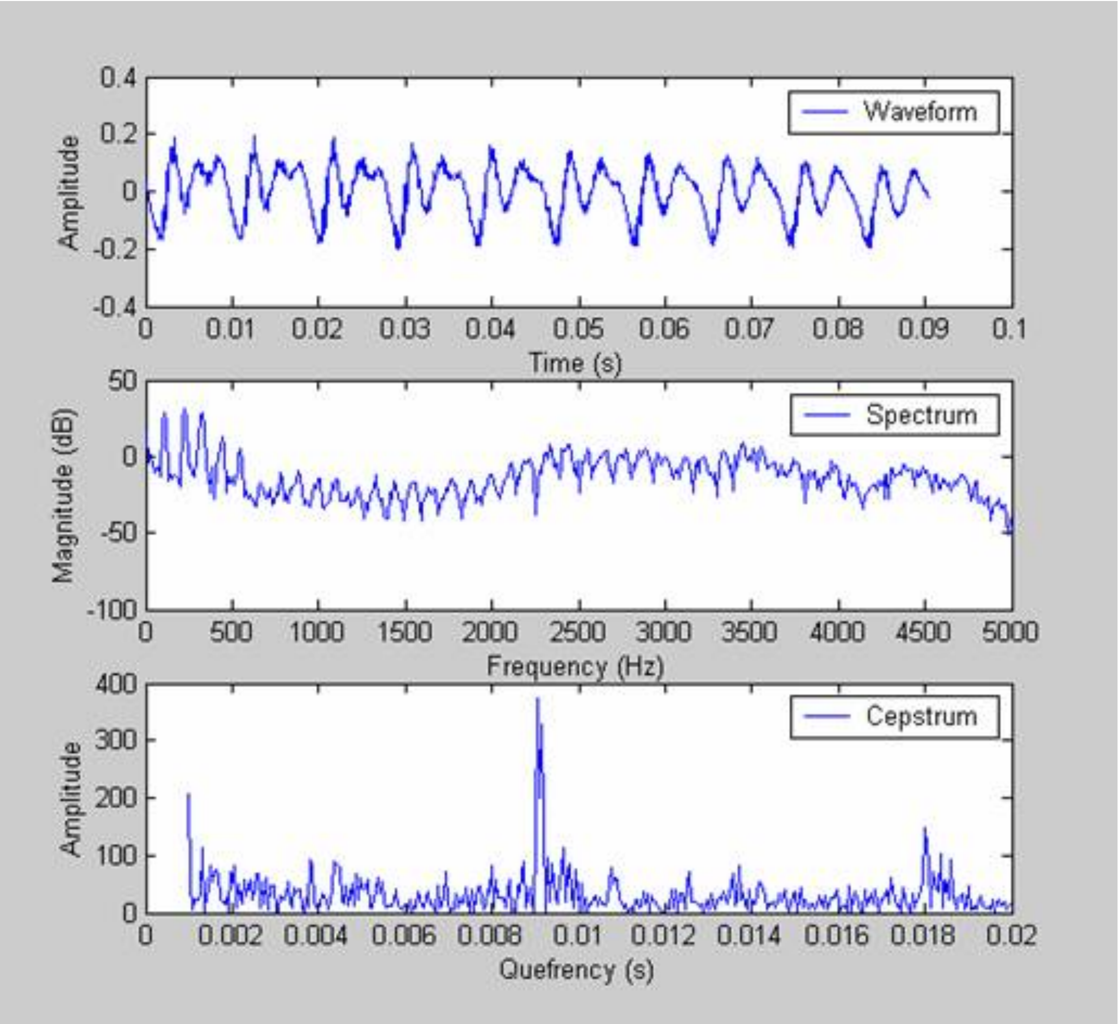
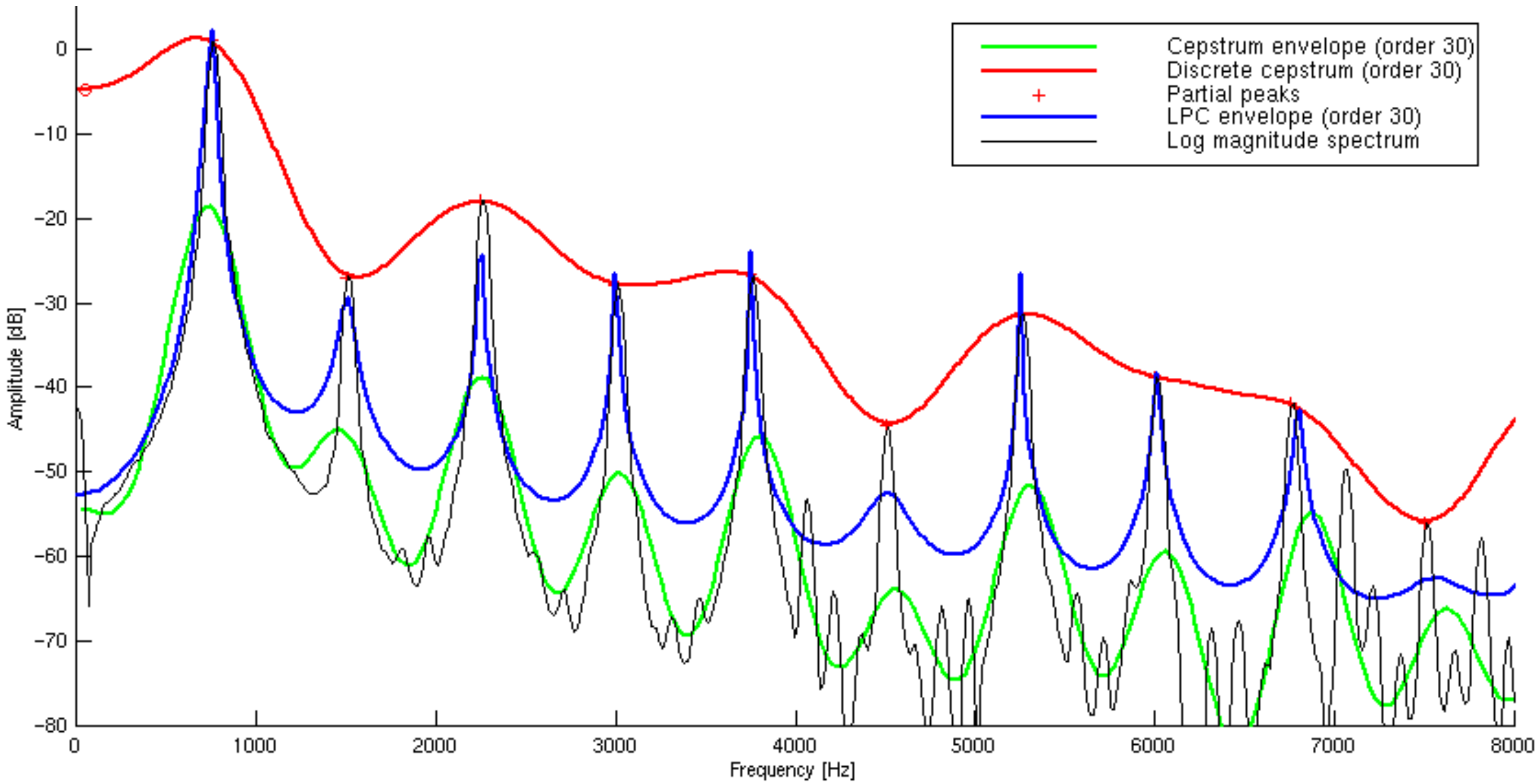
Spectrum and Cepstrum



Spectral envelope and Cepstrum



Cepstral coefficients (CC)

- Calculated by applying the discrete cosine transform (DCT) to the log-magnitude Fourier spectrum
- DCT is almost equivalent to principal component analysis
- DCT also sorts the transformed coefficients in order of increasing variance
- All the CC except the 0th one can be seen as combinations of spectral slopes that provide information about the rate of change in the spectrum across bands
- All subbands are involved in CC computation, so they are not localized in a particular frequency

Frequency-filtered band energies (FF)

- Spectral derivatives in the continuous frequency domain can be replaced by differences in values at discrete frequencies
- This derivative-type filter implies the subtraction of the logFBE of the two bands adjacent to the frequency band of interest.
- FF parameters are localized in frequency as they are obtained with explicit frequency filtering. They still lie in the frequency domain and preserve a frequency meaning.

$$FF(k) = \log E(k + 1) - \log E(k - 1)$$

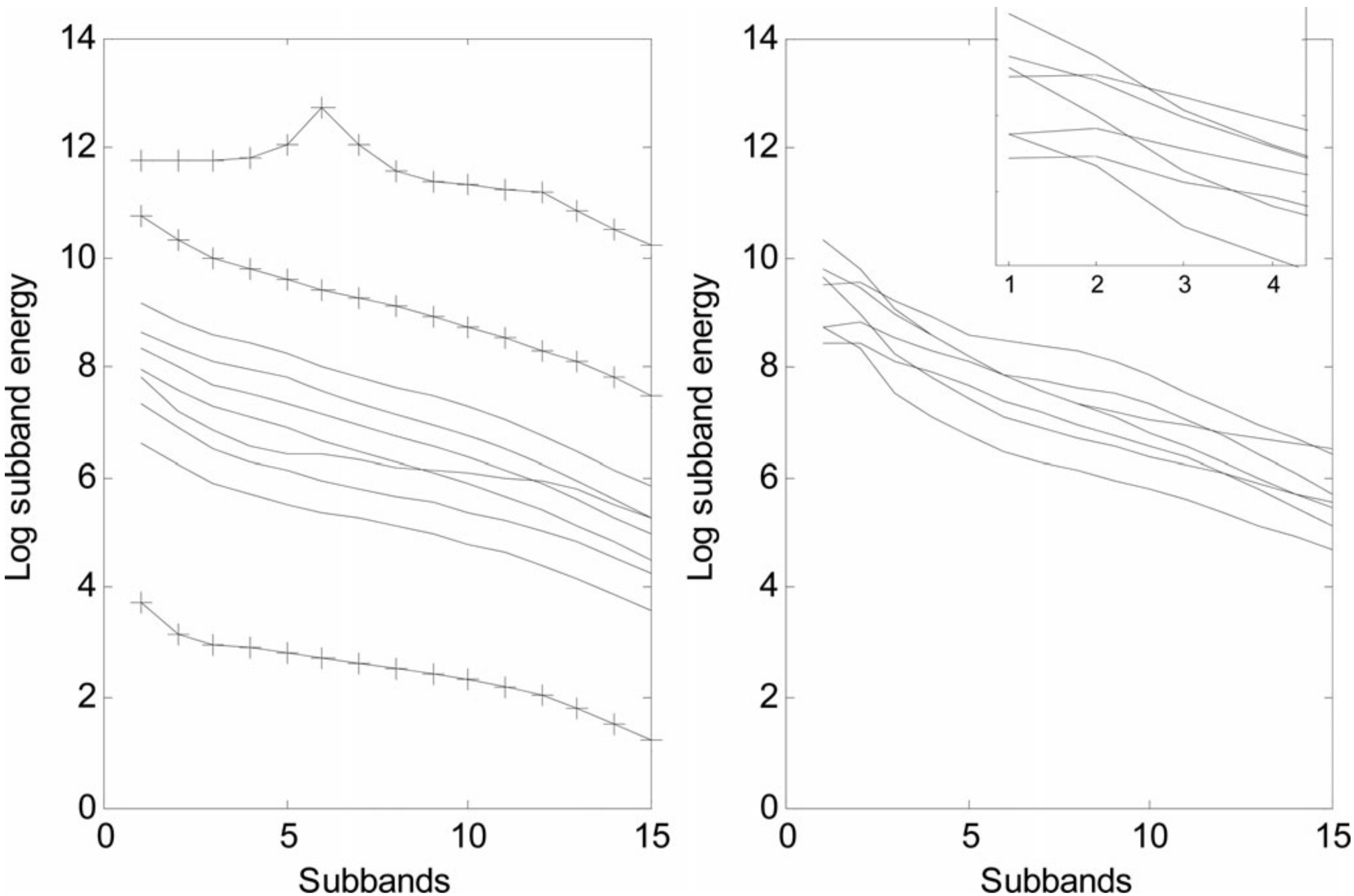
- where $E(\omega)$ is the spectral envelope of the current EEG epoch and k is the frequency sub-band index

Relative spectral difference (RSD)

$$\mathrm{RSD}\,(k) = \frac{E(k+1) - E(k-1)}{E(k+1) + E(k) + E(k-1)}$$

- smoothing is introduced in the denominator
- RSD parameters can be seen as an alternative to the FF parameters, which avoids the computation of the logarithm

Cluster centers of the log spectra for **non-seizure** and **seizure** classes

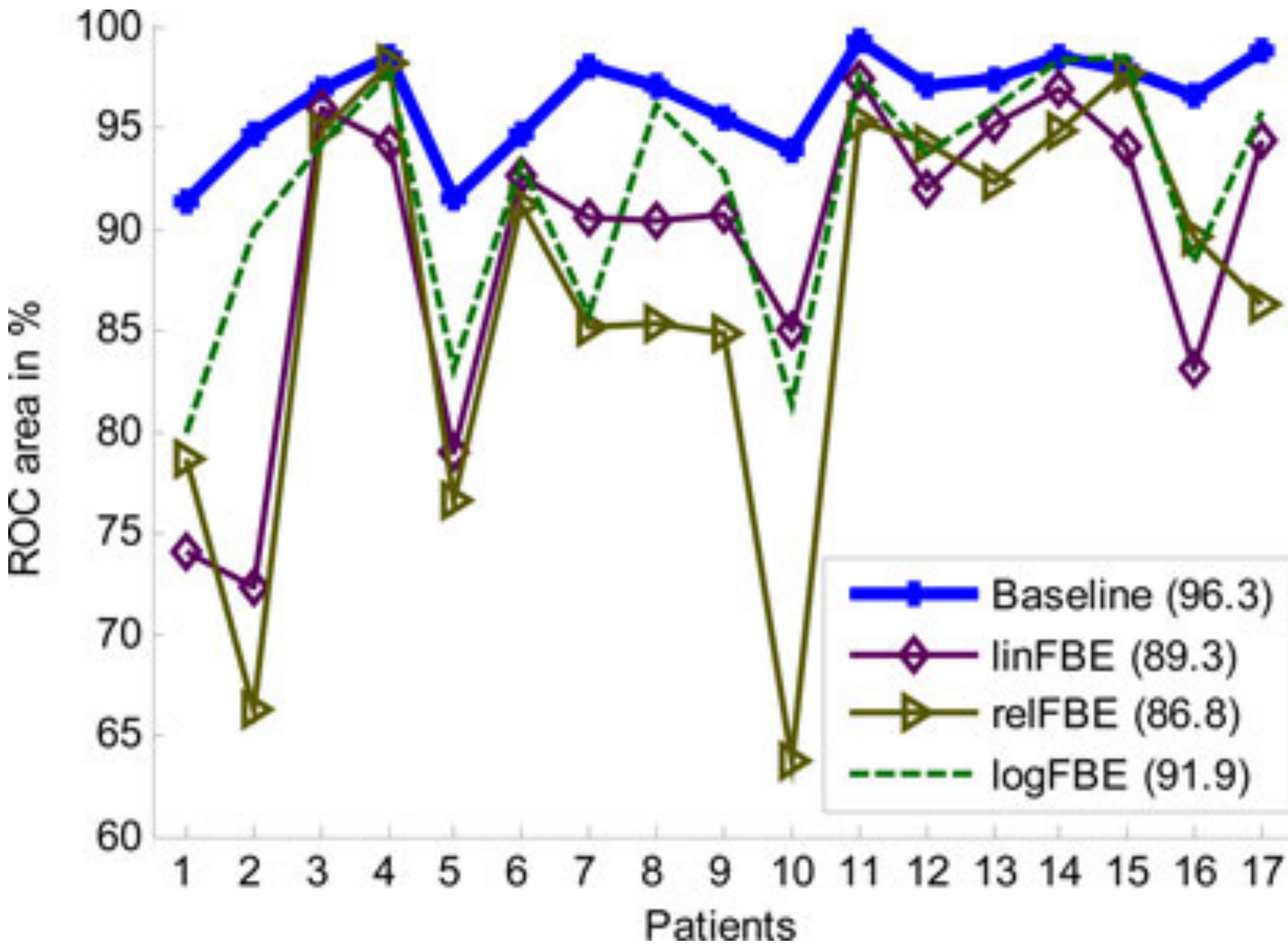


Feature performance evaluation and analysis

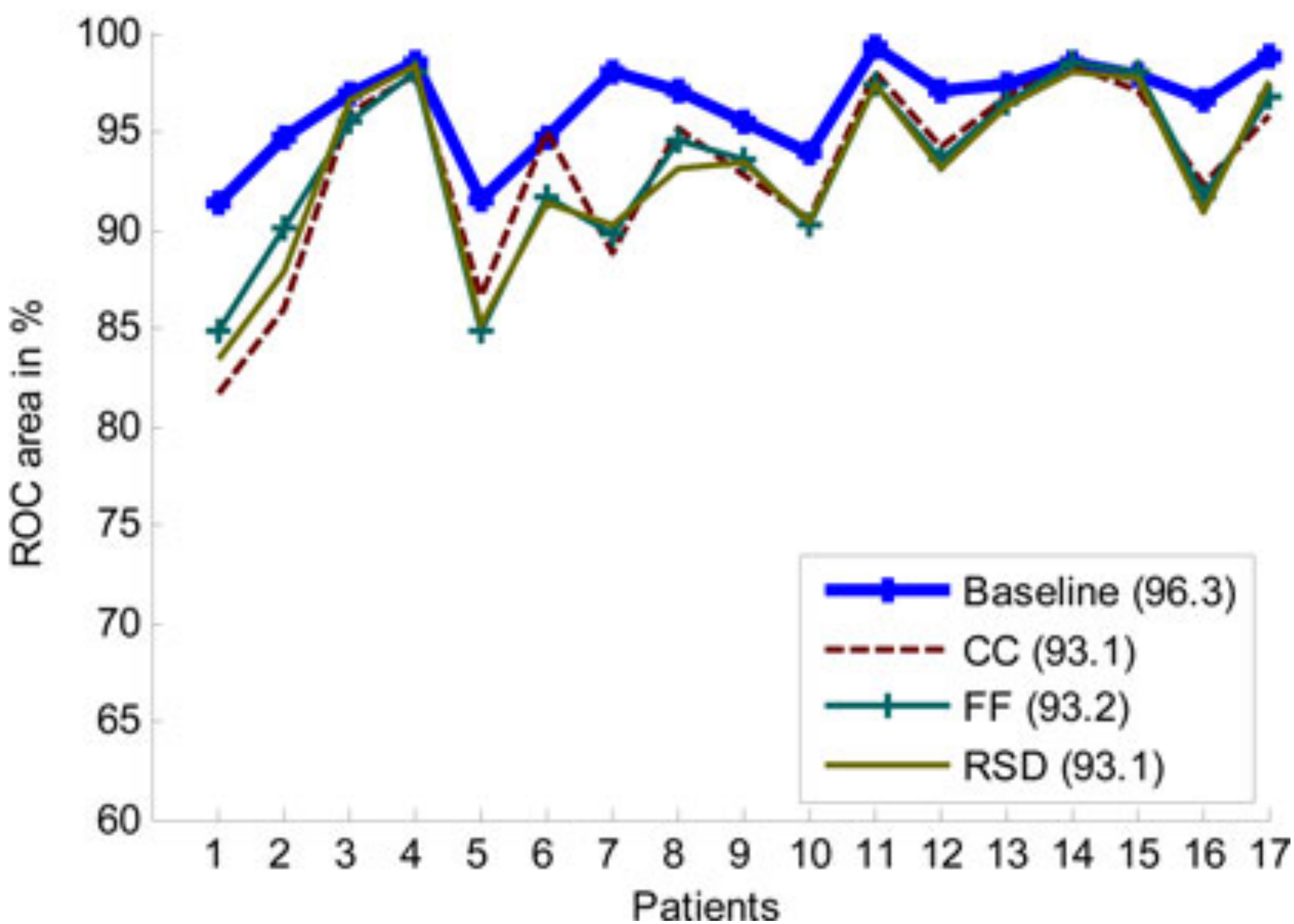
Performance Assessment and Metrics

- Leave-one out (LOO) cross-validation
- Average area under the ROC (sensitivity vs. specificity curve)

Spectral power feature sets



Spectral slope feature sets

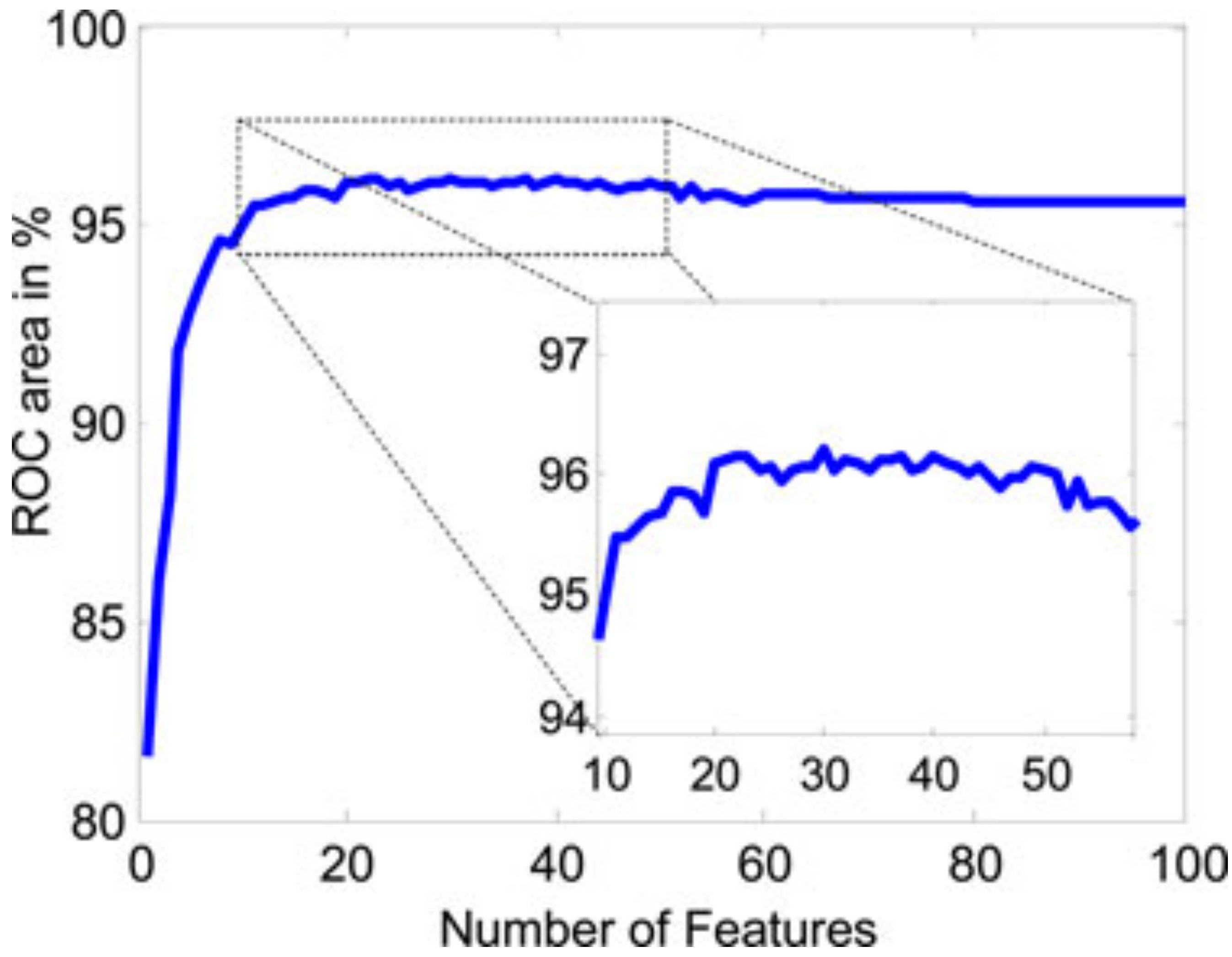


Feature Selection Routine

- Recursive feature elimination (RFE):

1. SVM classifier is trained on all features
2. The deviation in the loss function is computed for every single feature that is removed, while preserving the same set of support vectors
3. The feature corresponding to the smallest deviation is then removed.

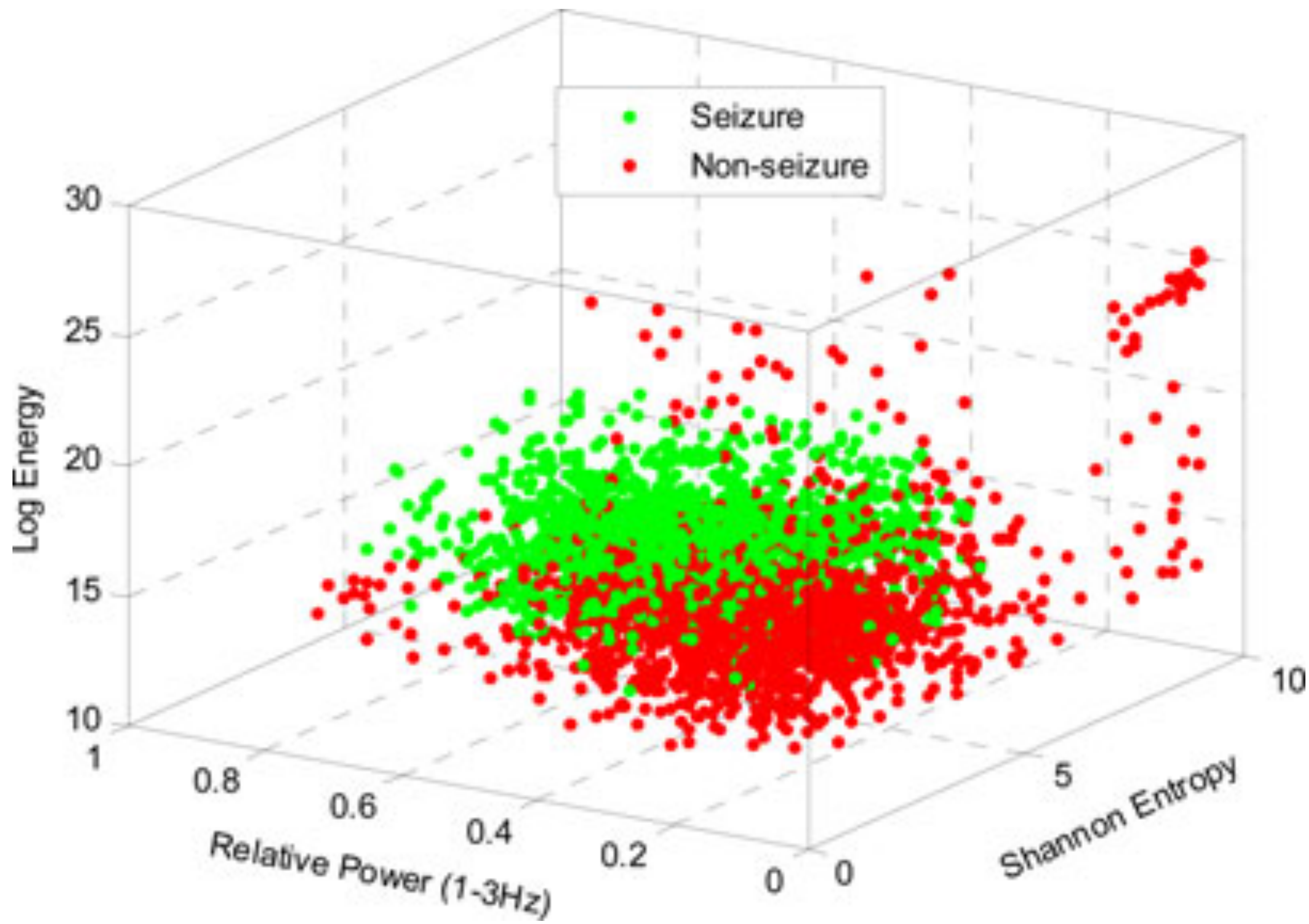
Recursive feature elimination



Feature ranking

Range	# Top Ranked (from ASR)	Features
Top 10	3 (1)	CC1, Shannon entropy, Normalised power in sub-band 1-3Hz
Top 20	11 (4)	Spectral Entropy, SEF95, Normalised power in sub-band 3-5Hz, FF2, FF3, ZCR of the Δ and the ΔΔ, CC2
Top 30	17 (7)	ZCR, FBE3, Normalised power in sub-band 2-4Hz, FF7, FF4, FF6
Top 40	22 (10)	FF8, FF9, Kurtosis, Normalised power in sub-band 8-10Hz, CC10
Top 50	34 (19)	CC5, AR modelling 1, FF11, FBE1, Skewness, FF10, CC12, CC13, Fisher information, CC4, CC11, FF5

Seizure and non-seizure epochs in 3D space composed of the 3 best features



Conclusion

- Spectral envelope-based features can serve as a better and more robust alternative to the original spectral features used in the EEG signal description

- Accompanied with several features from the information theory and time domains, ASR features form a good representation of the signal for neonatal seizure detection