ON-LINE DISHARMONY DETECTION FOR EARLY PREDICTION OF EPILEPSY SEIZURE ONSET

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ABSTRACT

Temporal lobe epilepsy is diagnosed by clinical symptoms and signs. Patients with medically refractory complex partial seizures are candidates to surgical treatment but the localization and characterization of the epileptogenic focus is often difficult to perform with routine brain imaging techniques. In recent years the injection of a radiotracer to localize precisely an epileptogenic focus with SPECT analysis has provided an essential contribution but its efficacy relies on the possibility to trigger the injection immediately after detecting the onset of epileptic seizures. Thus, it appears that the possibility to detect reliably the onset of temporal lobe epileptic seizures represents a major challenge in detecting the precise location of the epileptogenic focus. Once correctly localized, the surgical removal of the pathogenic tissue generally represents the best way to treat the patients on the long term.

The neurophysiological assumption is that temporal lobe epileptic seizures are manifestations of a paroxysmic synchronization among large neural networks that is not occurring suddenly but that requires some amount of time before reaching the all-or-none threshold that leads to the seizure onset. We assume that the build-up of the synchronizing waves is necessarily associated to subtle changes in the spectrum of electrophysiological signals such as field potentials recorded in the region of interest as well as in scalp and foveal EEG recordings.

The present study extends further a technique for early detection of sustained changes in quasi-stationary signals applied for prediction of seizure onset in patients affected by medial temporal lobe epilepsy based on real time analyses of standard scalp and foveal EEG [1].

The problem of early prediction of seizure onset is assumed to be a problem of real time on-line detection of changes in frequency domain characteristics of the signal. This is often addressed by modeling piecewise the original signal with autoregressive models (AR or ARMA) and then to detect the time corresponding to changes in model coefficients [2]. This approach is time consuming and sensitive to outliers. Our approach is original as it assumes that the signal is a piecewise stationary random vector process interrupted intermittently by segments with different spectral characteristics. Whenever the spectrum of random stationary process with zero mean changes, at the moment t^* the mean of the random process $(D_\alpha^1 x(t))^2$ changes at the same time, where $D_\alpha^1 x$ is the integral operator $D_\alpha^1 x(t) = \int_R \omega_\alpha^1(\tau - t)x(t)dt$, and the kernel function ω_α^1 is the derivative of ω_α that satisfied the following conditions:

a) $\omega_\alpha(t)=0$, if $|t| > \alpha$;

b) $\int_R \omega_\alpha(t)dt = 1$;

c) ω_α has continuous derivative.

Fast algorithms exist for calculation of $D_\alpha x(t)$ [3], thus simplifying the task of detection because the original problem becomes now the search for abrupt changes in the mean. Well-known algorithms exist for on-line detection of jumps in the mean based on cumulative sum [4,5]. Let $Y(t)$ be a sequence of independent random identically distributed $Y(t)$ and let $X(t)$ be the observations sequence such that with $r \neq 0$,

$$X(t) = \begin{cases} Y(t), & t < t^* \\ r + Y(t), & t \geq t^* \end{cases},$$

To detect an increase in the mean an alarm is set if the cumulative sum $S(t) > h$, where $S(t) = max\{0, S(t-1) + (Y(t)-r/2)\}$ and $h = (\sigma^2/r)\ ln((1-\alpha)/\alpha)$, where α is the probability of false alarm according to [4]. The confidence interval is set such that $r=3\sigma$. The same procedure is used to detect a decrease in the value of the mean. The number of events $\boldsymbol{A_i(t)}$, where i is the recording channel number, computed as the excess of cumulative sum over threshold per time unit, is used as a predictive index for the seizure onset.

The cumulative sum algorithm for jump detection is implemented as a fast real time procedure and may be used for all EEG channels simultaneously. The characteristic values $\boldsymbol{A_i(t)}$ were calculated for epochs of 5 seconds. Initial statistical analysis revealed that the mean of the characteristic values increased by one order of magnitude before seizure, while the variance increased at least by 4 times. The statistical distribution of $\boldsymbol{A_i(t)}$ was characterized by long tails. For the control records we found 1.1%-2.8% of data outside 3σ-confidence intervals leading to false alarms. In presence of large errors (outliers) the random variable was described as a mixture of normal distributions with parameters calculated following maximum-likelihood [6]. The confidence limit for large errors was used as a threshold to make the decision about the seizure onset. In the data set analyzed so far the seizure onset was predicted correctly with minimal number of false alarm at least 10 minutes before the actual onset.

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Keywords: Epileptic seizure, spectral analysis, synchronizing waves, signal detection.

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