COMPARATIVE PERFORMANCE OF TIME–FREQUENCY BASED NEWBORN EEG SEIZURE DETECTION USING SPIKE SIGNATURES

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ABSTRACT

This paper investigates the performance of four non-parametric newborn EEG seizure detection methods. The authors recently proposed a time-frequency (TF) based technique suitable for nonstationarity of EEG signal. This method attempts to detect seizure activities through analysing the interspike intervals of the EEG in the TF domain. The performance of this method is compared to those of three non-parametric techniques for seizure detection. These methods are: Autocorrelation, Spectrum and Singular Spectrum Analysis (SSA). The Autocorrelation method performs analysis in the time domain and is based on the autocorrelation function of short epochs of EEG data. The Spectrum technique is based on spectral analysis and is used to detect periodic discharges. The SSA technique employs singular spectrum analysis and information theoretic-based selection of the signal subspace. These three methods are based on the assumption that newborn EEG signal is quasi-stationary. The obtained results show the superior performance of the TF-based technique for detecting newborn EEG seizures.

1. INTRODUCTION

Brain abnormalities in newborns are usually first revealed by seizures, which are characterised by a synchronous discharge of a large number of neurons [1]. It has been shown that there is a correlation between the duration of the seizure and the severity of brain damage [1]. Therefore, failure to control seizures may lead to brain damage.

Monitoring brain activity through the electroencephalogram (EEG) is an important tool in the diagnosis of neurological disorders in newborns. The onset of an EEG seizure is often identified by sharp and repetitive waveforms [2]. The detection of these waveforms is complicated in the case of newborns since the brain of a normal neonate may produce spurious waveforms and sharp spikes which are the result of extra electrical activity associated with the maturing brain [3]. The problem is to differentiate between the waveforms related to seizure and those which are related to the normal brain activities.

The analysis of EEG data recorded by digital systems with a high sampling rate shows that in the frequency domain EEG activity ranges from almost DC to higher than 100 Hz [4]. Since seizure signatures may exist in different frequency ranges, from less than 10 Hz to as high as 75 Hz, some researchers tried to detect seizure activity using the low frequency signatures [5, 6, 7] while others used the high frequency ones [2, 4].

In this paper we compare the performance of the seizure detection method using the TF based technique, previously proposed by the authors [2], with three other methods [5, 6, 7]. The technique presented in [5] performs analysis in the time domain and is based on the autocorrelation function of short epochs of EEG data. In [6] Gotman et al used frequency analysis to determine the changes in the dominant peak of the frequency spectrum of short epochs of EEG data. The technique introduced in [7] is based on singular spectrum analysis and information of the signal subspace. All three techniques are based on the assumption that the EEG signals are stationary or at least quasi–stationary. However, a closer examination of these signals often shows that EEG signals exhibit significant nonstationary and multi component behaviours.

To take these characteristics into account, we have proposed a TF–based approach for seizure detection. The method is based on the spiky activities in the TF domain. Since the onset of a seizure in the EEG signal is mostly identified by a repetitive and sharp waveforms, these spiky events can be seen as short–time broadband events in the TF domain. It has been shown that the regularity of interspike intervals can be used as a discriminating feature between seizure and nonseizure activities.

The aim of this paper is to compare the performance of the four above–mentioned methods using the newborn EEG recorded data at the Royal Children's Hospital in Brisbane, Australia.

2. REVIEW OF SEIZURE DETECTION TECHNIQUES

2.1. The Autocorrelation Technique

The autocorrelation based technique proposed by Liu [5] relies on the assumption that the essential characteristic in newborn EEG seizures is periodicity. To asses the amount of periodicity, the EEG data is segmented into 30 second epochs and each epoch is divided into 5 windows. Depending on the autocorrelation function of a window, up to four primary periods are calculated for each window in an epoch. The windows are then scored whereby more evenly spaced primary periods are allocated larger scores. After each window in an epoch is scored, a rule based detection scheme is applied to classify each epoch as seizure positive or negative. If two or more channels of EEG data in the same epoch are seizure positive, the epoch is then classified as containing seizure activity.

2.2. The Spectrum Technique

The method introduced by Gotman et al was mainly based on the spectrum analysis of short epochs of EEG data [6, 8]. In this technique to detect seizure activities, the EEG data is segmented into 10-second epochs using a sliding window. The window is moved along the EEG in 2.5 seconds steps. The algorithm was designed to extract features from each epoch and compare them with those of the background. The background is defined as a 20–second segment of EEG finishing 60 seconds before the start of the current epoch. The main advantage of using a constantly updated background is that results are not dependent on the specific features of a fixed epoch.

The frequency spectrum of the individual epochs is calculated and the following features are extracted: 1) the frequency of the dominant spectral peak, 2) the width of the dominant spectral peak and 3) the ratio of the power in the dominant spectral peak to that of the background spectrum in the same frequency band.

The three features are used in detecting seizures in each epoch. If an epoch is recognised as containing seizure, a further three criteria are employed to reduce the rate of false detections. Detected seizures are ignored if the epoch is largely nonstationary, if there is a large amount of AC power noise present or if it appears that an EEG lead has been disconnected.

2.3. The SSA Technique

Celka et al [7] proposed a method for newborn EEG seizure detection using Singular Spectrum Analysis. The SSA method is suited for extracting information from stationary or at least quasi–stationary signals cluttered with noise.

In this method to detect seizure activity in EEG data, the signal is preprocessed. The preprocessing is based on a nonlinear whitening filter that spreads the spectrum of the background while keeping rhythmical features of the seizure activities. The filtered signal is then segmented into 10–second epochs using sliding window with a 1.25 second steps. The individual epochs are converted into a matrix for separating the noise subspace from the signal subspace. The signal subspace is obtained by using n_0 singular vectors related to the n_0 largest singular values of the matrix using the SVD technique. To find n_0, as a criterion for space division, they used the Rissanen minimum description length (MDL) method. In this technique if n_0 is equal to 1 the related epoch is considered as background otherwise it is a seizure.

2.4. The TF Technique

A number of neurons firing synchronously creates a signal with sharp waves [9]. The analysis of the EEG reveals many spikes together with low frequency activities. There are however, some differences between the spike patterns related to background activity and those which occur during the seizure activity.

Spikes, which are often difficult to characterize in the time domain, can be identified as lines or ridges in the TF domain, where the height of the ridge depends on the power of the spikes. Spikes during normal activity of EEG data are distributed infrequently and irregularly within the signal while in the case of seizure activity there is a regularity in the intervals of successive spikes.

Analysing interspike intervals (ISIs) in the TF domain allows one to distinguish the nature of spikes. It has been noticed that in the TF domain, spike lines extend to a higher frequency while the background activity of the EEG signal is usually restricted to the lower frequency region. Thus, analysing a higher frequency slice in the TF domain can result in a clear identification of the spike event origin.

One way to characterise the variation of intervals between successive spikes is by constructing a histogram of those intervals. In [2], it has been shown that one frequency slice extracted at about 75 Hz from the TF domain of the signal can be used as a feature to differentiate between spiky activities due to seizure and nonseizure. The TF slice is thresholded to keep only the most energetic spikes. The histograms of the ISIs are then formed and compared to that of a reference histogram using the Jenson function (similarity measure) to differentiate between seizure and nonseizure events.

3. PERFORMANCE COMPARISON

3.1. Implementation Of The Seizure Detection Methods

In this section, the four techniques are implemented using Matlab and their performance are compared using real newborn EEG data of four different newborn babies whose ages ranges between 2 days and 2 weeks. The 20 channels EEG data was collected and labeled by a neurologist at the Royal Children's Hospital in Brisbane, Australia. The criteria used for comparing the performances of the four different methods are: good detection rate (GDR) and false detection rate (FDR). We define the GDR and FDR as:

$$GDR = 100 \times \frac{GD}{R}$$

$$FDR = 100 \times \frac{FD}{GD + FD}$$

where GD and FD are the total number of good detections and false detections respectively and R represents the total number of seizures detected by the neurologist. A good detection occurs if the detected EEG epoch matches the epoch labeled as a seizure by the neurologist. The performance results are summarised in Table 1.

		Autocorrelation	Spectral	SSA	TF
Baby 1	GDR	50%	44%	50%	89%
	FDR	11%	14%	19%	11%
Baby 2	GDR	32%	47%	97%	100%
	FDR	7.5%	0	2%	2.5%
Baby 3	GDR	95%	85%	99%	75%
	FDR	37%	36%	35%	17%
Baby 4	GDR	31%	0	91%	100%
	FDR	0	0	0	0
Average	GDR	52%	44%	84.2%	91%
	FDR	13.8	12.5%	14%	7.6%

Table 1. Performance results on real EEG data

3.2. Discussion

The performance results represented in Table 1 show that except for baby 3, the TF–based technique has better GDR than the other methods. We have investigated a reason for the low GDR in the EEG data associated with baby 3 using the TF-based technique. One epoch of the data that was labeled as a seizure by the neurologist and detected correctly using the different techniques, except the TF–based technique, is shown in Figure 1. The figure shows the existence of a low frequency activity as well as high frequency spikes in the signal. The repetitiveness in the low frequency activity of the signal is a signature of the seizure. Since the Autocorrelation, Spectrum and SSA techniques are low frequency–based methods, they have succeeded in detecting the seizures. The histogram of interspike intervals extracted from the epoch using the TF–based technique is shown in Figure 2. In Figure 3 the histogram of ISIs related to seizure activities is shown for comparison. The histogram shows that in a seizure, interval 1 has the highest repetition, and the later intervals decline gradually toward zero.

The failure in detecting the seizure signal represented in Figure 1 is due to the fact that the seizure appeared to have the low frequency signature. In other words, the high frequency signature of the signal is absent or was corrupted by some artifacts.

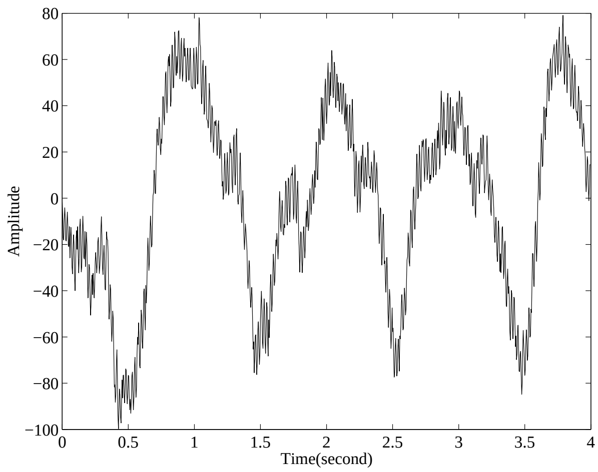

Fig. 1. Four seconds of the third baby's EEG signal represented in Table 1

For the first baby in Table 1 the TF technique has a remarkably better GDR than the other techniques with the lowest FDR. This could be due to the existence of seizures with mostly high frequency signature or to the nonstationary behaviour of the seizure. It needs to be noted that the TF technique is based on the high frequency signature of the seizure and it also take into account the nonstationary behaviour of the signal.

The average values of GDR and FDR extracted from the table shows that the TF method outperforms the three other methods in both those aspects.

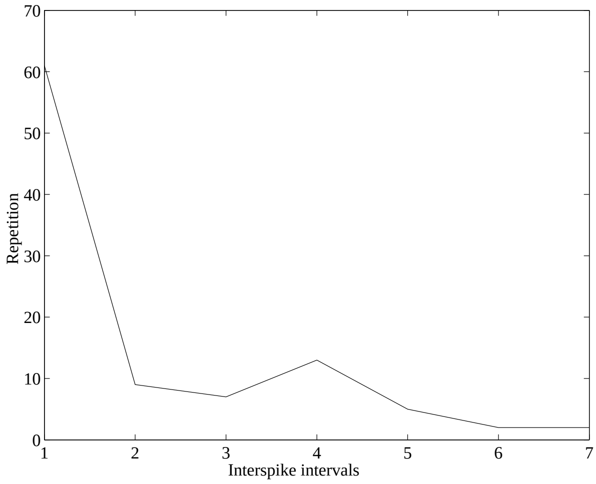

Fig. 2. Histogram of interspike intervals extracted from the EEG signal shown in Figure 1

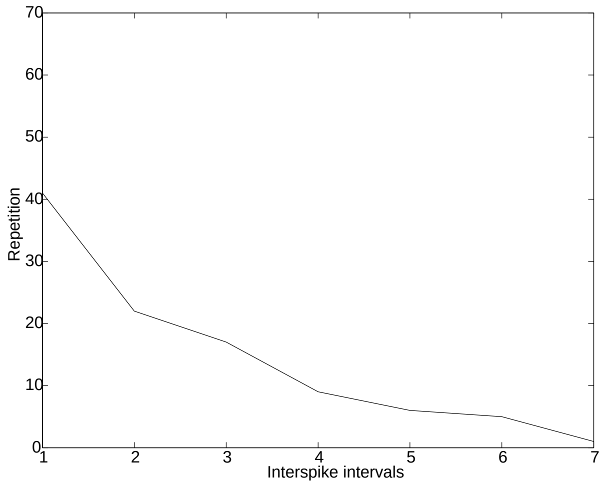

Fig. 3. Histogram of interspike intervals of a seizure activity

4. CONCLUSION

A comparison of the performance of four techniques for newborn EEG seizure detection has been performed using the EEG data of four newborn babies. The TF–based technique that uses EEG seizure signature in the high frequency area, recently proposed by the authors, clearly outperforms the three other techniques; namely Autocorrelation, the Spectrum, and the SSA in terms of good detection and false detection rates. Since EEG seizure is nonstationary with signatures occurring in low or high frequencies, the authors are currently working on a technique that combines two detection schemes [10, 11] using both low frequency and high frequency signatures to further ameliorate the detection rates.

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