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Using Fractal Dimension for EEG Spike Detection

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Abstract: Spikes in electroencephalogram (EEG) are usually an indication of abnormal brain activity. Spike detection is an important tool for clinical diagnosis of epileptic disorders. In this paper, a new spike detection method is introduced. In the proposed approach, the EEG signal is initially filtered using Savitzky-Golay filter to attenuate its short-term variations. Then, fractal dimension of the filtered signal is calculated in a sliding window. This technique is used to accentuate the signature of spikes. Spikes positions are detected by inspecting fractal dimension variations. The performance of this method is compared with that of two other existing methods using both synthetic signals and real newborn EEG. The results indicate that our proposed technique has better accuracy compared to existing methods.

Key words: EEG · Spike detection · Epileptic disorders · Savitzky-Golay filter · Fractal dimension

INTRODUCTION

The electroencephalogram (EEG) is an invaluable measurement tool for monitoring brain activity [1-3]. Brain functioning affects the morphology of EEG. Within the context of EEG, spikes can be considered as transient signal which is different from the background activity. They show a stereotypical pointed peak and duration of 20-70 ms [1-3]. Seizures, which are a result of synchronous discharge of a large number of neurons, can be detected using spikes and their firing pattern in EEG [1-3]. In this application, performance of the EEG seizure detection technique can be improved by increasing the accuracy of the spike detection method.

Traditionally, EEG signals are scanned for epileptic spikes by physicians. This process becomes very tedious and time-consuming in case of long EEG recordings. Therefore, it is increasingly necessary to present an efficient automatic method for spike detection.

This paper presents a new method for this task. In the proposed method, the Savitzky-Golay filter is initially applied to the signal under analysis to show the important underlying unadulterated form of the data by attenuating its short-term variations. Then, fractal dimension technique is used to accentuate the spike signature. Spikes positions can be detected through quantification of fractal dimension variations.

This paper is organized as follows: the existing spike detection methods are described in Section 2. Section 3 presents the theoretical foundation of Savitzky-Golay filter and fractal dimension techniques. The proposed spike detection method is explained in Sections 4. The performance evaluation of the proposed method and comparison results are provided in Section 5. Section 6 summarizes our conclusions.

Existing Spike Detection Methods: There are a number of spike detection methods in the literature. In [4], a spike detection method based on relative amplitude of the waveforms has been introduced. In this approach, only waves whose amplitudes are at least six times bigger than that of the background are considered as spike signals. However, it fails to detect small amplitude spikes after burst waves. In [5], the authors proposed a spike detection method using a nonlinear energy operator (NEO). This method however has been proven sensitive to noise [6]. In [6], the authors improved the performance of the NEO by using a smoothing window at its output. This new method is called the smoothed nonlinear energy operator (SNEO). But, the accuracy of this method critically depends on the method by which the threshold is chosen [7]. In another method, a spike detection using a Kalman filter has been proposed. In this method [8], the EEG signal is first modeled as an output of time-varying

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autoregressive model (TVAR). The TVAR parameters are estimated with a Kalman filter algorithm. Then, the output values of the filter above the threshold are considered to be the position of spikes.

Overview of Savitzky-golay Filter and Fractal Dimension: Since this research is based on Savitzky-Golay filter and fractal dimension, they are briefly reviewed here.

Savitzky-Golay Filter: In order to reduce the effect of noise on the original signal we use the Savitzky-Golay filter. This low-pass filter is suitable for smoothing data in time series as well as calculating the first up to the fifth derivatives [9-11]. In the Savitzky-Golay approach, a polynomial P of degree k is fitted to $n = n_l + n_r + 1$ data points, where n is frame or window size and it is acquired from n_l data points to the left and n_r data points to the right of a current data point [9-11].

Fractal Dimension: Fractal dimension (FD) indicates non-integer or fractional dimension of an object [12]. Along with other nonlinear methods, the FD has been frequently used in the analysis of biomedical signal processing, including EEG analysis. [13-15]. It has been revealed that non-stationary and transient characteristics of a signal could be represented by FD. Several algorithms have been proposed to estimate the FD of waveforms such as Higuchi [16], Petrosian [17] and Katz [18] methods. Selection of FD algorithm depends on the application [19]. Higuchi's method presents the most accurate estimation of the FD; however it is slower than Katz's method. Petrosian's method has less accuracy in calculating FD of a signal compared to Katz's approach. Katz's method is relatively insensitive to noise. In addition, FDs computed using Katz method have better Results regarding discrimination between states of brain function [19]. In this paper, we have used Katz's algorithm to calculate the FD of a time series. In the Katz's algorithm, the FD is obtained directly from the time series and can be defined as [18, 19]:

$$FD = \frac{\log(L/a)}{\log(d/a)} \qquad (1)$$

where L is the length of the time series, d is the distance (Euclidean) between the first point in the time series and the point that provides the furthest distance with respect to the first point and a is the average distance between the two successive data points.

Proposed Spike Detection Method: The proposed spike detection method consists of following steps:

- The Savitzky-Golay filter is initially applied to the original signal to represent the important underlying unadulterated form of the time series by attenuating its short-term variations. The main advantage of the Savitzky-Golay filter is that it tends to preserve the features of the time series distribution such as its relative maxima, minima and width [9-11]. In addition, this filter has no shifting effect on the patterns existing on the time-series after filtering compared to other FIR filters [9-11]. This property can be useful to detect the true positions of spikes.
- The fractal dimensions of the filtered signal are calculated in a sliding window. This technique has been used to accentuate the signature of spikes. For application of spike detection, FD variations are considered as follows:

$$G_m = |FD_{m+1} - FD_m| \quad m = 1,\ldots,M-1 \qquad (2)$$

where, M is the total number of analyzed windows.

- The local maxima of G function above the threshold represent the position of spikes in the time series.

Performance Evaluation: Algorithms of the proposed method and existing techniques were implemented using MATLAB from Math Works, Inc. The performance of these techniques was evaluated using both synthetic signal and real newborn EEG.

Synthetic Signal: For the purpose of evaluating the performance of the proposed method, the following synthetic signal has been generated [7, 8]:

$$x(t) = h(t) + s(t) \qquad (3)$$

where *h(t)* and *s(t)* are the spike train set and the background signal, respectively. The background signal is chosen according to equation (4).

$$s(t) = \sin(\omega t) - \sin(2\omega t + \phi) + \sin(4\omega t) + n(t) \qquad (4)$$

where $\omega = 2\pi/75$, $\phi = \pi/2$ and $n(t)$ is white Gaussian noise. The spikes are distributed randomly over the background signal. Spike signals are modeled as triangular symmetric pulses whose amplitudes were uniformly distributed in the interval of 2.5 and 5. The signal is sampled at a rate of 128 Hz (Fs=128 Hz). The signal in Figure 1.a represents 8 spikes with a randomly varying duration of 3 to 9 samples since the duration of real spikes ranges from 20 to 70 msec. Figure 1.b shows 2 s of $x(t)$ with SNR=0 dB.

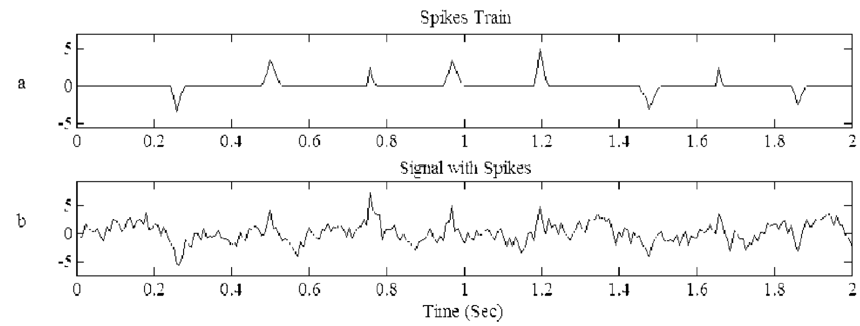

Fig. 1: (a) Spikes train. (b) Signal with spikes, *x(t)* with SNR=0 dB.

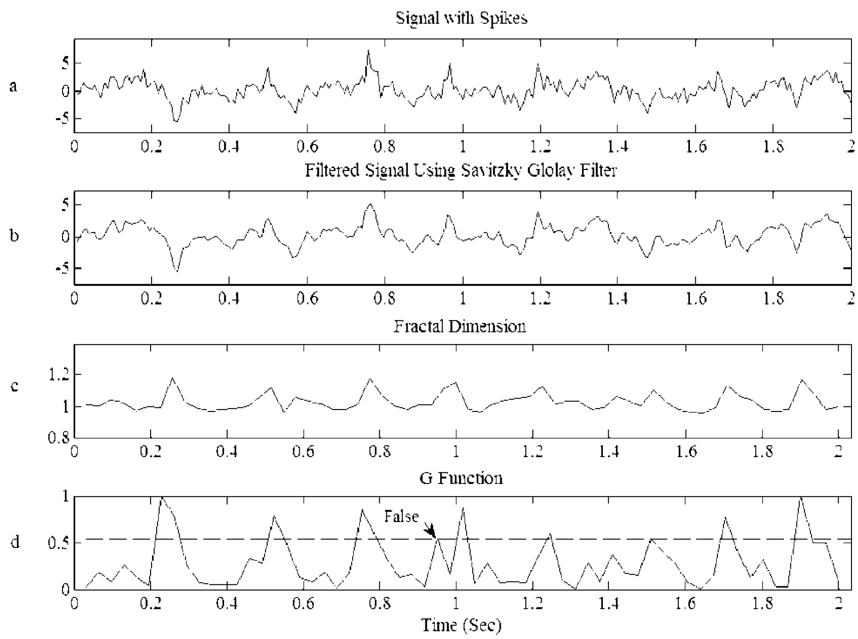

Fig. 2: Spike detection in synthetic signal using proposed method. (a) Signal with spikes. (b) Filtered signal using Savitzky-Golay filter, (c) The computed fractal dimension, (d) Output of the *G* function. As can be seen, the proposed method could successfully detect all spikes.

The signal in Figure 2.a is initially filtered using Savitzky-Golay filter. In this paper, we have used an order 3 polynomial Savitzky-Golay smoothing filter to remove noise from the time series. A frame size of 5 was chosen for the filter. These parameters have been experimentally chosen to have a better noise reduction results.

The filtered signal has been shown in Figure 2.b. FD of the signal in Figure 2.b is calculated using a sliding window with the length of 70 ms and 50 % overlapping is chosen for successive windows. Figure 2.c demonstrates the computed fractal dimension. Figure 2.d shows the computed G function. The threshold value for the proposed method is chosen as $\bar{G}+\sigma_G$, where $\bar{G}$ and σ_G represent mean and standard deviation of G function, respectively. The local maxima of G function above the threshold clearly reveal the position of all spikes.

The existing methods [7, 8] are also applied on the signal in Figure 2.a and the results are shown in Figure 3. This figure indicates that the existing methods have more false detection rate (marked with the arrows in the plots) compared to the proposed method.

In order to evaluate the performance of the proposed method, the true positive (TP), miss or false negative (FN) and false alarm or false positive (FP) ratios are used as defined below [7]:

$$TP = \frac{N_t}{N}, \quad FN = \frac{N_m}{N}, \quad FP = \frac{N_f}{N}, \tag{5}$$

where N_t, N_m, N_f and N represent the number of true, missed, falsely detected and actual number of spikes, respectively.

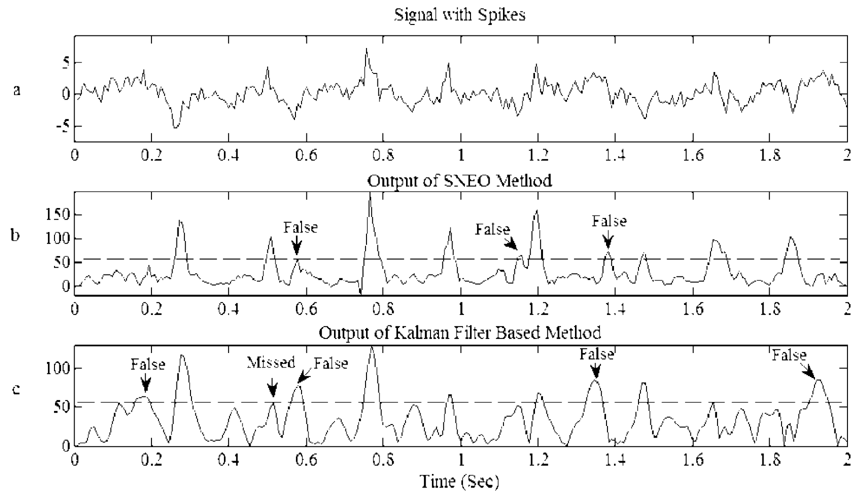

Fig. 3: Spike detection in synthetic signal using existing methods. (a) Signal with spikes, (b) The output of SNEO method, (c) The output of Kalman filter based method. Both missed and falsely detected spikes are depicted by arrows. As can be seen, the existing methods have more false detection rate compared to the proposed method

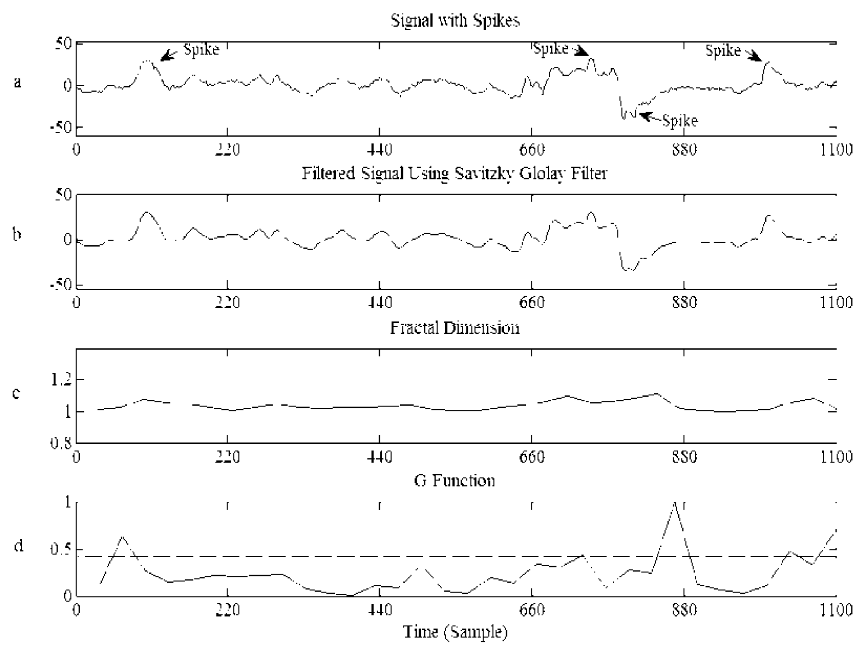

Fig. 4: Spike detection in real signal using proposed method. (a) Signal with spikes. (b) Filtered signal using Savitzky-Golay filter, (c) The computed fractal dimension, (d) Output of the *G* function. As can be seen, the proposed method could successfully detect the position of spikes

Table 1 reports the TP, FN and FP ratios obtained by applying the proposed method and the existing methods to 100 simulated signals with 10 dB, 100 simulated signals with 5 dB, 100 simulated signals with 0 dB and 100 simulated signals with-5dB SNR. As can be seen from the results, the proposed method has a better accuracy compared to the existing methods [7, 8]. The proposed Method has the highest value for TP ratio and the lowest value for both FN and FP ratios in each selected SNR. But, the method suggested in [8] offers a high TP ratio at the expense of a high FP ratio.

Real EEG Signal: For the purpose of evaluating the performance of the proposed method on real signal, the EEG of a newborn baby has been used. The signal have been sampled using Fs=256Hz.

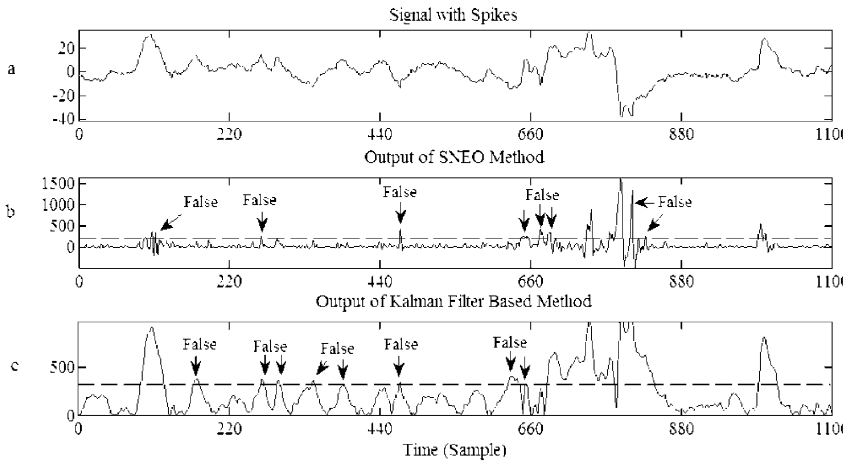

Fig. 5: Spike detection in real signal using existing methods. (a) Signal with spikes. (b) The output of SNEO method, (c) The output of Kalman filter based method. Both missed and falsely detected spikes are depicted by arrows. As can be seen, the existing methods have more false detection rate compared to the proposed method

Table 1: Results of applying proposed method and the existing methods on a set of synthetic data

	Proposed Method			
SNR	-5 dB	0 dB	5 dB	10 dB
TP	0.75	0.79	0.86	0.96
FN	0.25	0.21	0.14	0.04
FP	0.26	0.13	0.08	0.04
	SNEO Method			
SNR	-5 dB	0 dB	5 dB	10 dB
TP	0.72	0.76	0.83	0.92
FN	0.28	0.24	0.17	0.08
FP	0.63	0.41	0.11	0.06
	Kalman Based Method			
SNR	-5 dB	0 dB	5 dB	10 dB
TP	0.71	0.74	0.83	0.92
FN	0.29	0.26	0.17	0.08
FP	0.73	0.59	0.34	0.25

The proposed method is applied to five seconds of EEG signal and the result is shown in Figure 4. The position of the spikes has been depicted by arrows in Figure 4.a. The output of Savitzky-Golay filter and the calculated fractal dimension are shown in Figure 4.b and Figure 4.c, respectively. Figure 4.d indicates that all the spikes have been successfully detected using the proposed method.

The existing methods are also applied on the signal in Figure 4.a and the results are shown in Figure 5. This Figure reveals that existing methods have more false detection rate (marked with the arrows in the plots) compared to the proposed method.

CONCLUSIONS

In this paper a new spike detection method using Savitzky-Golay filter and fractal Dimension has been introduced. Savitzky-Golay filter attenuate short-term variations of the signal and fractal dimension is a powerful approach in transient detection. The performance of the proposed method was compared with two other exiting methods using both synthetic signals and data collected from human subjects. Simulation results indicated proposed method outperforms the existing methods in spike detection.

REFERENCES

1. Hassanpour, H., M. Mesbah and B. Boashash, 2004. “Time-frequency based newborn EEG seizure detection using low and high frequency signatures,” Physiological Measurement, 25: 935-944.
2. Hassanpour, H., M. Mesbah and B. Boashash, 2003. “Comparative performance of time-frequency based newborn EEG seizure detection using spike signatures,” Proc. IEEE Int Conference on Signal Processing, 2: 389-392.
3. Xu, G., J. Wang, Q Zhang, S. Zhang and J. Zhu, 2007. “Aspike detection method in EEG based on improved morphological filter,” Computers in Biol. Med., 37: 1647-1652.
4. Wilson, S.B. and R. Emerson, 2002. “Spike detection: a review and comparison of algorithms,” Clin. Neurophysiol., 113: 1873-1881.

5. Maragos, P., J.F. Kaiser and T.F. Quatieri, 1993. "On amplitude and frequency demodulation using energy operators", IEEE Trans. Signal Processing, 41: 1532-1550.
6. Mukhopadhyay, S. and G.C. Ray, 1998. "A new interpretation of nonlinear energy operator and its efficiency in spike detection," IEEE Trans. On Biomed. Eng., 45:180-187.
7. Malarvili, M., H. Hassanpour, M. Mesbah and B. Boashash, 2005. "A histogram-based electroencephalogram spike detection," Proc. IEEE Int. Symposium on Signal Processing and its App., 1: 207-210.
8. Tzallas, A.T., V.P. Oikonomou and D.I. Fotiadis, 2006. "Epileptic Spike Detection Using a Kalman Filter Based Approach," Proc. IEEE Int EMBS Conference, 1: 501-504.
9. Savitzky, A. and M.J.E. Golay, 1964. "Smoothing and differentiation of data by simplified least squares procedures", Analytical Chem., 36: 1627-1639.
10. Luo, J., K. Ying and J. Bai, 2005. "Savitzky-Golay smoothing and differentiation filter for even number data", Signal Process, 85: 1429-1434.
11. Hassanpour, H., 2008. "A time-frequency approach for noise reduction", Digital Signal Processing, 18: 728-738.
12. Falconer, J., 2003. Fractal Geometry-Mathematical Foundations and Applications, John Wiley and Sons.
13. Acharya, R., U.O. Faust, N. Kannathal, T. Chua and S. Laxminarayan, 2005. "Non-linear analysis of EEG signals at various sleep stages," Comput Methods Programs Biomed, 80: 37-45.
14. Paramanathan, P. And R. Uthayakumar, 2007. "Application of fractal theory in analysis of human electroencephalographic signals," Computers in Biol. Med., 38: 372-378.
15. Tykierko, M., 2008. "Using invariants to change detection in dynamical system with chaos," Physica D: Nonlinear Phenomena, 237: 6-13.
16. Higuchi, T., 1988. "Aproach to an irregular time series on the basis of the fractal theory," Physica D., 31: 277-283.
17. Petrosian, A., 1995. "Kolmogorov Complexity of Finite Sequences and Recognition of Different Preictal EEG Patterns," Proc. IEEE Symposium on Computer-Based Medical Systems, 5: 212-217.
18. Katz, M.J., 1988. "Fractals and the Analysis of Waveforms", Comput. Biol. Med., 18(3): 145-156.
19. Esteller, R., G. Vachtsevanos, J. Echauz and B. litt, 2001. "A comparison of fractal dimension algorithms using synthetic and experimental data," IEEE Trans. Circuits Syst., 48: 177-183.