Automatic Minimization of Eye Blink Artifacts Using Fractal Dimension of Independent Components of Multichannel EEG

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Abstract: *Eye blink artifact is an important artifact in EEG recordings that should be corrected before any other analysis in clinical or brain computer interface purposes. This artifact cannot be removed by frequency selective filters, because of its frequency overlap with EEG. Independent component analysis (ICA) is an effective method that can separate ocular source from brain sources. The main problem in ICA is to recognize components related to ocular artifact source, automatically. In recent years, some methods have been proposed to recognize these components based on some features of independent components. In this work, we use Higuchi's fractal dimension of independent components, because of the difference between fractal structure of the ocular and brain sources. The method has been tested by EEG data recorded for diagnose attention deficit/hyperactivity disorder (ADHD) in children. The results show that the proposed method is appropriate for automatic minimization of eye blink artifact.*

Keywords: Electroencephalogram, eye blink artifact, Independent component analysis, fractal dimension.

1. Introduction

Ocular artifact is one of the most important artifacts that contaminates EEG signal and is originated from electrooculogram (EOG) by eye movement and eye blink. Because of the high magnitude of the eye blink artifacts and the high resistance of the skull and scalp tissues, the EOG may contaminate most of the EEG channels, even those in the occipital area. As ocular artifact has frequency overlap with EEG data, it cannot be corrected by frequency selective filters. The traditional method is to remove the segment of EEG data in which eye blinks occur. In recent years, various methods for eye blink artifact minimization have been proposed, which are mainly based on linear regression, principle component analysis (PCA), and independent component analysis (ICA).

It has been demonstrated that ICA is an effective technique for minimizing ocular artifact in EEG signal. However, methods based on ICA need to visual investigation to recognize the eye blink related independent components (ICs), so they are time consuming and not automatic. It is essential to propose a method for automatic correction. While ICA is used to automatically minimize ocular artifact, the main point is how to recognize the independent component (IC) related to ocular artifact after ICA decomposition. Some researchers have been worked in this field. Higher order statistics like kurtosis, mutual information, and sample entropy have been investigated [1,2,3].

In this study, the fractal structure difference between eye blink artifact component and other components was investigated. Then a method based on ICA and Higuchi's fractal dimension was proposed for automatic minimization of eye blink artifact. As far as we know, it is first time that Higuchi's fractal dimension is applied to recognition of eye blink artifact IC. The results show that the method is appropriate for automatic minimization of eye blink artifact in multichannel EEG.

2. Materials and Methods

2.1 Data Acquisition

EEG data was recorded during visual attention-based protocol in order to diagnose attention deficit/hyperactivity disorder (ADHD) in 7-12 year old children. Electric brain potentials were recorded from 20 electrodes mounted on an elastic cap according to 10/20 system. The EOG electrode was positioned below the left eye. All signals were sampled at a rate of 128 Hz and were band-pass filtered between 2 and 30 Hz using a zero phase filter. Electrode impedances were below 5k Ohms.

In this work, the EEG recordings contaminated by eye blink artifact were chosen by means of visual inspection. 76 epochs were used for calculation and the data length was set to be 4s.

2.2 Independent Component Analysis

ICA is a statistical technique in which observed random data are linearly transformed into components that are mutually independent. Assume a vector of N observed signals provided by an array of sensors:

$$X(t) = [X_1(t), X_2(t), \ldots, X_N(t)] \quad (1)$$

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Which are linear combinations of N unobservable sources:

$$S(t) = [S_1(t), S_2(t), ..., S_N(t)] \qquad (2)$$

The sources are real-value, non-gaussian, and mutually independent. The goal of ICA is to estimate the weigting matrix such that:

$$S = WX \ . \qquad (3)$$

Many algorithms have been developed to apply ICA, such as Extended InfoMax [4], and FastICA [5]. In this work we used Extended InfoMax algorithm.

2.3 Automatic Component Recognition

In order to recognize eye blink artifact components, we use Higuchi's fractal dimension proposed by Higuchi in 1988, because the fractal structure of eye blink artifact is different from the fractal structure of brain activities.

Suppose a data vector X(1),X(2),…,X(N), calculation of Higuchi's fractal dimension needs to construct new time series, X_k^m as below:

$$X_k^m = [X(m), X(m+k), X(m+2k), ..., X(m + \left[\frac{N-m}{k}\right]k] \qquad (4)$$

Where [] denotes integer part. m indicates the initial time and k is the interval time. For each time series, the length of the curve is defined as follows:

$$L_m(k) = \left\{ \left(\sum_{i=1}^{\left[\frac{N-m}{k}\right]} \left| X(m+ik) - X(m+(i-1)k) \right| \right) \frac{N-1}{\left[\frac{N-m}{k}\right] k} \right\} \Big/ k \qquad (5)$$

The mean length of the original vector is defined as the average of $L_m(k)$.

$$L(k) = \frac{1}{k} \sum_{m=1}^{k} L_m(k) \qquad (6)$$

$L(k)$ is proportional to k^{-FD}, so the fractal dimension of the data vector can be obtained as the slope of the curve $Ln(L(k))$ versus $Ln(1/k)$ using the least square linear best fitting method.

It is expected that the fractal dimension of the eye blink artifact is smaller than the fractal dimension of the other activities. However, in order to set a threshold to recognize the eye blink artifact components, we need to normalize the fractal dimensions of each subject's components, because the fractal structure of the EEG and EOG signals of each subject is different from others. After calculating the fractal dimension for all components of each epoch, we normalize them as follows:

$$NFD(k) = \frac{FD(k) - Mean}{STD} \qquad (7)$$

Where Mean and STD are the average and the standard deviation of fractal dimensions of components on the same epoch, respectively.

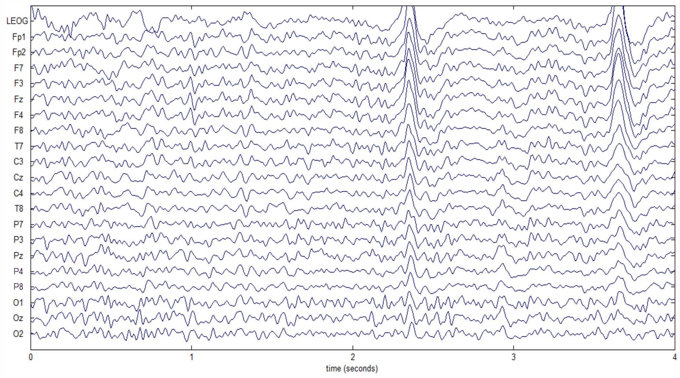
2.4 EEG Signal Reconstruction

After eye blink artifact IC recognition, the value of the eye blink artifact IC vector was set to zero. Then the inverse form of equation (3) was used to reconstruct the EEG signal.

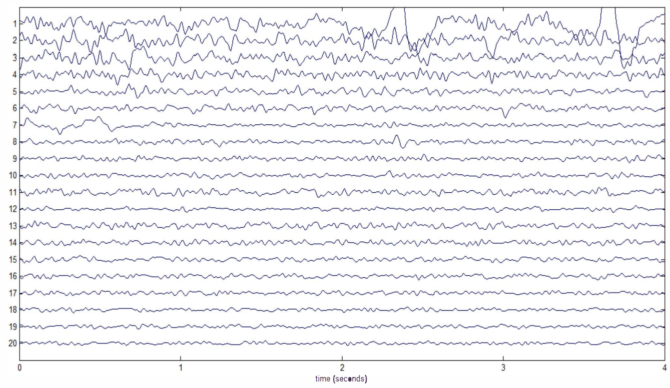
2.5 Evaluation of The Proposed Method

After ICA decomposition of all epochs, normalized Higuchi's fractal dimension was calculated for all ICs of all epochs and eye-blink artifact components were recognized by one experienced investigator. The criteria used to recognize eye blink artifact ICs was based on time domain of ICs and topographic maps of ICs that are made by the coefficients of EEG channels to make the related IC in equation(2).

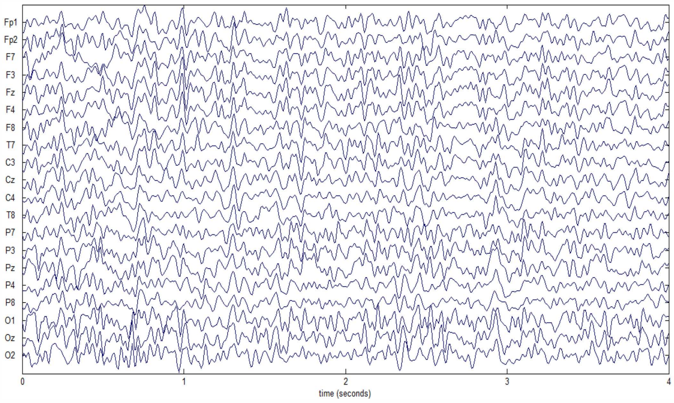
Afterward, the epochs were divided into two subsets: training subset and validation subset. The training subset included 38 epochs and the validation subset consisted of 38 epochs too. The training subset was used to obtain a optimal threshold for normalized Higuchi's fractal dimension to recognize eye blink artifact ICs. Then, the obtained threshold was applied to the normalized Higuchi's fractal dimension of all ICs in validation subset in order to evaluate the efficiency proposed method to recognize the eye blink artifact ICs.



(a)



(b)



(c)

Fig. 1: (a) Original signal. (b) Independent components. (c) Reconstructed signal after ocular artifact removal.

The ratio between the total number of correctly detected ICs and all ICs, called independent component detection ratio (ICDR) proposed in [6], was used to set the performance of the proposed method.

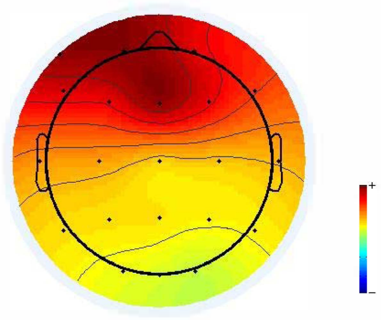


Fig. 2: An example of topographic map of an eye blink artefact IC.

3. Results

Fig. 1 (a) shows an example of one epoch with two eye blink artifacts around 2.4s and 3.7s. The independent components of this epoch are shown in Fig. 1 (b). From the time interval of IC1 shown in Fig. 1 (b) and its topographic map shown in Fig. 2, it is manually recognized to be an eye blink artifact IC. Fig. 3 shows the histogram of normalized Higuchi's fractal dimension of eye blink artifact ICs and other activities ICs. According to the histogram, we set the threshold to -1.89 in this paper. Fig.1 (c) shows the reconstructed EEG signal. Applying the threshold to the validation subset, 15 out of 760 components were misclassified, so we achieved ICDR equal to 98.02%.

4. Conclusion

In this paper, an automatic method is proposed to minimize eye blink artifact to a great extent. This method is based on ICA and fractal dimension and does not need to manual investigation. In comparison with other works [1,2,3] Higuchi's fractal dimension could recognize eye blink artefact components at a high rate. The future work would focus on using other nonlinear features to increase detection rate of independent components.

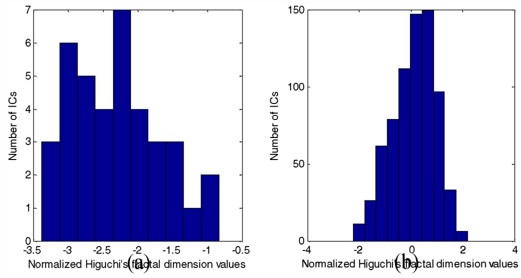


Fig. 3: Histogram of normalized Higuchi's fractal dimension (a) for eye blink artefact ICs. (b) for other activities ICs.

References

[1] D. Zhu, J. Tong, and Y. Chen, "An ICA based method foe automatic eye blink artifact correction in multi-channel EEG" in Proc. 2008 5th International Conference on Information Technology and Application in Biomedicine, pp. 338-341

[2] H. Ghandeharion, and A. Erfanian, "A fully automatic ocular artifact suppression from EEG data using higher order statistics: improved performance by wavelet analysis" Medical Engineering & Physics, vol. 32, pp. 720-729, 2010.

[3] J. Ma, S. Bayram, P. Tao, and V. Svetnik. "High-throughput ocular artifact reduction in multichannel electroencephalogram (EEG) using component subspace projection" *Journal of Neuroscience Methods,* vol. 196 pp.131-140 2011.

[4] T.W. Lee, M. Girolami, T.J. Sejnowski, "Independent component analysis using an extended Infomax algorithm for mixed subgaussian and supergaussian sources". *Neural Comput,* vol.11 pp.409–433, 1999.

[5] Hyvrinen A. Fast and robust fixed-point algorithms for independent component analysis. *IEEE Trans. Neural Netw,* vol.10, pp. 626–630, 1999.

[6] D. Mantini, R. Franciotti, G.L. Romani, and V. Pizzella, "Improving MEG source localizations: An automated method for complete artifact removal based on independent component analysis", *NeuroImage,* vol 40, pp. 160-173, 2008.

[7] N. Y. Bian, B. Wang, and Y. Cao, "Automatic removal of artifacts from EEG data using ICA and nonlinear exponential analysis," *Actabiophysica sinica,* vol. 22, pp. 149-156, 2006.

[8] K. Nazarpour, Y. Wongsawat, S. Sanei, J. A. Chambers, and S. Oraintara, "Removal of the Eye-Blink Artifacts From EEGs via STF-TS Modeling and Robust Minimum Variance Beamforming" *IEEE Trans. Biomedical engineering,* vol. 55, NO. 9, September 2008.

[9] T. Higuchi, "Approach to an irregular time series on the basis of the fractal theory" *Physica D*, vol. 31 pp. 277-283, 1988.

[10] C.J. James, and C.W. Hesse, "Independent component analysis for biomedical signals" *Physiol Meas*, vol. 26, pp.15–39, 2005.