A method for automatic removal of EOG artifacts from EEG based on ICA-EMD

1st Pengpai Li
Shandong University
Jinan, China
378666649@qq.com

2nd Zhenxin Chen
Shandong University
Jinan, China
993363680@qq.com

3rd Yongmei Hu
Shandong University
Jinan, China
huyongmei@sdu.edu.cn

***Abstract*—According to the interference of the ocular artifacts in the measurement process of EEG, a method combined independent component analysis (ICA) and empirical mode decomposition (EMD) is proposed. Firstly, ICA is applied to the mixed signal including EEG and EOG so as to obtain the independent components. Secondly, EMD threshold denoising is used to remove the ocular artifacts which have larger amplitude in the independent components, then the EEG signals are rebuilt by using the inverse ICA based on the new independent components. In order to evaluate the effect of the method quantitatively, the simulation data containing EOG interference is constructed. The correlation coefficient and the mean square error are used as indexes to evaluate the denoising performance. The results show that the proposed method can automatically and effectively remove the EOG interference, the reserved EEG information provide good conditions for further feature extraction and pattern recognition.**

Keywords—ICA-EDM, EOG artifact, simulation signal

I. INTRODUCTION

EEG is an important tool to record human brain activity, it has been widely applied in many fields [1-2]. EEG is inevitably mixed with physiological signal interference, such as EOG, ECG and EMG. EOG interference is one of the most major interference component and it has high amplitude and overlaps in the same frequency band with EEG [3].

In recent years, several methods have been used to remove EEG artifact. P. He [4] proposed adaptive filtering method for removing EOG, which required eye signal as a reference signal. S. Makeig [5] proposed a method using ICA to remove EOG artifact. This method could separate the artifact from EEG. But the order of each component was uncertain, the process of removing EOG artifact required manual intervention. Z. Ling [6] proposed a method combined ICA and wave let(ICA-WT) to automatically eliminate EOG artifacts. This method could automatically remove ocular artifacts, but the effect depended on the selection of wavelet function and decomposition levels, which were not adaptable. In order to realize automatic removal of EOG interference without reference signal, an artifact elimination method combined ICA and EMD is proposed.

II. MATERIAL AND METHODS

A. *Experimental data*

The EEG data was recorded by MedEx dynamic EEG device according to the international 10/20 system of electrode placement method and referenced with ear lobes. The bandwidths of amplifiers were 0.1-35Hz and sampling frequency was 200Hz. Recordings were made with a subject in a relaxed state with minimal body movements. The subject focused on the screen in which checkerboard experiments was performed. We manually selected two 5s data segments, one of which contained the obvious EOG interference and the other was pure EEG.

B. *Constructed the simulation signal*

Firstly, the pure EOG is extracted from the recorded 5s data segment with the EOG interference. ICA is used to separate EOG artifact source signal from the measured EEG with EOG artifact. But the independent component related with EOG is mixed with some low amplitude EEG information, it can't be used to construct the simulated signal. Threshold processing removal EEG signal should be done to get pure EOG signal. Then the pure EOG was mixed with the pure EEG signal to construct simulation

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signal containing EOG artifact. Thus, correlation coefficient and mean square error could be used as two indicators to evaluate the performance of removal artifacts. EOG signal and EEG signal activation diffusion are bidirectional [7], so simulation data is constructed according to Eq. (1).

$$EEG_{rec}(t) = EEG_{pure}(t) + k \times EOG_{pure}(t) \qquad (1)$$

C. Proposed method for removal EOG artifact

In this paper, a new hybrid algorithm ICA-EMD is presented. This paper adds EMD threshold denoising method on the basis of ICA. EMD is a new adaptive signal processing method and a key technology in Hilbert Huang transform [9]. EMD threshold denoising and wavelet threshold denoising is similar, but the former avoids selection of wavelet function and decomposition levels, and denoising effect is more stable. EMD threshold denosing is used in all independent components acquired by ICA in this paper, thus the method only removes EOG artifacts of each component and retains the useful EEG as much as possible. The procedure for removing the EOG artifact is summarized as follows:

1. Multichannel mixed signals $X = (x_1, x_2, \ldots\ldots x_n)^T$ containing EOG artifact are decomposed by fast ICA to obtain the mixing matrix W and independent components $U = (u_1, u_2, \ldots\ldots u_n)^T$.
2. Each independent component in the previous step is respectively decomposed by EMD to get the corresponding intrinsic mode functions c_{ij}.
3. Determine a threshold λ for each c_{ij} [10]. The threshold selection uses a universal threshold method proposed by Donoho as Eq. (2), in which N is the length of the signal, σ is the former estimation of the neural signal with broad band and low amplitude in the signal, expression as shown in Eq. (3).

$$\lambda = \sqrt{2 \log_N \sigma} \qquad (2)$$

$$\sigma = \frac{median(|c_{ij}|)}{0.6745} \qquad (3)$$

4. Inverse EMD is applied on the IMFs removed artifacts to get the independent components only containing the low amplitude EEG information $Y = (y_1, y_2, \ldots\ldots y_n)^T$.
5. ICA reconstruction is performed. Each denoised independent component is mapped back to the skin electrodes, thus the clean EEG signals without EOG artifact are obtained.

III. RESULT AND DISCUSSION

Simulation signals containing EOG artifact are constructed showed in Figure 1. 5s pure EEG signals are showed on the left, five channels are selected to build the simulation signal on the right, and obvious EOG interference could be seen in 3.4s position. The ICA-EMD is applied to the simulation signal to verify the effectiveness of the method. The results separately using ICA and ICA-EMD in Figure 2 shows that the EOG artifacts in 3.4s are commendably removed and the rest of the EEG information be well preserved by ICA-EMD. To quantitatively evaluate the ICA-EMD algorithm and analyze its ability removal EOG interference, the correlation coefficient and mean square error as two indicators was used to measure the denoising results and compared with ICA and ICA-WT proposed by previous researchers.

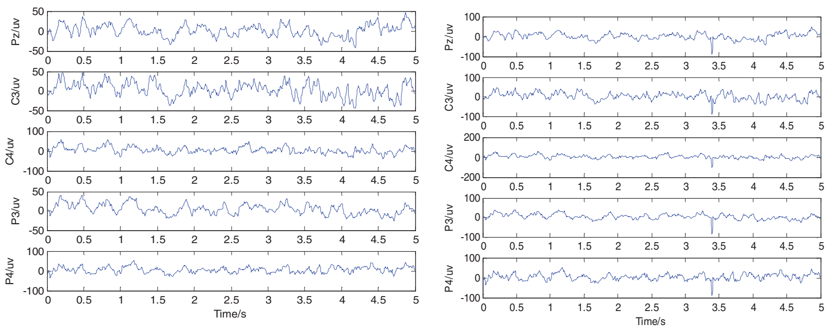

Fig.1. The results of construction simulation signal with EOG artifact, the left was pure EEG, the right was the simulation constructed using the pure EEG

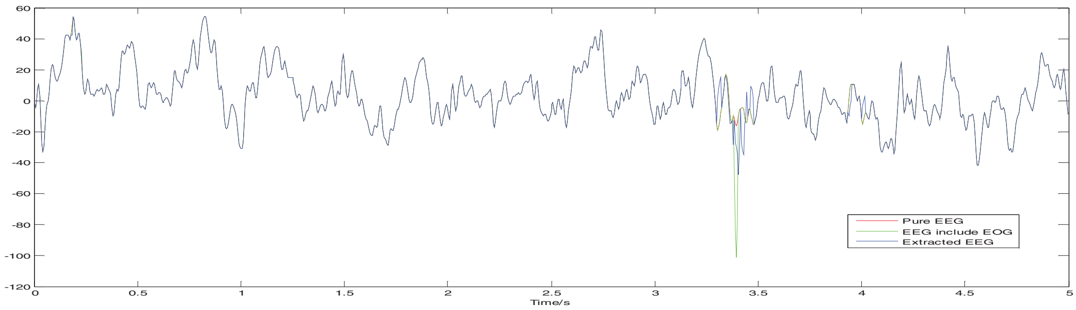

Fig. 2. The comparison results of pure EEG, simulation signal and signal removed EOG artifact by using ICA-EMD

TABLE1 THE STATISTICAL COMPARISONS OF CORRELATION COEFFICIENT BY USING THREE DIFFERENT ALGORITHMS

Methods	P3	P4	Pz	C3	C4
ICA	0.7928	0.6153	0.7383	0.7580	0.8016
ICA-WT	0.9810	0.9845	0.9791	0.9731	0.9777
ICA-EMD	0.9826	0.9862	0.9828	0.9767	0.9813

TABLE 2 THE STATISTICAL COMPARISONS OF MEAN SQUARE ERROR BY USING THREE DIFFERENT ALGORITHMS

Methods	P3	P4	Pz	C3	C4
ICA	104.54	216.39	146.22	94.733	97.328
ICA-WT	9.2482	10.2279	13.272	9.2460	10.196
ICA-EMD	8.3237	8.9645	9.9348	7.9396	8.4613

Table 1 and Table 2 respectively was the calculation results of correlation coefficient and mean square error by ICA, ICA-WT, ICA-EMD removal results EOG interference. As can be seen, correlation coefficient increased and mean square error reduced, when used ICA-EMD removal EOG interference compared with ICA and ICA-WT. It means ICA-EMD has a certain degree of improvement in ability to remove interference and retention of EEG signal.

IV. CONCLUSION

This paper proposes a method of EOG removal algorithm combing ICA and EMD threshold denoising, which can automatically remove the EOG artifact. In order to quantitatively evaluate the algorithm, the simulation signal was constructed. The method overcomes the issue that need to select EOG artifact components manually when using ICA and don't need to set the number of layers and other parameters like ICA-WT. Another advantage is that the method does not require a reference signal. The ICA-EMD algorithm provides a good premise for the feature extraction and pattern recognition. Subsequent work may use the method for the elimination of other artifacts such as ECG and EMG.

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