

Automatic removal of EOG artifacts using SOBI algorithm combined with intelligent source identification technique

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Abstract— Electrooculography (EOG) artifacts, generated by winking or other eye's movements, should be eliminated because they are the cause of the wrong decision in analysis the Electroencephalography (EEG) data, especially in the diagnosis of epilepsy. One of the efficient methods for signal separation is the Second order blind identification (SOBI), a blind source separation technique. In most cases, the activities of the two eyes are the same, and SOBI identify that there is only one source of artifact. However, in some cases, the activities of the two eyes are different, and SOBI identify that there are two different sources of artifacts [1]. The problem is that SOBI cannot provide the information about the order of sources. It means that, it cannot point out how many sources of EOG. It would lead to the wrong decision in EEG analysis. To solve this current limitation, in this paper, we propose an effective method to remove EOG from EEG using SOBI combined with intelligent source identification technique. The proposed method was evaluated carefully using experimental data. It determined successfully the number of EOG sources and removes these artifacts more accurately and efficiently.

Keywords— Second order blind identification (SOBI); intelligent source identification technique; Electrooculography (EOG); EEG.

I. INTRODUCTION

Epilepsy can be detected through the EEG signal analyzing process. Nevertheless, this signal often affected by artifacts such as: eye movements, muscle and heart activities, etc. Hence, recorded EEG signal is a combination of multi-signals (EEG background, EOG artifacts, EMG artifacts, heart signals, environment noises, etc.).

EEG is affected by EOG artifacts when eyes winking or movements. Winking of the eyes usually is generally high-amplitude signal patterns in the brain, while low-frequency patterns are caused by movements. EOG artifacts will cause of wrong decision in EEG analysis. Therefore, it is very essential to remove these artifacts before the process of EEG analysis.

SOBI is an effective algorithm that has been applied in various types of researches such as [2] - [4]. For EEG, the signal we obtained from a channel can be a mixture of a pure signal with other artifacts such as EOG, EMG, etc. SOBI can be applied to separate these sources. However, SOBI cannot provide the information about the order of sources, thus, we cannot remove the artifact signal correctly.

In most cases, the activities of the two eyes are the same, and SOBI identify that there is only one source of artifact. However, in some cases, the activities of the two eyes are different, and SOBI identify that there are two different sources of artifacts. Therefore, in this study, we propose an intelligent evaluation method to determine exactly the number of sources of EOG so that the elimination of this artifact will be more effective. Our proposed method was confirmed by using experimental data.

II. MATERIALS AND METHODS

II.1 Material

EOG signal is the voltage difference between the cornea and the retina of the eye, it changes during eye movements. The strength of the EOG signal depends on the position of the electrode to the eyes and the direction that the eyes are moving. EOG artifacts are normally measured in both the right eye and the left eye by ROC and LOC channels [6]. EOG artifacts separated by SOBI algorithm will have the same characteristics with ROC and LOC channels.

For that all, the combination of input channels is created by the number of sources is greater than the number of actual channels, some input signals having similar characteristics will be included in one output channel, usually two sources of eye artifact will be combined into one because it bears the characteristics of eye artifacts.

II.2 Using blind source separation method and SOBI algorithm

The blind source separation technique allows to recover a set of source signals from a linear combination of them with unknown coefficients of the linear combination. Assuming that the source signals are independent and uncorrelated. Hence, if we use only the second level of statistics (SOS) information, the complexity of the algorithm SOBI and signal strength may be reduced. Real linear mixed models, at each time instant k , can be written as:

$$x(k) = As(k) + n(k), \quad (1)$$

where x is a vector of M signals observed in the EEG channel, A is the mixing matrix of size $N \times M$ ($M > N$), s is a vector of N independent unknown source and n is the vector Gaussian

size $M \times 1$. Mixing matrix \mathbf{A} is unknown and the goal of an ICA is to find an estimate of its inverse matrix \mathbf{W} such as:

$$y(k) = \mathbf{W}x(k). \quad (2)$$

SOBI which is an ICA algorithm based on second order statistics can be derived [7], for all time lags τ the source correlation matrices are diagonal:

$$R_x(\tau) = E\{x(t)x(t+\tau)^T\} = AR_s(\tau)A^T, \forall \tau \quad (3)$$

where R_s represents the correlation matrix of the source signals. Considering that this equation holds all values of τ , the mixing matrix \mathbf{A} is a joint diagonalization of all the correlation matrices

EOG separation method using the SOBI algorithm combined with intelligent source identification technique can be applied with input channel numbers from 4 to 8. Considering that the combination of input channel is symmetric (such as LOC, ROC, Fz, Cz, see Fig. 1), in most cases, the activities of the two eyes are the same, and SOBI identify that there is only one source of artifact [5]. However, in some cases, the activities of the two eyes are different, and SOBI identify that there are two different sources of artifacts (e.g. one eye blink is stronger than the other).

In contrast, if the input combination is asymmetrical (LOC, ROC, Fz, F7), in most cases, SOBI will separate 2 sources of EOG because of 2 EOG sources to the mixture signal is different.

Choosing channel combination is important for SOBI to separate the EOG artifacts. To the way of choosing a combination as above, the identified EOG artifact channel will be quite similar to two EOG measurement channels: LOC and ROC. In order to get the best output signals, input combination channels should include LOC and ROC channels. Then, identified artifact sources will be similar to LOC and ROC. It should be noted that the chosen channel combination will be under the impact of the same source combination to guarantee the precision. If SOBI separates two sources and only one source is eliminated, EOG artifact will not be completely eliminated.

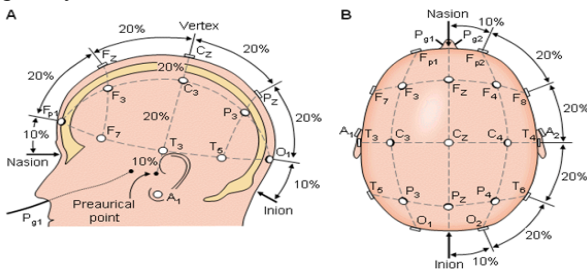


Fig 1. Allocation of electrodes according to standard 10-20 [8]

II.3 Proposed scheme

The disadvantage of SOBI is that we cannot obtain the information about the order of sources. Thus, we cannot compensate the artifact signal correctly. In this paper, we propose a method that integrates SOBI and intelligent source identification technique in order to remove EOG artifacts out of EEG signals more effectively.

$$x(k)' = x(k) - As \quad (4)$$

With a fixed-size window N , the energy of every output signal of the SOBI block is limited. In the frequency domain, the energy of an EOG signal is maximized at low frequency [5]. Thus we have exploited these properties to identify EOG as the below Algorithm scheme:

The process to identify EOG using moving window

Step 1: Initiate a moving window whose size is $N = 1$ s

Step 2: Calculate the weighting parameter for all SOBI's output channels $w = E(f < 5\text{Hz}) / E(f > 5\text{Hz})$

Step 3: Define EOG artifact by Method 1

Step 4: Compensate the noisy EEG channel

Step 5: Continue with the next window

The reason for choosing the ratio $w = E(f < 5\text{Hz}) / E(f > 5\text{Hz})$ because EOG artifacts often appear in a range of frequencies from 0 to 5Hz [9]. Although EEG signals also have delta and theta pulses at a range of frequencies from 0.5 to 7.5Hz [10], but EOG artifacts have only a few of energies at high frequencies, while the frequency spectrum of the EEG signal stretches from 0 to 70Hz.

SOBI algorithm can separate 1 or 2 sources of EOG artifacts. Hence, we will identify those sources to eliminate them better.

Algorithm:

Input channels combination $\text{Data}(n)$ have the same length with measured signal channels.

$$\text{Data}(n) = [\text{Input}_1; \text{Input}_2; \dots; \text{Input}_n];$$

After SOBI separates m sources, that equivalents with n inputs ($m=n$). Arranging sources in descending order of ω , we will have:

$$S(m) = [S_1, S_2 \dots S_m];$$

In this paper, we chose the input channels containing two channels ROC and LOC, and channel S_1 are defined as eye artifact. There will be two eyes artifact channels (S_2 is eye artifact) if:

$$S_2 \geq k \frac{S_1 + \text{Mean}(S_3, \dots, S_m)}{2} \quad (5)$$

with

$$\text{Mean}(S_3, \dots, S_m) = \frac{S_3 + \dots + S_m}{m-2} \quad (6)$$

To calculate k , we calculate

$$r = \frac{S_1 - S_2}{S_2 - \text{Mean}} \quad (7)$$

$k = 0.7$ when $0.8 \leq r \leq 1.5$ and $k = 1$ in remain cases.

If the formula (5) is not satisfied, there will have one eye artifact source.

III. THE EXPERIMENTAL RESULTS

III.1 The experimental data

Our data measured from 20 patients who had been clinically diagnosed to have epilepsy and their ages range from 4 to 22. Recording time for each person is in a range of from 20 minutes to 30 minutes. Before measuring, the patients will be removed all metal like watch, ear-rings and telephone. Besides, everybody in the room must turn off telephone and keep silent to avoid effecting to patients. During the

measurement process, the patients were asked to perform some tasks such as deep breathing, close eyes, open eyes. The data were recorded from 26 channels (19 EEG channels and 7 other channels for measuring EOG, EMG, and ECG) with the frequency sampling of 256Hz. We used high pass, low-pass, and notch filters for cutoff frequencies of 0.5Hz, 70Hz and 50Hz, respectively in order to remove environment and electrical noises.

III.3 The effect of the combination of input channel

A. The combination of symmetric input channels

A.1. One source of EOG

When the combination of input channels (see Fig. 2) is symmetric (such as LOC, ROC, Fz, Cz), in most cases, SOBI provide a single channel of EOG because the effect of two sources toward the combination of channels is similar. Using SOBI with input as a combination of four mentioned channels, four sources as shown in Fig. 3 are separated. Among them, Source 1 is EOG artifact [9].

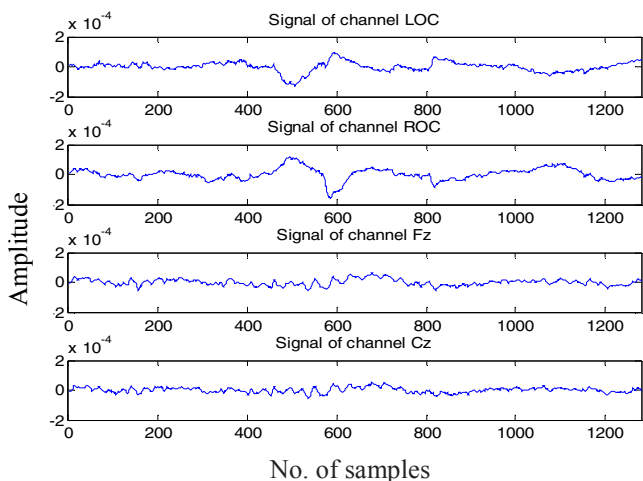


Fig 2. Signal of the four input channels

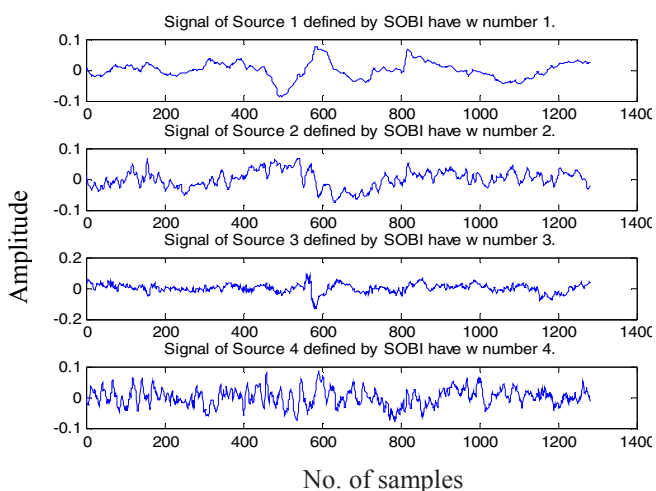


Fig 3. Signal of four sources that SOBI separated.

In order to eliminate EOG artifact, we subtract the identified EOG from the input signal, then multiply with the estimated coefficient on each channel. Consequently, the EOG artifacts were decreased as shown in Fig. 4.

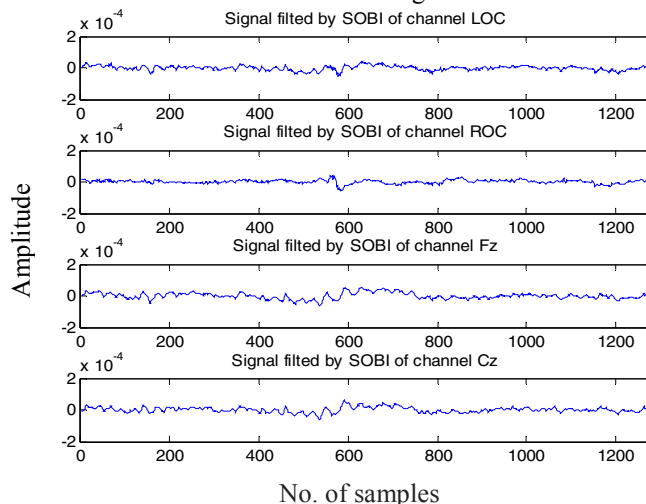


Fig 4. Signal after subtracting artifacts

A.2. Two sources of EOG artifacts.

In a few cases, the combination of symmetric inputs (see Fig. 5) can provide two sources because the activity of the two eyes are not the same, and the difference between two EOG sources can be observed in the time or the frequency domains.

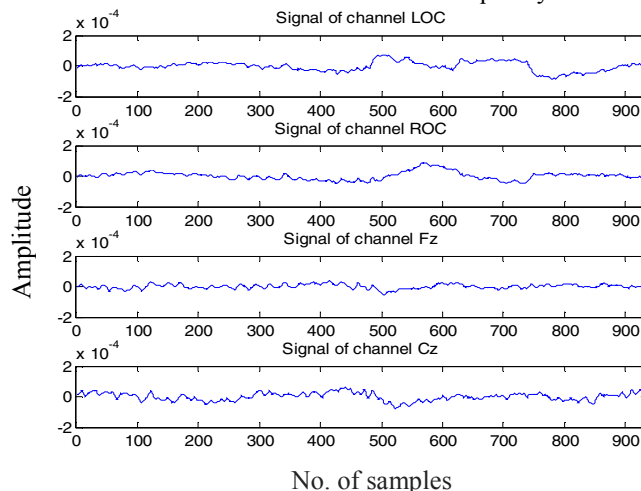


Fig 5. Signal of four input channels.

With the same combination of input channel (LOC, ROC, Fz, Cz). However, with data of different patients, SOBI identified two different EOG sources as shown in Fig. 6 (source 1 and source 2). After subtracting these EOG sources, the channel affected by EOG artifact was more clean, other channels (Fz, Pz) were also removed EOG successfully (see Fig. 7).

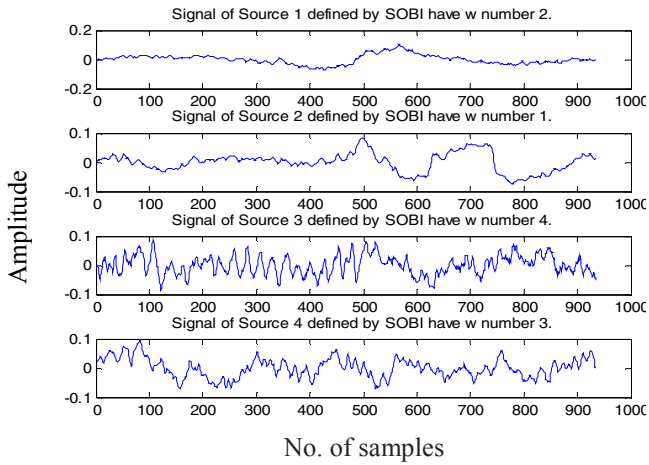


Fig 6. Four signal of SOBI source separation.

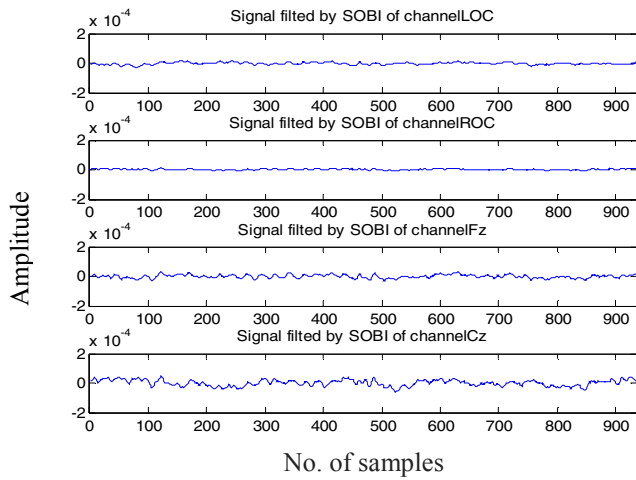


Fig 7. Signal after subtracting two sources.

B. Asymmetrical input combination

When the input combination is asymmetrical such as LOC, ROC, Fz, F7 (see Fig. 8), in most cases, SOBI will separate the two sources of EOG because the impact of two EOG sources on the input combination is different. In Fig. 9, SOBI identified and separated two EOG sources: 1 and 2.

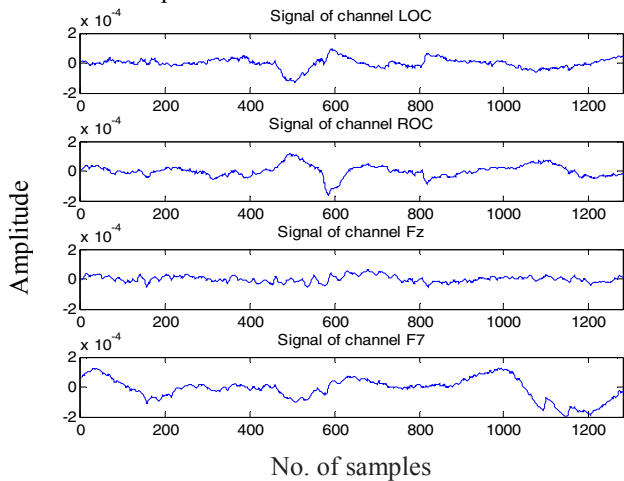


Fig 8. Signal of four input channels

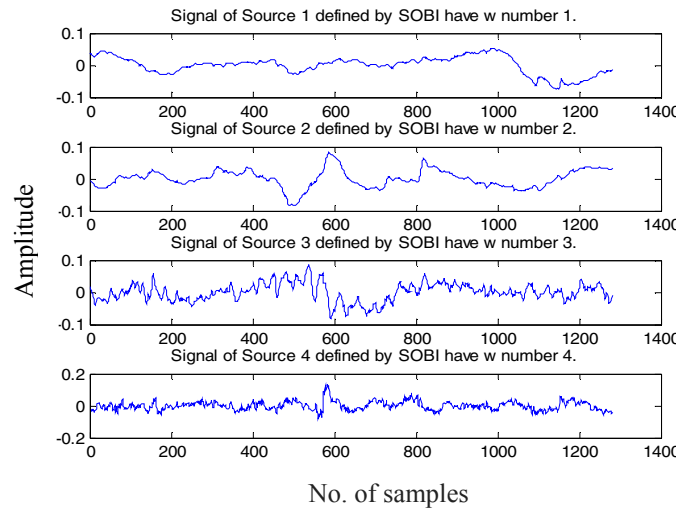


Fig 9. A signal of four sources identified by SOBI.

Figure 10 shows the signals after removing EOG from two identified sources.

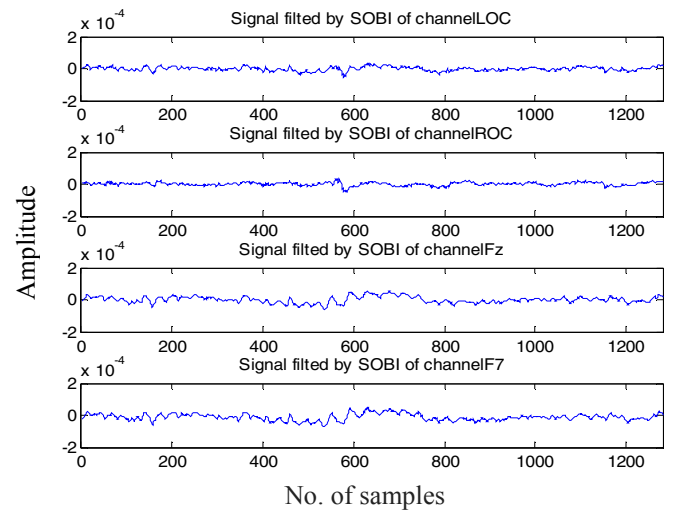


Fig 10. Signals after subtracting two sources of EOG.

III.4 Evaluation of EOG removal

The ratio R^2 is used to determine the performance of our propose algorithms in removing EOG artifacts from recorded EEG signals [11]

$$R^2 = \frac{\sum_{n=1}^N (y(n) - \hat{s}(n))^2}{\sum_{n=1}^N \hat{s}(n)^2}, \quad (8)$$

where $y(n)$ is the measured EEG signal, $\hat{s}(n)$ is the estimated EEG signal, and N is the number of samples.

It can be seen that the higher value of R^2 means that the proposed algorithms are more accurate. Nevertheless, in case the EEG signal that does not contain artifacts, the higher value of R^2 will cause of removing the useful EEG signal. Therefore, the applying our intelligent source identification technique to detect exactly the number of artifact sources is

very important to enhance the performance of our proposed algorithms. In Fig. 11, the inputs have one EOG source. If we eliminate one artifact source, the reconstructed signal on Fz and Pz channels are good enough. Nevertheless, if we subtract 2 artifact sources of EOG, it will be a falsify in Fz and Pz signals because the useful part of signals were removed.

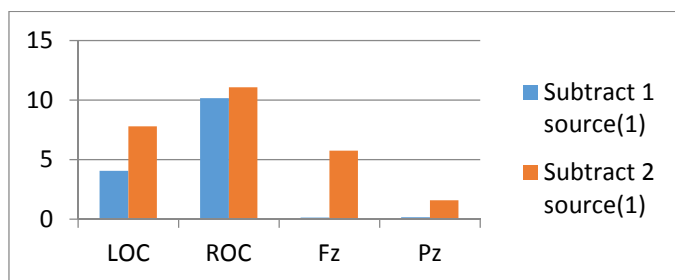


Fig 11. R^2 ratio after eliminating sources in case the inputs have one EOG sources

In Fig. 12, the inputs have two EOG sources. If we eliminate one artifact source only, both of two EOG channels are subtracted only a small amount, there are still a lot of eye artifacts. When we subtract 2 artifact sources of EOG, signals will be cleaned after removing it.

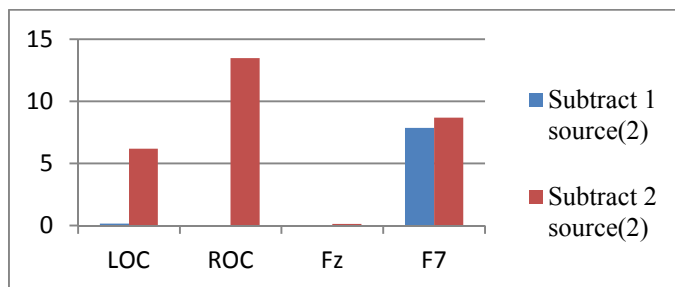


Fig 12. R^2 ratio after eliminating sources in case the inputs have two EOG sources.

For the combination of symmetric channels, when the combination of channels is similar, we should use one source subtracted. Nevertheless, when the activities of the two eyes are not the same in the combination of symmetric input, we should use two sources subtracted.

For the combination of asymmetric channels, if the impact of two EOG artifact sources on input combination is different, signals after subtracting two artifact sources will get rid of artifacts.

IV. CONCLUSION

In this paper, we propose a new method to identify and eliminate eye artifacts using SOBI algorithm. The experimental results showed that our proposed method

effectively improved the removal of EOG artifact, and detected exactly the number of the artifact sources that SOBI algorithm can separate. We also traced the eye artifacts on the whole of patient's data length, not just a segment of it. Nevertheless, it is still doubtful that how much the artifact filtering process may affect the EEG signals. In the future, we will continue to address this problem and develop the algorithms to increase the productivity of the elimination of eye artifacts.

ACKNOWLEDGMENT

The authors would like to thank Prof. Nguyen Linh-Trung for his willingness to allow us to use his experimental data.

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