Journal of Biomimetics, Biomaterials and Biomedical Engineering
ISSN: 2296-9845, Vol. 23, pp 9-17
doi:10.4028/www.scientific.net/JBBBE.23.9

Submitted: 2014-11-25
Revised: 2015-03-20
Accepted: 2015-03-23
Online: 2015-06-09

Discussion of Approach for Extracting Pure EOG Reference Signal from EEG Mixture Based On Wavelet Denoising Technique

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Keywords: Blind source separation (BSS), Electroencephalogram (EEG), Electrooculogram (EOG), Artifact rejection, wavelet denoising.

Abstract. Several problems in EEG-brain signal analysis are not solved, such as presence of an artifact during the recording process, particularly the eye artifact (ElectroOculoGram (EOG)) which makes the analysis of EEG-brain signals very difficult. Blind source separation technique is one of the important techniques used to clean the EEG signals from different types of artifacts. Independent component analysis (ICA) techniques are widely used for this purpose, but unfortunately the ICA techniques have inherent shortcoming such as source ambiguity and unordered components. Therefore, the researchers used ICA-Reference algorithm. The main problem in ICA-Reference algorithm is to find clean reference signal to extract the wanted signal. Recently, many algorithms proposed to generate the artifact reference, but unfortunately, clean artifact signal not satisfied. In this paper wavelet denoising technique is used to solve this problem by decompose the artifact reference signal into pure artifact signal and residual neural signal. The proposed algorithm used frontal channels instead of EOG channels to extract the EOG reference signal.

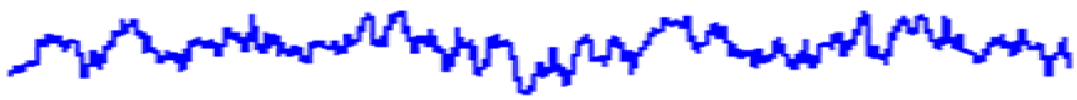
Introduction

Eye blink artifacts are common artifacts in the EEG signal analysis. These artifacts have been high-amplitude greater than the EEG signals by many times with spike's shapes and interfaced with all electrodes even those at the head back. The effect of the ocular artifacts will be dominant in the frontal and frontopolar channels like FP1, FP2, F7, and F8 [1, 2]. EOG channel method is the classical way to measure the ocular artifact from human eyes by using a pair of electrodes named EOG electrodes above and around the eyes. Unfortunately, the EOG electrodes are contaminated by other signals produced from the brain or external sources [3]. The classical method is widely used to evaluate the performance of the eye blink artifact removing algorithms by comparing the extracted eye blink artifact with vEOG channel as well as a constrained signal in blind source separation techniques to enhance the separation process. A modification for the classical method was presented in [4] based on the morphologies and relative timings of the contaminating electrodes to extract the eye blink reference from EEG electrodes. This modification takes the EEG channel that is most considered as the eye blink artifact then filter it to produce a reference signal for the artifact under the assumption that the variation in the rest of channels is insignificant [4]. Unfortunately, in this method the residual neural signals remain in artifact reference signal. Constrained Blind source separation (CBSS) attempts to separate the wanted signals based on constrained or reference signal; the separation result based on CBSS is inadequate if the reference signal is contaminated by other signals. Wavelet transforms (WT) is a common technique to analysis the signal. It's let signal decomposition on multiple scales with further analysis of the wavelet coefficients. WT is used for analysis EEG mixture in different situations such as seizure detection, epilepsy, event-related potentials, mental tasks, and separation of a fetal heart beat from mother [5]. Wavelet denoising technique is used to enhance the performance of the independent component analysis of raw EEG mixture as explained in [6]. Good artifact removal algorithm is described in [7] to remove automatically the short duration and high-amplitude artifacts from EEG mixture. Encouraging results obtained by [7] and [5] to remove the EEG artifacts based on wavelet-ICA algorithm. In this paper, an efficient eye blink artifact reference algorithm called enhanced channel-reference is discussed based on the filtering process and wavelet denoising technique to obtain a pure artifact reference signal.

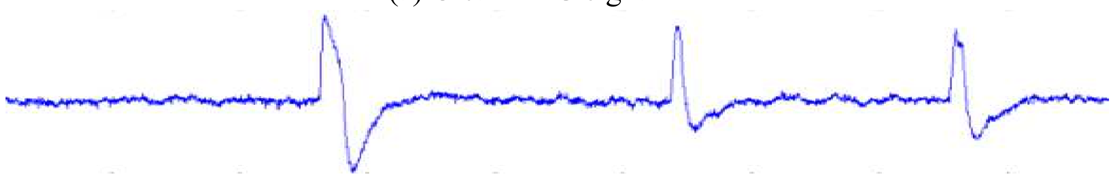
EOG Artifacts

Electroencephalogram (EEG) is designed to record the brain signals; but it is also record the electrical activities arising from other sites. EEG signal is a random weak amplitude signal (Fig.1a) compared with the artifacts [1]. The recorded activity that is not of cerebral origin is termed artifact and can be classified into: (i) Technical Artifacts (such as : power line noise interference, electrode artifact, and sweating) and (ii) Biological Artifacts (such as: Electroocularigram EOG, Muscle Activity artifact MEG, and Electrocardiogram ECG artifact) [8]. Generally, the artifact signals have much higher amplitude compared with EEG signals and the amplitude of the artifacts in different channels is varying significantly. One of the most important characteristics used to detect the artifact signal is that the EEG and artifacts are not orthogonal [9].

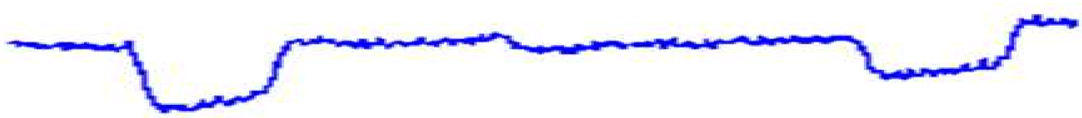
ElectroOculoGram (EOG) or ocular artifact (OA) is a very common artifact in EEG signal analysis, produced due to eye blinking or eye movements. Eye blinking generates a high-amplitude signal and greater than the EEG signal by many times. It is interference with all electrodes even those at the back, particularly the effect of ocular artifacts will be dominant in the frontal and frontopolar channels like Fp1, Fp2, F7, and F8 [1, 10]. The ocular artifacts can be measured by pairs of electrodes named EOG electrodes placed above and around the eyes. Eye movement artifact is produced by the reorientation of the retinal corneal dipole [11]. It has a stronger effect but often occurred at close intervals with an eye blinked. Unfortunately, EOG electrodes also interference with brain signals, therefore, a subtraction process form EEG signal is not a removal option [12]. Eye blinks has spike's shape (Fig.1b), while eye movements have a square shapes as shown in Fig.1c.



(a) Clean EEG signal



(b) EEG contaminated by eye blinks



(c) EEG contaminated by Eye movement

FIGURE 1. EEG signals and EOG artifacts waveforms

EOG Channels and Artifact-Reference Methods

EOG electrodes (vEOG and hEOG) are used to measure the face activity (artifacts) and used as a reference in EEG signal analysis. These electrodes paced above and on the side of the left eye socket as shown in Fig. 2.

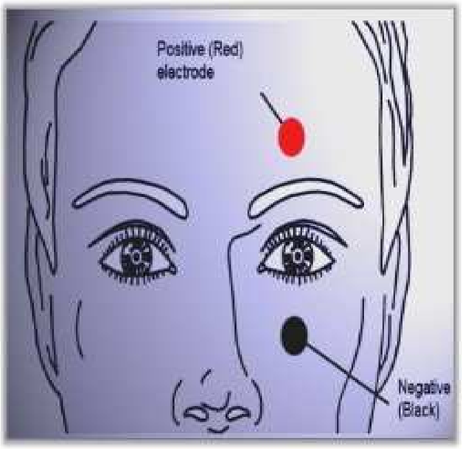


FIGURE 2. EOG channels placement over single eye for the EOG recording

EOG channels are widely used as a reference signal of the ocular artifact in constrained blind source separation techniques or used to measure the performance of the removing techniques by compare the separated components with EOG signals [3]. Unfortunately, EOG electrode are contaminated by another signals produced from brain or external sources [3]. Two common methods are used to generate the EOG artifact reference:

(i) Channel-reference signal
(ii) Principle component- reference

In Channel-reference signal, the artifact reference signal is generated based on the application area in the brain and the type of the extracted signal. In EEG analysis, the traces of artifacts are available at some instance, such as the morphologies and relative timings of contaminating eye blink artifacts, which can be derived from the recorded EEG data. In this method, the EEG channels (such as Fp1 or Fp2) are filtered to produce a reference signals for the artifact under the assumption that the variation of eye blinking in the rest channels is insignificant [4]. Unfortunately, in this method the residual neural signals remain in the extracted artifact. This method was named the channel-reference signal which governed by:

$$r_i(t) = f\left(q_j\,(t)\right)\ i = 1,2,\dots,k, j = 1,2,\dots l, \tag{1}$$

Where *i* is the number of reference signals used, *q* is the recorded signal, *j* is the channel number, *l* is the total number of channels recorded, and *f* is the filtering process.

The second method which called principle component- reference is based on the data projected on the major principle components in EEG analysis. Principle component analysis PCA is a second-order statistic's techniques used to find the orthogonal components. The Performs of the ICA significantly better than PCA for the artifact removal in EEG spike data as detonated in [13]. With any techniques used to decompose EEG signals on the basis of variance in the independent components the projected data should represent the general features of the artifacts. For EEG mixture contaminated EOG artifacts, the EEG data projected onto the major principal components (highest eigenvalues) then the projected data represent the general features of the EOG artifacts. In this method, the data projected on the major principle components are used as reference signals for EEG mixture contaminated by eye artifacts as demonstrated in [4]. This method is governed by [4]:

$$pc(t) = E^T x(t) \quad \text{with } pc(t) = \begin{bmatrix} pc_1(t) \\ pc_2(t) \\ \vdots \\ pc_n(t) \end{bmatrix} \tag{2}$$

$$r_i(t) = pc_i(t) \qquad i = 1,2,\dots,k \tag{3}$$

Where E is an eigenvectors matrix of the covariance matrix of X, pc is a vector of projections on the eigenvectors, and i is the number of principal components selected.

Proposed algorithm

A novel proposed approach called Enhanced Channel-Reference algorithm is discussed to extract pure eye blink artifact signal based on a combination between filtering process and wavelet denoising technique. The proposed algorithm takes the artifact distribution on the brain's scalp in the account. Fig.3 shows the block diagram of the proposed work.

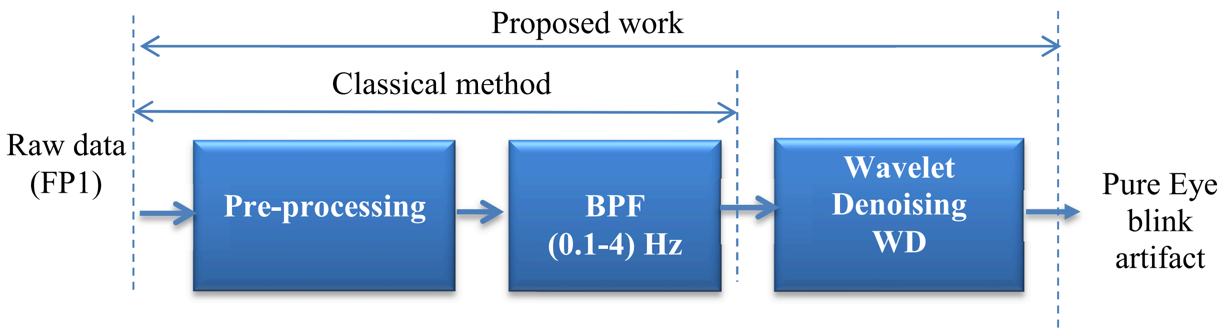


FIGURE 3. Block diagram of the proposed approach: Enhanced Channel-Reference algorithm

The effect of ocular artifacts will be dominant in the Frontal and Frontopolar channels, particularly in Fp1 and Fp2 [10]. The eyes are blink together and have the same effect on frontal channels Fp1 and Fp2; therefore we take Fp1 channel as an input signal to the proposed algorithm. The preprocessing technique is used to simplify the algorithm. Band-pass filter (BPF) is implemented by a Windowed-Sinc FIR filter to narrow the eye blinking artifact in a limited frequency band. The eye blink artifact lies within Delta's rhythm frequency range (0.5 to 4 Hz), therefore, we chose BPF with frequency range (0.1- 4Hz), the filter kernel length M of 1024 calculated according to:

$$M \approx \frac{4}{BW} \tag{4}$$

Where, BW is a width of the transition band.
A Blackman window has been used in this implementation. The filter kernel of the low-pass filter is calculated according to:

$$h[i] = K\frac{\sin(2\pi f_c(i-M/2))}{i-M/2}\left[0.42 - 0.5\cos\left(\frac{2\pi i}{M}\right) + 0.08\cos\left(\frac{4\pi i}{M}\right)\right] \tag{4}$$

Where h[i] is a filter kernel; K is a filter gain; M is the kernel length filter; fc is a cut-off frequency; and i is the index.
Calculating algorithm of the band-pass filter with cut-off frequencies of fc_1=0.1 Hz, fc_2=4Hz and the sampling rate 256 Hz is shown below [14]:

(a) Initialization: Let M=1025, S_{rate}= 256, f_1= fc_1/S_{rate} , and f_2= fc_2/S_{rate}.

(b) Calculate low-pass filter kernel at f_1
(c) Calculate low-pass filter kernel at f_2
(d) Normalize both filter kernels
(e) Change the low-pass filter kernel to high-pass filter using spectral inversion
(f) Add the low-pass filter kernel to the high filter kernel to obtain a band-reject filter kernel
(g) Change the band-reject filter kernel to a band-pass filter using spectral inversion.

The filtered signal is obtained by convolve the input signal with the filter kernel using (conv) command in Matlab.
Wavelet technique is used to enhance the performance of the filtering process by removing the residual neural signal in recorded-filtered signal. The filtered signal had a considerable amount of brain activity (such as Delta rhythm). After WD, the filtered signal can be splinted into low amplitude residual neural signal n(t) and a high-amplitude artifact a(t):

$$F_{p1f}(t) = a(t) + n(t) \tag{5}$$

Where F_{p1f} is a filtered frontal channel signal (i.e. a signal after BPF). The artifact a(t) is localized in the time and/or in frequency domains, but n (t) is a broad-band spectrum. The wavelet decomposition technique is suitable to obtain an optimal resolution in time and frequency domains, without requiring the signal stationarity [5]. Wavelet denoising WD is used to remove the cerebral electivity n(t) without losing any part of an artifact a(t) as described below:

- ❖ Compute wavelet coefficients $a_{j,k}$ by discrete wavelet transformation of $F_P1(t)$ channel.
- ❖ Soft threshold for wavelet coefficients:

$$\hat{a}_{j,k} = \begin{cases} \mathrm{sgn}(a_{j,k})(|a_{j,k}| - T) & \text{if } |a_{j,k}| \geq T, \\ 0 & \text{if } |a_{j,k}| < T. \end{cases} \tag{6}$$

- ❖ Compute inverse discrete wavelet transformation $\tilde{a}(t)$ of the soft coefficient $\hat{a}_{j,k}$

Where $\tilde{a}(t)$ represent the artifact signal a(t) without neural signal n(t). Level seven decomposition with the Daubechies wavelet ψD6 is applied in the proposed algorithm. The threshold value for denoising is calculating by:

$$T = \sqrt{2\log(d)} \tag{7}$$

Where d is the number of samples to be processed.

Experimental Result

Real EEG signals measured by computerized EEG (Fig.4) are taken in this study. The EEG signals are contaminated by eye blink artifacts. The signals are measured from healthy volunteer, male, 24 years old, 19 electrodes sited on the scalp based on 10-20 system (Fig.5), digitized at 256 Hz, and the volunteer is allowed to do eye blink artifacts. Figure 6 shows the contaminated frontal channels (Fp1 and Fp2) signals, the trail length is 10 second ($10\text{ second} \times 256\text{ Hz} = 2560\text{ sampls}$). The eye blink artifacts in frontal channels are approximately smiler and symmetric, because the eyes blinking together. Therefore, only Fp1 channel is taken as input for the proposed work.

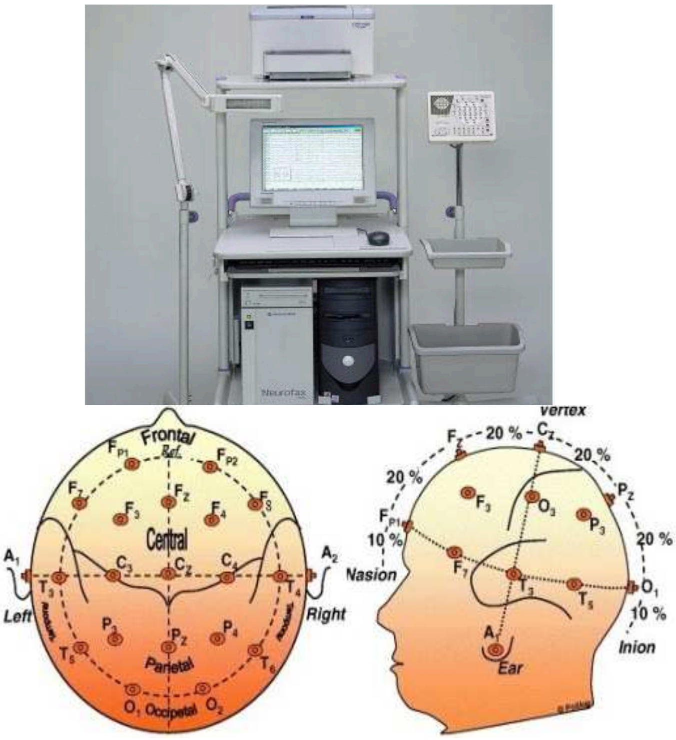


FIGURE 5. Electrode placement over the scalp

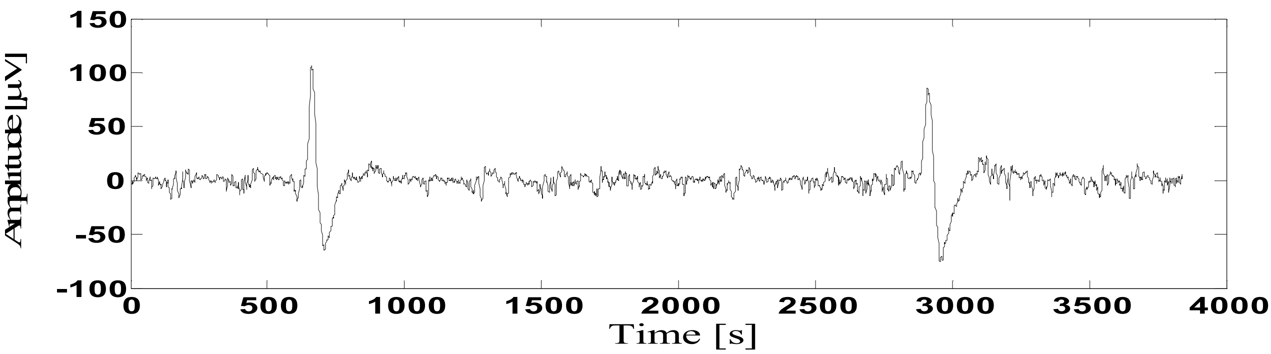


FIGURE 6. Raw Fp1 signal

Fig.7 illustrates the decomposition of Fp1 signal into artifactual and neural parts based on the proposed algorithm. Fp1 signal is passed through a pre-processing block for centring and whitening the signal as shown in Fig.7A, then the signal is filtered (Fig.7B) by BPF (0.1-4) Hz as mentioned above in the proposed algorithm section. According to classical method (Channel- Reference method) assumed the filtered signal cannot include any cerebral activity and identified as an eye blink artifact [4]. However, in fact, it is not a pure reference signal because it has some considerable amount of cerebral activities (Fig.7C). This is the main advantage of the proposed algorithm, i.e. the cerebral activities will be removed from the artifact reference signal by wavelet denoising WD (Fig.7D).

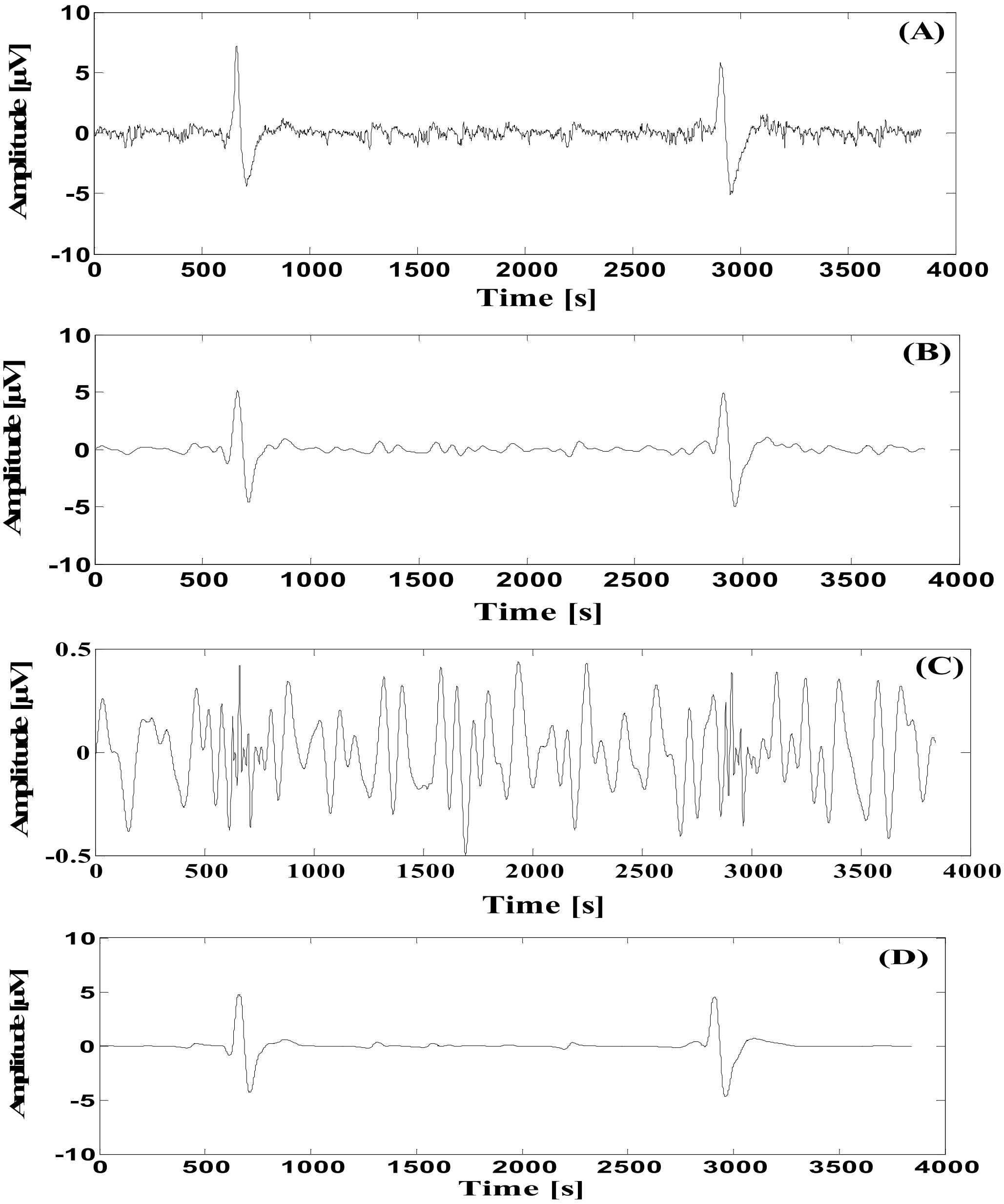


FIGURE 7. Decomposition of FP1 channel

(A) Original FP1

(B) Filtered FP1 (Classical method))

(C) Underlying signal leaked into the filtered Fp1

(D) Pure artifact signal (proposed algorithm)

Visual inspection of the eye blink artifact signals confirms that the proposed way is better than the classical way as shown in the zoomed signal (Fig.8A), where in the classical method some of the neural activities are observed as shown in (Fig.8B).

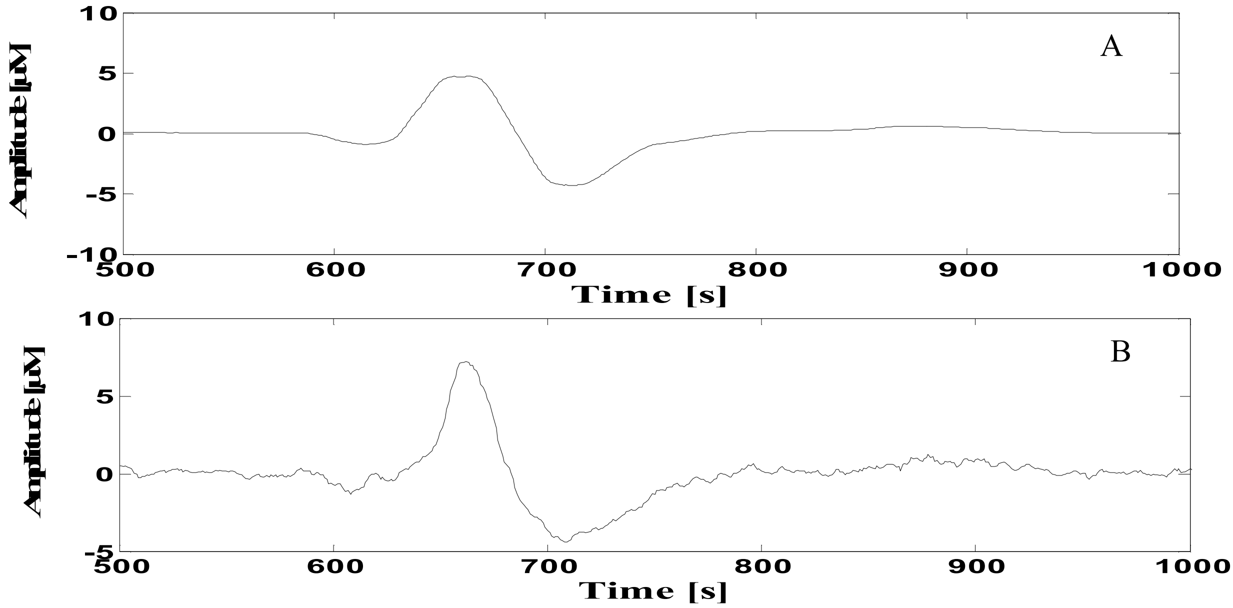


FIGURE 8. Zoomed signals (500-1000 second) from

(A) Proposed way

(B) Classical way

Conclusion

Clean and pure eye blink artifact reference from frontal channel (Fp1) has been obtained in the proposed work. We can use this reference directly as a constrained in blind source separation technique for separating the eye blink artifact in EEG signal analysis. Another advantage of the proposed work is dispensing the additional electrodes (i.e. EOG electrodes). The results achieved by this work are encouraging for other types of artifacts such as ECG and EMG artifacts.

For future work, the pure artifact reference which obtained from proposed work can be used directly as a reference in ICA with a Reference (ICA-R) technique to extract the EOG artifacts from mixtures. Where in EEG signal processing, if some information about the data components is available, then can be easily formulated and extracted the desired signal by a reference signal.

Acknowledgments. This work was supported by the National Natural Science Foundation of China (Grant No.61172159) and the Fundamental Research Funds for the central Universities (HEUCFT1101).

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