Ballistocardiac artifact removal from the electroencephalogram recorded in fMRI with adaptive window size and different delay

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Introduction

Ballistocardiogram (BCG) signals caused by the heart beat of the subjects, which reflect artifacts in all EEG channels, is one of the difficult problems in measuring and interpreting electroencephalogram (EEG) signals. A BCG signal is BCG-dominant signal that can be used as a reference signal for the detection of heart beats signal. Especially when the EEG is simultaneously measured with functional MRI (fMRI), it can be more serious. Due to this reason, the removal of BCG artifact is quite essential in carrying out researches with simultaneously measured EEG and fMRI. One of the approaches to solve these problems is the mean subtraction method, which averages BCG artifacts by a specific window size, the width of one averaging BCG artifact, and delay, the difference between a plus peak in BCG signal and a plus peak in BCG artifacts. As an improvement to this approach, we propose an approach using different window sizes and delays.

Methods

As a pre-processing, Delta (1~4Hz), Theta (4~8Hz), Alpha (8~13Hz), and Beta (13~35Hz) signals are obtained from EEG and EOG channels by band-pass filtering (0.5~55Hz). Using K-teager energy operator (TEO) as defined in eq.(1), the peaks of BCG signals are detected.

$$\psi_k\{x(n)\} = x^2(n) - x(n-k)x(n+k)$$, where x(n); signals from all channels (1)

Using 10-TEO with empirically determined k (k=10), we found the plus peaks of BCG signal obtained from EOG channel. For determining the precise position of a peak, we thresholded the plus peaks of BCG signal with the median value acquired from 10-TEO. Then, we searched for the position corresponding the maximum value of the plus peaks in the BCG signal. To decide adaptive window size, the minus peaks in the BCG signal were additionally detected using the same process. Since it was inappropriate to apply the same method for minus peaks due to TEO-s characteristics, BCG signal was inversed and flipped. From the information of two precise positions, we could define the window size, which is six times the distance between the plus and the minus peaks. Then, to calculate each delay, we found the plus peaks of BCG artifact in EEG channel using TEO and subtracted the position from that of the BCG signal. With previously acquired window sizes and delays, the signal (artifact-free EEG signals + BCG artifacts) in the EEG channel was averaged 10 times and the averaged signal was subtracted from the signal (artifact-free EEG signals + BCG artifacts) in the EEG channel. Note that we assumed the BCG artifact in EEG channel is sufficiently larger than the actual EEG signal.

Results

To apply the proposed method, we made a simulation wave by compounding Alpha wave in EEG signal and BCG artifact that has different window sizes and different delays between BCG signal and BCG artifact in EEG channel. Figure 1 shows the EEG signal with BCG artifacts including the Alpha wave and the BCG artifact (A), BCG signal (B) and the result from the mean subtraction algorithm with a same window size and delay, which was suggested by Allen et al in 1998 (C). This still has unremoved BCG artifacts left because the artifacts actually have different delays and window sizes. However, the proposed method with different delays and different window sizes has successfully removed BCG artifact and the Alpha wave (D).

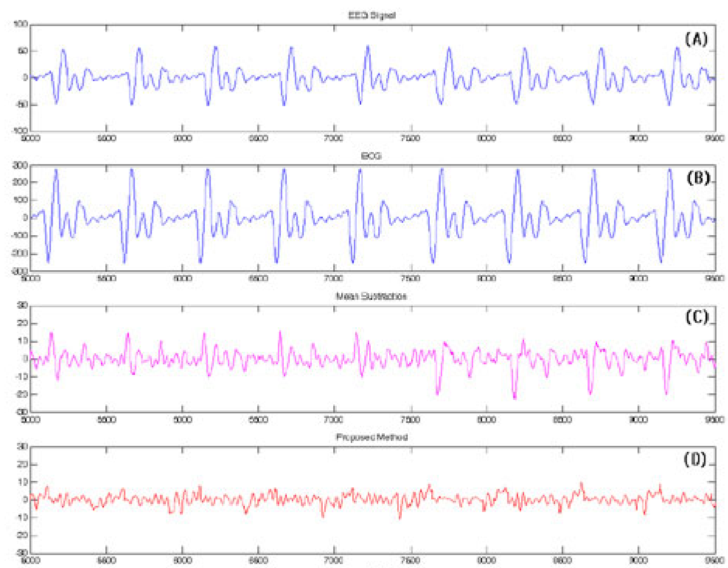

Fig.1 (A) EEG signal with BCG artifacts, (B) BCG signal, (C) Result by mean subtraction (D) Result by the proposed algorithm

Discussions

The proposed algorithm is similar to the mean subtraction algorithm by Allen et al. However, it generates better results because of the high-performance heartbeat detector based on a slight modification of the TEO, which has been proved to be useful for many pulsatile wave form detections. In addition, we applied the adaptive window sizes and different delays. As shown in fig.1, the mean subtraction algorithm of Allen et al. cannot remove the BCG artifact in EEG channel while the proposed method removes it using changeable delays and window sizes. In addition, the proposed method can find the window size from the BCG signal. In summary, we suggest a method to detect the peak of BCG artifact in EEG channel which results in an accurate detection of the delays between BCG signal and BCG artifact in EEG channel. This could also result in the improvement of the EEG signal recorded in MR-scanner by removing BCG artifact.

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References

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