# Principal Subspace Analysis Based BCG Artifact Removal in Single Channel EEG Signal Measured Inside MRI Scanner

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**Abstract.** Single channel EEG analysis is vital for clinical as well as for brain computer interface (BCI) studies. The measured EEG signal contains different artifacts. Among these artifacts Ballistocardiogram artifact is most prominent; it gets amplified when measurements are made inside the MRI scanner making the EEG analysis practically impossible. There are different methods to remove these artifacts from single channel observation. However, these conventional methods either require an estimation of artifact template or reference signal for the artifact. In this study, we propose a method based on principal subspace analysis for BCG artifact removal from EEG signal measured inside MRI. This method does not suffer from any of the above mentioned disadvantages of conventional methods. We have removed the BCG artifacts from both the continuous as well as visual evoked potentials measured inside MRI scanner. The results presented in the manuscript suggest that the proposed method could be used for single channel EEG studies.

**Keywords:** Electroencephalography (EEG), Principal Subspace Analysis (PSA), Artifact Removal, Ballistocardiogram (BCG).

## 1 Introduction

Electromagnetic (EM) brain signals represent the functionality of underlying sources. By combining the two modalities, electroencephalography (EEG) and functional magnetic resonance imaging (fMRI), brain activities can be mapped at superior spatiotemporal resolution. However, one of the limitations is that EEG signal measured inside the MR scanner get significantly corrupted by artifacts: most significant of which are gradient, ballistocardiogram (BCG) and electrooculogram (EOG) artifacts. It is known that the gradient artifact is due to changing fMRI magnetic fields, the BCG artifact due to the tiny movement of EEG electrodes inside the MRI scanner because of the pulsatile changes in blood flow tied to cardiac cycle and the EOG artifact by the eyes movement of the subject. It has been reported that the magnitude of these artifacts is much higher compared with the alpha rhythm of EEG [1] [2].

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Allen et al in 1998 [1], was the fist who proposed a method to remove BCG artifacts. In this method, know as average artifact subtraction method (AAS), an artifact template was obtained by averaging the artifacts per heart beat and then subtracting from the EEG signal. The standard AAS method is the most common technique used in available commercial software for artifact removal. Attempts have been made using this procedure not only for spontaneous EEG but also to recover the visual evoked potentials measured during fMRI [3][4]. One critical requirement for AAS is the simultaneous acquisition of ECG to identify each heart beat. However, as the ECG is a non-stationary signal and is affected by the magnetic field as well, this method is associated with less representative templates. Attempts for real-time artifact removal have also been made. In one such attempt, motion sensors were used to measure the head movements and the adaptive filters were utilized to remove the artifacts [2]. Later Kalman filtering of EEG signals, using EOG channel as reference, for the BCG artifact removal has been done by our group [5]. Usually these adaptive filtering techniques assume known variances and therefore require reference channels for generating the artifacts. A statistical method, independent component analysis have also been applied for artifact removal from multichannel observed EEG signals [6] [7]. However, little work is available for single channel artifact removal using ICA analysis. The interest in sparse signal representation is growing, in which the signals are decomposed into several sparse components. Recently in 2009, Yong *et. al.* [8] presented a technique based on sparse signal representation for artifact removal form single channel EEG.

In comparison to biomedical signals sufficient amount of work is available for single channel audio signal extraction. In 2000, Casey and his colleague introduced independent subspace analysis (ISA) [9] for separation of mixed audio sources. Motivated by ISA; in this study, we propose a method based on principal subspace analysis (PSA) for single channel artifact removal for EEG signal measure inside MRI. The proposed method has a advantage over the conventional single channel techniques; it does not require templates of artifacts or reference signals. Based on the results we believe that the proposed artifact removal method could be an effective tool for single channel EEG studies measured inside MRI.

## 2 Experimental Setup

Continuous as well as Visual evoked potentials upon checker-board reversals (1 or 2Hz) were recorded from four healthy volunteers inside and outside the 3.0T whole body MRI scanner (Magnum 3.0, Medinus, Korea). The volunteers (four men, mean age of 26.6) with no previous history of neurological and psychiatric disturbance were recruited from an academic environment. We used a MRI-compatible 32-channel EEG recording system (BrainAmp MR, Brain Products GmbH, Germany) for EEG data acquisition. The EEG signal was amplified and then transformed into optical signal in the EEG amplifier to be transmitted to the EEG data acquisition system placed outside the MRI shield room. We used the sampling rate

of 1 KHz and the bandwidth of 1-60Hz for band-pass filtering. All the EEG recordings were performed with the standard 10-20 uni-polar system referenced to FCz. Electrode skin impedance was kept below 1KHz. To minimize motion artifact in EEG on the scalp electrode of the subject, we tightly fixed the EEG cap on the scalp using adhesive tapes. Furthermore, to minimize the motion artifacts of the EEG lead wires between the EEG cap and the EEG amplifier, we fixed the lead wires to a supportive structure using plastic ties. The study was approved by the institutional ethics review committee of Kyung Hee University, Korea, and written informed consent was obtained from each subject.

## 3 Principal Subspace Analysis

The principal subspace analysis operates on a assumption that the source mixture signal is composed of $n$ principal sources,

$$c(t) = \sum_{j=1}^{n} c_j(t) \tag{1}$$

The input signal *c(t)* is split into finite-length segments; $c^{(k)}$, where $1 \leq k \leq m$ is the segment index. Each segment is multiplied by a transformation matrix $M$. The absolute value of the transformed segment $k$ produces an observation vector $\mathbf{x} \in \mathbf{R^n}$ and all the frames makes a complete spectrogram. The transformation used is the fourier transform.

$$\mathbf{x}^{(k)} = M^t \mathbf{c}^{(k)} \tag{2}$$

The column of a spectrogram corresponds to spectral slice which is a snapshot of the spectrum at time $k$. Each frame of the input spectrogram can be expressed as a weighted sum of $\rho$ principle basis vectors, $\mathbf{e}_i$. The basis vectors remains constant but their weighted sum reconstructs a spectrogram frame:

$$\mathbf{x}^{(k)} = \sum_{i=1}^{\rho} \mathbf{y}_i^{(k)} \mathbf{e}_i \tag{3}$$

The principal basis are orthonormal, the weight coefficients $\mathbf{Y}$ for all the frames of the spectrogram can be obtained by projecting the input (spectrogram) onto basis components:

$$\mathbf{Y} = \mathbf{E}^t \mathbf{X} \tag{4}$$

The input spectrogram can be decomposed into sums of principal subspaces according to the following equation:

$$\mathbf{X} = \mathbf{e}_1 {\mathbf{y}_1}^t + \mathbf{e}_2 {\mathbf{y}_2}^t + \ldots + \mathbf{e}_n {\mathbf{y}_n}^t \tag{5}$$

Each spectrogram $\mathbf{X}_j = \mathbf{e}_j \mathbf{y}_j^t$ corresponding to a subspace, obtained from a set of basis vectors, is transformed back by inverting the transformation carried out by Equation 2.

$$\mathbf{s}_j = M^{-1} \mathbf{X}_j \tag{6}$$

By all the above mentioned procedure we have divided the single mixture into number of components that corresponds to principal subspace in the transformed domain. Grouping of these time domain components is carried out.

$$\mathbf{S}_j = [\mathbf{s}_1, \mathbf{s}_2, \ldots, \mathbf{s}_p], \;\; \mathbf{S}_j \subseteq \{\mathbf{S}\} \tag{7}$$

Finally, the separated source signal are obtained by point to point sum of the signals in each group.

$$\mathbf{c}_i = \sum_{j=1}^{p} \mathbf{s}_j \tag{8}$$

The grouping criteria depends on the application area. In our implementation we have grouped the components into two groups; depending on the ordering of the components.

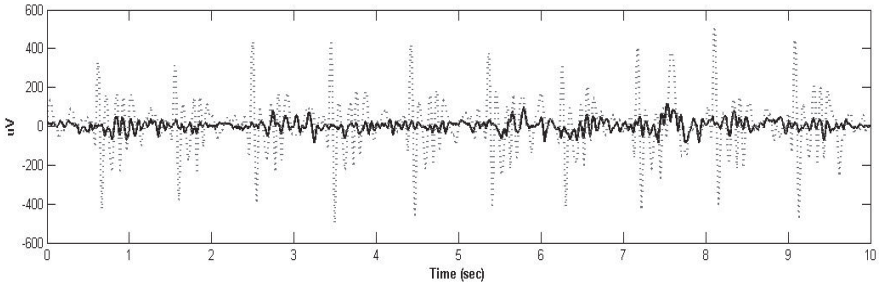
## 4 Results

Single channel EEG signal is segmented and transformed into the frequency domain using the fourier transform. The segments should be short enough so that the segmented signal is stationary. The magnitude and angles are calculated. The magnitude forms the spectrogram that needs to be split and the angle information is used during the inverse fourier transform. Depending on the length of the input EEG signal, data reduction may also be required. In our study we did the data reduction by keeping the 80% of the variance. The input EEG signal is decomposed in to source signals according to the procedure mentioned in the section 3. As the principal subspaces in the spectrogram domain are ordered according to variance, i.e., high variance to low variance or vice versa,that is way the source signals in time domain are also ordered accordingly.

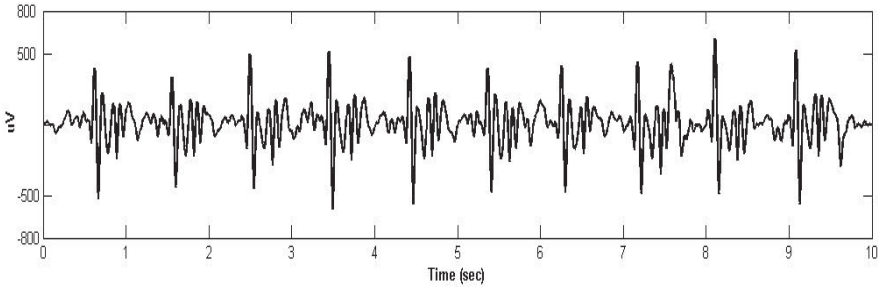
The BCG artifacts are due to pulsatile changes in blood flow tied to the cardiac cycle inside the MRI scanner. These artifacts have high amplitudes (variance) as compared to the normal EEG. Therefore, the first two to three source signals (i.e., components that corresponds to high variance) can capture these artifacts and be placed into the first group. The rest all components are placed into the second group.

### 4.1 Continuous EEG

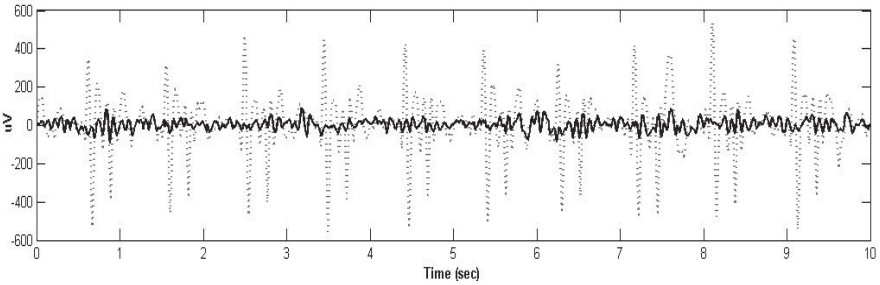
Figure 1, shows the results of BCG artifact removal from two representative channels O9 and O10. Figure 1(a), shows the original channel O9 (gray) overlayed with the signal after artifact removal (dark). Figure 1(b), shows the recovered BCG artifact signal. Similarly, Figure 1(c) shows the original channel O10 (gray) overlayed with the signal after artifact removal (dark) and Figrue 1(d) shows the recovered BCG artifact. The results clearly depicts that the BCG artifact is well extracted by the proposed method.



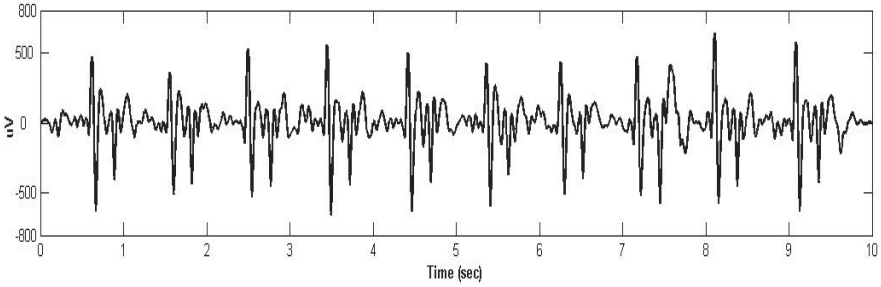

(a) Channel O9, before (gray) and after (dark) artifact removal




(b) Extracted BCG signal from channel O9

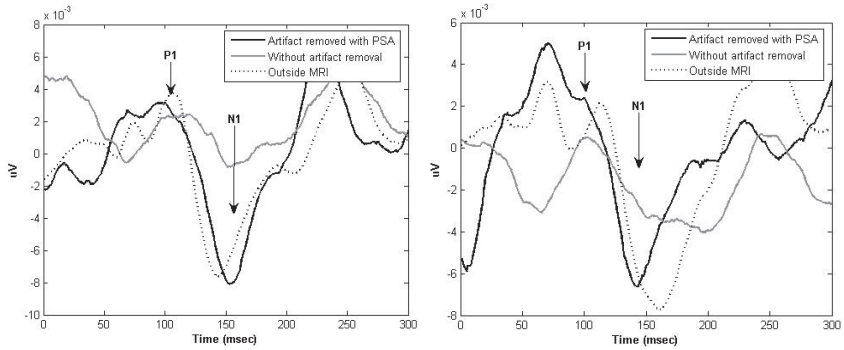



(c) Channel O10, before (gray) and after (dark) artifact removal

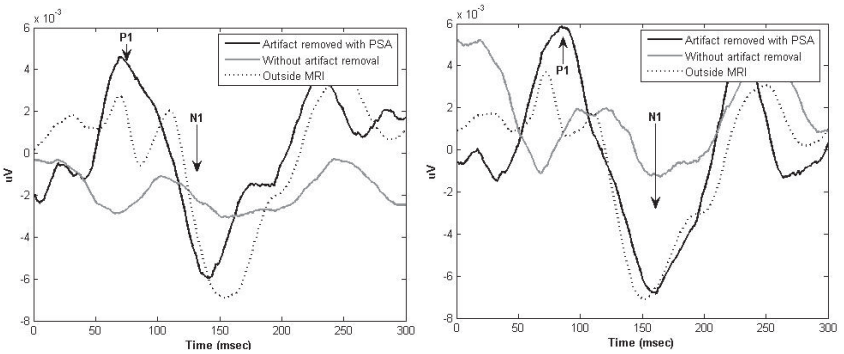



(d) Extracted BCG signal from channel O10

**Fig. 1.** Channels O9 and O10, signals before (gray) and after (dark) artifact removal and the extracted BCG signal




(a) VEPs from channel P4, cc= 0.85 (b) VEPs from channel O9, cc=0.65




(c) VEPs from channel O10, cc=0.82 (d) VEPs from channel P8, cc=0.80

**Fig. 2.** Comparison between VEPs obtained after artifact removal (solid), without artifact removal (gray) and outside MRI (dotted)

### 4.2 Visual Evoked EEG

In the case of evoked potentials, EEG signal was averaged according to the event timings after artifact removal. The recovered VEP is compared against the VEPs from the EEG signal acquired outside MRI (taken as the gold standard) under the identical experimental settings. The VEPs from some representative channels, before and after artifact removal against the outside VEPs are shown in Figure 2. The results clearly shows that the VEPs obtained after artifact removal are much similar to those of outside MRI VEPs. The computed cc (correlation coefficient) values indicate a high similarity between the after artifact removed VEPs and outside MRI VEPs. It is clear that the recovered VEPs are much similar to the outside VEPs. The P1ŰN1 complex is also detected in all cases.

## 5 Discussion and Conclusions

In this study, single channel artifact removal method is presented. The proposed method decomposes a mixture signal into a number of signals based on

principal subspace analysis. Grouping these signals according to some criteria separate the mixture signal into constituents. The proposed method does not require any template or reference signals thus overcoming the already described disadvantages posed by conventional methods. In this study we presented the idea, in future we plan to compare its performance with already existing methods and to extend this method for EEG measured outside MRI scanner. Based on the results we believe that the proposed methods may be an effective tool for EEG analysis.

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