Reduction of Ballistocardiogram Artifact Using EMD-AF

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Abstract. Concurrent acquisition of functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) is widely used to monitor the neuronal activities of brain. However, this simultaneous recording suffers from complex artifacts. The Ballistocardiogram (BCG) artifact in specific, is as yet poorly assumed, appears to be more challenging and hinders to exploit the full strength of both modalities. In this paper, a hybrid method is implemented which combines Empirical Mode Decomposition (EMD) with Adaptive Filtering (AF) using notch filter to reduce the BCG artifact. Results of this study demonstrate that the proposed algorithm is generally useful and effective for the reduction of the BCG artifact.

Keywords: Simultaneous EEG-fMRI, Ballistocardiogram artifact, Empirical Mode Decomposition, Notch Filter.

1 Introduction

The quality of Electroencephalography (EEG) that can be attained from simultaneous acquisition with Functional Magnetic Resonance Imaging (fMRI) is still an on-going matter of investigation. The reduction of artifacts from EEG signal is essential to ensure full use of strengths of simultaneous acquisitions. The artifact which appeared to be more challenging for researchers to combine the strengths of EEG and fMRI is Ballistocardiogram (BCG) artifact which represents complex, non-linear and non-stationary characteristics [1].

The BCG artifact arises when the active circulatory system (endogenous contribution) interacts with the static magnetic field inside the MRI scanner (exogenous contribution) [2]. Ballistocardiogram artifact effect adds in the frequency range of the conventional EEG data, with the amplitude of 50μV (at 1.5 Tesla). Moreover, the BCG artifact is very similar to spikes of epilepsy [2]. It has duration of ~500 ms starting from Q wave of the Electrocardiogram (ECG). It has a rather complex and dynamic influence on the EEG signals.

Numerous researchers have proposed different methods for reduction of BCG artifacts. These include averaging [3], [4], adaptive filtering [5], Independent Component Analysis (ICA) [6], Principle Component Analysis (PCA) [1], [7], [8] and joint

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methods [4], [9]. The very first work on BCG removal was anticipated by Allen et al. [3]. They obtained a template window of artifact for each channel by calculating the average of the artifact per cardiac beat. The method was named as Average Artifact Subtraction (AAS). Bonmassar et al. in 2002 [5] used the adaptive Kalman filters and utilized motion sensors to measure the head movements to reduce BCG artifact.

The spatial methods like ICA and PCA have been suggested after their success in removal of ocular artifacts [7]. In the assessment of ICA, Optimal Basis Set (OBS) and OBS-ICA approaches performed by Debener et al. [8], it was observed that OBS and OBS-ICA provides better reduction of artifact.

Researchers also used other techniques, such as Kim et al. [9] who used a joint method based on wavelet denoising and filtering using adaptive recursive filters as post processing. Likewise, Adaptive Noise Cancellation following Optimal Basis Set is used by Niazy et al. [4]. In spite of several efforts to find an appropriate methodology for removing BCG artifact, quite a significant inconsistency exists between EEG-fMRI studies [8]. In this paper, a hybrid technique has been employed, in which the BCG artifact is reduced using Notch filter after applying Empirical Mode Decomposition (EMD).

The rest of the paper is organized as follows: Section 2 gives the theoretical background of the proposed method. The methodology is discussed in the section 3 and the results are presented in section 4 with validation. Section 5 consists of conclusion and future work.

2 Background

2.1 Empirical Mode Decomposition (EMD)

EMD was introduced to deal with both the nonlinear and non-stationary data. Unlike almost all existing methods; EMD is spontaneous, adaptive and does not require prior knowledge. The decomposed basis is based on, and results from the original signal [10]. The decomposed components are known as Intrinsic Mode Functions (IMFs). The IMFs have time-varying frequencies and amplitudes [10]. By definition the component will be called as IMF, if it satisfies two conditions which are as follows:

1. In complete dataset, the sum of total number of local maxima and local minima equals the number of zero crossings or their difference is at most one.
2. The local mean of lower and upper envelope is zero.

The IMFs can be extracted from original data using sifting process [10], described as;

1. Locate the local maxima and local minima of the original signal $X(t)$, and interpolate the extreme points via splines to obtain upper and lower envelopes.
2. Calculate the mean of two envelopes, m_1.
3. Obtain $h_1 = X(t) - m_1$ and inspect the conditions for IMF.
4. If not, repeat the sifting process to obtain $h_{1k} = h_k - m_{1k}$.
5. If h_{1k} constitutes an IMF, then designate it $c_1 = h_{1k}$.
6. Now we obtain the first residual r_1 via $r_1 = X(t) - c_1$.