# Removing ECG Artifact from the Surface EMG Signal Using Adaptive Subtraction Technique

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## ABSTRACT

**Background:** The electrocardiogram artifact is a major contamination in the electromyogram signals when electromyogram signal is recorded from upper trunk muscles and because of that the contaminated electromyogram is not useful.

**Objective:** Removing electrocardiogram contamination from electromyogram signals.

**Methods:** In this paper, the clean electromyogram signal, electrocardiogram artifact and electrocardiogram signal were recorded from leg muscles, the pectoralis major muscle of the left side and V4, respectively. After the pre-processing, contaminated electromyogram signal is simulated with a combination of clean electromyogram and electrocardiogram artifact. Then, contaminated electromyogram is cleaned using adaptive subtraction method. This method contains some steps; (1) QRS detection, (2) formation of electrocardiogram template by averaging the electrocardiogram complexes, (3) using low pass filter to remove undesirable artifacts, (4) subtraction.

**Results:** Performance of our method is evaluated using qualitative criteria, power spectrum density and coherence and quantitative criteria signal to noise ratio, relative error and cross correlation. The result of signal to noise ratio, relative error and cross correlation is equal to 10.493, 0.04 and %97 respectively. Finally, there is a comparison between proposed method and some existing methods.

**Conclusion:** The result indicates that adaptive subtraction method is somewhat effective to remove electrocardiogram artifact from contaminated electromyogram signal and has an acceptable result.

## Keywords

Electrocardiogram artifact, Surface electromyogram, Contamination, Noise removal, Adaptive subtraction

## Introduction

The electromyogram (EMG) signal indicates electrical activity of the muscles which comprises the summation of all the motor unit action potentials within the detection area of the electrode. EMG recording has been widely used in the field of neuroscience, sports medicine and rehabilitation [1]. A major difficulty during analysis of surface EMG signal is electrocardiogram (ECG) contamination. This causes an increase in the power content of the EMG signal and a distortion of its frequency content [2]. Generally, the ECG interference is large in amplitude and overlapped with the frequency of the EMG [3]. Early techniques employed to reduce the level of contamination include amplitude clipping, gating technique and high pass filtering, neither of which have proved effective [2]. Investigations of ECG contamination in EMG signals have employed techniques such as spike clipping, real

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time filtering, independent component analysis, wavelet, artificial neural network, adaptive filtering and subtraction [1]. Conventional high pass filtering essentially fails since the ECG has a frequency spectrum that overlaps markedly with that of the surface EMG signal of the upper trunk muscles [3]. The gating method, perhaps the loss of the portions of the EMG signals overlying QRS complexes. The adaptive filter has been recently used to reduce the ECG artifacts but it needs a reference input either recorded from an additional channel. This method is not suitable for clinical application due to the heavy computation burden. It takes a lot of time to get the cleaned signal [3]. The main drawback of wavelet method is that a mother wavelet has to be defined a priori and this choice may influence the final results [4]. A method based on the combined use of wavelet transform and ICA is presented in [5]. In this paper, the adaptive subtraction technique has been studied to remove ECG interference from the surface EMG signal of the upper trunk muscles. The method is applied to the collection of EMG data set contaminated by ECG artifacts and then the noise would be eliminated. Also, the result of some existing methods is presented. Finally, the performance of these methods is evaluated. To evaluate the obtained results, the contaminated EMG signal is simulated and the signals to noise ratio (SNR), the relative error (RE) and cross correlation (CC) criteria are calculated. Also, power spectrum density (PSD) and coherence are determined.

## Material and Methods

Five 19-24 years old male (height= 173-180cm, mass= 70-85kg) was recruited from the university population. The surface EMG, ECG artifact and ECG signals used in the study were collected from leg muscles, the pectoralis major muscle of the left side and V4 respectively, at Amirkabir University of Technology, Faculty of Biomedical Engineering, Biological Systems Control Laboratory. When EMG signal was recorded, the subjects were seated in a chair and during the experiment, the subjects were asked to activate their leg muscles. Between each activation a rest time was intended. When ECG and ECG artifact signals were recorded, the subjects were asked to lie completely relaxed. The signals were recorded using electrodes placed on the skin. The skin was first prepared by shaving, light abrasion and cleaning alcohol. The EMG signal from these electrodes was fed into a biological amplifier (Dual Bio Amp/simulator). After the pre- amplification and before sampling, the raw EMG signals were band pass filtered from 0.3 to 500Hz with an analogue filter. The signals were recorded with a sampling frequency of 2000Hz. To remove undesirable motion artifacts, clean EMG signal was high pass filtered with cutoff frequency of 10Hz, ECG and ECG artifact were high pass filtered with cutoff frequency of 1Hz. For simulating the contaminated EMG signal, ECG artifact was added to the clean EMG signal. Signal to noise ratio for contaminated EMG signal was considered zero. ECG, ECG artifact, clean EMG and contaminated EMG are presented in figure 1 respectively.

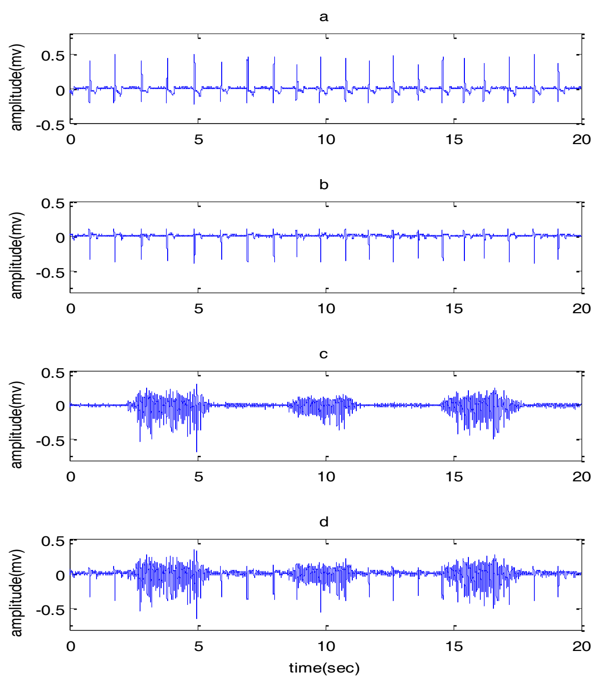


**Figure 1:** (a) ECG, (b) ECG artifact, (c) clean EMG and (d) contaminated EMG.

## Adaptive subtraction technique

### ECG template

ECG template subtracting takes advantage of the quasi-periodic characteristics of ECG signal. It involves subtraction of an ECG template from the EMG signal at each occurrence of an ECG waveform [1]. The first step involves the finding QRS complex in the contaminated EMG signals using ECG signals that was recorded simultaneously with ECG artifact. A QRS detection algorithm [6] was used to identify the position of the ECG artifacts in the signal. This algorithm was applied to ECG signal. The second step is formation of ECG template that contaminated the EMG signal. This could be done by averaging the ECG complexes based on assumption that the EMG has a zero mean Gaussian distribution, so the ECG template set is consisting of QRS detection and a subtraction template, which was selected from the averaged waveform. The subtraction template presented longer duration including the complete ECG waveform (i.e. the whole QRS complex as well as P and T waves), which was used to subtract the ECG artifacts from the signal [1]. A sample of the created ECG template is presented in figure 2.

During the formation of the ECG template, for each R wave detected, average of 30 QRS complex ago (This number is gained experimentally) were calculated. Therefore we will have a template that will change. Adaptation of this method is at this step, because each R wave detected has its own ECG template.

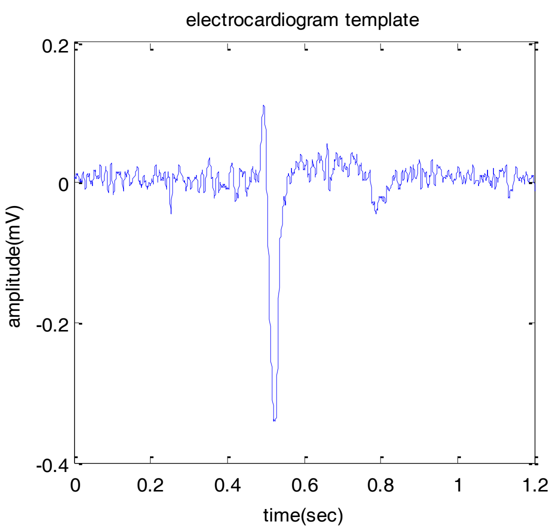


**Figure 2:** A sample of the created ECG template.

### Low pass filter

To remove undesirable artifacts, after creating ECG template, this signal was low pass filtered with cutoff frequency of 50Hz. Since the highest frequency power of the ECG signal is between 0.1 Hz and 45 Hz, cutoff frequency of 50Hz is the best choice. Filtered ECG template is presented in figure 3.

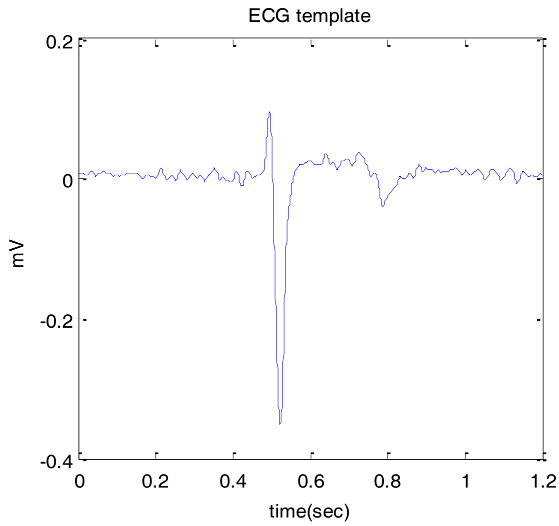


**Figure 3:** The filtered ECG template.

### Subtraction

With information obtained in step 1, the occurrence of ECG spikes in the signal was detected. The second step of the subtraction process was to create the ECG template. Then, ECG template was low pass filtered. In the subtraction step, created ECG template was subtracted from contaminated EMG in places where there was an R wave.

## Evaluation criteria

In this paper, Quantitative criteria such as signal to noise ratio, relative error and cross correlation are calculated. Since average of EMG signal is zero, so equation (1) is used to calculate signal to noise ratio.

$$\mathrm{SNR} = 10\log_{10}\frac{\mathrm{var}(s(\mathrm{k}))}{\mathrm{var}(s(\mathrm{k})-\hat{s}(\mathrm{k}))} \qquad (1)$$

Where, S(k) and Ŝ(k) were the variance operator, clean EMG and cleaned EMG respectively [7]. Increase of signal to noise ratio is represent better performance of approach. Equation (2) is used to calculate relative error.

$$RE = \frac{\sum\left(S(\mathrm{f})-\hat{S}(\mathrm{f})\right)^2}{\sum(S(\mathrm{f}))^2} \qquad (2)$$

Where s(f) and ŝ(f) were spectral density of clean EMG and cleaned EMG respectively [3,8,9]. Decrease of relative error is representing better performance of approach. Equation (3) is used to calculate cross correlation.

$$CC = 100\times\left(\frac{\sum s(k)\hat{s}(k)}{\sqrt{\sum(s(k))^2\sum(\hat{s}(k))^2}}\right) \qquad (3)$$

## Results

Adaptive subtraction method for substantial removal of the ECG contamination in the surface EMG signal was achieved using the proposed method. This method applied to 60 seconds of the contaminated EMG signal. An example of the performance for this method is presented in figure 4.

In figure 4, section (a) is an example of the raw simulated EMG signal. The ECG contamination in the signal is obvious. The noise estimated is shown in figure 4 (b). The cleaned EMG signal is obtained when ECG template is subtracted from the contaminated signal. This signal can be seen in figure 4 (c). The ECG artifact removal algorithm was implemented using Matlab 10.b. It is clear from figure 4 that the ECG artifacts were substantially reduced. To qualitative validation of the proposed ECG artifact removal method, power spectrum density and coherence in figure 5 and figure 6 were compared before and after noise removal.

In the coherence curve being close to one indicates that the cleaned signal and the clean signal are very similar. The result of signal to

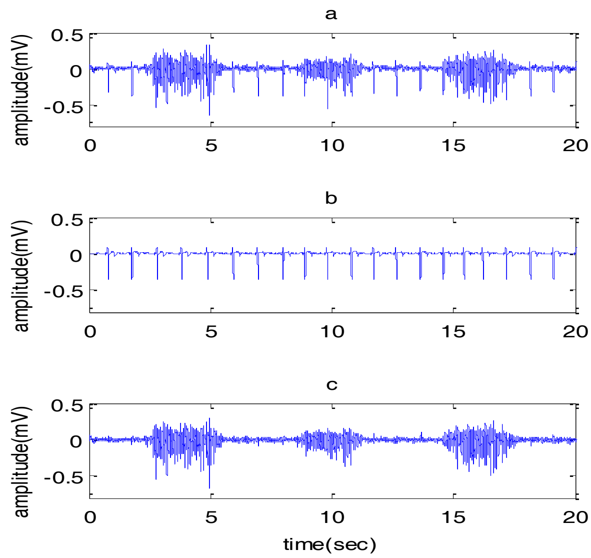


**Figure 4:** (a) contaminated EMG, (b) noise estimated and (c) cleaned EMG.

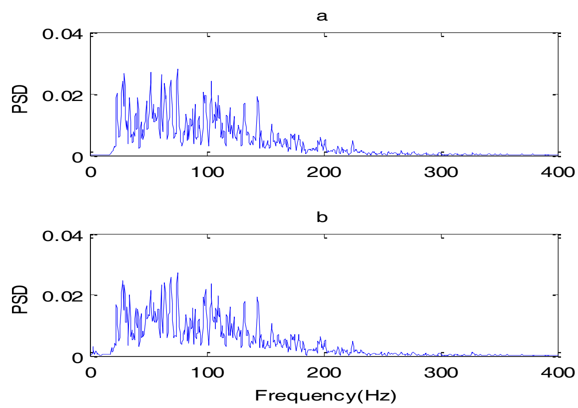


**Figure 5:** (a) PSD of clean EMG signal and (b) PSD of cleaned EMG using adaptive subtraction technique.

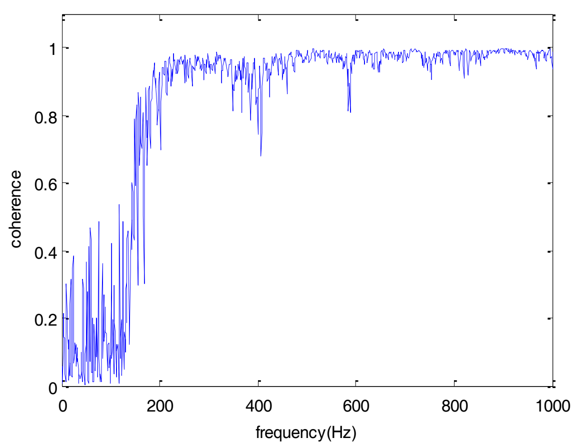


**Figure 6:** Coherence of clean EMG and cleaned EMG signals.

noise ratio, relative error (RE) and cross correlation (CC) for one of subjects is equal to 8.86, 0.08 and %93 respectively. This method was applied to the five signals recorded from five subjects. Results for these signals can be seen in the table 1.

**Table 1:** Calculating evaluation criteria (SNR, RE and CC) and their mean and standard deviation (SD) for the five simulated signals recorded from five subjects.

| | SNR | RE | CC |
|---|---|---|---|
| Subject1 | 10.49 | 0.04 | %97 |
| Subject2 | 9.06 | 0.07 | %94 |
| Subject3 | 8.05 | 0.10 | %92 |
| Subject4 | 9.97 | 0.06 | %95 |
| Subject5 | 8.86 | 0.08 | %93 |
| mean ± SD | 9.28 ± 0.96 | 0.07 ± 0.02 | %94.2 ± 1.92 |

Finally, the result of presented method in this paper was compared with the results of some existing methods such as high pass filter with a cutoff frequency of 30 Hz, wavelet transform based on nonlinear thresholding and adaptive filter. Signal to noise ratio for these methods are equal to 7.63, 5.36 and 8.09 respectively. This result shows that operation of adaptive subtraction method is somewhat better than the result of three other methods.

## Discussion

In this paper we have proposed an adaptive subtraction technique for the elimination of ECG contamination. The performance of the algorithm was first evaluated on computer simulation. The application of proposed method was investigated using applying that to simulated EMG signals obtained from five healthy subjects.

The results of this method were expressed with quantitative criteria. The SNR, Relative Error and cross correlation was used as performance indicator to assess the proposed method. These criteria for the best results respectively is equal to; 10.493, 0.04 and %97. The power spectral analysis and coherence has been used for qualitative evaluation. It was found that ECG artifacts could be successfully removed from EMG signal. This algorithm was capable of eliminating the ECG artifacts, which is a promising result. Algorithm performance was improved when the ECG template created was low pass filtered. The adaptive subtraction technique shown in this study is general scheme to elimination the ECG contamination. The effectiveness of the method is evident in the results section, but this method has some limitations, such as time consuming and high computational cost. Finally, the result of this method was compared with the result of three existing methods such as high pass filter, wavelet transform and adaptive filter.

## Conflict of Interest

None

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