ECG Artifact Removal from Surface EMG Using Adaptive filter Algorithm

Hojun Yeom[1] and UkjinYoon[2]

[1]Department of Biomedical Engineering, Eulji Univ., South Korea
[2]Mediana Inc., Wonju, South Korea
hyeom@eulji.ac.kr

Abstract

The electrocardiography (ECG) artifact corrupts the surface electromyography (sEMG) signals recorded from the trunk area We assessed the effectiveness of three methods used to remove the ECG. We compared the performance of bandpass filtering methods, the commonly used mathematical morphology operator (MMO) method and the Adaptive filter on both simulationed and real sEMG data. False positive and false negative errors increased with larger ECG to EMG ratios for all 3 methods. However, the Adaptive filter showed better performance as compared to bandpass filtering and the MMO particularly for low signal-to-artifact ratios of a lower computational load.

Keywords: *Adaptive filter, trunk muscle, EMG, ECG artifact*

1. Introduction

Surface electromyography (EMG) has been commonly used to assess the neuromuscular demand on muscles while performing various tasks and is being rapidly introduced to the field of health care [1]. A major problem encountered in the analysis of sEMG signals is contamination by the surface electrocardiographic (sECG) signal.

The methods for removing the sECG artifacts include high pass filtering, the gating technique, the subtraction technique, adaptive filtering, and the wavelet threshold denoising technique [2]. It has been demonstrated that the high-pass filter technique is not efficient in removing the ECG. The gating technique is simple to implement; however, there are major limitations. Subtraction techniques can remove the sECG artifacts without sacrificing segments of diaphragmatic EMG signal corrupted by sECG. However, it should manually select the sECG templates [3].

Adaptive filters for noise cancellation were developed to optimally estimate signal components embedded in noisy environments without requiring explicit a priori knowledge. Adaptive filters adjust their parameters based on the statistical properties of the inputs which permit real-time adaptation to track dynamic changes in the signal and noise components.

In signal processing for QRS Complex detection, a comparative analysis was performed on adaptive filters, morphological operations, and bandpass filter methods.

2. Methods

-Simulation data

For the analysis of by ECG100C muscle activity, we have to compare actual and known values of parameters with the values obtained using the new methods. The sEMG was simulated as an additive band-limited Gaussian noise between 30Hz and 300Hz. The ECG signals were acquired with instrumentation from BIOPAC Systems Inc. using AcknowledgeTM software and sECG electrodes. Performance of the filters was first quantified as a function of signal-to-noise ratio in simulated noisy EMG signals and then with the addition of baseline drift and motion artifact.

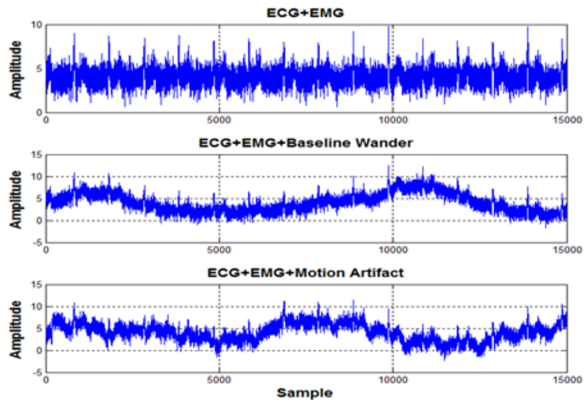

Figure 1. Simulated EMG signals with ECG signals in the condition (1) without environmental noise, (2) with baseline drift, and (3) movement artifacts

-Real data

Surface EMGs were recorded (Bagnoli 8, Delsys Incorporated, Boston, MA) from 14 muscles including pectoralis major (sternal fibers), while human subjects generated isometric force at the wrist, in 210 directions, homogeneously distributed in the three-dimensional force-space. For each trial, 9 seconds(including the first 2 seconds for use as a baseline) were given for a subject to maintain a 1-sec stable force production after visually guided target matching. Electrodes were placed in accordance with the guidelines of Delagi et al. (1980) [4]. EMG signals were amplified (x 1000), band-pass filtered (20-450 Hz) and sampled at 1800 Hz. The original EMG dataset was recorded to identify basic motor patterns in the upper extremity of neurologically intact human. Further data analysis for ECG removal was performed with the EMG response collected from pectoralis major. The data have been partially published [5].

-Filtering methods.

We compared the performance of 3 algorithms for detection of the QRS complex.

First, we used a bandpass IIR filter with cutoff frequencies of 5 and 20 Hz to detect the QRS complex. Second, the mathematical morphology operator (MMO) was used to identify the QRS complex. MMOs are typically used to extract structure information from geometrical objects with non-linear signal-processing operators [6].

AF method used NLMS algorithm, which normalized standard LMS algorithm. The least mean squares (LMS) algorithms adjust the filter coefficients to minimize the cost function. The normalized LMS(NLMS) algorithm is a modified form of the standard LMS algorithm. This method has been used as the effective method for removing the specifically motion artifact in many researches so far.

3. Results

-Simulated data

Performance evaluation of each QRS complex detection algorithm was made on sensitivity (SE) and positive predictive values (P) through the statistical methods.

$$Se(\%) = \frac{TP}{TP + FN} \quad (2)$$

$$P(\%) = \frac{TP}{TP + FP} \quad (3)$$

FN, FP, and TP represent the number of false negatives, false positives and total points, which indicates the total number of QRS complexes detected by the algorithm.We show the results of quantitative analysis of the three filtering algorithms in Table 1 and Fig. 2.

Table 1. Comparison of detection rates for various SNRs

SNR		FN	FP	Se(%)	P(%)
-10db	BAND	0	0	100	100
	MMO	8	5	65.21	75
	AF	0	0	100	100
-20db	BAND	2	0	88.23	100
	MMO	7	20	68.18	42.85
	AF	1	0	93.75	100
-25db	BAND	7	9	68.18	62.5
	MMO	12	11	55.55	57.69
	AF	4	1	78.94	93.75

SNR: signal-to-noise ratio; FN: false negative; FP: false positive; MMO mathematical morphology operator; AF: Adaptive filter(NLMS).

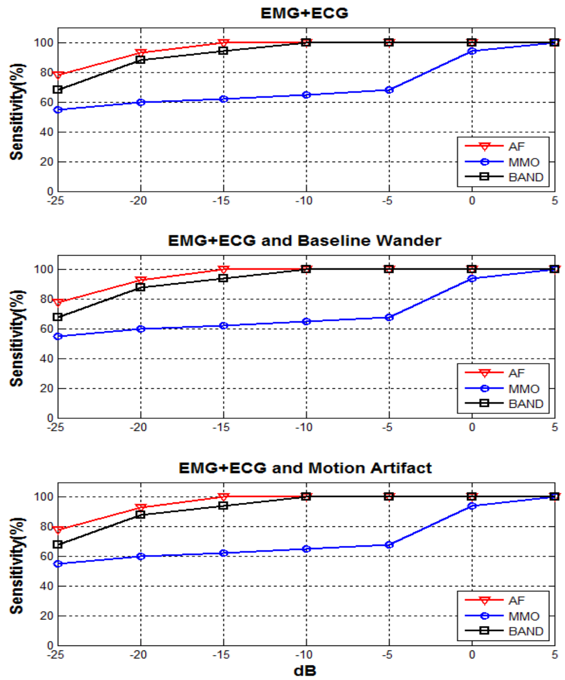

Figure 2. Comparison of three removal algorithm performances in Sensitivity associated with leaving the EMG in the ECG signal

The BAND produced lower Sensitivity percent in the range from -5 dB to -25 dB. The BAND looks better than MMO in EMG+ECG and EMG + Baseline drift, however it produced lower Sensitivity percent that ranged from -5 dB to -25 dB in the case of EMG+ECG and motion artifact. The AF method consistently produced higher sensitivity than the MMO and BAND.

4. Discussion

The proposed processing steps include detection and reduction of the ECG signal with the AF algorithm. The results of QRS complex detection with simulated and real data show a consistently higher percentage of accurate detection and thus we could retain the clean EMG signal.

Acknowledgements

"This work (Grants No. 00048056-1) was supported by Business for Cooperative R&D between Industry, Academy, and Research Institute funded Korea Small and Medium Business Administration in 2011."

References

[1] P. Zhou, B. Blair Lock and T. Kuiken, “Real time ECG artifact removal for myoelectric prosthesis control”, Physiological Measurement vol. 28, pp.397-413, **(2007)**.

[2] S. Levineand M. Gillen, “Diaphragmatic pressure waveform can predict electromyographic signs of diaphragmatic fatigue”, J. Appl. Physiol., vol. 64 no.5, pp.1681–9, **(1987)**.

[3] G. Lu, J. Brittain and Wang, “Removing ECG noise from surface EMG signals using adaptive filtering”, Neuroscience Letters, vol. 462, pp. 14-19, **(2009)**.

[4] E. F. Delagiand A. Perotto, “Anatomical Guide for the Electromyographer”, Springfield, IL: Charles C. Thomas, **(1980)**.

[5] J. Roh, W. Z. Rymerand R. F. Beer, “Robustness of muscle synergies underlying three dimensional force generation at the hand in healthy humans”, Journal of Neuophysiology, Epub, **(2012)**.

[6] V. Tscharner, B. Eskofierand P. Federolf, “Removal of the electrocardiogram signal from surface EMG recordings using non-linearly scaled wavelets”, J. Electromyogr. Kinesiol., vol. 21, pp.683-688, **(2011)**.

[7] U. Yoon, Y. Nohand H. Yoon, “Optimization methods for improving the performance of heart rate detection by a wearable ECG system during high-intensity exercise”, Biomedical Engineering Letters, vol.2, pp.143-150, **(2011)**.

Authors

Hojun Yeom

He received his BS, MS and Ph.D in Biomedical Engineering from Yonsei University. He spent a three years as postdoctoral fellow at the Georgia Institute of Technology. He has been an Assistant Professor of Medical Engineering at the Eulji University since 2008. His main research interests involve studying rehabilitation engineering and biomedical signal processing.

Ukgin Yoon

He received his BS, MS in Biomedical Engineering from Yonsei University. He is working at Mediana Inc., Wonju, South Korea. His main research interests are biomedical signal processing.