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Original article

Removal of ECG interference from surface respiratory electromyography

Filtrage de l'interférence ECG du signal électromyographique respiratoire de surface

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Abstract

The signal to noise ratio (SNR) of surface respiratory electromyography signal is very low. Indeed EMG signal is contaminated by different types of noise especially the cardiac artefact ECG. This article explores the problem of removing ECG artefact from respiratory EMG signal. The new method uses an adaptive structure with an electrocardyographic ECG reference signal carried out by wavelet decomposition. The proposed algorithm requires only one channel to both estimating the adaptive filter input reference noise and the respiratory EMG signal. This new technique demonstrates how two steps will be combined: the first step decomposes the signal with forward discrete wavelet transform into sub-bands to get the wavelet coefficients. Then, an improved soft thresholding function was applied. And the ECG input reference signal is reconstructed with the transformed coefficients whereas, the second uses an adaptive filter especially the LMS one to remove the ECG signal. After trying statistical as well as mathematical analysis, the complete investigation ensures that all details and steps make proof that our rigorous method is appropriate. Compared to the results obtained using previous techniques, the results achieved using the new algorithm show a significant improvement in the efficiency of the ECG rejection.

Keywords: Surface EMG; Adaptive filter; Wavelet decomposition; De-noising; ECG artefact

Résumé

Le signal électromyographique respiratoire de surface présente un rapport signal sur bruit très défavorable. En effet le signal EMG est contaminé par plusieurs bruits, le plus important en termes de puissance est le signal ECG. Dans cette étude nous étudions le cas de l'élimination du signal ECG du signal EMG respiratoire. Nous proposons une nouvelle structure adaptative où la référence bruit ECG est extraite par décomposition en ondelette. Cette méthode utilise une seule voie pour estimer en même temps la référence bruit et le signal EMG respiratoire d'origine. La nouvelle technique combine deux types de méthodes : premièrement, le signal est décomposé a l'aide d'une transformation directe en ondelette discrète en sous-bande. Les coefficients ainsi obtenus seront transformés à l'aide d'une nouvelle fonction de seuillage doux puis utilisés pour reconstruire une nouvelle référence bruit ECG. Deuxièmement, le signal ECG sera éliminé avec un filtre adaptatif de type LMS. L'analyse statistique et mathématique adoptée pour l'évaluation des résultats nous assurent du bien fondé de tous les détails et de toutes les étapes de la nouvelle méthode. La comparaison des résultats obtenus avec la méthode proposée à ceux obtenus avec d'autres techniques montre une amélioration notable dans le filtrage du signal ECG.

Mots clés : EMG de surface ; Filtrage adaptatif ; Décomposition en ondelette ; Debruitage ; Artéfact ECG

1. Introduction

The EMG surface acquisition of the intercostals and diaphragm muscles generally has, in quiet activity, a bad signal to noise ratio. The most important noise that contaminates

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the surface EMG signal are the motion artefact, the electromagnetic interference 50 Hz (60 Hz) and the ECG artefact [1]. So in order to have a clear spectral content of the surface EMG signal and to estimate some useful parameters, the amelioration of the SNR is needed.

ECG interference is large in amplitude and overlaps in frequency and time domain with the surface respiratory EMG signal [2–5]. This makes the separation between ECG and EMG difficult. Bloch [6] suggested using a filter for the cardiac artefact when the EMG signal is stationary. His method depends largely on the temporal cardiac artefact detection.

Lindstrom and Magnussom [7] used a technique founded on the choice of a window where the ECG signal is absent but their method failed in the case of high cardiac rhythm. Redfern et al. [8] used a high-pass cutoff frequency to estimate the spectral component of the EMG. However, this method results in signal information loss, which will affect the original signal. Marque and Akkiraju [3,9] proposed an adaptive noise canceller using the Widrow adaptive filter. This method requires an additional channel to record the ECG signal for use as a reference input for the noise canceller. Hualou [2] developed a nonlinear filtering based on a statistical technique. This method requires intensive matrix computation making it inappropriate for real time application.

In this study, we suggest the use of a new adaptive noise canceller algorithm based on Widrow's adaptive theory [10–12]. This approach needs a reference noise signal and therefore, uses supplementary electrodes near the heart. To avoid using additional electrodes Raoof in [13] proposes a band-pass filter in the 20–40 Hz range to estimate an ECG reference signal. This method was not really effective because the existence of EMG residual in the reference signal caused the distortion of the original EMG signal.

For the ECG analysis, the most important feature is the QRS complex wave. Other waves like P and T waves are defined relative to the QRS complex. In order to enhance the reference signal suggested by [13], we propose in [14,15] to estimate the reference noise signal with a band-pass filter in the 10–15 Hz range fixed on the QRS signal. The results show a better estimation of the reference signal [16] but EMG residual signal is still present.

For many years, the wavelet techniques have proved their efficiency for ECG detection [17], de-noising [18], compression [19,20] and QRS detection [21]. These techniques seem to be well suited cases where there is spectral overlapping between noise and desired components of signal.

The power spectral analysis of the ECG signal shows that QRS complex lies in the 3–17 Hz band and P and T waves have a spectral density up to 10 Hz [22], while the EMG (diaphragm) appears at different frequency band between 10–230 Hz [23]. Thus, a good approach to extract the ECG signal from the respiratory EMG may be obtained by analyzing the different sub-bands of the noisy signal, with a wavelet transformation. By exploiting this powerful tool, a description of the signal in the time-scale domain is obtained allowing the representation of the temporal features of the signal at different resolutions.

The proposed extraction method consists in decomposing the respiratory EMG signal contaminated with ECG signal into frequency sub-bands. In order to achieve the best reference noise signal estimation of the ECG without any EMG components; we apply a new modified soft threshold function. Then the reference signal will be reconstructed with the transformed coefficients using an inverse discrete wavelet transform (DWT).

2. Algorithm

The new combined adaptive approach proposed for de-noising the respiratory EMG signal (Figs. 1 and 2) may be divided into two main steps:

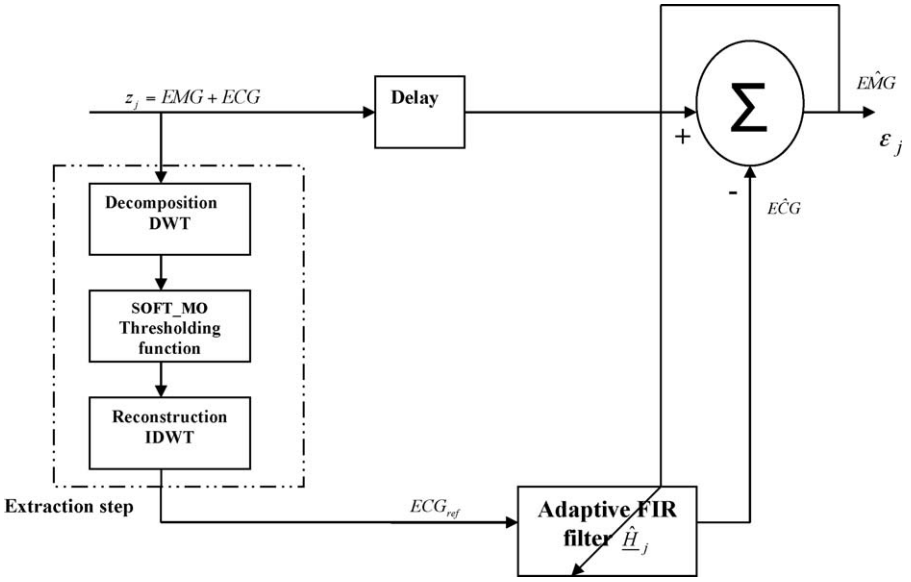

Fig. 1. The ECG noise canceller algorithm: $z_j = EMG + ECG$, raw signal; EMG, signal of interest; ECG, noise; ECG_{ref}, reference noise ; $\hat{ECG}$, estimate of the noise with the adaptive filter; $\hat{H}_j$, adaptive filter coefficient; $\hat{EMG}$, filtered signal.