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Separation of electrocardiographic from electromyographic signals using dynamic filtration

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ABSTRACT

Trunk muscle electromyographic (EMG) signals are often contaminated by the electrical activity of the heart. During low or moderate muscle force, these electrocardiographic (ECG) signals disturb the estimation of muscle activity. Butterworth high-pass filters with cut-off frequency of up to 60 Hz are often used to suppress the ECG signal. Such filters disturb the EMG signal in both frequency and time domain. A new method based on the dynamic application of Savitzky-Golay filter is proposed. EMG signals of three left trunk muscles and pure ECG signal were recorded during different motor tasks. The efficiency of the method was tested and verified both with the experimental EMG signals and with modeled signals obtained by summing the pure ECG signal with EMG signals at different levels of signal-to-noise ratio. The results were compared with those obtained by application of high-pass, 4th order Butterworth filter with cut-off frequency of 30 Hz. The suggested method is separating the EMG signal from the ECG signal without EMG signal distortion across its entire frequency range regardless of amplitudes. Butterworth filter suppresses the signals in the 0–30 Hz range thus preventing the low-frequency analysis of the EMG signal. An additional disadvantage is that it passes high-frequency ECG signal components which is apparent at equal and higher amplitudes of the ECG signal as compared to the EMG signal. The new method was also successfully verified with abnormal ECG signals.

1. Introduction

Electromyographic (EMG) signals of surface placed muscles are often used for: estimation of the force developed by a muscle [1]; conclusions about the role of different types of muscle motor units in different motor tasks [2,3]; analysis of changes in muscle functioning caused by different neuro-muscular diseases [4,5]; control of different technical devices as ortheses [6,7], exoskeletons, prosthesis, etc. It is clearly visible that electrocardiographic (ECG) signals superimpose the EMG signal when some of the investigated muscles are trunk muscles and especially for those ones placed on the left. Different methods were developed to remove (filter) the ECG artifact. Most of them are critically analyzed in [8]. The ECG signal power spectrum is mostly below 20–30 Hz. An exception is the QRS-complex with frequency of about 100 Hz and rarely reaching up to 200 Hz in children. The evidence for the presence of higher-frequency diagnostic components in ECG signals is the reason that the American Heart Association changed its low-pass filter recommendations from 35 Hz cut-off to 150 Hz cut-off for adolescents and adults and to 250 Hz cut-off for children in 2007 [9].

The usable energy of the EMG signals is in the 0 to 500 Hz frequency range [10], and the useful information is contained within the range 10–400 Hz [11]. For that reason, the 30 Hz high-pass 4th order Butterworth filter recommended in [8] will cut useful information between 10 and 30 Hz and will not filter the high-frequency components of the ECG signal thus destroying the EMG signal. Considering the fact that ECG and EMG signals superimpose linearly, Sbrollini et al. [12] are applying their Segmented-Beat Modulation Method for signals separation providing first the ECG signal, and then the EMG signal by subtraction.

ECG signals are always presented in EMG recordings of the upper muscles of the left trunk like latissimus dorsi and pectoralis major. The success of ECG signal removing depends on the amplitude ratio between the EMG signal and the ECG signal. Butterworth high-pass filter with cut-off frequency of 30 Hz and order of 4 will not be successful, when these two amplitudes are similar or when the amplitude of the ECG signal is higher than the amplitude of the EMG signal [13]. Lu et al. [14] are using adaptive filter in removing ECG interference from surface EMG signal recorded from the trapezius muscles of patients with cervical dystonia. The efficiency of their method is decreasing when the signal-to-noise ratio

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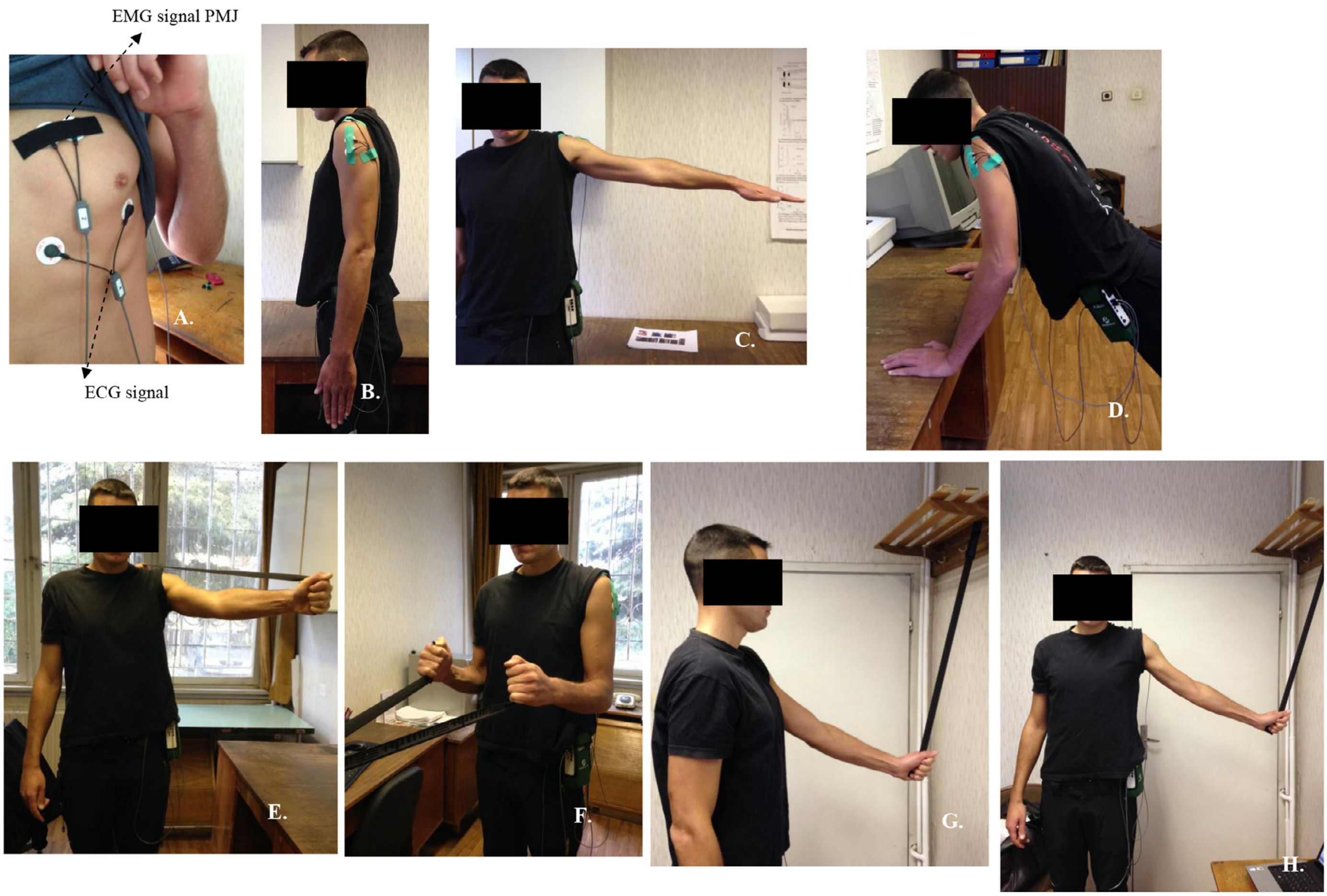

Fig. 1. Position of the electrodes for registration of ECG signal and EMG signal of m.pectoralis major (A) and example snap-shots from the saved movies of the performed seven motor tasks (B–H).

(SNR) is reduced but it still achieves meaningful performance even when the SNR is below −5 dB.

The aim of this study is to present a method based on a dynamic filter procedure to separate ECG signals from EMG signals and to demonstrate the usefulness of the method in exploring left trunk muscle activities in different movement conditions.

2. Method

2.1. Experiments description

To demonstrate the method for removing ECG signals from EMG signals, special experiments were performed on a person (male, 25 years old, training fitness). The study and the experimental procedure were approved by the Etical Scientific Commission of the Institute of Biophysics and Biomedical Engineering (Bulgarian Academy of Sciences) and the subject gave his informed consent. He signed an Inform Consent Form. The study is in accordance with the Declaration of Helsinki. The 8-channel electromyographic and kinematics measuring telemetric system Telemyo 2400T G2, (Noraxon USA, Inc.) was used for the experiments. Ag/AgCl surface circle electrodes “Skintact-premier” F-301 with 9 mm diameter were used. The sampling frequency was 1500 Hz. The reference electrode was placed at the scapular acromion. The pairs of electrodes were placed at 3 cm center-to-center distance on the skin of the subject which was first cleaned with alcohol and dried. Hellige EMG conductive gel for better skin-to-electrode contact was used. The following muscles were examined on the left side of the trunk: m. deltoideus pars acromialis (DELacr), m pectoralis major (PMJ) and m. latissimus dorsi (LDS). The electrode locations were determined according to the international EMG guidance (SENIAM project - http://www.seniam.org/). The EMG signal of the DELacr muscle was almost free of ECG signal but in the recordings of the other two muscles that are closer to the heart the ECG signal is clearly visible. Two additional electrodes were put in suitable places (Fig. 1A) with the aim to register the pure ECG signal. Seven motor tasks with duration of one minute each were performed. The aim was to register 3 different cases: low EMG signal to high ECG signal, low ECG signal to high EMG signal and an EMG and an ECG signal with almost equal amplitude. The first motor task (static task) was the reference position: standing upright with his arms down beside the body (Fig. 1B). The next dynamic motor tasks were as follows:

1. From the reference position an abduction in the shoulder joint was performed in the horizontal plane to an angle of approximately 90° (Fig. 1C) and after a 5-s pause the arm was returned to the reference position. The motion was repeated 3 times with a rest of about 10 s between the trials;
2. With both upper limbs placed on a table in an extended position, the subject made 3 pushups (Fig. 1D) with about 10 s rest between the exercises;
3. The left arm was abducted to 90° with the wrist in a neutral position grasping a ribbon tape; the motion is flexion in the shoulder joint to an angle of 90° against resistance (Fig. 1E). The subject stayed in this position for 5 s and then returned to his original position. The other end of the tape was held

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