FILTERING OF ELECTROMYOGRAM ARTIFACTS FROM THE ELECTROCARDIOGRAM

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Summary: *Electromyogram (EMG) artifacts often contaminate the electrocardiogram (ECG). They are difficult to suppress or eliminate due to their random character and to the considerable overlapping of the frequency spectra of both signals obtained from the same pair of electrodes. Low-pass filtering (cutoff frequency of min. 35 Hz) results in limited suppression of the EMG artifact and considerable reduction of sharp Q, R and S wave amplitudes. A solution of this problem is proposed by applying approximation filtering with dynamically varied number of samples and weighting coefficients depending on the ECG signal slope. The slope measure used is the absolute value of the product of the tilts of two adjacent 10 ms segments sliding along the signal. The results obtained show a slight widening of the sharp ECG waves but a virtual preservation of their amplitudes and considerable reduction of the EMG artifact.*

Introduction

EMG artifacts in ECG are quite common in subjects with uncontrollable tremor, in disabled persons having to exert effort in maintaining a position of their extremities or a body posture, in children, etc.

Attempts at filtering out of the EMG were only partially successful. Application of low pass filtering (cut-off 35 Hz) is recommended by standards. The result is a limited suppression of the EMG artifact and a reduction in the amplitudes of sharp ECG waves, such as Q, R and S. This fact precludes accurate ECG diagnostic measurements if an EMG filter was applied [2].

Adaptive filtering of the EMG artifact was attempted. The QRS complex disturbs the adaptation process, readaptation occurs resulting of reoccurrence of the artifact [7]. A modification of the algorithm could deal with this inconvenient, but the price again is a reduction of the sharp ECG amplitudes [1]. Better results with a faster convergence approach were obtained by Lio and Tompkins [4], but at the price of using an additional channel for the EMG.

Rossi *et al.* [5] proposed a low pass comb filter with reduced lobes in the frequency band above 50 Hz by cascaded filters and a compensating filter gradually enhancing components from 10 to 100 Hz, with first zero at 200 Hz. The goal was to obtain the -3 dB cutoff at 35 Hz, as required by the standard. Unfortunately, no data on the compensating filter were given and no results with real signals were presented.

Levkov [3] used comb filters for suppression of 50 Hz interference and EMG artifacts, but -3 dB at 35 Hz resulted in a lobe with a maximum of 95% at 70 Hz.

In an attempt to improve the traditional compromise between efficient EMG artifact suppression and preservation of the ECG waveform, we applied approximation filtering, adding dynamic modification of the approximation function parameters, depending on the ECG signal slew rate.

Method

The proposed method is based on an approximation filter, whose characteristics are dynamically changed depending on the ECG signal slope. This procedure requires evaluation of the slope regardless of the EMG noise component. For this purpose a function we called 'wings' is applied. An appropriate relation is established between slope values and number of samples over which the approximation is to be accomplished.

A. Signal slope evaluation

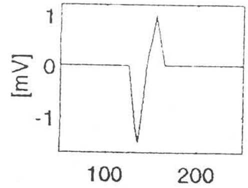
We apply the 'wings' function, obtained by multiplying the slopes of two adjacent segments of 10 ms length having a common point. Then the product absolute value is taken and inverted. For a 400 Hz sampling rate the 'wings' function is:

$$\text{Wings}=-\text{abs}((S_i-S_{i-4})(S_i-S_{i+4})).$$

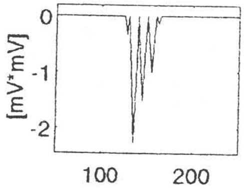
The segment length of 10 ms was chosen in order to obtain a certain level of smoothing in the process of slope evaluation. This value is not especially critical, as smaller interval results in more varying 'wings' function and thus stronger additional smoothing is needed, and vice versa.

Well-shaped negative peaks of the function correspond to every Q, R and S wave of the ECG. Negative peaks appear also at the maximum slew rate of the QR and RS segments. An example is given in Fig. 1, where (a) is an artificial signal consisting of two waves having different slopes. and polarity. The 'wings' function is presented in (b) together with its smoothed version (c). The smoothing involves a running approximation procedure (discussed in section B), applied on segments of 35 ms length. Then a comb filter is applied with a first zero at 50 Hz. The result is a negative wave that corresponds to the high slew rate elements (QRS complexes and/or T waves) of the ECG.

(a) Synthesised signal



(b) "Wings" function



(c) Smoothed "wings"

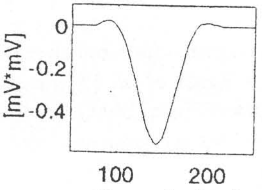


Figure 1

Real EMG contaminated ECG signals are first preprocessed for EMG suppression by the same 50 Hz comb filter and by a running approximation over 75 ms segments. Then the above-described procedure of slope evaluation is applied.

B. Approximation

A smoothing procedure adopted from the work of Savitzky and Golay [6] is applied. It makes use of the least squares approximation method. The mathematical description of the process is:

$$Y_i = \frac{1}{N}\sum_{j=-n}^{j=n} C_j X_{i+j}$$

Y and X represent the signal after and before approximation respectively and j=2n+1 is the number of samples on which the procedure is applied. **n** is the length of the approximation interval at both sides of a sample. C_j are weighted approximation coefficients, and N is a normalization coefficient.

The approximation coefficients are

$$C_j = 3n^2 + 3n - 1 - 5j^2$$

and the normalization coefficient is

$$N = \frac{(2n+1)(4n^2+4n-3)}{3}$$

C. Dynamic approximation

Lengthening the approximation segment results in better EMG suppression, but stronger amplitude reduction of the Q, R and S peaks will occur. This incited us to use approximation with adaptively adjusted segment length. Thus weaker smoothing is done on QRS complexes and/or T waves of high slew rate and stronger on the remaining signal components. The values of the smoothed 'wings' function are made to correspond to the approximation interval **n.** The time-course of **n** is given in Fig. 1c. The smoothed 'wings' minimum value corresponds to n=1 and its maximum to n=20. These values were chosen after careful testing of a multitude of ECG signals from a 400 12-channel ECG records database.

EMG artifact

An EMG signal was obtained from two ECG electrodes placed on one forearm. The ECG amplifier was used and the recording was made during sustained voluntary effort. The artifact thus obtained was weighted and additively mixed with the different ECG signals subjected to processing.

Results

A pure ECG signal (V1 lead) having QRS complexes of varying amplitude and with high and sharp R and S waves was selected as a difficult filtering example (Fig. 2a, 1st trace). It was mixed with EMG artifact of amplitude about 35% of the QRS

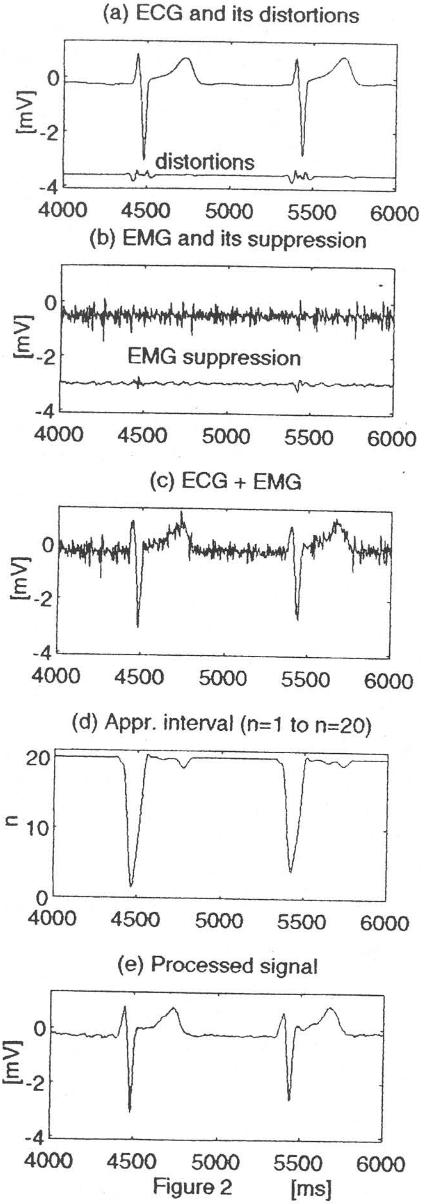


Figure 2

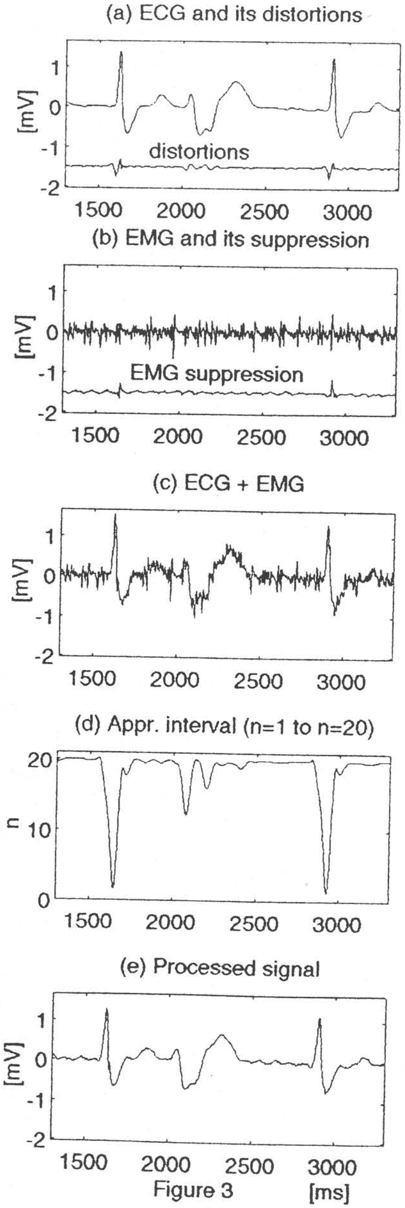


Figure 3

(Fig. 2b, -1st trace and 2c). The corresponding approximation interval, scaled from n=1 to n=20, is shown in Fig. 2d. The result of the dynamic approximation is presented in Fig. 2e.

The peak amplitudes of the steep R and S waves are reduced by only 0.01 and 0.02 mV respectively. The distortions involved by the procedure are shown in Fig. 2a (second trace), which represents the difference between the pure ECG (first trace) and its processed version. The difference amplitudes are higher than the measured R and S reductions due to the fact that they occur within the slopes, which are of lesser diagnostic significance.

The EMG artifact is reduced about than 5 times. Its suppression is more accurately presented in Fig. 2b (2nd trace), where the first trace shows the same interference that was mixed with the pure ECG signal. The suppression after dynamic approximation is higher outside the QRS complex interval and lower inside it, which is to be expected, according to the proposed method.

Another example is given in Fig. 3, using the same arrangement as in Fig. 2. The processed signal R and S amplitudes are reduced with 0.128 and 0.064 mV respectively. The EMG artifact is reduced several times.

Discussion

The results obtained with the dynamic approximation filtering, considering the preservation of sharp wave amplitudes and reduction of artifacts are clearly superior to any other kind of EMG filtering known to us. Thus automatic ECG interpretation could be applied even in the presence of considerable EMG artifacts.

However, a more detailed observation of the error signals (Fig. 2e and 3e) reveals that slight distortions are induced in the first ascending component of a sharp ECG wave. This leads to a widening of the R-wave at the baseline with 9.3 ms in the case of Fig. 2c and 4.8 ms of the R-wave of Fig. 3c. We observed similar widening in deep Q-waves, but normal amplitude Q-waves remained virtually unchanged. Having in mind the criteria for Q and R wave amplitudes and duration, these errors can be accepted as considerably less critical compared to those obtained by existing filtering methods.

Conclusion

The use of approximation filtering with dynamically varied number of samples and weighting coefficients depending on the ECG signal slope is a relatively simple method. It yields better waveform preservation and EMG artifact suppression, compared to existing filtering approaches. A procedure for slope evaluation is proposed by sliding two adjacent segments along the signal and using the absolute value of the product of their slopes as a measure.

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