MAINS INTERFERENCE SUBTRACTION FROM ECG IN CASE OF ACCOMPANYING TREMOR

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Summary: A subtraction procedure was developed previously, totally subtracts the mains interference from the electrocardiogram and fully preserves the ECG frequency spectrum. However, its efficiency is slightly reduced in case of continuous well-expressed tremor. The existing algorithm was considerably improved by the introduction of a pre-filtering procedure.

Introduction

The mains interference and the muscle disturbances (tremor) are presented very often together in the ECG recordings. The interference part is due to the parasitic currents through the patient body and the connecting cables. This setting transmits false differential instead of common mode signals to the amplifier input that cannot be suppressed even by an infinite CMRR. The tremor is introduced by involuntary electromyographic activity of the patient in a large frequency band. The use of conventional filters affects the ECG signal components.

In accordance to the international recommendations (OIML R 90, 1990) an analog antitremor filter is required, defined as first order with 35-45 Hz cut-off. This is a compromise between preservation of the low and middle frequency components of the signal and suppression of the disturbances. In digital electrocardiographs running averaging may be used, e.g. a comb filter. However, if its first zero is at 50 Hz, the equivalent cut-off frequency is about 24 Hz, which do not respond to the requirements. A very good study of these problems has been done by GRAMATIKOV (1992).

The mains interference may be subjected to a subtraction procedure (LEVKOV *et al.*, 1984; CHRISTOV and DOTSINSKY, 1988; DOTSINSKY and DASKALOV, 1996), that totally preserves the frequency ECG spectrum. The procedure consists briefly of the following steps:

- The mains period T_M is measured and the sampling period $t_S=T_M/n$ is defined, where $n=f_S/f_M$ is the sample number and f_S and f_M are the sampling rate and the rated mains frequency, respectively.
- Short segments in which the ECG signal evolves linearly are detected.
- Moving averaging over **n** samples is applied. The obtained values are free of interference.
- They are used to compute **n** interference samples, phase located to T_M, called phase corrections.

• The corrections are subtracted from the corresponding samples of the signal in non-linear segments.

The subtraction procedure is extremely efficient even with changing amplitude and frequency of the interference. Its performance is slightly reduced in case of continuous well-expressed tremor. This is due to the smallest number of linear segments detected. It reflects:

• In incorrect preservation of the tremor as a part of the 'pure' ECG signal in false non-linear segments, where subtraction is applied instead of moving averaging.

• In a relatively rare re-calculation of the phase corrections involved, they may not correspond to the already changed interference amplitudes.

Algorithm

The solution of the problem was found in searching linear segments in a preliminary filtered signal, where the tremor is considerably suppressed. Thereby the application of moving averaging will be confirmed in the long linear segments thus obtained. The preliminary filtering must be done in a separate file, since the subtraction procedure has to be accomplished over the original signal, kept not affected during the procedure.

There is a new drawback arising with the question from which signal to compute the phase corrections. If it was done from the pre-filtered signal, then the corrections would contain both tremor and interference components. If the original signal is taken, the re-calculations will rarely occur. In our opinion, the first solution is convenient in cases of smaller tremor amplitudes. The second may be applied in signals with limited amplitude variation of the 50 Hz interference.

Results and discussion

ECG signals from our own database are processed by the software package MATLAB. Fig. 1 shows an expected effect using the known subtraction procedure in case of muscle disturbances. The first trace of Fig. 1a represents a 'clear' ECG signal. The second trace is an EMG signal obtained from two ECG electrodes placed on one forearm. The recording was made during sustained voluntary effort. Fig. 1b represents the compound (ECG+EMG) signal. A modulated in amplitude interference (Fig. 1c) is superimposed afterward (Fig. 1d). The results of the subtraction procedure are shown in Fig. 1e. The linear and non-linear segments (Fig. 1f) are presented in the diagram by "**0**" and "**1**", respectively. The curve of Fig. 1g is the difference of the processed (e) and the compound signal (b). As it can be seen, the subtraction procedure does not suppress the tremor. Even more it passes off the modulated interference, where long periods of nonlinearity occurs.

The signal of Fig. 1d is processed by detecting linear segments in the pre-filtered input ECG signal, shown as curve **a** in Fig. 2. The result is presented in Fig. 2b. Fig. 2c shows again the compound signal of Fig. 1b for a better comparison. The diagram **d** in Fig. 2 points out the only one non-linear segment around each QRS

complex. Substantial tremor suppression may be observed. Some disturbances remain near the offset of the non-linear segment. However, the general improvement obtained by the modified algorithm is evident.

Acknowledgment

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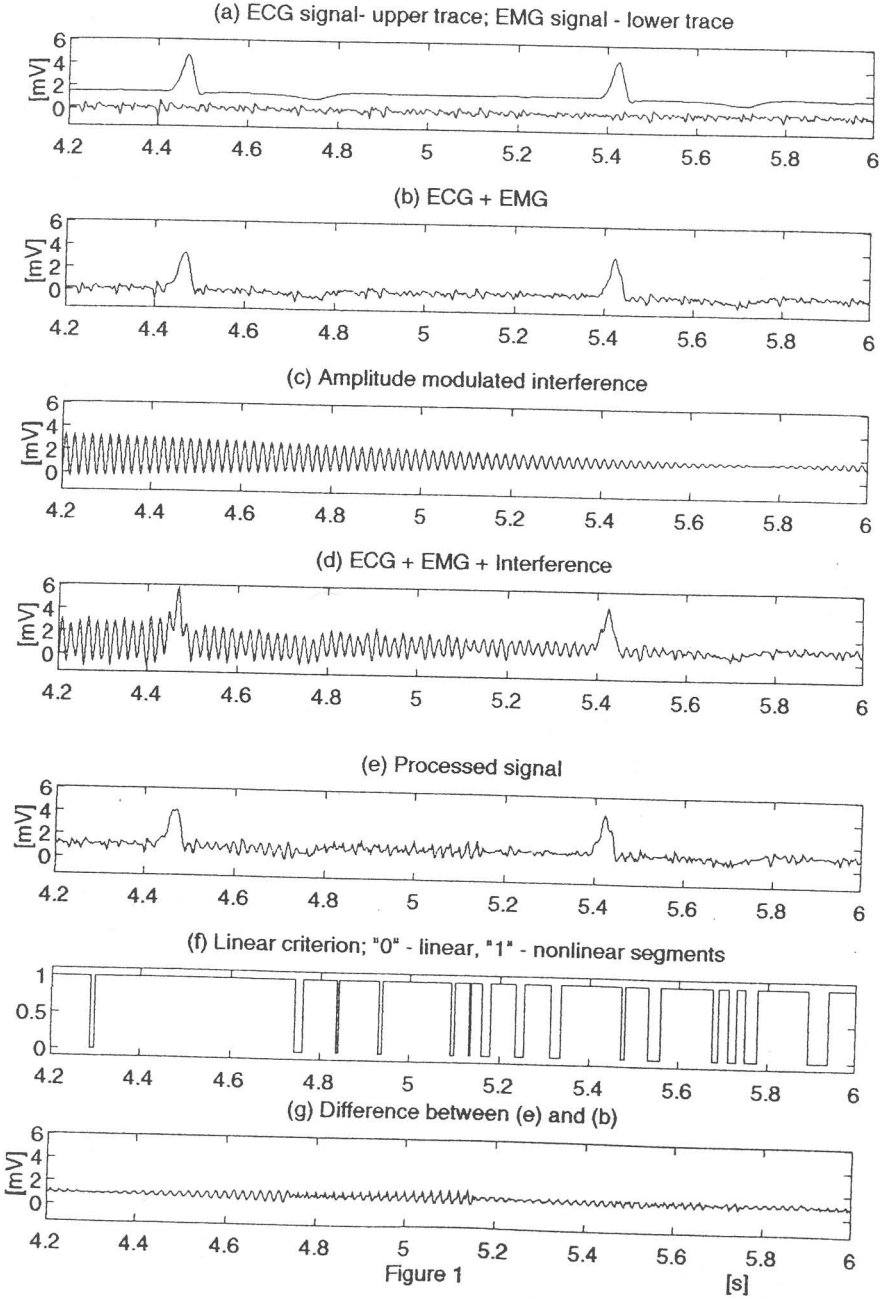
(a) ECG signal- upper trace; EMG signal - lower trace
[mV]
6
4
2
0
4.2
4.4
4.6
4.8
5
5.2
5.4
5.6
5.8
6
(b) ECG + EMG
(c) Amplitude modulated interference
(d) ECG + EMG + Interference
(e) Processed signal
(f) Linear criterion; "0" - linear, "1" - nonlinear segments
1
0.5
0
(g) Difference between (e) and (b)
[s]

Figure 1

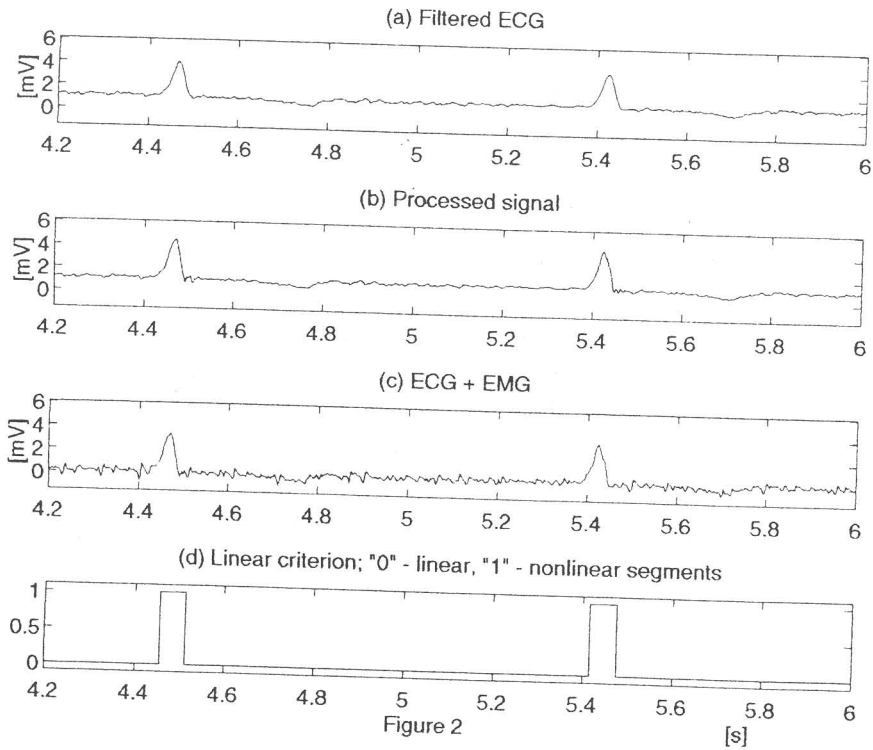
(a) Filtered ECG
[mV]
6
4
2
0
4.2
4.4
4.6
4.8
5
5.2
5.4
5.6
5.8
6
(b) Processed signal
[mV]
6
4
2
0
4.2
4.4
4.6
4.8
5
5.2
5.4
5.6
5.8
6
(c) ECG + EMG
[mV]
6
4
2
0
4.2
4.4
4.6
4.8
5
5.2
5.4
5.6
5.8
6
(d) Linear criterion; "0" - linear, "1" - nonlinear segments
1
0.5
0
4.2
4.4
4.6
4.8
5
5.2
5.4
5.6
5.8
6
[s]

Figure 2