Simple Approach for Tremor Suppression in Electrocardiograms

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Abstract: *Electrocardiogram recordings are very often contaminated by high-frequency noise usually power-line interference and EMG disturbances (tremor). Filtering out the tremor remains a priori partially successful since it has a relatively wide spectrum, which overlaps the useful ECG frequency band by aperiodic noise. The proposed simple approach for tremor suppression uses heuristic relations between the ECG signal parts and parameters of the applied moving averaging. The results obtained are assessed and compared to tremor suppression obtained by moving averaging with constant sample numbers throughout the signal.*

Keywords: *ECG, Tremor suppression, EMG disturbances.*

Introduction

Power-line interference and base-line drift are known as main obstacles to a correct automatic interpretation of the electrocardiogram (ECG). However, the artefacts and the EMG disturbances due to involuntary muscle contractions of the patients (tremor) also have sizable impact on the recording quality. Something more, the tremor suppression is extremely difficult since its spectrum overlaps the useful ECG frequency band. Several approaches have been developed for reducing the EMG disturbances [1, 2, 9, 11, 12]. Some of them are aimed at common suppression of interference and tremor (high frequency disorders because of the similar contaminations of the signal [3, 4]. Still, there is an important difference: the interference is practically with constant waveform while the tremor varies significantly in amplitude and frequency.

Elementary but well spread approach for high frequency noise suppression consists of moving averaging (comb filter with first zero at the power-line frequency) throughout the recording [10]. Low-pass filtering with cut-off within the range of 35 through 45 Hz was also used in times past in case of visual ECG interpretation. As a result, the tremor suppression was unsatisfactory and the peaks of the QRS complexes were very often intolerably smoothed.

Recently Tabakov et al. [15] reported online digital filter, which combines interference and drift suppression. The figures presented show this filter is also able to cope with artefacts provoked by bad electrode-to-skin contact.

Christov and Daskalov [2] applied an adopted by Savitzky and Golay [14] smoothing procedure, which uses least square approximation and a special ‘wings’ function for defining the weighting coefficients. The obtained suppression ratio of the EMG artefact is about 6. Low reduction of R and S waves is reported depending of the wave shape. The authors pointed out that Savitzky-Golay filtering leads to small widening of the R wave at the baseline.

Gotchev et al. [6] applied Savitzky-Golay filter inside the QRS complexes and wavelet shrinkage outside them. The first technique gives a good preservation of the RS amplitude of about 30 μV but with low tremor suppression, while the second one offers good suppression with 440 μV decreasing in the RS amplitude. The combined method incorporates the features of both approaches. They are switched depending on the value of the “wings” function.

Nikolaev and Gotchev [11] denoised ECG signals by applying wavelet domain Wiener filtering. They mixed original signals and EMG noise with a SNR = 14 dB. Two-stage algorithm improves the traditional technique by involving time-frequency dependent threshold for calculating the first stage pilot estimate. A SNR over 20 dB is obtained together with less than 10% QRS amplitudes reduction.

Another technique is reported by Christov [3]. He modified the linear criterion of a specific digital filter for interference cancellation [8] that does not affect the signal frequency components around the mains frequency. The introduced criterion threshold is variable depending on the ECG waves and is aimed to reach a reasonable compromise between tremor suppression and QRS amplitudes reduction.

Kotas [7] published projective filtering of time-aligned ECG beats. This is an extension of time averaging, which preserves the variability of the beat morphology. The method employs rules of the principal component analysis to retain to some extent the normal deviations from the averaged component changes, rejecting in the same time the deviations caused by noise. However, the nonlinear projective filtering is computationally intensive and is known to be sensitive to noise changes.

Sameni et al. [13] proposed a nonlinear Bayesian filtering framework consisting of suboptimal filtering schemes. They are based on modified dynamic ECG model thus utilizing *a priori* information about the underlying dynamics of ECG signals. Nevertheless, several abnormalities different from brady- or tachycardia may lead to large errors in the Gaussian functions locations.

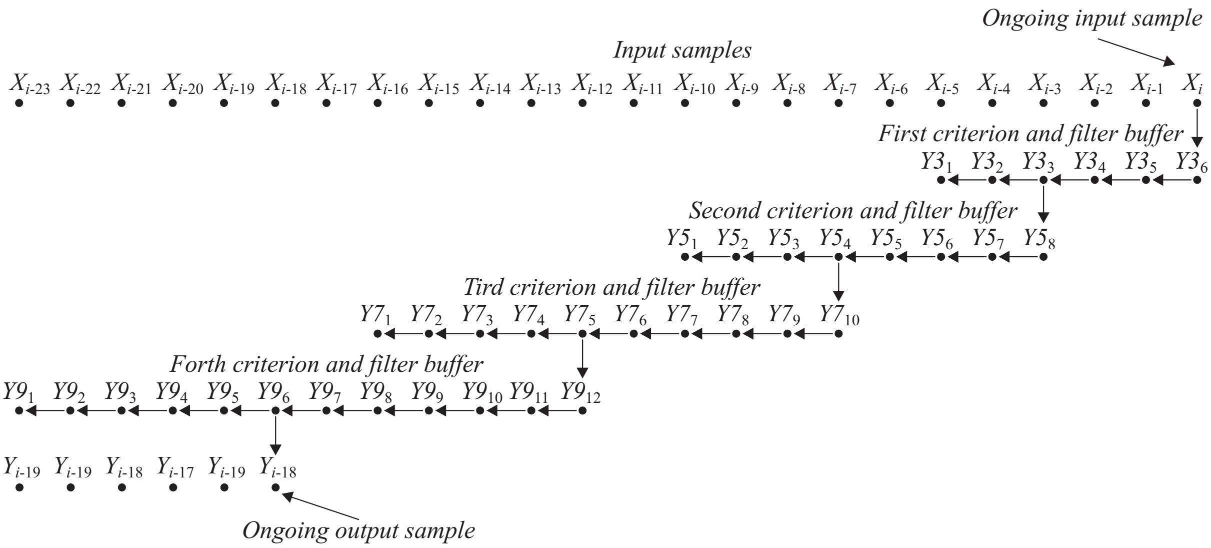
Recently Mihov and Dotsinsky [5] published a method for tremor suppression that implements the following three procedures. Contaminated ECG signals are subjected to moving averaging to suppress tremor and interference simultaneously. The reduced peaks of the QRS complexes are then restored by a special procedure, so that the useful high frequency components are preserved in the range specified by the embedded in the ECG instrument filter, usually up to 125 Hz. Finally, a Savitzky-Golay smoothing filter is applied for supplementary tremor suppression outside the QRS complexes.

Aim of the study

This study was aimed to develop simple approach for tremor suppression using heuristic relations between the ECG waves and parameters of some types of comb filters applied specifically on selected parts of the signal.

Algorithm

The heuristic relations are performed with appropriate criteria that determine comb filters to be applied or not to the signal (conditional partial filtration). Each criterion operates on corresponding interval around the processed sample. The associated comb filter is applied if the criterion value becomes lower than an experimentally defined threshold. The filters are applied consecutively, starting with the shortest interval. To perform the procedure in a real-time mode, each criterion and filter uses a temporal buffer where a pipe-lined processing is carried out. The conditional filtration is illustrated by the following diagram. The first index of *Y3*, *Y5*, *Y7* and *Y9* used in the filtered windows are associated with the number of the averaged samples.



The algorithm is developed in MATLAB environment for sampling rate SR = 250 Hz as it is tested with recordings taken from the AHA database. Nevertheless, the algorithm can be easily adapted for any other SR by changing the values of limited number of parameters.

First criterion and comb filter

The idea of the algorithm will be presented by discussing the first filter. Window overlapping 5 samples is moved step by step. The absolute differences between the first sample and the next ones are calculated. The minimum difference is subtracted from the maximum. If the result is lower than a threshold, the internal three samples are averaged and the obtained value is substituted for the middle sample.

The differences are computed towards one initial sample outside the examined interval to investigate relatively straight lines. The checked values are absolute since the presence of tremor and/or other noise is marked by quasi-symmetric differences while a second difference obtained by signed maximum and minimum is associated with ascendant or descendant part of the signal, e.g. QRS complexes where the averaging is critical.

Below is presented the part of the MATLAB program for one sample processing by the first comb filter.

```
for k = 6:-1:2;
   Y5(k) = Y5(k - 1);                    % Y5 buffer shifting
end;

for j = 1:1:5;
   diff(j) = abs(Y3(1) - Y3(j + 1));
end;
if max(diff(1:1:5)) - min(diff(1:1:5)) < threshold3; % First criterion
   Y5(1) = (Y3(3) + Y3(4) + Y3(5))/3;             % First comb filter
else;
   Y5(1) = Y3(4);
end;
```

The first zero is approximately at 83 Hz. Threshold3 is equal to 2.4 mV, thus the maximum slope allowed is 120 $\mu V \cdot ms^{-1}$. In this way the ascendant and descendant parts of the QRS complexes are protected again filtering that may reduce them while the peak of the contaminated complexes will be smoothed and moved near to the "clean" signal.

Second criterion and comb filter

The parameters of the second filter are: window of 7 samples, threshold5 = 0.6 mV and number of averaged samples equal to 5. The first zero is at 50 Hz. This filter suppresses tremor components in intervals with a slope lower than 21 $\mu V \cdot ms^{-1}$.

Third criterion and comb filter

The parameters are as following: 9 samples, threshold7 = 0.4 mV, 7 averaged samples, first zero at about 36 Hz and maximum slope of 14 $\mu V \cdot ms^{-1}$.

Fourth criterion and comb filter

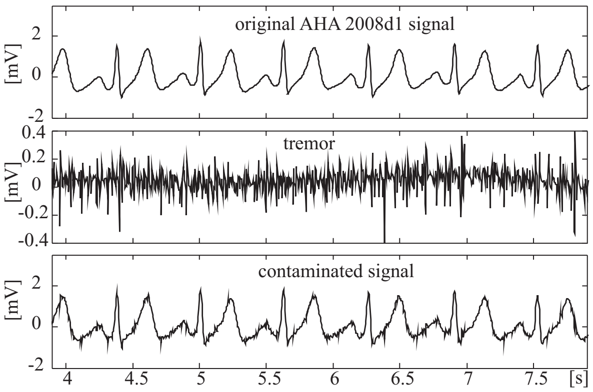
Here the parameters used are: 11 samples, threshold9 = 0.2 mV, 9 averaged samples, first zero at about 28 Hz and maximum slope of 6 $\mu V \cdot ms^{-1}$. The values of the last two filters are aimed to preserve the P wave shapes.

Real time going procedure is obtained by starting the algorithm after an interval of 20 samples of the incoming signal is reached. The intervals for averaging are spaced at appropriate distances. The filters are started in the above order to determine in sequence the processed values. The intervals are moved by one sample with every next incoming sample.

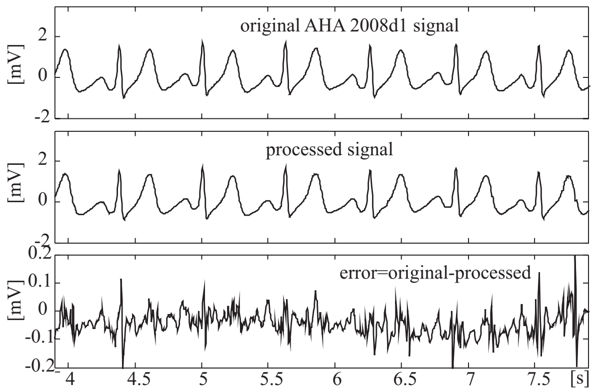
Results

The AHA recordings used for testing the algorithm are preliminary processed to become close to a conditionally clean signal. The signals are mixed with tremor obtained by two ECG electrodes placed on one forearm. The contaminated signals are then processed and the efficiency is assessed once by the difference between original and processed signals and secondly by superimposing one on top of the other.

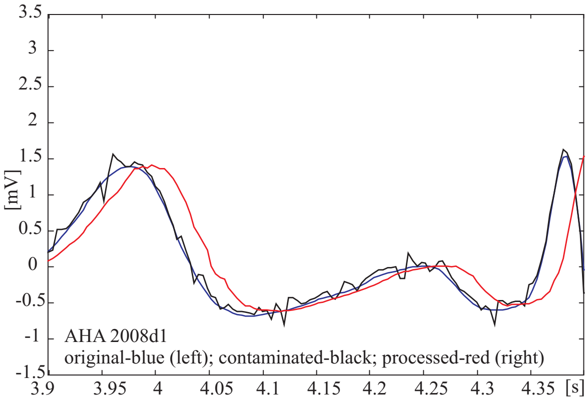
Fig. 1 and Fig. 2 present the experiments with AHA 2008d1 and AHA 5001d1, respectively.



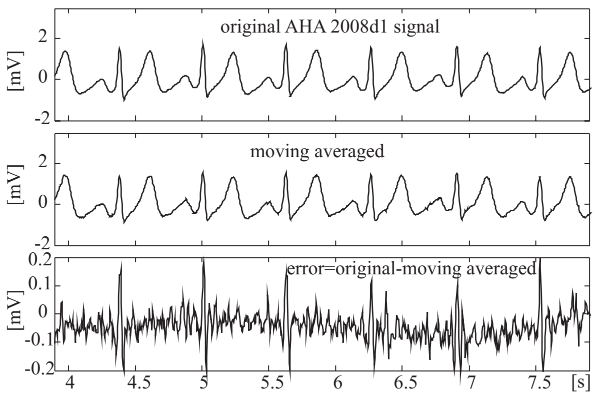
a) Upper trace – original conditionally clean signal; middle trace – added tremor; lower trace – contaminated signal



b) Upper trace – original signal; middle trace – processed signal; lower trace – difference between them in zoomed scale



c) Zoomed in time original signal (blue, left); contaminated signal (black) processed signal (red, right)

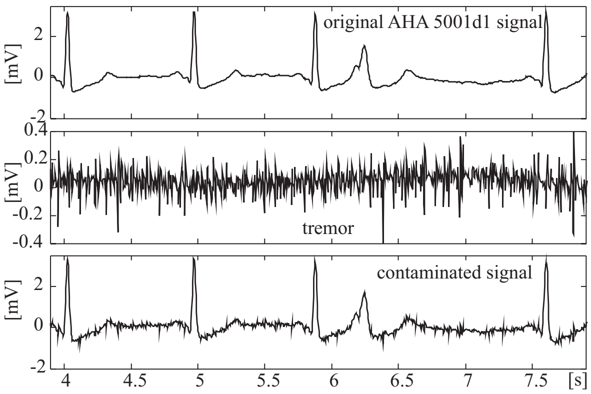


d) Upper trace – original signal; middle trace – moving averaged signal; lower trace – difference between them in zoomed scale

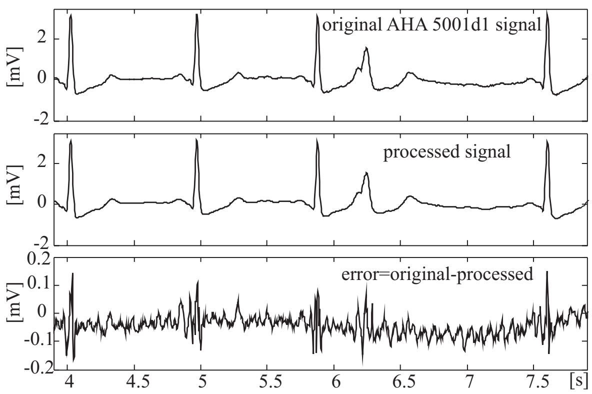
Fig. 1

Fig. 1a and Fig. 2a show how the signals assumed to be "clean" are contaminated by tremor. Original and processed signals can be observed in Fig. 1b and Fig. 2b together with the zoomed in amplitude error committed. Almost everywhere the maximum errors committed are in the QRS complexes but they do not exceed 80-100 μV. Something more, a good part of the differences between original and processed signals is due to the eliminated noise inherent to the accepted as "clean" original signals. Fig. 1c and Fig. 2c show original (blue, left), contaminated (black, middle) and processed (red, right) signals in time zoomed scale. The results with constant in parameter comb filter applied all over the signal are available for comparison in the third subplots of Fig. 1d and Fig. 2d.

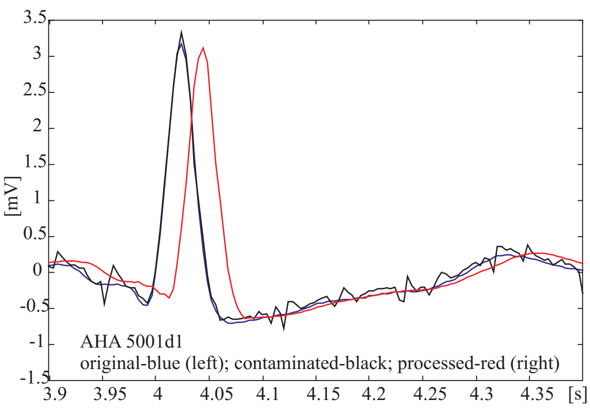
The Figs. 3-8 present the results of processing some other recordings taken for AHA database mixed with the same tremor. The third subplots show superimposed original and processed signals. The processed are slightly shifted right to be better observed. As can be seen, they do not contain tremor and can be assumed as identical to the originals for the purposes of most of the diagnostic tasks. No distortions can be found in the critical ECG parts like the susceptible for analysis ST segments.



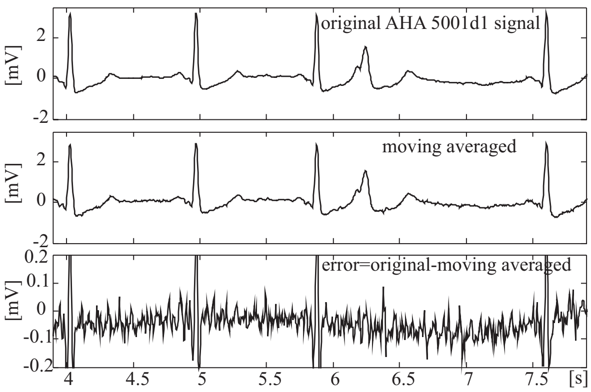
a) Upper trace – original conditionally clean signal; middle trace – added tremor; lower trace – contaminated signal



b) Upper trace – original signal; middle trace – processed signal; lower trace – difference between them in zoomed scale



c) Zoomed in time original signal (blue, left); contaminated signal (black) processed signal (red, right)



d) Upper trace – original signal; middle trace – moving averaged signal; lower trace – difference between them in zoomed scale

Fig. 2

The processed signals in the third subplots (red traces) in the next figures are slightly right shifted to be better observed.

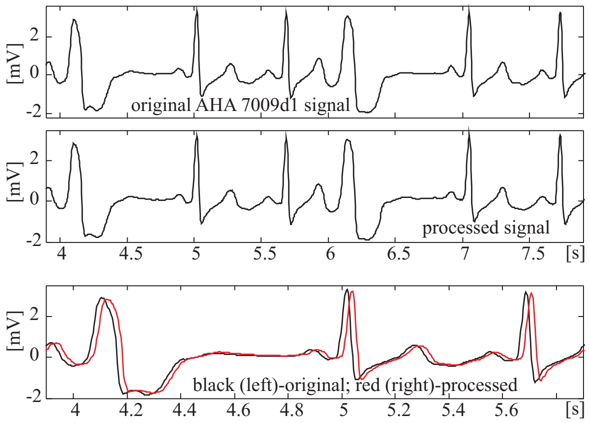


Fig. 3 Result with AHA 7009d1

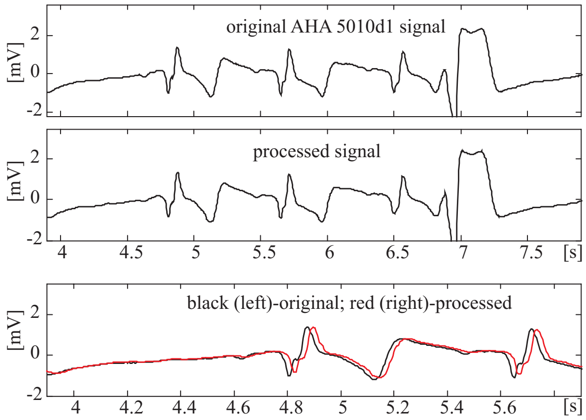


Fig. 4 Result with AHA 5010d1

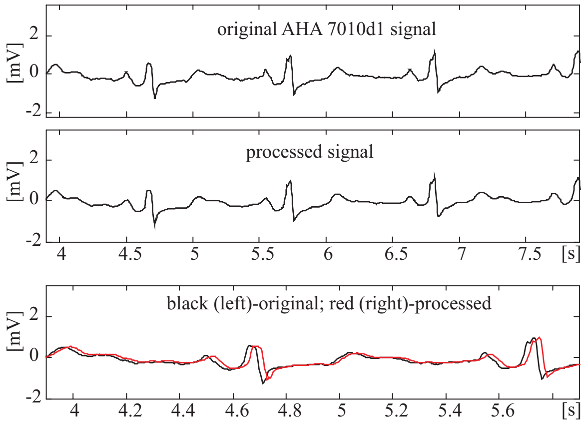


Fig. 5 Result with AHA 7010d1

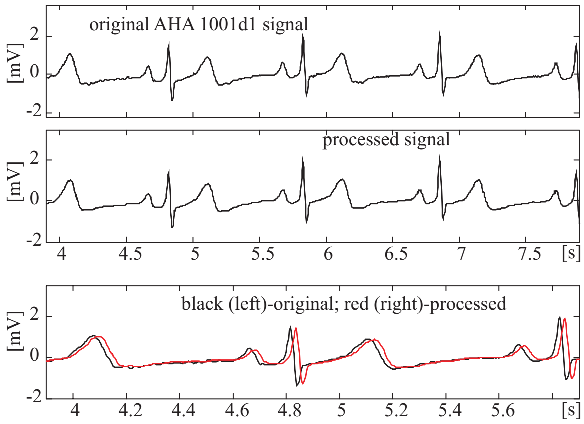


Fig. 6 Result with AHA 1001d1

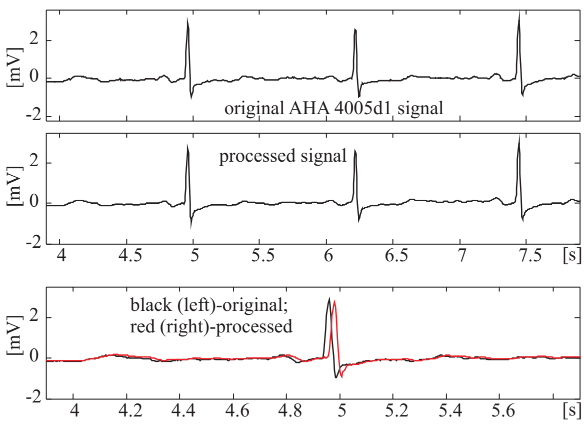


Fig. 7 Result with AHA 4005d1

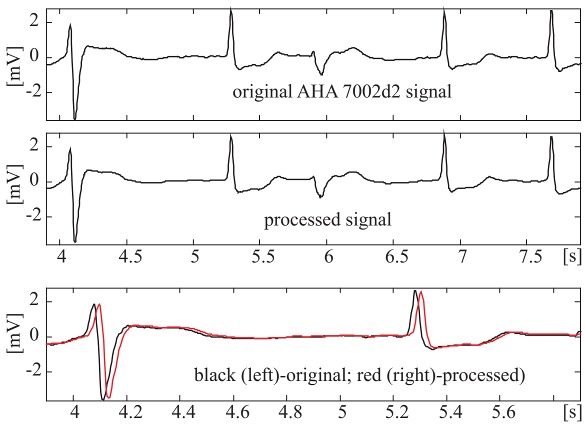


Fig. 8 Result with AHA 7002d2

The last Fig. 9 proves that the reported procedure suppress the power-line interference too. The first trace represents conditionally clean signal mixed with tremor and synthesized interference with constant frequency.

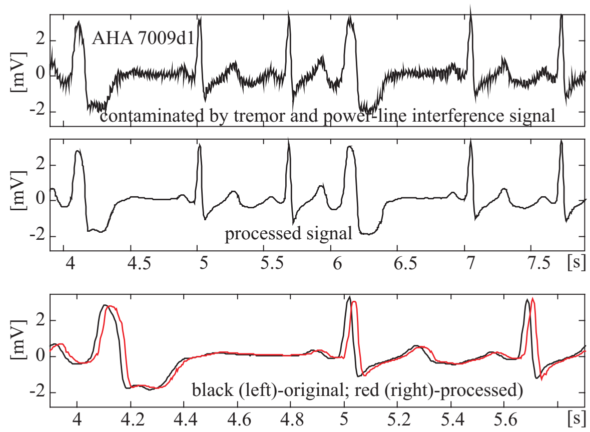


Fig. 9 Common suppression of tremor and interference

Conclusions

The results obtained with many recordings taken from the AHA database show that the heuristic approach consisting of partial moving averaging over selected signal intervals with different parameters gives good possibilities of suppressing tremor and interference accompanying the ECG signals. Compared to the moving averaging all over the signal with one type of comb filter, the proposed approach provokes smaller disturbances including within the QRS complexes. The limited distortions of the signal have no impact on the interpretation. It is necessary also to point out the preservation of the susceptible to analysis ST segments.

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