NEW APPROACH TO SUBTRACTION FILTRATION OF MAINS INTERFERENCE FROM ECG SIGNALS

Tsveta Simeonova Georgieva, Ms. Sc.
(tel. +359 2 965 32 81, E-mail: tsvetad@vmei.acad.bg)
Assoc. Prof. Georgy Slavchev Mihov, Ph.D.
(tel. +359 2 965 32 81, E-mail: gsm@vmei.acad.bg)
Department of Electronics, Technical University - Sofia, Bulgaria

1. INTRODUCTION

Many of existent methods for suppressing mains interference from the electrocardiograms (ECG) used digital filtering [1], but it affects some of the high frequency components of the signal. This is due to the fact that for most biomedical signals whose frequency spectrum includes 50/60 Hz, the signal components of 50/60 Hz will reduce as well as mains interference. Moreover, as the digital filters are not ideal and Q-factor of the notch cannot be very high, the signal components around 50/60 Hz will be reduced to different extents. Therefor the wave shape of the ECG signal will be distorted after passing a filter, especially in high frequency area as QRS complexes. This signal distortion may be unacceptable in some situations, such as high frequency ECG measurement and later potential measurement.

One kind of mains interference subtraction computes and filters the interference values in the linear (which contains only low-frequency components) segments of the signal and compensates the interference in the non-linear segments [2]. This subtraction method has no effect on the high-frequency components of the ECG signals.

In broad outlines this filtration procedure has three parts:

1. Every sample of the input signal is checked up whether it belongs to a linear segment of the signal.
2. With a low pass digital filter the interference is removed in the linear segments. The interference values are computed in these segments and kept in a buffer.
3. These buffered values are used to compensate the interference, where non-linear segments are encountered.

The second part of the proposed procedure involves a search for a linear segment in the ECG signal according to a criteria $|D| \leq M$, where M is an experimentally chosen limit [3]. D is the second difference between samples: $D_i = (X_{i+2n} - X_i) - (X_i - X_{i-2n})$. This criteria estimates linearity in any vicinity of the processed sample from the ECG signal (fig. 1a). The curve from that figure shows the normalized values of this criteria – D_i. The constant normalized value of the threshold M is displayed as straight line on fig. 1b. The value of the threshold M has been chosen empirically. It is very difficult to assess the effect of threshold selection upon the accuracy of the procedure, because the errors depend on the particular type of signal to be filtered. The lower values of M increase accuracy, but only if the magnitude of the mains interference remains constant at a time of the ECG record. Otherwise, higher values of M allow including some linear sections in P and T waves and make possible frequently finding of linear sampled segments. Therefore the magnitude variations of interference in non-linear sections are more precisely compensated.

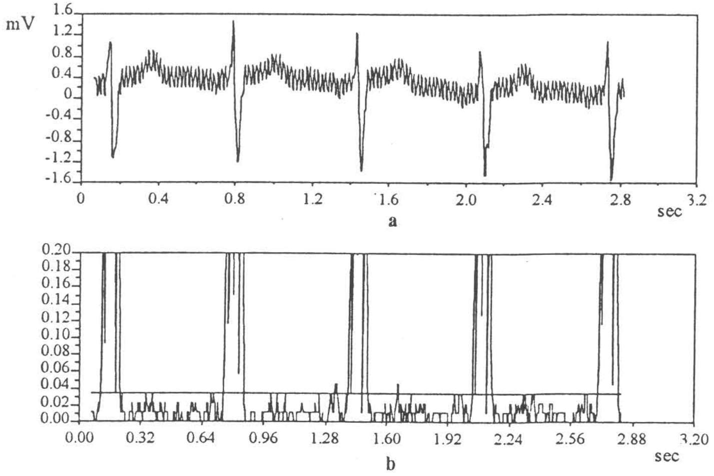

Fig.1. (a) ECG signal whit addede mains interference (b) the linearity criteria, based on partial differences and the experimentally chosen threshold

2. NEW METHOD

This paper represents the other way to form the criteria for linear segments in the ECG signals. The idea is to make a spectral estimation of several points, surrounding every current sample. The criteria for linearity is sum of spectral density, obtained by using a fast Fourier transform (FFT) for finite number of points. When in any area of points appears an abrupt share, as QRS complex, the sum of spectral density for current sample, belong to this area sharply grow up and when this abrupt share disappears this sum sharply become smaller. Therefore the sum of spectral density for each sample very clearly shows if this sample belong to the linear segment or not. The average value of sums for all samples serves as a threshold to determine the boundaries of each linear segment in the signal. If the value of sum for processed sample is above that threshold, then a beginning of a non-linear segment can be confirmed, whereas a linearity may be proved if the value of sum for any next processed sample became smaller then the threshold. Fig. 1a shows one ECG signal with added mains interference. The curve on fig. 1b represents the new criteria for linearity or the sum of the spectral density in any vicinity of each sample from the signal on fig. 1a. The straight line from such figure (b) is the constant value of the new threshold.

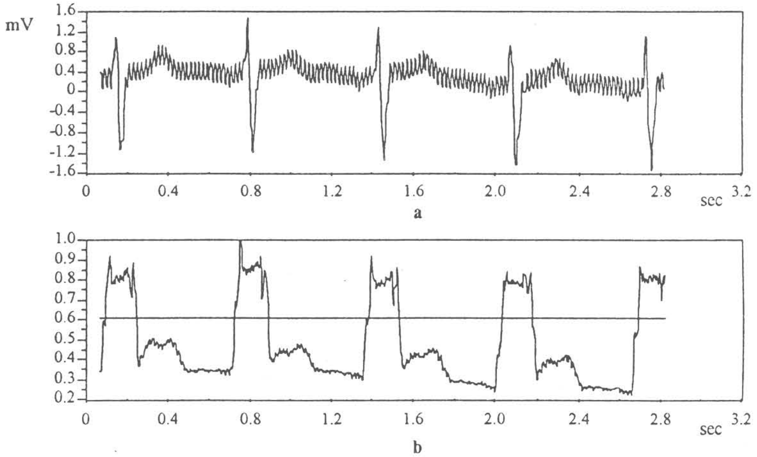

Fig.2. (a) ECG signal whit addede mains interference (b) the new linearity criteria based on sum of spectral density and the new threshold, calculated as an average value of the sums for all samples.

The non linear segments defined by this threshold include only QRS complexes and any kinds of high or sharp P and T waves. All other segments, which include smooth P and T waves are defined as linear, thereby the correction values are more frequent updating and the corrections are more accurate.

Naturally the choice of optimal number of points needful for spectral estimation is a problem. If the points for FFT are as many as they cover two neighbouring QRS complexes, than the linear segment between this QRS complexes will not be indicated. Therefore the number of points for spectral estimation must be carefully selected according to the pulse-rate. Using the sum of spectral density as linearity criteria is efficient when maximum value of magnitudes in linear segments is one and half time smaller than those in non-linear.

3. EXPERIMENTS AND RESULTS

We apply the subtraction method on eight primary standard leads - LA (left arm), RA (right arm) and C_1, C_2, C_3, C_4, C_5, C_6 to approximately 400 real ECG signals, collected in data base. The ECG signals are digitized at a rate of 250 samples per second (4ms sample space) and a resolution of 8 bits (256 levels), where one bit equals 20 μV referred to the input. ECG data are from different patients, with heart diseases and healthy. There are unfiltered and filtered with 50 Hz reject filter signals in this database.

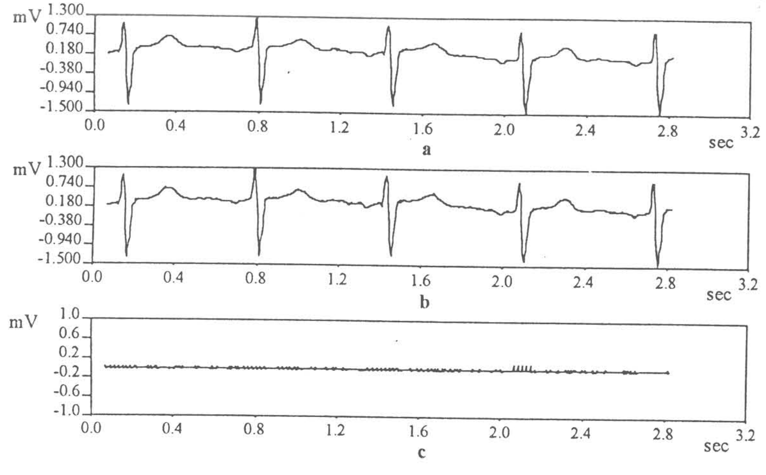

Fig.3. Results of the subtraction method for removing mains interference from ECG, using linearity criteria, based on partial differences.

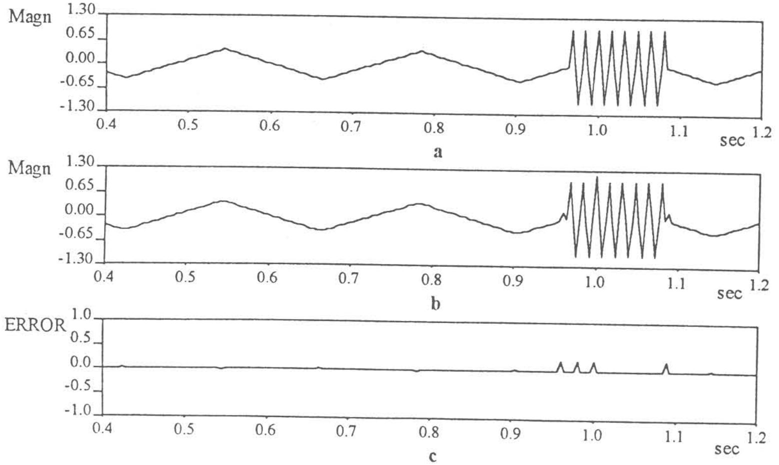

Fig.4. Results of the subtraction method for removing mains interference from triangular signal, using linearity criteria, based on partial differences.

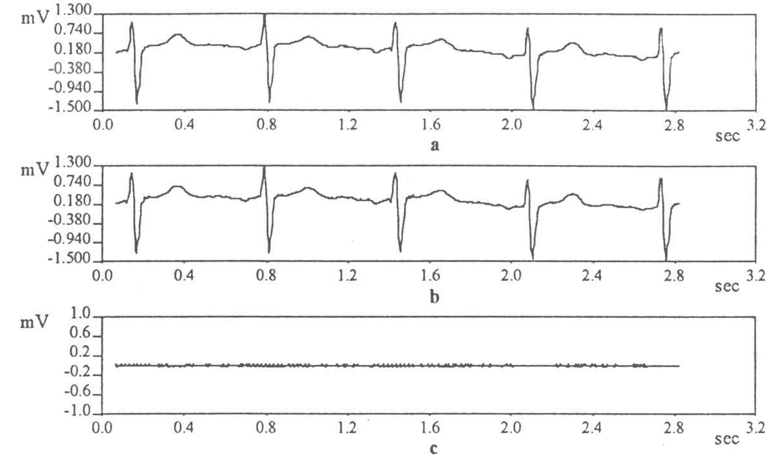

Fig.5. Results of the subtraction method for removing mains interference from ECG, using linearity criteria, based on sum of spectral density.

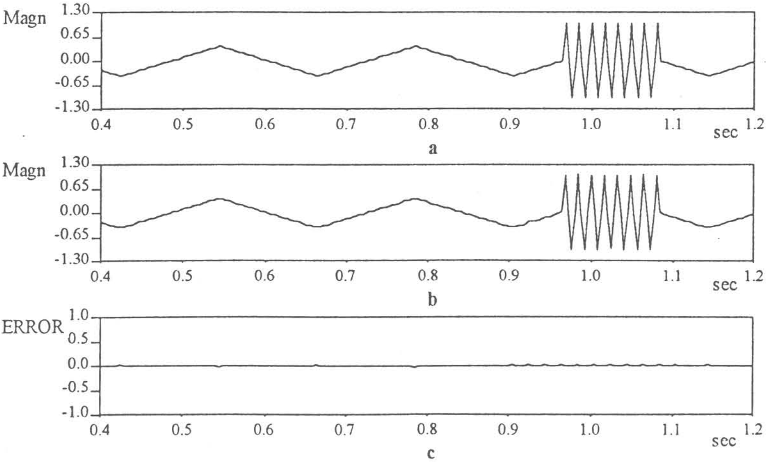

Fig.6. Results of the subtraction method for removing mains interference from triangular signal, using linearity criteria, based on sum of spectral density.

The number of points for FFT must be less or equal to 62, because of the maximum pulse-rate in tahicardia reachs 200-240 pulse for minut. The experiments are made by using 16 points FFT. The new method has been compared with the original method, by using the language of technical computing Scilab-2.5. The results are presented on the figures above. We also use triangular shaped signals containing linear and strongly non-linear parts

Fig. 3a and fig. 5a present an arbitrarily chosen interference-free ECG signals. A test triangular signal with linear and strongly non-linear segments is demonstrated in fig. 4a and fig. 6a. A 50 Hz signal has been added by the computer, so that a noisy signals has been obtained. So all this signals with added mains interference are processed with subtraction procedure, using two criteria to identify the linear segments in the signals - the criterion based on the partial differences (fig. 3b and fig. 4b) and new criteria based on the sum of spectral density (fig. 5b and fig. 6b). The last graphics (c) in the figures present amplified differences between original and filtered signals.

4. CONCLUSIONS

This article aims to propose the other way to determine the linear segments in ECG signals for subtraction filtration of mains interference from these signals. Because the new criterion is sum of spectral density, we need to make a spectral estimation in any vicinity of the processed sample. This is obtained by FFT for finite number of points, according to the human pulse-rate. The process of Fourie transform in real time will be faster by using a system, based on digital signal processors. The threshold for linearity is calculated as an average value of sums for all points, while the threshold of the original subtraction method is experimentally chosen and determines the maximal permitted error.

In the future planes the new method, which is describe in the paper will be developed, tested and applied in a system whit digital signal processor, which will allow easier and faster patient processing in ECG measurement and ECG recording and evaluation

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