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Adaptive ECG signal denoising approach in the initial signal processing stage of electrocardiograph system

***Streszczenie**: Autorzy prezentują model laboratoryjny podejścia do automatycznego oczyszczania sygnałów EKG. Struktura ta skonstruowana jest w postaci zestawu elementów realizujących przy relatywnie niskiej złożoności obliczeniowej ocenę poziomu szumu, dobierając tym samym w sposób płynny odpowiedni zestaw współczynników filtrów.*

***Abstract** The research presents a concept/laboratory model of the proposed approach to ECG signal denoising. An adaptive module is designed for the pre-processing ECG signal enhancement and noise rejection. The research aims at the proposal of the processing method for removing these distortions with relatively low computational complexity. (**Adaptacyjna eliminacja zakłóceń sygnału ECG na początkowym etapie przetwarzania**).*

Słowa kluczowe: EKG, automatyczna eliminacja zakłóceń, określenie jakości sygnału, SNR, estymata szumu.
Keywords: ECG, Automated artefacts elimination, Signal quality determining and improvement, Adaptive filtering, noise estimate.

Introduction

The paper presents a concept/laboratory model for an adaptive raw ECG signal denoising front-end module which is intended to deliver possibly pure ECG signals. During a typical patient diagnostic process, the ECG signal is distorted by various types of disturbances in clinical environment. One can divide them into the physiological artefacts (i.e. muscle tremor, patient's breathing and movement) and technical artefacts (i.e. noise of the signal conditioning input circuit, electrode electrical contact dysfunction, power line interferences and electromagnetic high frequency interferences. Consequently, these factors have crucial influence on quality of detection important ECG parameters resulting in final diagnosis of automated analysis.

System structure

Article covers selected problems of Authors proposal structure of the digital ECG signal front-end, intended to use in real ECG applications [1]. The major problem is to find a reliable compromise between extracting fundamental ECG signals and computational efficiency with accordance to IEC 60601-2-51 medical standard satisfied. The structure of the system was divided into two parts: Adaptive ECG Signal Denoising Module (SDM) and Diagnostic Module (DM) [11].

SDM module contains the Adaptive Filtering Block (AFB) which is responsible for the noise presence and level identification and filter parameters modification [2].

Idea and background

Authors have prepared an adaptive and semi-adaptive FIR structure based filtering block (two separate AFB configurations) during SDM research process. The paper describes development process of the second of the mentioned approaches of AFB. This structure is designed to be used in real time and low computational power applications. So it was necessary to substitute relatively computation demanding classic adaptive filtering scheme for any simpler procedure. As the simpler proposition Authors decided to use FIR filter structures with a smoothly switched coefficients, thus variable spectrum parameters.

One need to know the current noise content in the signal or signal-to-noise ratio (SNR) in order to evaluate proper filter coefficients during system operation. Authors decided to find a likely best noise estimation function that produces an estimation of real SNR calculation (based on frequency) outcome. Moreover the four local bandwidths of the electrocardiogram (LBE) [3] were used to calculate each SNR factor to extend possible area of comparison (0.47Hz-20Hz, 0.47Hz-40Hz, 0.47Hz-50Hz, and finally 0.47Hz-80Hz). The starting point of the bandwidth was selected arbitrary to remove baseline and on the basis of recommendations of the American Heart Association (AHA) [4], [5]. A high-pass filtering with cuf-off frequency of about 0.8Hz may introduce unacceptable distortions in the ST segment [6], therefore authors have used the much lower value.

Research and results

The software used for processing the ECG has been evaluated with CSE database [7] according to the same IEC standard [8], [9]. The 125 10-seconds long records were used for computerised algorithm testing in the essential performance standard IEC 60601-2-51. The parameters of the CSE 10-seconds records were 500S/s and 5μV per LSB.

It was assumed that signal-to-noise ratio (or noise content estimation in a ECG signal) can reflect in the outcomes of ECG signal processing with a use of differential equations. They all act as highpass filters. Based on the equations used in R-wave detectors [10], Authors have proposed and check over a dozen of them, after first tests only a few was selected. The most interesting have been listed below in table 1 with a frequency spectrum presented in the figure 5.

Table 1. Differential equations verified in the research.

(1)	$y(n) = x(n) - x(n-1)$
(2)	$y(n) = x(n+1) - x(n-1)$
(3)	$y(n) = 2x(n+2) + x(n+1) - x(n-1) - 2x(n-2)$
(4)	$y(n) = x(n+2) + x(n+1) - x(n-1) - x(n-2)$
(5)	$y(n) = x(n+1) - 2x(n) + x(n-1)$
(6)	$y(n) = x(n+2) - 2x(n) + x(x-2)$

To obtain a reference model used as an archetype to perform noise estimation product comparison, the average spectrum of all CSE MO1 signals was prepared (based on the complete set of 125 signals). One can see this level as a red spectrum line in the figure 4 and in the frequency SNR histogram for CSE database recordings (fig. 2) with different bandwidth ranges.

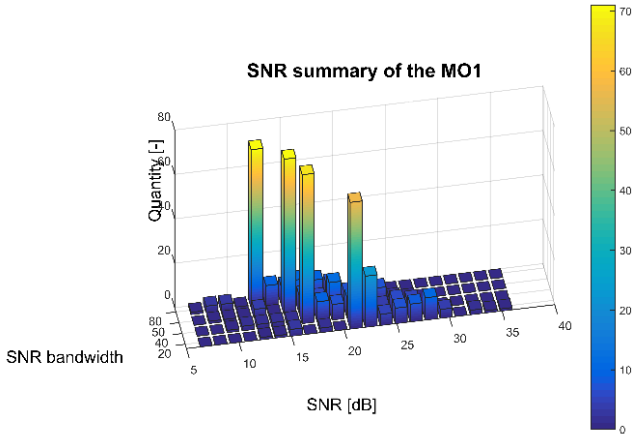

Fig. 1. The frequency based SNR histogram of 125 CSE MO signals as a reference model for selecting proper differential equation for the following considerations. A five approaches were shown (for different SNR bandwidths)

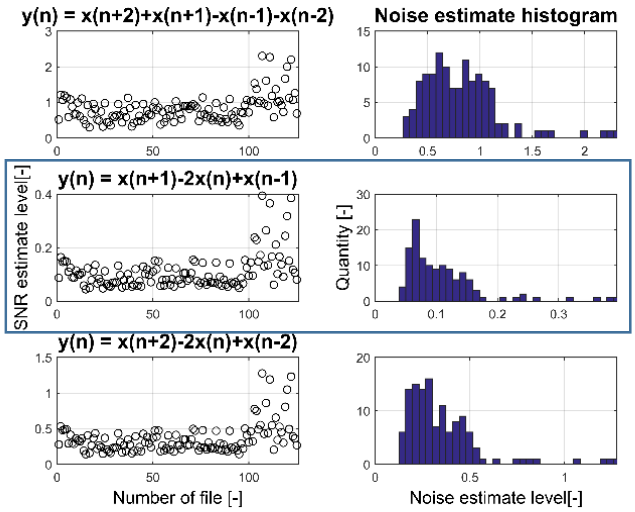

Fig. 2. A part of set of difference equations used in presented research. First column is a proposal of signal to noise estimation based on the derivative, second is its histogram to compare with SNR calculated in the frequency domain.

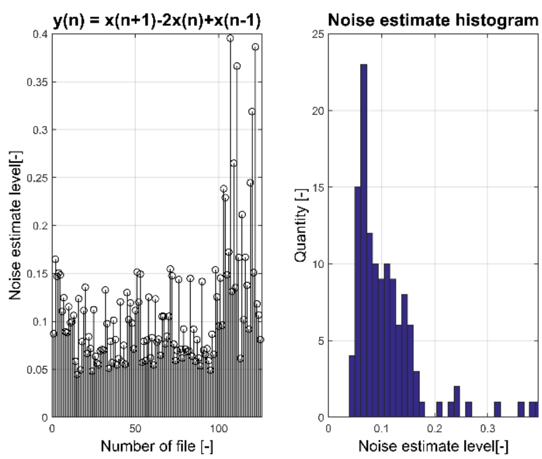

Fig. 4. The chosen noise content estimation based on (5) equation

As it can be observed, the equation no. 5 (Tab. 1) corresponds with reference SNR histogram, in all proposed LBE (fig. 3 and 4). Processing ECG signal with equation no. 5 results in most wanted form of the ECG signal attenuation.

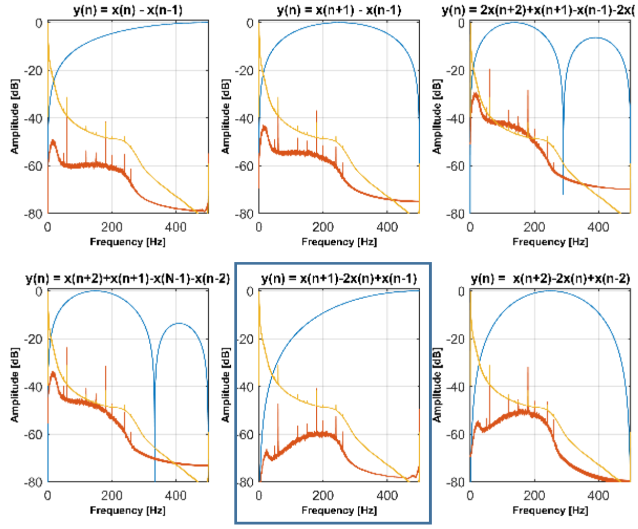

Fig. 5. A comparison of the derivatives frequency response (blue), a mean of 125 CSE MO signals (orange) and mean product of the difference equation filtering (red) (125 signals). Equation no. 5 (Table 1) was selected as having the best signal rejection

Conclusions

During a typical patient diagnostic process, the ECG signal is distorted by various types of disturbances in clinical environment. The noise factors have crucial influence on quality of detection important ECG parameters resulting in final diagnosis of the automated analysis performed. That is the reason why Authors develop a “novel” proposal adaptive filter stage into the digital front-end module. It is a new proposition of the structure of the digital ECG signal front-end, intended to use in real ECG applications. The major problem is to find a reliable compromise between extracting fundamental ECG signals and computational efficiency with accordance to IEC 60601 medical standard satisfied.

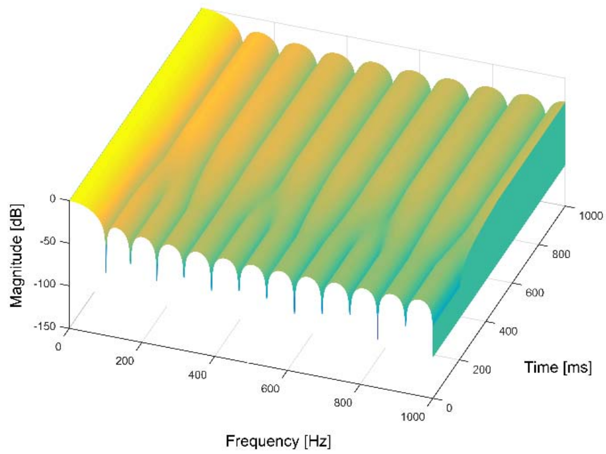

Fig. 6. An example of the adaptive filter coefficient switch-over as a result of proper filter bank selection based on selected difference equation

The proposition of the „Adaptive Filtering Block” aims at smooth switching filter coefficients following changes of the signal distortion level (fig. 6). Presented results can be helpful in development of the filtering stage of the ECG recorder or monitor. The proposal adaptive procedure is less complex (in terms of computational effort) as compared to the classic adaptive approach. Authors intend to extend it to the rest of ECG common disturbances, both physiological and technical (i.e. muscle tremor, patient's breathing and movement, noise of the signal conditioning input circuit, electrode electrical contact dysfunction, power line and electromagnetic high frequency interferences).

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