REAL-TIME ESTIMATION OF ECG SIGNAL QUALITY

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Abstract: In this study, we focus on the estimation of ECG signal quality. It consists of two parts, first includes generating artificial ECG, artificial myopotentials, implementation of Adaptive Wavelet Wiener Filter and continuous calculation of the Signal-to-Noise Ratio (SNR). The second part includes segmentation process, which sorts parts of ECG signal into three categories: suitable for full wave analysis, good for QRS detection and unsuitable for further processing

Keywords: ECG signal, noise estimation, ECG quality, Adaptive Wavelet Wiener Filter, ECG segmentation

1 INTRODUCTION

Nowdays, cardiovascular diseases are very serious. Electrocardiography (ECG) is a basic examining method used in cardiology. Heart activity is captured and visualised by electrocardiogram (ECG). The ECG can reveal the full spectrum of heart defects. Problems, we can run into while analysing ECG signal is presence of a noise. This is why we deal with the estimation of ECG signal quality in this study. There are various approaches for the quality estimation: methods based on statistical functions (Std, Skewness, Kurtosis) [1], the method based on the Independent Components Analysis (ICA) [2], or methods based on filtering [3]. Our method is based on the signal filtering, continuous calculation of the Signal-to-Noise Ratio (SNR) and segmentation of ECG signals into three quality categories (Q1, Q2, Q3).

2 DESIGNED METHOD

Determination of the quality of ECG signal consists of using Adaptive Wavelet Wiener Filter (AWWF) to remove myopotential noise, followed by the estimation of the SNR. In pursuance of the SNR values and determined decision rules, such as length of the quality section, we set the signal quality.

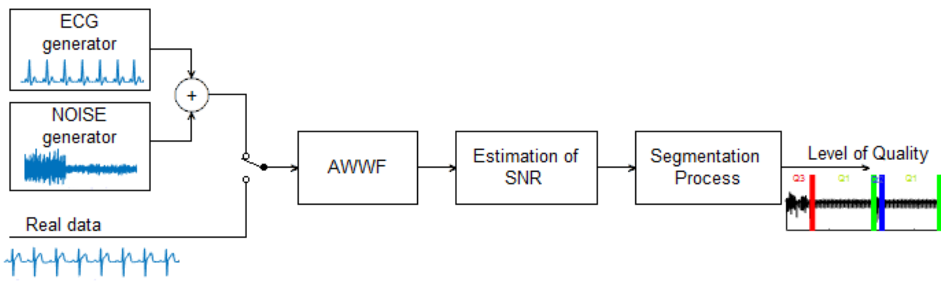

Figure 1: Block diagram of the real-time estimation of ECG signal quality

The algorithm was implemented in Matlab R2014a programming environment. Our method was tested on artificial ECG signal (block ECG generator) with added artificial noise (block Noise generator), see Fig. 1. The noise generator is set on the known level of myopotential noise.

2.1 Adaptive Wavelet Wiener Filter and estimation of SNR

We applied Adaptive Wavelet Wiener Filter (block AWWF in Fig. 1) on artificial ECG signal. This block consists of two wavelet transformations, a block for modification of wavelet coefficients using adaptive threshold and Wiener filter, that corrects the wavelet coefficients using a correction factor. Subtracting the filtered signal from the original signal, we get the noise. Once we have noise component and clear ECG signal we can calculate the continuous SNR signal, according to the formula:

$$SNR = 10log_{10}\frac{\sum_{n=0}^{N-1}[s(n)-s']^2}{\sum_{n=0}^{N-1}w(n)^2}[dB], \quad (1)$$

when s is the clear ECG signal, s' is its mean value and w is noise component. In Fig. 2 a), we can see comparison of required SNR curve (green) and our estimation (black). Fig. 2 b) and c) shows results for real data, when the noise in signal from real data (b) increases, the SNR value (c) decreases.

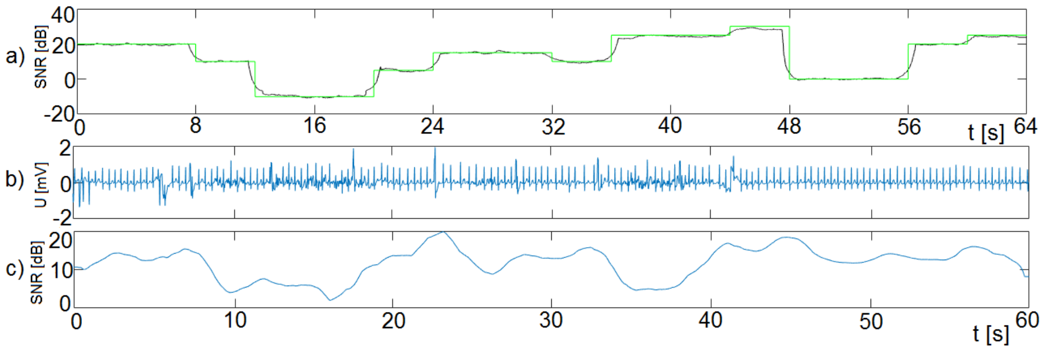

Figure 2: a) Comparison of required SNR curve (green) and our estimation (black), b) Signal from real data, c) Estimation of SNR from real data.

2.2 Segmentation Process

The process of segmentation is based on processing of the continuous estimation of the SNR. The segmentation is performed in real-time. Signal is divided into three categories: Q1, Q2 and Q3.

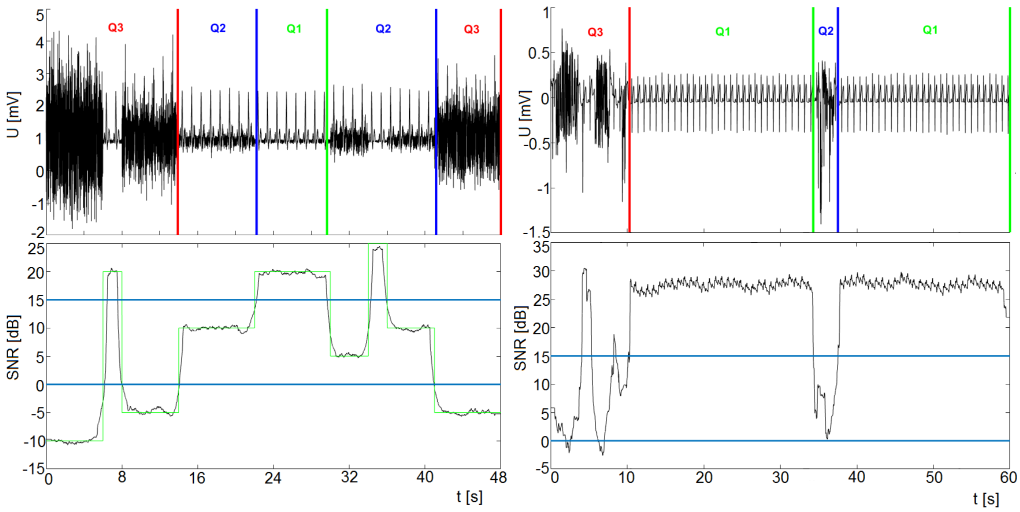

Figure 3: Left top: Artificial ECG signal with detected segments borders (vertical lines). Left bottom: Continuous SNR curve estimation (black), required SNR curve (green) and thresholds values (blue). Right top: Real ECG signal with detected segments borders (vertical lines). Right bottom: Continuous SNR curve estimation (black) and thresholds values (blue).

Category Q1 represents the highest quality. These parts of ECG signals are suitable for full wave analysis. Category Q2 contains moderate level of noise, from which we can correctly detect QRS waves but no P and T waves. Parts of ECG signals with high level of noise are put in the Q3 category. These parts are not suitable for any reliable analysis. The example of segmentation process is shown in Fig. 3. The boundary between Q1 and Q2 was set to 15 dB, and between Q2 and Q3 to 0 dB. The boundaries were experimentally estimated in order to maximize the abilities of detectors to detect P, QRS and T waves.

We also take into account the length of the segments. If a short signal of higher quality (Q1/Q2) is found in the middle of a very noisy signal (Q3), the short signal part has no information value, and we classify it in the Q3 category. Further, if in the Q2 category is a short high-quality (Q1) signal, this short signal part is not suitable for full wave analysis and we classify it in the Q2 category – reliable calculation of the heart rate only. Threshold, which defines whether it is a short signal or not, was experimentally set to 3 seconds. If a short noisy part is in a good quality signal then this short part will be classified as Q3 category – unsuitable for further processing.

3 RESULTS AND DISCUSSION

The proposed algorithm was tested on 10 artificial ECG signals and 10 ECG signals from real dataset obtained from Department of Biomedical Engineering - Brno University of Technology. Quality of segments in real dataset were determined by human expert. Table 1 shows overall averaged results aquired from all examined signals. In Table 1 we can see, that the values of Sensitivity and Positive predictivity to detect the segments reaches 100 %. Based on the results we assume, that our algorithm is able to detect all segments in ECG signals. In the columns Mean Value and Standard Deviation, we can see deviations from the real borders of the segments. Deviations are very low and thus, we can declare our segmentation algorithm not just robust, but also accurate.

Table 1: The experimental results of segmentation

ECG signal	Mean Value [s]	Standard deviation [s]	Sensitivity [%]	Positive predictivity [%]
Artificial	0.32	0.2	100	100
Real dataset	0.53	0.32	100	100

4 CONCLUSION

This article deals with the real-time estimation of the ECG signal quality. The algorithm is based on the signal filtering using Adaptive Wavelet Wiener Filter, followed by the continuous estimate of SNR. We divide the quality of the ECG signal into three categories: Q1, Q2 and Q3 by SNR values. The proposed method was evaluated on both artificial and real signals. The achieved experimental results proved reliability and accuracy of our segmentation method.

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