ПРОГРЕСИВНІ ІНФОРМАЦІЙНІ ТЕХНОЛОГІЇ

ПРОГРЕССИВНЫЕ ИНФОРМАЦИОННЫЕ ТЕХНОЛОГИИ

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R-PEAKS DETECTION USING WAVELET TECHNOLOGY

The given work presents the methodology of R-peaks detection in an electrocardiogram signal based on Discrete Wavelet Transformation. The optimal level decomposition of the detail coefficients can be determined by energy, frequency and cross-correlation analyses. The effectiveness of the proposed algorithm has been tested by using records obtained from the MIT/BIH Physionet arrhythmia database.

Keywords: ECG, wavelet transformation, R-peaks detection.

INTRODUCTION

An electrocardiogram (ECG) is a graphic record of the direction and magnitude of electrical activity of the heart that is generated by depolarization and repolarization of the atria and ventricles [1]. ECG gives information about the current state of the cardiovascular system and the pathological changes in the heart. Automatic analysis of the ECG signal is complex theoretical problem. It is closely related to the signal's physiological origin, which is the cause of its non-determination, diversity, variability, unpredictability, non-stationarity and susceptibility to many kinds of noise. A number of modern mathematics methods have been developed for non-stationary signals' analysis. The most famous one is wavelet transformation, which allows to work with non-stationary signals, detect their features and determine the signal's frequency components' time localization unlike Fourier transformation. The wavelet transformation is signal decomposition into basis functions sets, which are derived from a single prototype wavelet by scaling (dilatations and contractions) and translations (shifts).

A typical ECG tracing of normal heartbeat (or cardiac cycle) consists of P-wave, QRS-complex and T-wave. A small «U-wave» is normally visible in 50 to 75 % of ECGs. The baseline voltage of the electrocardiogram is known as the isoelectric line [1–3]. The starting point for a number of modern computer electrocardiography techniques is localizing of QRS-complexes, which positions are determined by positions of their maxima – R-peaks. Now there are a lot of methods for detecting the time R-peaks locations, which are based on finding the first and second derivatives, the amplitude estimation etc. Existing methods do not meet the requirements of researches, as they often give insufficient accuracy in R-peaks detection.

In this paper the method of ECG R-peaks detection based on the discrete wavelet transformation is proposed.

1 DISCRETE WAVELET TRANSFORMATION

In the multilevel discrete wavelet transformation the tree connection of low-pass and high-pass filters with different cut-off frequencies is used to analyze the signal through different scales. The approximation coefficients cA (smoothed signal) and the detail coefficients cD (high-frequency fluctuations of the signal) can be determined. The approximation coefficients are obtained by convolving the input signal s through the low-pass filter transfer function by formula (1) and then downsampling the convolution result by 2:

$$cA_n = \sum_{k \in Z} h_k s_{2n-k}, \qquad (1)$$

where h_k represents the k-th low-pass filter coefficient.

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The detail coefficients are obtained by convolving the input signal s with a high-pass filter transfer function by formula (2) and then downsampling the convolution result by 2:

$$cD_n = \sum_{k \in Z} g_k s_{2n-k} \,, \qquad (2)$$

where g_k denotes the k-th high-pass filter coefficient.

2 WAVELET BASIS SELECTION

The selection of mother wavelet is important problem before starting of the detection procedure. But there is no universal method suggested selecting the wavelet basis. The choice of the wavelet depends on the initial signal.

In the given work the wavelet proposed in [4] was used to analyze the ECG signal. It is a wavelet from Daubechies family («db6»). Daubechies wavelets show similarity with QRS-complexes and their energy spectrum is concentrated around the low frequencies [4].

3 R-PEAKS DETECTION METHODOLOGY

Let's consider the fragment of the ECG signal with duration of 3 minutes from the record No. 100 of MIT/BIH arrhythmia database [5].The wavelet decomposition structure of ECG signal using «db6» wavelet is shown in Fig. 1. The original signal is shown at the top of the plot. The decomposed signal's reconstructed components within eight wavelet scales are shown below.

The detail coefficients of the fourth decomposition level are chosen to detect the R-peaks based on energy, frequency and cross-correlation analyses [4].

Energy analysis. Most of ECG energy of the QRS-complex is concentrated in the frequency range from 4 Hz to 50 Hz. Normally isoelectric segments (PQ, ST and TP) contain no energy and the signal amplitude is zero over these corresponding intervals [4]. The distribution curve of the signal decomposed levels energy is shown in Fig. 2.

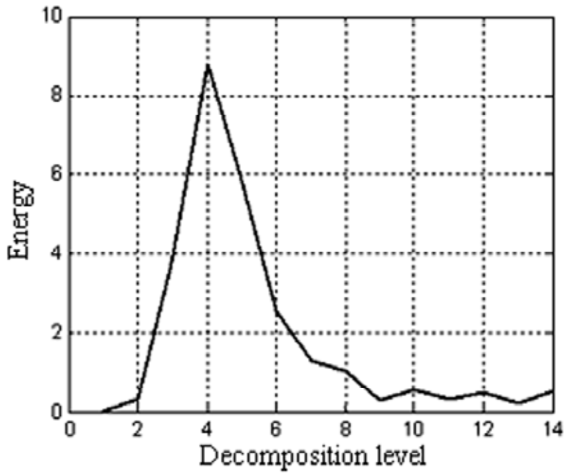

Fig. 2. Energy plot of wavelet decomposition structure (record No. 100)

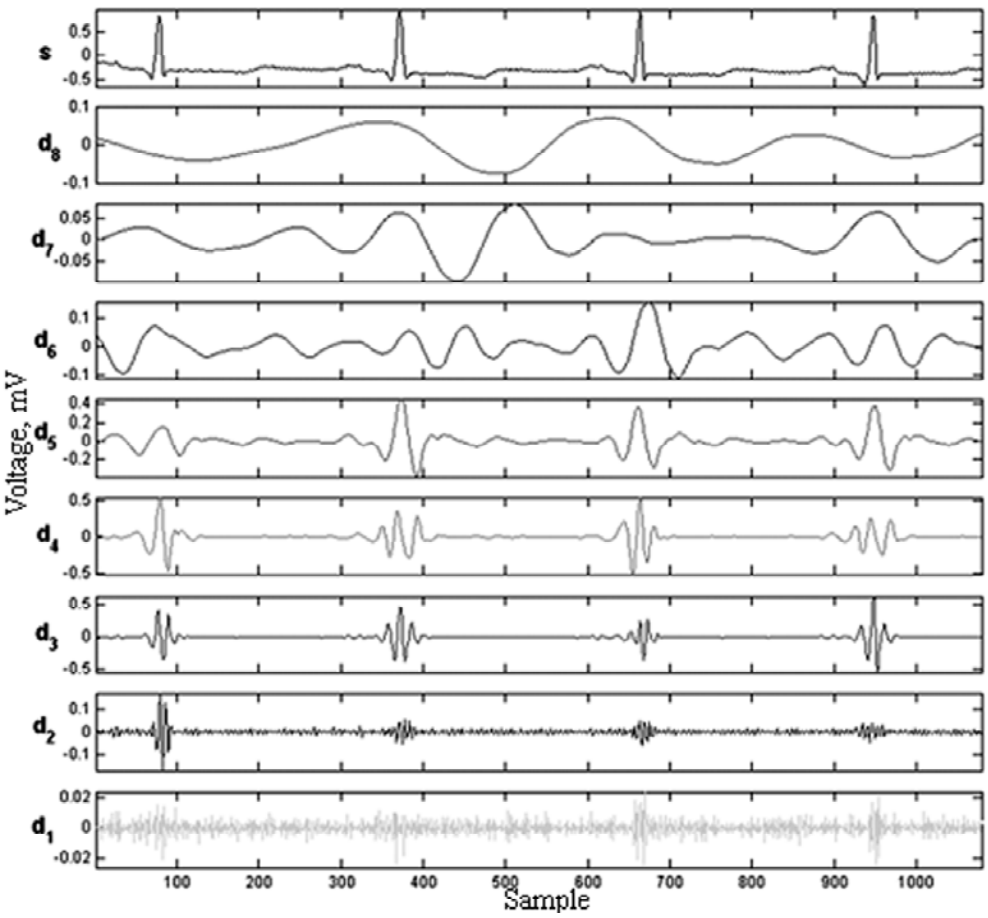

Fig. 1. Decomposition of the ECG signal (record No. 100)

The energy curve shows that the energy is highest at level-4. Therefore, we consider that it consists the significant details of QRS-complexes.

Frequency analysis. Another justification of selecting d4 signal is its available frequency components correlated with that of the QRS-complex. The Fourier Transform of the d4 signal is performed and shown in Fig. 3. The bandwidth of the d4 signal is 2,5–39,5 Hz which is almost same as that of a QRS-complex [1].

As the signal has the sampling frequency of 360 Hz, the signal's frequency spectrum is limited by the maximum frequency of 180 Hz according to the Nyquist rule.

Correlation analysis. In addition to the above two analyses the cross-correlation analysis between the reconstructed components and the original ECG signal was performed. This provides us the time domain relationship between the original and the decomposed signals. The analysis results are shown in table 1.

Table 1. Cross-correlation coefficients

Details	Cross-correlation coefficient
d1	0,025
d2	0,112
d3	0,384
d4	0,585
d5	0,479
d6	0,317
d7	0,227
d8	0,202

From table 1 it is clear that the cross-correlation coefficient value of d4 is highest. So, it is obvious that the signal can be reconstructed by one branch of the wavelet coefficients. The 4th decomposition level is highly correlated with the original signal in time domain.

The algorithm of R-peaks detection consists of the following steps.

Step 1. Compute the signal decomposition up to 4 level.

Step 2. Carry out the signal reconstruction of the 4th decomposition level based on one branch of the wavelet coefficients.

Step 3. Determine the R-peaks locations as non-zero samples of d4.

Step 4. Eliminate the fault founded R-peaks using the following conditions:

– the normal QRS-complex duration must be 100 ms;

– the minimum value of RR-interval must be 200 ms.

4 RESULTS AND DISCUSSION

The proposed algorithm for R-peaks detection was implemented in the MatLab environment (v. 6.5) with the Wavelet Toolbox. The sample ECG signals of the present study were obtained from the MIT/BIH database via Physionet website [5]. MIT/BIH is a de facto standard of the testing of devices, systems and software intended for cardiac monitoring. The MIT/BIH arrhythmia database contains 48 two-channel records (each 30 minutes long) with the sampling frequency of 360 Hz annotated by qualified medical professionals. As the annotations are assumed to

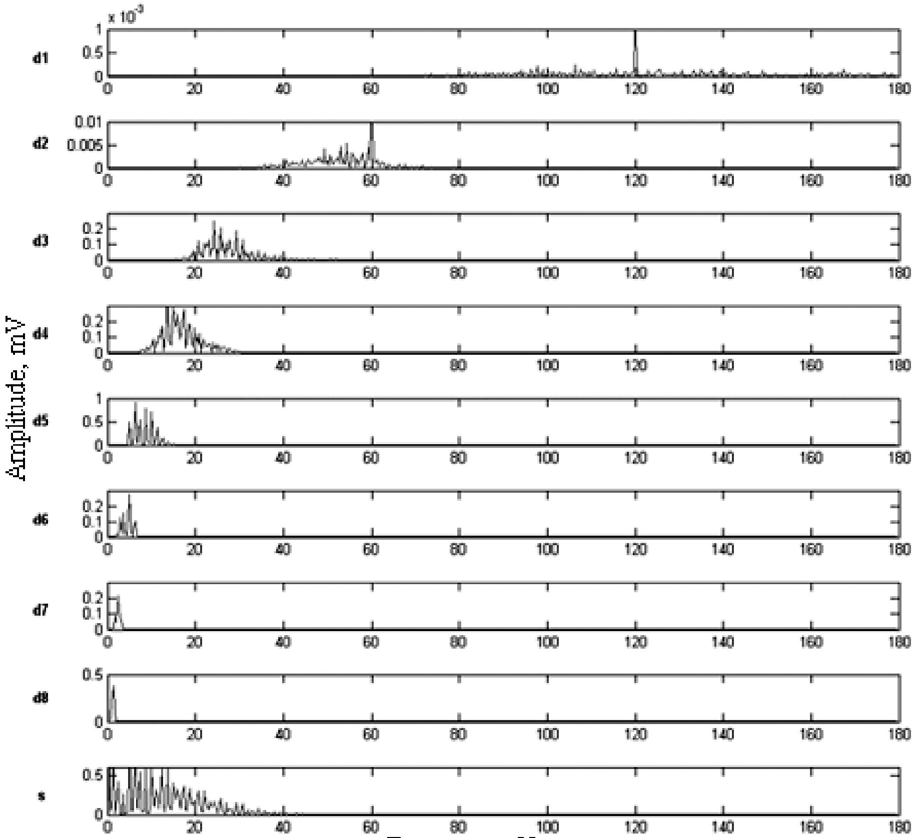

Fig. 3. Frequency distribution of details and ECG (record No. 100)

be 100 % correct, the algorithm efficiency is determined by comparing the obtained results with them.

To assess the performance two statistical measurements were used [6]. These are the Sensitivity (Se), which gives the fraction of real events that are correctly detected and it is defined by formula (3):

$$Se = \frac{TP}{TP + FN} \cdot 100\%, \quad (3)$$

and the Positive Predictivity (P_+), which is the fraction of detections that are real events and it is defined by formula (4):

$$P_+ = \frac{TP}{TP + FP} \cdot 100\%, \quad (4)$$

where *FN* (False Negatives) denotes the number of missed detections, *FP* (False Positives) represents the number of extra detections and *TP* (True Positives) is the number of the correctly detected QRS-complexes.

The average Sensitivity of the algorithm is 99,64 % and its Positive Predictivity is 99,82 %.

CONCLUSION

The algorithm is presented for the detection of the R-peaks in an ECG signal. This algorithm is based on the discrete wavelet transformation. The detail coefficients of the fourth decomposition level are chosen to detect the R-peaks based on energy, frequency and cross-correlation analyses. The algorithm is evaluated for a number of records obtained from the MIT/BIH arrhythmia database. The accuracy of the algorithm is high due to the criteria (average Sensitivity is 99,64 % and average Positive Predictivity is 99,82 %.).

SPISOK LITERATURY

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ВЫЯВЛЕНИЕ R-ПИКОВ КАРДИОСИГНАЛ С ИСПОЛЬЗОВАНИЕМ ВЕЙВЛЕТ-ТЕХНОЛОГИИ

Данная работа посвящена методике обнаружения R-пиков сигнала ЭКГ, основанной на применении дискретного вейвлет-преобразования. Выбор детализирующих коэффициентов 4-го уровня разложения кардиосигнала был сделан на основании результатов проведенных энергетического, частотного и корреляционного анализов. Эффективность предложенного алгоритма была проверена с использованием записей из базы данных аритмий MIT-BIH Physionet.

Ключевые слова: ЭКГ, вейвлет-преобразование, обнаружение R-пиков.

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ВИЯВЛЕННЯ R-ПІКІВ КАРДІОСИГНАЛУ З ВИКОРИСТАННЯМ ВЕЙВЛЕТ-ТЕХНОЛОГІЇ

Дана робота присвячена методиці виявлення R-піків сигналу ЕКГ, заснованій на застосуванні дискретного вейвлет-перетворення. Вибір деталізуючих коефіцієнтів 4-го рівня розкладання кардіосигнала було зроблено на підставі результатів проведених енергетичного, частотного та кореляційного аналізів. Ефективність запропонованого алгоритму була перевірена з використанням записів з бази даних аритмій MIT-BIH Physionet.

Ключові слова: ЕКГ, вейвлет-перетворення, виявлення R-піків.

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