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Development of an algorithm for preprocessing ultra-high resolution electrocardiosignals

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Abstract. The necessity of developing an algorithm for preprocessing ultra-high resolution electrocardiosignals (UHR ECS) is substantiated. The causes of distortion of the useful signal are analyzed, two filtering methods have been developed for cardiac signals obtained from high-frequency (HF) and low-frequency (LF) channels for recording electrocardiograms (ECG). An algorithm for identifying the characteristic points of the ECS, denoted by the Latin letters P, Q, R, S, T, necessary for synchronization has been developed. The efficiency of the presented algorithm is estimated using the processing time of one signal record, as well as using the error matrix and calculating the Recall and Precision parameters.

Keywords: UHR ECS, UHR ECG, cardiogram, algorithm, characteristic points, signal processing, filtering, release

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Разработка алгоритма предварительной обработки электрокардиосигналов сверхвысокого разрешения

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Аннотация. Обоснована необходимость разработки алгоритма предварительной обработки электрокардиосигналов сверхвысокого разрешения (ЭКС СВР). Проанализированы причины искажения полезного сигнала, разработаны два метода фильтрации для кардиосигналов, полученных из высокочастотного (ВЧ) и низкочастотного (НЧ) каналов регистрации электрокардиосигналов (ЭКС). Разработан алгоритм выделения характерных точек ЭКС, обозначаемых латинскими буквами P, Q, R, S, T, необходимых для синхронизации. Эффективность представленного алгоритма оценена с помощью времени обработки одной записи сигнала, а также с помощью матрицы ошибок и вычисления параметров Recall и Precision.

Ключевые слова: ЭКС СВР, ЭКГ СВР, кардиограмма, алгоритм, характерные точки, обработка сигналов, фильтрация, ишемия

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Introduction

Every year there are more and more people suffering from diseases of the cardiovascular system (CVS), in particular, coronary heart disease. To obtain more complete information about the stages of its development, the staff of the laboratory Radio and Optoelectronic Devices for Early Diagnosis of Pathologies of Living Systems of the Institute of Analytical Instrumentation of the Russian Academy of Sciences performs studies on modeling this disease in experimental animals based on the use of a new author's method of ultra-high resolution electrocardiography (UHR ECG) [1–4]. However, the recorded electrocardiosignals (ECS) are influenced by various factors. The purpose of this work is to develop an algorithm for preprocessing the ECS obtained by the UHR ECG method. To do this, it is necessary to solve the following tasks: development of an algorithm for filtering ECS obtained from low-frequency (LF) and high-frequency (HF) channels of their registration; selection of characteristic points of ECS from LF-channels, which are analogous to the information obtained using a standard ECG [5].

Algorithm for filtering ECS from the low-frequency and high-frequency channels of ECG registration

To detect samples on the cardiogram that are outliers that occur on the curve with accidental exposure to the device for registering the ECS, an algorithm was developed based on the assumption that the number of outliers is many times less than the number of working points. This can also be seen from the distribution of signal values. The values of all samples declared as outliers are replaced by the value of the nearest useful sample on the left.

As is known, a useful ECS for a standard ECG method is recorded in the frequency range from 1 to 100 Hz. The next stage of preprocessing the ECS from the LF-channel is the use of a bandpass filter with the appropriate bandwidth. In addition, the use of a notch filter reduces the impact of network interference (50 Hz).

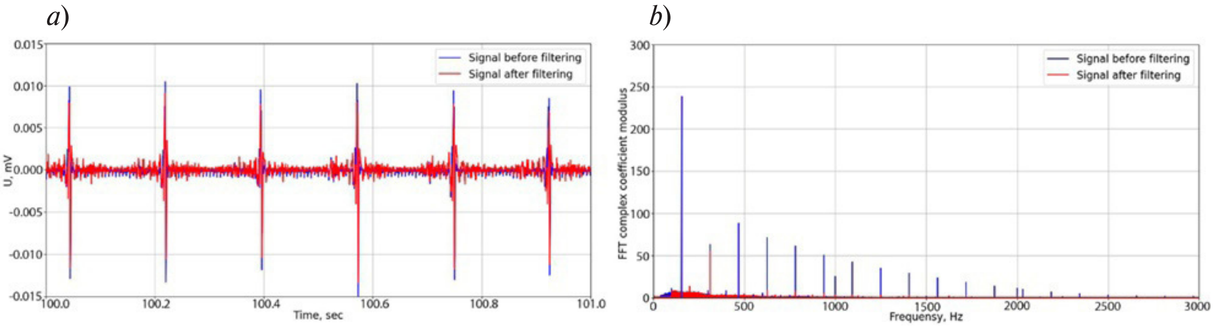

Fig. 1. UHR ECS from the HF-channel before and after filtration (*a*), UHR ECS spectra from the HF-channel before and after filtration (*b*)

The useful UHR ECS received from the high frequency (HF) channel is recorded in the frequency range from 100 to 2000 Hz [5]. Therefore, the further stage of signal preprocessing is the use of a bandpass filter with the appropriate bandwidth. The signal spectrum contains harmonics with frequencies that are multiples of 156 Hz, the amplitude of which significantly exceeds the amplitudes of neighboring spectral components. These harmonics are interference, so it must be removed from the signal. Fig. 1a shows the superimposed unfiltered and filtered UHR ECS obtained from the HF-channel of ECG registration, Fig. 1,*b* shows their spectra.

Algorithm for the selection of characteristic points of the ECS from LF-channel

To selecting the characteristic points of the ECG, that are traditionally designated by Latin letters P, Q, R, S, T, the standard command from the native Python waveform-database (WFDB) package for ECG processing is used - wfdb.processing [6]. This function identifies two groups of points: suspicious for R-peaks and suspicious for P, Q, S, T-peaks. If one of the found points is higher by 3 standard deviations from the base line, then it is a P, T or R-peak [7]. A point above the base line is followed by a point below (Q or S-peaks).

A fragment of the ECS with selected P, Q, R, S, T-peaks is shown in Fig. 2.

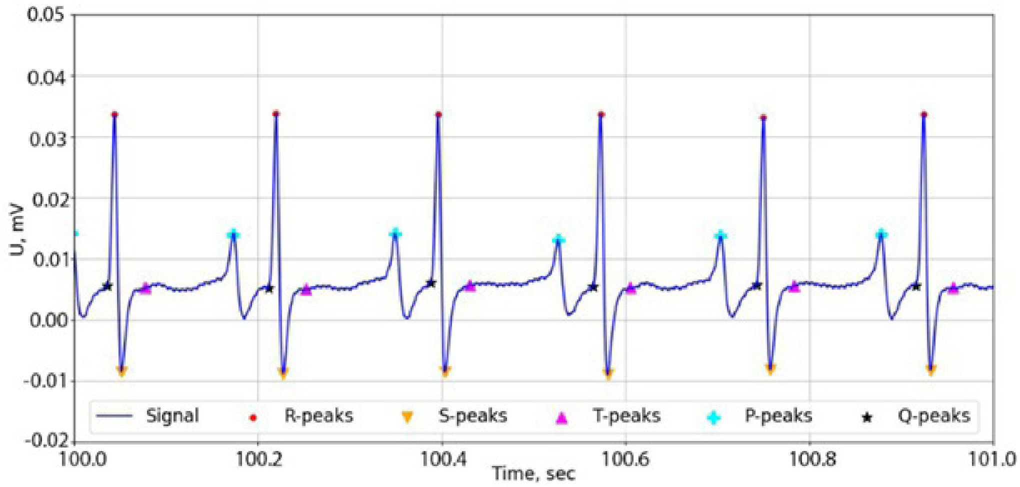

Fig. 2. UHR ECS with selected characteristic points

Results and discussion

To evaluate the effectiveness of the developed algorithm, an error matrix was constructed for the algorithm for selecting characteristic points of the ECS from the LF-channel, and the values were obtained for filtered and unfiltered signals during the comparison of the coordinates of the selected characteristic points with the reference markup. Due to the lack of evidence, the True Negative parameter is not calculated. The error matrix is presented in the form of Table 1.

The data presented in Table 2 confirm the validity of the application of the developed UHR ECS filtering algorithm, since during the processing of the filtered signal, 2 times fewer points that are not P, Q, R, S, T-peaks were allocated. Using the error matrix, you can get the values of the *Recall* and *Precision* parameters, which are calculated using formulas (1) and (2), respectively.

Table 1

Error matrix

Signal before filtration			Signal after filtration		
	True	False		True	False
Positive	22638	160	Positive	22795	77
Negative	–	812	Negative	–	648

$$Recall = \frac{\text{TP}}{\text{TP+FN}}; \tag{1}$$

$$Precision = \frac{\text{TP}}{\text{TP} + \text{FP}}. \tag{2}$$

The values of the parameters for evaluating the efficiency of the preprocessing algorithm are presented in Table 2.

Based on the data obtained, it can be concluded that the developed algorithm for preprocessing UHR ECG allows to improve the quality of *Recall* and *Precision*.

Table 2

Parameters for evaluating the efficiency of the algorithm of preprocessing ECS

	Signal before filtration	Signal after filtration
Recall	0.7646	0.9966
Precision	0.9723	0.9929

Conclusion

The results obtained show the validity of the application of the developed algorithm for the preprocessing of the UHR ECS. The developed algorithm makes it possible to filter the signal with minimal distortion of useful information, as well as to identify characteristic points on the ECS from the LF-recording channel. This will facilitate the task of identifying new diagnostically significant markers of coronary heart disease in the signal obtained by the UHR ECG method. On the other hand, studies conducted on experimental animals with artificially induced myocardial ischemia have revealed certain limitations in the use of the developed algorithm. The main one is related to the need to adjust the parameters of the function when changing the living object of study. In this regard, the work on further improvement of the developed application software and the development of new methods of filtering UHR ECS are relevant.

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