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IMPROVING THE QUALITY OF FILTERING ECG SIGNALS DUE TO THE USE OF WIENER AND CHEBYSHEV FILTERS

The paper investigates the causes of noise in electrocardiograms (ECG) and disadvantages of high-pass and low-pass filters by the example of a portable electrocardiograph. The use of Wiener and Chebyshev filters in an electrocardiograph is proposed. It is shown that the quality of ECG signal filtering with the use of Chebyshev and Wiener filters increased about 2 times as compared with high- and low-pass filters.

Key words: *ECG signal, signal processing, noise, filtering.*

Introduction

Despite the rapid development of medicine over the past two centuries, heart diseases remain the most common cause of death in the world. In Ukraine, coronary heart disorders are leading the way in the structure of the causes of mortality from diseases. Therefore, it is important to timely identify manifestations of the disease at an early stage and control the patient's treatment process [1].

The importance of diagnosing the cardiovascular system of a person by ECG signal was pointed out by such researchers as L. M. Makarov, O.V. Nedostup, A. Dubrovsky, P. Dickinson, O. Scott and others over a long period of time [2] .

The problem of obtaining complete information from the registered bioelectric potentials remains a relevant issue for today's diagnostics. Detecting a signal in a noisy cardiogram and increasing the accuracy and validity of the registered ECG signal parameters is becoming increasingly important for remote on-line patient counsulting and diagnosing. Recognition of informative locations, configurations and temporary positions of ECG signals carries diagnostic information and can be performed using modern digital signal processing methods [3].

Analysis of the literature and problem set-up

Insufficient validity and accuracy of registering ECG signal parameters for their further processing, particularly, of informative low-amplitude ECG components, as well as drawbacks of the existing ECG processing methods is the most complicated problem.

Most medical signals have complex time-frequency characteristics. As a rule, such signals consist of short-lived high-frequency components of similar duration and long-time low-frequency components of similar frequency. For analyzing such signals a method is required, which is capable to provide sufficient time and frequency resolution. The first is necessary for localization of low-frequency components and the second – for detecting high-frequency components.

Various types of noise and other disturbances can interfere with ECG signals. The main sources of noise and interference are:

- the effect of the network interference with the frequency of 50 Hz (or 60 Hz) and network voltage harmonics;
- the effect of the change in the parameters of the electrode contact with skin, which causes drift of the permanent components;
- muscle contractions: signals of the myogram type interfere with ECG signals;
- respiratory movements cause displacement of the constant component;
- electromagnetic interference of other electronic devices, when the wires of ECG electrodes play the role of antennas;
- high-frequency noise from other electronic devices.

At present, a variety of methods for processing electromyography of the signals is increasingly used in functional diagnostics: linear and nonlinear analysis, methods of frequency-time conversion, spectral methods, etc. Filtering the heart rate signals is of the primary value in cardiology at the diagnostic stage. To produce correct diagnosis, the physician needs to receive such data from the cardiographer, which are related only to the activity of cardiac rhythms. After recording and digitizing ECG signal, digital filtering is usually its next processing stage. This is necessary to improve the quality of recording and inhibition of various noise, mainly related to muscle tremor, displacement of electrodes and electrical interference [4].

Digital filters, used for electrocardiography, are divided into 3 main groups: non-recursive filters with finite-pulse response (FPR), recursive filters with infinite-pulse response (IPR), adaptive filters and frequency filters that perform signal filtering in a certain frequency range using Local Fourier transform.

Research aim and tasks

The research aims at increasing accuracy and validity of registering ECG signal parameters, improving the quality of processing and filtering the signals.

To achieve the aim, the following tasks should be addressed:

• performing analysis of the existing electrocardiographs and biosignal processing systems;
• development of a common structural diagram of ECG signal processing system;
• simulation of electrocardiograph biosignals in Matlab system;
• investigation of the negative effects on ECG signal and noise simulation;
• development of ECG signal filtering method using Wiener and Chebyshev filters.

Scientific novelty of the obtained results

– An improved procedure of ECG signal processing using Wiener and Chebyshev filters;
– improvement of the portable ECG systems by application of Wiener and Chebyshev filters for increasing accuracy of ECG processing and for cost saving.

Filtering the signals

Filtering methods are based on using difference in the properties of the useful signal and of the noise component (interference). A variety of algorithms and methods are used for various types of biosignals [5]. All the algorithms are adapted to the method of obtaining the signal and its properties.

The most common approaches to signal processing are as follows:

- synchronous averaging or ensemble-averaging for many implementations;
- filtering by the moving-average method;
- filtering in the frequency domain;
- optimal filtering (Wiener filtering);
- adaptive filtering;
- wavelet transform.

Hardware or software realization of a mathematical algorithm, the input of which is digital signal and the output is another digital signal with the shape, amplitude and phase characteristics modified in a special way, is referred to as digital filter. Unlike the digital filter, the analog filter deals with the analog signal, its properties are indiscrete and its transfer function, respectively, depends on the internal properties of its components. The main advantage of digital filters over analog ones is their possibility to realize complex signal processing algorithms, which cannot be created using analog equipment, e.g. adaptive algorithms, which are changed with the change of input signal parameters.

The accuracy of signal processing with digital filters is determined by the accuracy of calculations performed. It could be higher than the signal processing accuracy of analog filters.

Thus, the advantages of digital filters over analog filters are as follows:

– high accuracy (the accuracy of analog filters is limited by tolerances for the elements);
– transfer function does not depend on the drift of the characteristics of the elements;
– adjustment flexibility, ease of changes;
– compactness

Digital filters have the following disadvantages as compared with analog filters:

- difficulties of processing high-frequency signals. The frequency band is limited to the Nyquist frequency, which is equal to half the sampling rate of the signal. Therefore, for high-frequency signals analog filters are used, or if there is no useful signal at high frequencies, first high-frequency components are suppressed by means of an analog filter and then the signal is processed by a digital filter;

– difficulties during real-time operation: calculations have to be completed within discretization period.

To achieve higher accuracy and signal processing rate, not only a powerful processor, but also additional expensive hardware in the form of high-accuracy and fast-response digital-to-analog and analog-to-digital converters are required.

Additional use of Wiener and Chebyshev filters in a portable electrocardiograph. ECG signal simulation

In medical practice, for diagnostic purposes and control over the functional state of patients, equipment is widely used for registering biomedical signals and determining their parameters in normal state and when there are physiological or pathological deviations from the norm. Most often, electrographic methods are used for registering biomedical signals to provide measurement and control of biopotentials that occur naturally or under the influence of external factors in different parts and organs of the human body.

Measurement of biopotentials is carried out using electrodes, which are installed on the surface of the body or human organs. Not the absolute potential is measured, but the potential difference between the two points of the surface, which reflects its bioelectric activity and the nature of metabolic processes. Biopotentials are used to obtain information about the state and functioning of various organs. Electrographic methods include electrocardiography, rheography, electroencephalography, electromyography, electrogastrography, etc. [6].

For finding, obtaining and analyzing various electrocardiogram components different digital signal processing methods are used. Among them the wavelet transform method gives promising results for the analysis of frequency-time characteristics of electrocardiograms [7]. A classical approach in cardiology is the use of procedures for analyzing a signal frequency domain, which have various applications (standard ECG measurement, heart rate measurements). However, measurements of the amplitude and time of ECG components using the time domain analysis methods are not always sufficient for describing all the features of ECG signal. For example, determination of the late potential, which is in the QRS complex, cannot be performed with this method. At the same time, analysis of the heart rate time domain gives complete information about the behavior of RR intervals and parasympathetic effects. However, sympathetic ordering cannot be evaluated by measuring the heart rate in the time domain. Thus, the use of information of both time and frequency domains gives qualitative results [8].

There are single- and multichannel electrocardiographs (with three, six and 12 channels). All of them register indicators of 12 leads. The difference is that to obtain the ECG rdsults using a single-channel device, it is necessary to register the data of 12 leads in turn. This increases the investigation time as well as the efforts of a specialist.

There are stationary and portable electrocardiographs. The latter are more compact and **could be used in emergency situations, in ambulances** for both initial and more substantial diagnostics.

Portable cardiograph is designed for registering electric activity of the heart (ECG), it conducts initial analysis of the indicators obtained from standard leads and can transmit information at a distance for further interpretation.

The process of analyzing cardiosignals could be conventionally divided into 2 stages: the stage of initial processing and the feature-detection stage (Fig. 1).

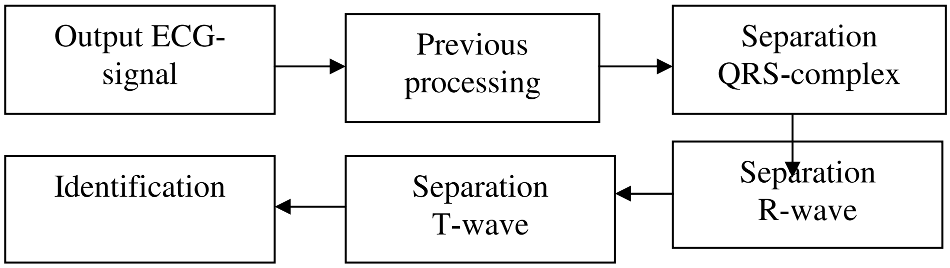

Fig. 1. ECG signal processing structure

The initial processing stage consists in removing the noise (electromyogenic muscle potentials, artifacts of interaction of the electrodes with the skin, electronic noise of the amplifiers and background noise of the network). Noise is usually represented by high-frequency components of the cardiac signal. Removal of the noise leads to compression and smoothing of ECG signal. Feature detection stage is a process of obtaining the necessary information (waves, complexes, etc.)

Let us consider the set problem by the example of portable cardiograph “Ucard-100”, which is the most functional device used in multi-parameter heart activity invesigations.

The main drawback of a portable cardiograph is incomplete useful signal detection against the background of the whole set of interferences and distortions due to the noisiness of a cardiac signal. The interference could be removed using additional (digital) filters.

In «Ucard-100» digital high-pass and low-pass filters are used (Fig. 2), although the high-pass filter application for isoline drift elimination very often results in the change of P- and T-wave shapes.

Digital high-pass and low-pass filters have the following drawbacks:

• when low-pass filters are used, insufficient value of the cutoff frequency makes signals almost invisible in the cardiogram;

• the ripple of the filter amplitude-frequency response in the passband and nonlinear character of the phase characteristic introduce disturbances into the cardiac signal, the values of which are of the same order as informative low-amplitude biopotentials of the heart.

• maximal flatness of the amplitude-frequency response in the passband is accompanied by worsening of the phase characteristic linearity. The nonlinearity leads to phase distortions, as signals of different frequencies have different delay times.

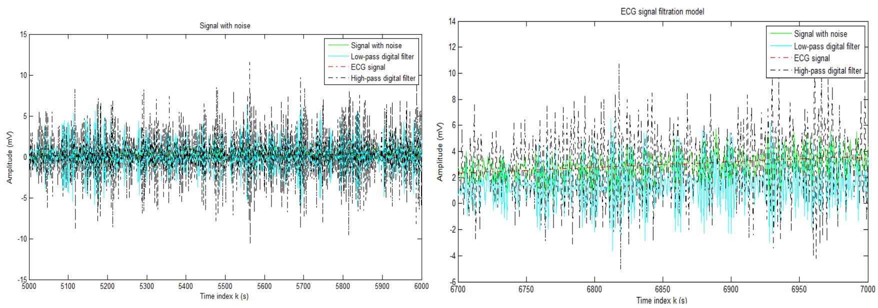

Fig. 2. ECG signal filtration using digital high-pass and low-pass filters

Therefore, for achieving more accurate results Chebyshev and Wiener digital filters of the second kind were chosen. They have the following advantages:

•. Chebyshev filter has a narrower non-linear band of phase-frequency response (PFR) as well as high stability if it is necessary to provide narrow suppression bands;

• removal of artefacts from a cardiac signal can be effectively realized using Wiener filter;

• the main advantage of Wiener filters is their optimality according to a certain efficiency criterion, typically it is a minimum mean square error, which enables obtaining the best achievable estimate;

• these filters can provide the highest indices of ECG filtering efficiency;

• they ensure highly efficient suppression of ECG noise, stability to a priori uncertainty of the model of signal change and interference dispersion;

• they do not require estimation of dispersion and time for adaptation of the filter parameters;

• fast response, which enables prompt signal processing and which is important for monitoring systems.

Investigation process and its results

A standard ECG signal was simulated in Matlab Starter Application - 2014 with the addition of harmful effects and then the proposed methods for filtering this signal with Wiener and Chebyshev filters were investigated.

A standard ECG signal model (Fig. 3) with the following parameters was investigated:

1) heart rate F_ECG = 70 bpm;

2) frequency of signal discretization Fd = 1000 Hz;

3) amplitude of the cardiac signal A_ECG = 20 mV;

4) the required signal duration T_sign = 5 sec.

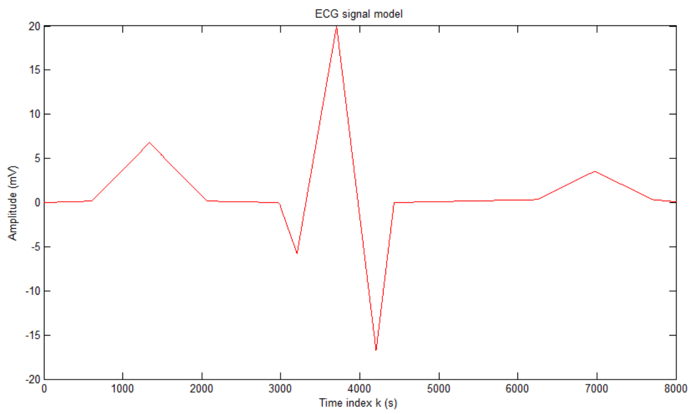

Fig. 3. Model of ECG signal

Then high-frequency noise (e.g. leads from the equipment) (Fig. 4), low-frequency noise and white noise were added to ECG signal.

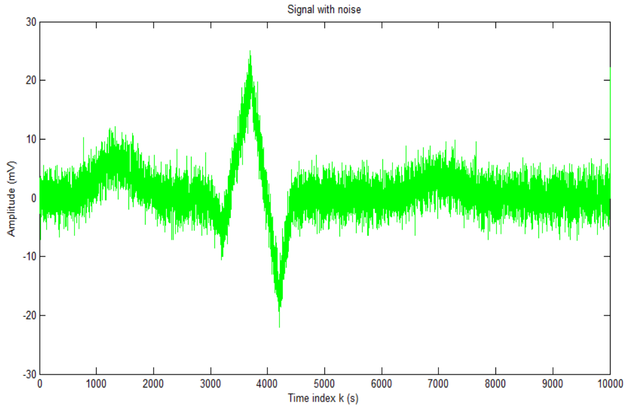

Fig. 4. Signal with noise

To create white noise (Fig. 5), it is sufficient to set a sampling interval (i.e. time interval between the adjacent numbers) *Ts*, to form an array (vector) *t* of time moments in the required range of its variation and then, using said function, create a vector - string with the length equal to the length of vector *t*, e.g.:

1) sampling interval *Ts* = 0.01;

2) the vector of time moments *t* = 0: *Ts*: 20;

3)white noise x1 = randn (1, length (t)).

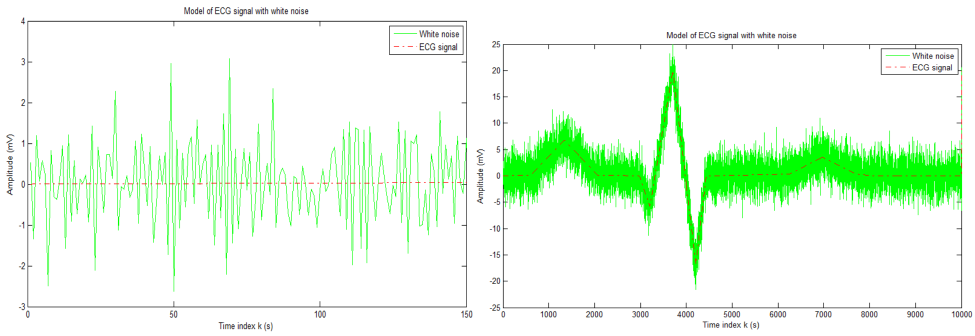

Fig. 5. ECG signal with white noise

Fig. 6 shows ECG signal filtered with the application of low-pass Wiener and Chebyshev filters of the second kind with the finite-pulse response (FPR) and transfer function $h(z) = z + 0{,}8z^{-1} + 0{,}4z^{-2} - 0{,}z^{-3}$.

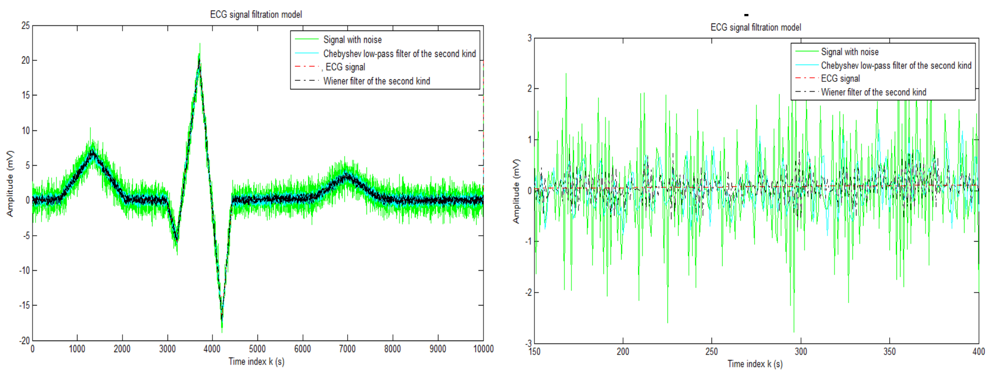

Fig. 6. ECG signal filtering

It was calculated how many times signal accuracy was increased due to the use of proposed filters as well as the accuracy of the signal filtered by standard filters with the effect of high- and low-frequency interference by the formula $z = \left|\sqrt{y_1^2 - y_2^2}\right|$, where y_1 and y_2 – the filtered signal and ECG signal respectively. For high- and low-frequency interference the accuracy increased 1.7 times and for the white noise a 2.1 time accuracy increase was achieved.

Fig. 7 presents the proposed structural diagram of a computer-based portable electrocardiograph.

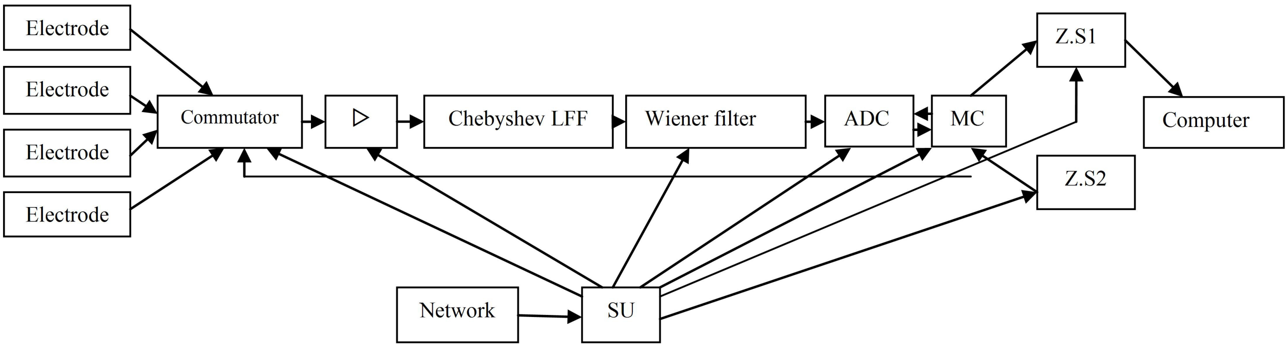

Fig. 7. Initial structural diagram of a computer-based electrocardiograph, where MC – microcontroller ZS – galvamic separation, SU – supply umit, ADC – analog-digital converter, C – computer

Electrodes take biopotentials of the heart muscle from the human skin. The commutator sends signals from the sensors according to the selected lead. The amplifier scales the signal from sensors to the required level. The low-pass Chebyshev filter limits the spectrum of the investigated signal. Wiener filter removes the network interference of 50 Hz. ADC converts the investigated signal into a digital form. The microcontroller implements the ADC and the commutator control as well as signal preparation for its transmission to the computer, which displays the electrocardiogram and saves it on the disk drives. The unit generates supply voltage, required for operation of other units, from the network voltage of 220 V.

Conclusion

The paper has investigated the causes of noise, which occurs in electrocardiograms of portable electrocardiographs. Disadvantages of high- and low-pass filters in the investigated electrocardiograph "UCARD-100" have been revealed.

ECG signal with standard interference has been simulated in Matlab system. Low-pass and high-pass filters have been investigated as well as the proposed Wiener and Chebyshev filters.

Wiener and Chebyshev filters are proposed to be used in portable electrocardiograph "UCARD-100". Additive component, caused by high-frequency interference, is practically removed from the filtered signal. No changes of ECG signal amplitude shape are observed. It should be noted that the effect of all the interference types was reduced within one filtering cycle.

The accuracy of the electrocardiograph data processing algorithm was increased due to the increased quality of filtering the signals in the presence of high- and low-frequency interference (1.7 time increase) and white noise (2.1 time increase).

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