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# ELECTROCARDIOGRAPHIC SIGNAL MODELING IN A LINEAR AND VECTOR PLANE

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***Abstract**: The study presents algorithms for modeling the ECG signal and its phase portrait to ensure high recognition of individual fragments in the analysis of cardiac signals and their response to various conditions of healthy people and patients after cardiac diseases. A software system for modeling of electrogardiographic signal in linear and phase planes based on the proposed models and algorithms has been developed. The proposed algorithms and software system for modeling ECG signals provide quality analysis and justification for health prevention, as well as a theoretical learning environment to ensure a healthy lifestyle..*

***Keywords:** electrocardiographic signal, algorithm, modeling, phase portrait*

## INTRODUCTION

During the construction of the modern medical equipment and software, methods for diagnostics of healthy people are constantly improved and developed, with the help of which the working function of their vital organs is preserved [Dingfei, G., et al. (2002), Owis, M. I., et al., (2002), Manukova A., et al. (2020, 2019, 2018)]. The research uses functional electrophysiological diagnostics, which is based on measuring the bioelectrical activity of various human organs and tissues.

Improving the quality and accessibility of medical care is related to: providing quality health prevention; early diagnosis of life-threatening diseases; theoretical prevention for healthy living; introduction of high-tech and quality devices for control and medical care.

The aim of the research is to present an algorithm and software system for modeling of electrocardiographic signal in linear and phase planes, increasing the reliability of the processing means in the analysis of cardiac diseases and their response to the electrocardiogram. The presented methodology allows analysis of different conditions of healthy people and patients after cardiac diseases.

## LINEAR AND VECTOR CARDIOGRAM

Heart rate variability is determined by analyzing the duration of the intervals between heart contractions based on ECG curves or blood pressure. The dynamics of the cardiovascular system was studied by analyzing the parts of the electrocardiographic signal. In healthy people, the time interval from the beginning of the heartbeat to the beginning of the next is not the same, and is constantly changing within certain limits [Manukova A., et al. (2016)]. Analysis of the variability of the heart rate of the ECG signal shows that changes in some nonlinear parameters give a classification of various pathological conditions.

With each contraction of the heart, certain changes in the electrical potential are observed, such as time and amplitude in the line diagram. The characteristic waves on the electrocardiogram are P, Q, R, S, T, Figure 1.a, resulting in the repetition of the following elements. The interval from the beginning of the peak of the P wave to the beginning of the Q wave shows the time for conducting the excitation from the atria to the ventricle, during which all parts of the atria are covered by the excitation. The repolarization of the atria coincides with the beginning of the ventricular complex, ie. from the beginning of the Q wave to the end of the T wave. Q, R, S and T waves are a reflection of the electrical changes due to the excitation of the chambers, as Q, R, S waves characterize the initial part of the excitation of the chambers, and the T wave of its final part, their repolarization. The interval from the beginning of the S wave to the beginning of the T wave corresponds to the excited state of all parts of the chambers. Sometimes a U wave is registered after the T wave, which reflects the repolarization of the terminal branches of the conducting system.

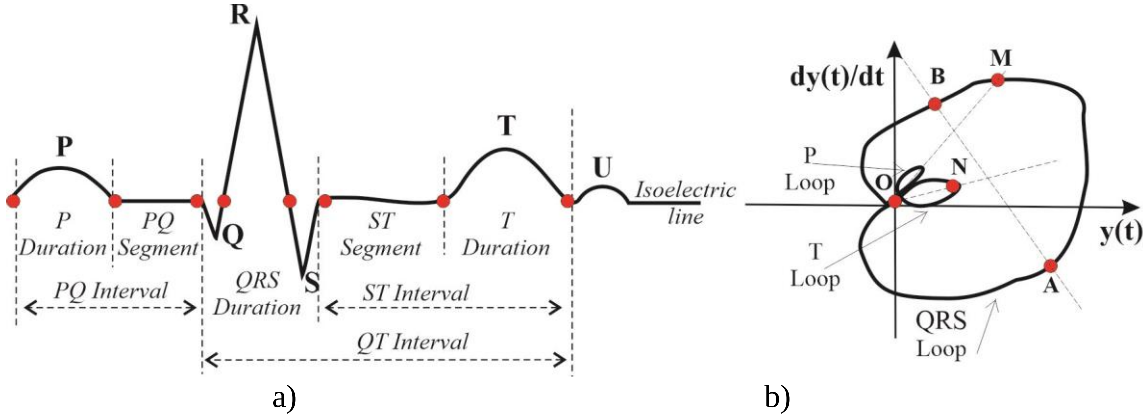


Fig. 1. Components of an electrocardiogram a) Linear model with the corresponding time and amplitude intervals; b) Phase portrait with the corresponding loops

In the electrocardiogram, the individual waves appear in relatively constant parameters, with the exception of extrasystoles, which appear sporadically in one or more cardiac cycles. Extrasystoles may be deformed or premature QRS complexes induced by another excitation center before the normal signal from the sinus node appears.

Vector electrocardiography is a method for examining the bipotentials of the heart, in which the QRS P and T loops are recorded, corresponding to the projections of the spatial curves that describe the end of the integral electrical vector of the heart (IEVH) on the three mutually perpendicular planes patient. This method is an indirect method. The loops (Figure 1.b) formed by the geometric addition of the instantaneous values of the normal ECG signals in two of the leads are observed. The name of each loop corresponds to the interval from the electrocardiogram of Fig. 1.b [Dingfei, G., et al. (2002), Rudenko M., et al. (2009)]. Diagnosis in vector cardiograms is performed taking into account the shape of the loop, its area, the maximum vector (OM and ON) and width (AB), the rate of formation, localization and spatial location. The vector electrocardiogram is the basis of analysis of cardiac activity by phase portrait.

The type of loops on the flat vector cardiograms varies depending on the individual characteristics of each organism, but their shape is preserved. In heart disease, this form changes and the new pattern allows diagnoses based on the relevant parameters [Dingfei, G., et al. (2002), Rudenko M., et al. (2009)].

## ECG SIGNAL ANALYSIS AND MODELING

The traditional morphological analysis of ECG signals is reduced to the assessment of the polarity, amplitude, duration and shape of the characteristic segments and teeth.

ECG processing in the frequency domain is required to obtain additional diagnostic information. Spectral analysis is imposed when estimating the frequency, amplitude and initial phases of the harmonic components of the signal.

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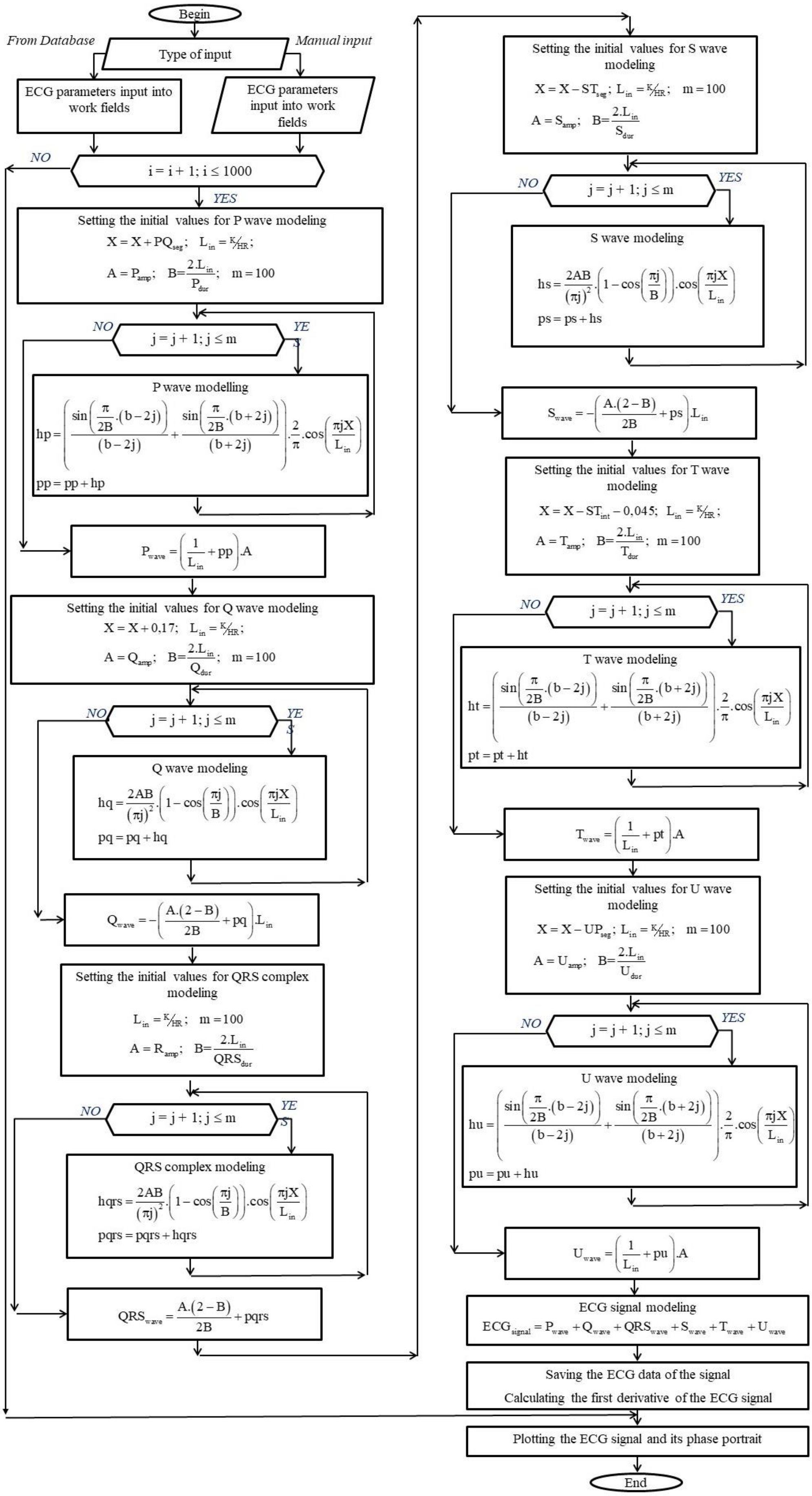


Fig. 2. Algorithm for ECG signal modeling

The basis of the spectral analysis is the Fourier transform, which represents each periodic function y (t) decomposed into a trigonometric form:

$$y(t)= a_0 + \sum_{n=1}^{\infty}\left(a_n\, cos\,\frac{2\pi t}{T_0}\,n + \,b_n \sin\frac{2\pi t}{T_0}\,n\right), \qquad (1)$$

where $T_0 = \frac{2\pi}{\omega} = \frac{1}{f}$ is the period of the function, ω is the circular frequency, and f is the frequency measured in Hz.

Qualitative ECG analysis includes visual inspection to identify the nature and location of the pathology. The quantitative analysis of the ECG determines the amplitude-time indicators of the ECG, carrying the basic information about the state of cardiac activity, which allows to monitor the dynamics of cardiac activity - amplitude, dynamics of intervals, segments, ECG teeth, frequency and rhythm. To assess the heart rate of a healthy person, it is sufficient to analyze one of the standard ECG leads [Rudenko M., et al. (2009), R.S. Khandpur, et al. (2014), Leslie Cromwell, et al. (2014)]. As a qualitative criterion in the analysis is used the computer analysis of the phase portrait of the ECG signal, which evaluates the shape of the individual fragments in the ECG gives deviations that are hidden in the analysis in the time domain.

**Modeling of ECG signals**

The analysis of the ECG curve of a healthy person is performed from the standpoint of the physiology of his cardiac activity at different loads to extract the possible risks of pathological changes. The developed algorithms and software system evaluate the individual information of the ECG curve.

All periodic functions corresponding to Derichle's conditions can be expressed as a series of scaled sine or cosine values in terms of the frequency with which the oscillations of the fundamental frequency occur. The ECG signal is a typical representative and meets the Dirichlet conditions - it is periodic and has a basic frequency that determines the heart rate. Its characteristics are: single estimation and limitation of a given interval; absolute integrability; finite number of highs and lows between end intervals; there are a finite number of interruptions. Therefore, Fourier series are suitable for ECG signal modeling.

The simulated fragments of the ECG curve are presented in Figure 2. The resulting ECG signal is a set of individual ECG waves, with a certain duration, amplitude and interval. The technique for decomposition of the P wave forms an algorithm of the low-amplitude deviation expressing the excitation of the atria. The methodology for QRS wave decomposition forms an algorithm of high-amplitude steep deviations, which express the chamber activation.

The modeling of each wave is performed in a fixed time interval of 10s with a certain coefficient relative to the heart rate. The number of samples is 100 for analysis of one component of the ECG signal.

**Results and discussion**

The software system provides two modes of operation - manual entry of instantaneous values and file entry of medical information from specialized databases. When entering data manually, the program module simulates the ECG according to the entered moment values and draws a linear cardiogram and the phase portrait. When recognizing records with medical information, the ECG signal is plotted in a linear and phase plane..

After applying the methods described in the methodology, a phase portrait for the specific medical record is derived from mathematical operations, which allows to accurately assess the shape of the individual fragments in the cardiographic signal and to distinguish deviations that are not usually visible in the time domain.

Output data from the software system and the algorithm are the on-screen windows after each analysis with the possibility of recording, as well as recording a file with the signal

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parameters. There is a possibility for manual entry of data corrections, in order to flexibility in research and the ability to simulate various conditions and diseases.

Figure 3 shows the HMI dialog interface of the ECG-Phasagraph software system with simulated ECG signal and phase portrait. The individual data for the researched object are extracted from a file or entered manually in the User input Sector. On each screen of the HMI dialog interface of the ECG-Phasagraph system, the exact markings of each fragment of the ECG signal in the linear and phase planes are visualized to facilitate the reading of the obtained cardiogram.

The Graph button draws the modeled ECG signal and its phase portrait. A magnifying measurement window has been implemented to facilitate manual data acquisition in a short period of time. The ScreenShot button saves the entire work screen under an individual name, and the Save Data button saves the data received in a file database.

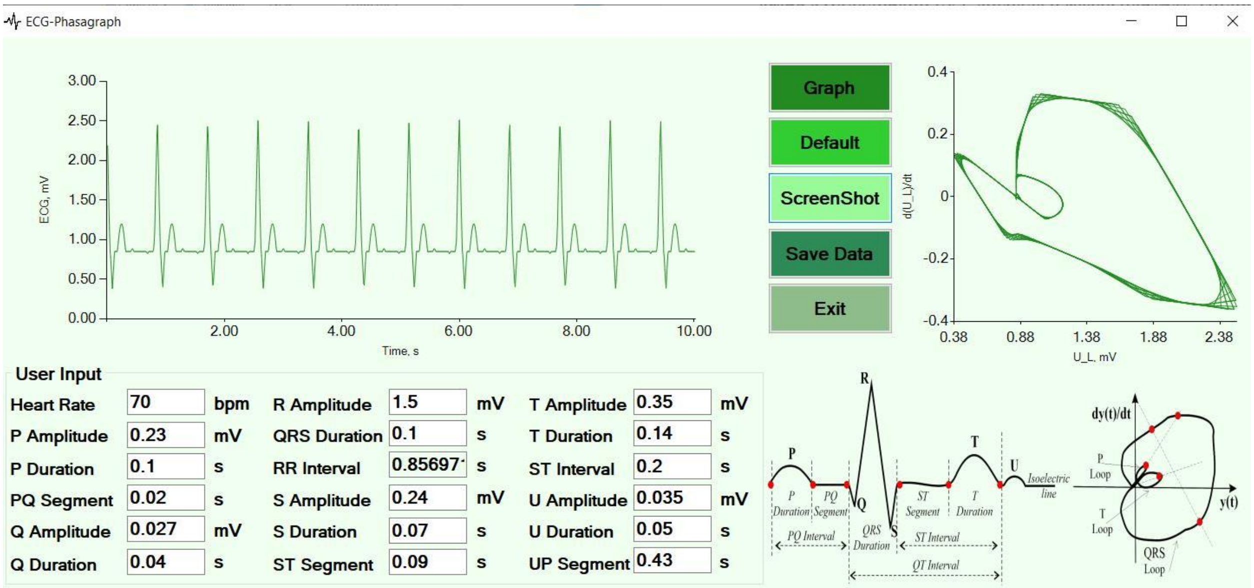


Figure 3. HMI dialog interface of the ECG-Phasagraph software system

## CONCLUSION

Algorithms for modeling ECG signal and its phase portrait have been developed and presented in order to ensure high recognition of individual fragments in the analysis of cardiac signals and their response to various conditions of healthy people and patients after cardiac diseases.

A software system for modeling of electrogardiographic signal in linear and phase planes based on the proposed models and algorithms has been developed and presented.

The proposed algorithms and software system provide quality analysis and visual justification for health prevention, as well as a theoretical learning environment to ensure a healthy lifestyle.

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