Information-analytical system of cardiographic information functional diagnostics

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Abstract. The article considers the Information-analytical system of cardiographic information functional diagnostics, which allows expanding the functionality of using miniature medical devices for non-invasive diagnostics of parameters of complex dynamic biomedical systems, using the example of cardio-intervals of the cardiovascular system. The system is based not only on the methods of the deterministic-stochastic approach but also on the methods of the theory of chaos-self-organization, as a new scientific approach in the natural sciences. The method is based on calculating the parameters of quasi attractors and analyzing matrices of pairwise comparisons of time series of complex biomedical systems, which allows quantitatively and qualitatively describing the chaotic dynamics of the system state vector behaviour, obtaining objective information about changes in the functional state of the system, and also warning about these changes in time (if pathologies), which creates conditions for the status of the functional systems of the human body physiological monitoring.

1. Introduction

In all countries of the world, the main cause of mortality is primarily associated with diseases of the cardiovascular system (CVS). According to WHO (World Health Organization) information data, 17 million people die from cardiovascular diseases each year, which is approximately 29% (2015) of all deaths. Russia, in the list of countries, comes first. In this regard, fast and accurate diagnosis of heart diseases is an urgent need of modern medicine, since the use of highly effective methods of non-invasive diagnostics, including those before the hospital period, allows to reduce the patient's stay in the hospital, earlier returning a patient to active working life. One way to solve this problem is to monitor the condition of the heart [1-5].

Currently, methods of non-invasive cardiac diagnostics are being actively developed through the use of miniature medical devices for recording the physiological parameters of a person capable of continuous monitoring of the cardiac signal, not only when receiving a patient, but also outside the clinic.

In Russia and abroad, computer diagnostics of the physiological and functional state of the heart is actively developing, a lot of software and hardware have been developed that allow the analysis of CVS and heart rate variability (HRV) (V.M. Eskov, G.V. Ryabykina, R. M. Baevsky, O.N. Bodin, L. Katz, H.J.J. Wellens, etc.) [2-9]. The use of such information is a promising method for monitoring the state of people in critical state medicine.
One of such devices is special pulse wave converters, which allow obtaining a visual pulsogram reflecting the functional state of internal organs and systems through an analogue-digital electronic pulse sensor without distortion - pulse oximeters. A pulse oximeter is used to monitor the condition of a subject during surgical interventions, in the postoperative period, to monitor heart indicators at home, as well as for various studies in the field of medicine and biology [4].

The main methods for processing a cardio signal in pulse oximeters are the methods of the deterministic-stochastic approach and in particular the methods of statistical analysis. The HRV indicators and a histogram of the distribution of durations of cardio intervals (NN intervals), which allows you to evaluate HRV in real-time, are displayed on the monitor screen. The pulse oximeter takes the following indicators: NN\(\times\)10, MS (heart rate intervals); SPO2, % (percentage of blood oxygen saturation); SIM (indices characterizing the activity of the sympathetic part of the autonomic nervous system); PAR (indices characterizing the activity of the parasympathetic part of the autonomic nervous system); SDNN (standard deviation of the values of the intervals NN); HRV (heart rate variability) [10-15].

Cardiovascular intervals (CI) CVS show the rhythm of the heart. Normal is a condition in which the intervals between heartbeats vary, but without significant deviations, i.e. approximately equal to each other, and equality or a significant deviation from the average value of cardiac intervals indicates the presence of pathology: arrhythmia, bradycardia (slowing down) and tachycardia (speeding up) [2-4]. Figure 1 shows an example of a cardiointervalogram for conditional normogenesis and pathogenesis.

![Cardiointervalogram](image)

**Figure 1.** An example of cardiointervalogram: (a) in nomogenesis; (b) in the pathogenesis.

However, the functionality of such devices for medical diagnosis of heart rhythm based on this method is not very informative and limited [4].

There are a number of approaches in the study of cardiac signals, and due to the fact that the obtained experimental data of heart indicators are arrays of statistical data in the form of unsteady time series in which it is necessary to establish certain patterns, one should turn to well-known methods for processing this kind of information. When using the methods of the deterministic approach, the repeated repetition of any process should ensure the identification of models of a complex dynamic biomedical system in the phase space of states. In the stochastic approach, such a state vector of the system \(x(t)\) should have a repeating initial value \(x(t_0)\) and a reproducible distribution function \(f(x)\) for all final states. If the initial state \(x(t_0)\) cannot be exactly reproduced, then the application of the stochastic approach is already limited (there are no repetitions of tests, the system is unique and irreproducible) (V.M. Eskov, O.E. Filatova, A.A. Hadarcev, 1992-2019) [1-15].

2. Information and analytical system

As a solution to this problem, the paper presents the developed information-analytical system for functional diagnostics of cardiographic information (IASFDCI), which allows expanding the functionality of such devices. The system is based on not only the methods of the deterministic-stochastic approach but also the methods of the theory of chaos-self-organization, as a new scientific approach in the natural sciences. The method is based on calculating the parameters of quasi attractors and analyzing matrices of pairwise comparisons of time series of complex biomedical systems, which
allows quantitatively and qualitatively describing the chaotic dynamics of the system state vector behaviour, obtaining objective information about changes in the functional state of the system, and also warning about these changes in time (if pathologies), which creates conditions for the status of the functional systems of the human body physiological monitoring.

IASFDCI is a set of blocks that ensure the implementation of certain automated procedures for computational research (testing) and obtain results in the form of relevant output information.

3. The structure of the information-analytical system
The main components included in IASFDCI include:

1. Scientific and methodological support, consisting of methods, methods, techniques, algorithms for conducting an experiment, as well as methods for processing and presenting experimental data.

2. Technical support includes the complex of used technical means: computers, measuring equipment (pulse oximeter), communication devices with the object, and other devices that ensure the functioning of the IASFDCI and its individual parts.

3. The software is a set of computer programs that allows you to implement the basic functions of IASFDCI, providing work with existing and new incoming information, various modes of its operation, effective interaction of users with the technical resources of IASFDCI.

4. Information support includes a database and a knowledge base, relevant information documents.

5. Organizational and legal support includes methodological and guidance materials, regulations, orders, state standards, etc.

Figure 2 shows the composition of the information-analytical system of functional diagnostics of cardiographic information.

![Figure 2. Composition of IASFDCI architecture.](image)

IASFDCI architecture is horizontally divided into three parts: software user interface, software, hardware. The user interacts at the first level with the user interface of the application package, which is an external module of IASFDCI; with IASFDCI user interface; with the user interface of the pulse oximeter using the automated information system "Elograph". At the second level is the software implemented by the IASFDCI modules, as well as external software. At the third level is hardware, which consists of a computer and an analogue-to-digital electronic heart rate sensor without distortion - a pulse oximeter.
Figure 3 shows the decomposition of the IASFDCI architecture.

Figure 3. Decomposition of IAS architecture of functional diagnostics of cardiographic information.

The decomposition of the IAS architecture of functional diagnostics of cardiographic information can also be described in three levels.

At the hardware level - measuring equipment pulse oximeter Elox-01M, which allows getting a pulsogram of the subject.

At the software level: a special program "Elograph 3.0", which allows seeing the heart rhythm signals and the main parameters of the CVS on the monitor screen in the form of data series, graphs and histograms.

A database that stores information about the state of the CVS in the form of relational tables, time series of cardio intervals, coming from the measuring equipment. The knowledgebase is a relational database that stores mathematical formulas, laws, models and hypotheses, the rules of SHuhart control charts, and All-Union State Standards.

From the database, information falls into the calculation block. In the calculation block, the process of primary data processing is carried out using the subsystem "Pulsogram", and a package of application programs for various mathematical calculations is also used: block of primary data processing; filters; a numerical experiment of the onset of the fatal state of CVS; Shuhart control charts; compliance of the data structure with the law of normal distribution; calculation of quasi attractor parameters; calculation of the autocorrelation function, construction of correlograms; approximation of the autocorrelation function by higher-order polynomials; approximation of data by the Pearson curve family; paired comparison matrices; Kendall correlation coefficient; model of age-related evolution of quasi-attractor parameters (Verhulst-Pearl); calculation of the Shannon entropy value; time series analysis.

An analysis unit in which conclusions are formulated based on the calculated data. Data from the database, knowledge base and calculation unit are sent to the unit of analysis of the research results. In the analysis block, conclusions are formulated based on the calculated data obtained:
After initial data processing, based on the analysis of outliers of the value of cardio intervals beyond the standard deviation, an assumption is formed about the presence of changes in the functional state of a complex biomedical system for this data set.

Checking the data for belonging to the normal distribution law, using four criteria, allows drawing conclusions about the limited application of the stochastic approach for specific biomedical data.

Using filters allows determining whether the outliers of individual values in the time series of cardio intervals are individual characteristics of the human body or whether these artefacts are due to the presence of noise of a different nature, and also improve the quality of further processing of non-stationary time series.

A numerical experiment simulating the fatal state of the CVS allows concluding that, adding model points corresponding to the process of cardiac arrest in the rows of cardio intervals, the probability of such an event is a priori impossible.

Based on the identification of one of the rules of the Shuhart control charts on the array of the chain of values of cardio-intervals, the onset of a critical state of CVS is predicted.

Analysis of the parameters of quasi attractors (area, volume, centre coordinates) in the phase space of states of the human body, using methods of system analysis and synthesis in the framework of the theory of chaos-self-organization, makes it possible to use a new theoretical and practical description in the diagnosis and treatment of pathological conditions of CVS. Also, such an analysis allows comparing the state of homeostasis of the body of different groups of subjects.

The analysis of time series (autocorrelation analysis) of biomedical data allows concluding not only about the change in the values of the parameters themselves over time but also about the change in the internal signal structure of the recorded indicators. This fact is a confirmation of the "flickering" effect: the specific state of the system state vector at any given time does not make sense since there is a constant chaotic movement of this vector in the phase space of states.

The approximation of the initial data of cardio intervals by the family of Pearson curves and higher-order polynomials shows that this chaotic process can be described adequately for forecasting purposes only by high polynomial functions. This analysis allows for obtaining complete uncertainty in predicting the future state of third-type systems using the example of CVS parameters.

The analysis of paired comparison matrices allows concluding that in the study of biomedical data, a single experiment is not enough to determine the functional state of the human body.

Based on calculations based on the model of age-related evolution of parameters of quasiattractors (Ferhulst-Pirl), a conclusion is made about real evolutionary changes in cardio intervals during normal or pathological ageing of the human body.

Calculating the value of the Shannon entropy allows us to estimate the level of determinism (randomness) in the signal of cardio intervals, that is, what is the probability distribution of the amplitude of the oscillation of the cardio interval.

Based on the analysis of outliers beyond the various limits of the standard deviation, a conclusion is made either about the individual characteristics of the human body, or about age-related changes in the body (of one individual), or about the pathological state of the heart.

Visualization of the results of the system is presented at the user interface level.

4. Conclusion
As a result of the developed information-analytical system of cardiographic information functional diagnostics, it was possible to expand the possibilities of using a miniature medical device pulse oximeter for express analysis of the state of operation of the parameters of complex dynamic biomedical systems.

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