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ESTIMATION OF HEART RATE COMPLEXITY OF BEHAVIOR USING DIFFERENT METHODS OF NONLINEAR DYNAMICS

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ABSTRACT

The main goal of the research is a development of system for analysis of heart rate behavior complexity by methods of nonlinear dynamics. For this task main algorithms for qualitative and quantified estimation of 24-hours heart rate regularity were explored. Also, the software utilizing the Kolmogorov's algorithm, Poincare equation, approximate entropy, flicker noise, distribution bar chart as well the Lorenz diagram, is developed. The results of calculation can be used to define the diagnostic signs of human health state on the basis of daily heart rate regularity estimation.

INTRODUCTION

Formation of a new interdisciplinary field – Synergetics, opens new opportunities for assessment and analysis of complex biomedical systems, in particular of the cardiovascular system.

Heart rate is an integrative indicator that reflects integral properties of the circulatory system and whole body. Creation of the new systems analysis of the heart rate based on the nonlinear dynamic parameters gives an opportunity to evaluate a wide range of regulatory, the state regulatory body reserves and to diagnose the reduction of adaptive properties and approximation regulatory limits to the range at a new level. It is important for diagnostics of pathological processes, dysadaptation states of practical healthy persons, sportsmen's "overtraining", elimination of overload regimes emergencies etc.

Main methods of heart rate variability (HRV) analysis, which found the most application of modern diagnostic systems, can be divided into statistical, geometric and temporal frequency. But the chaotic process of HRV requires the use of mathematical apparatus to refine results of diagnostic and predictable assessments obtained by standard methods. This instrument is the mathematical theory of nonlinear dynamics.

The goal of the research is synthesis of diagnostic system based on the combined estimates of nonlinear dynamics to refine methods of predicted dysadaptive states and to bring an organism to limits of the regulatory range.

1. METHODS OF NONLINEAR DYNAMICS FOR ESTIMATION OF HEART RATE VARIABILITY

A literature review showed that to describe the nonlinear properties of heart rate variability the Poincare equation, cluster spectral analysis, Lorentz graphics, singular expansion, Lyapunov's exponent, Kolmohorov entropy and others are used.

1.1. Algorithmic compression method by Kolmohorov

A great interest is the definition of algorithmic methods (in opposition to physical and chemical methods), or computing of complexity, the concept was introduced by Kolmohorov. Using this approach, a numerical sequence is processed using linear algorithms of archiving, as it is made in

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computer systems. The length of minimized, archived, packed sequence is compared with the original length. It enables to determine quantitatively the ratio of organized and random components of numerical series.

HRV assessment method based on Kolmogorov's algorithmic approach is to determine the level of algorithmic complexity of heart rate variations. The essence of the method is to use linear archiver and to compare the original and compressed sequences of cardiac intervals. Additionally, this method along with an approximating entropy index can be used to assess the frequency of fragments of heart rhythm. By output plot of heart rhythm and/or sequence of differences is built regularity dictionary. It is estimated as the frequency of repetition and length of the analyzed regularities and their temporary location (time of day when they meet).

Selection of regularities in time sequence allows archiving. Thus, the compression coefficient (the ratio of length of archived sequences to the length of output sequences) is a quantitative characteristic of HRV.

To identify repetitive areas of heart rate Lempel-Ziv-Welch (LZW) compression algorithm is used.

To register cardiointervals's sequences, found in the SR, the dictionary is used. Dictionary is a table that contains the code sequence, the sequence itself and its number of occurrences in the output. Based on this dictionary the conclusions about the variability of heart patients can be drawn.

1.2. The method of fractal dimension

In the theory of fractals the method of fractal dimension is used. It is the most known method of return map, or that the same thing, the box counting method. With it quantitatively determined by self-similarity, repeatability fragments (x_i, x_{i+1}) of numeric sequence depending on changes of the scale Dx.

1.3. The method of approximating entropy

Approximating entropy is a quantitative assessment of the frequency of fragments of dynamic series of cardio intervals regardless of frequency range. A sharp drop of index approximating entropy, especially in combination with a lower variability of interval’s plot is quite formidable feature reducing regulatory redundancy organism and can be viewed as a sign of increasing the likelihood of occurrence of sudden cardiac death. Such situations are often observed in patients of cardioreanimation offices in particularly serious condition (e.g., acute myocardial infarction (MI), several transferred MI in anamnesis, etc.). The advantage of this estimation is its applicability for processing sequences cardio intervals relatively small length. For example, one minute, ten minutes.

Method of calculating approximation entropy was established as a conventional quantitative assessment of the availability of regular structures, i.e. structures, repetitive sequences in temporal parameters. Such as may be monitoring records of physiological indicators.

1.4. Flicker-noise method

Universal theory of flicker-noise, proposed in 1987 by P. Bak and entered intensive development in subsequent years, is called the theory of self-organized criticality (SOC).

To the characteristics of the variety of behavior, at least in part, be attributed and β flicker-noise characteristics used in the theory of self organized criticality (SOC). According to the latter, much of the complex processes of nature, represented as time sequences, has a reverse dependence of spectral power on frequency $E = 1/f^{\beta}$. This dependence corresponds to the so-called flicker noise or flickering noise - low-rate fluctuations in the frequency range ($4,0*10^{-3}$ ... $4,0*10^{-2}$ Hz), which is compared, or even exceeds the observation time system.

It is known that the flicker-noise observed in fluctuations of many indicators of living systems: heart rate, blood pressure, brain electrical activity and others.

2. PROGRAM REALIZATION METHODS OF NONLINEAR DYNAMICS FOR EVALUATION HEART RATE VARIABILITY

Methods for estimation of heart rate variability was developed using special software:

- graphical programming environment NI LabVIEW;
- mathematical modeling system MatLab 6.0;
- Visual Studio.NET.

The main availability of the developed software:

1) analysis of heart rate variability in time domain;
2) analysis of heart rate variability in the frequency domain (calculation of spectral indices of heart rate, construction diagrams balance of power frequency ranges HF / LF / VLF);
3) analysis of heart rate variability using methods of fractal dimension (Lorentz plot and Poincare points);
4) analysis of heart rate variability by flicker-noise method;
5) analysis of heart rate variability using algorithmic compression method by Kolmohorov;
6) generation of the report of the calculation for each selected time interval.

Interfaces of some functional modules are shown in Fig. 1 and 2.

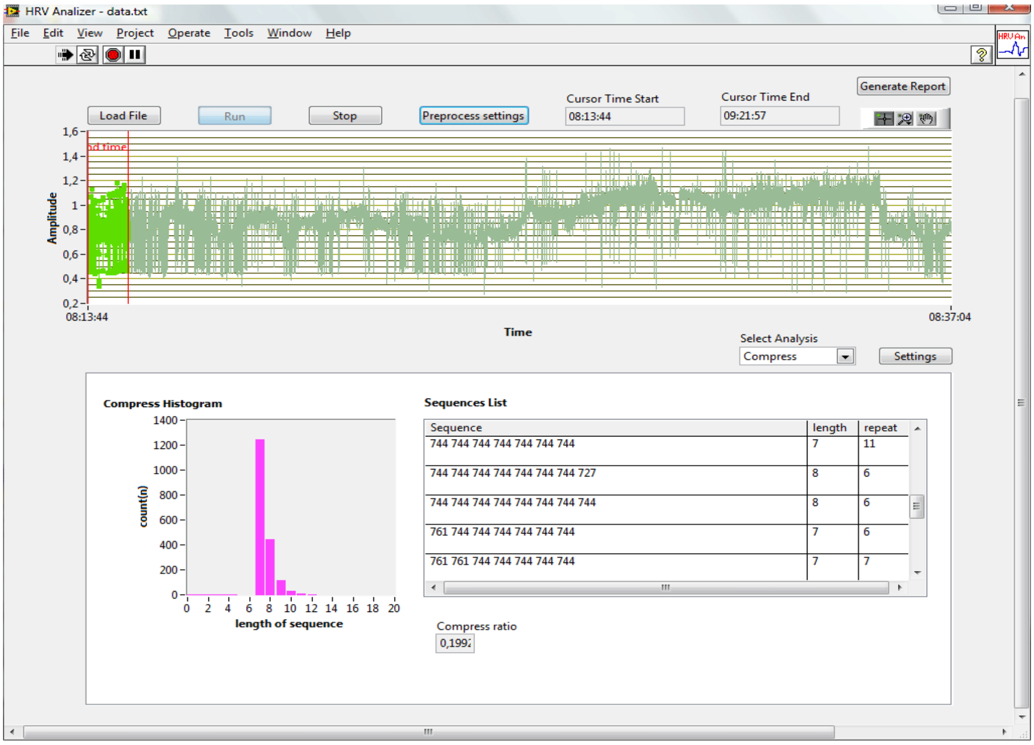

Fig. 1 The interface of software (algorithmic compression method by Kolmohorov)

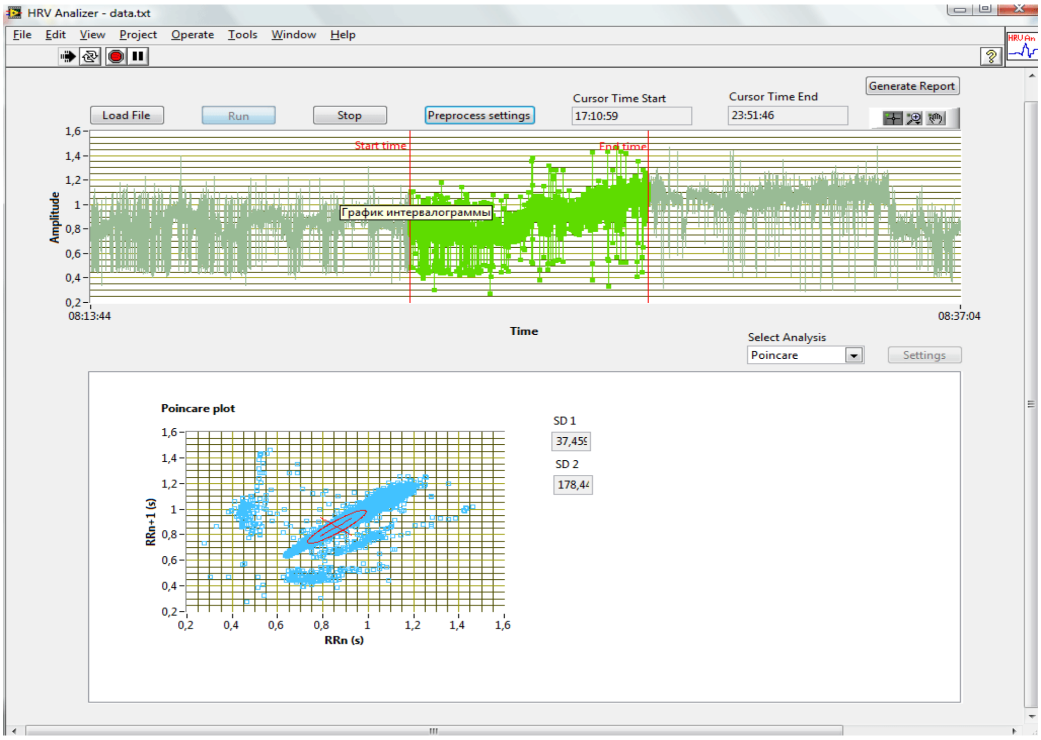

Fig. 1 The interface of software (analysis of heart rate variability using methods of Lorentz plot)

CONCLUSIONS

The above estimates describe various aspects of complex behavior of the cardiovascular system. Therefore, they represent of interest investigation of their values and comparing and mutual correlation, to find the most convenient method of estimation of complexity of behavior of the cardiovascular system. The successful solution of this problem will provide a quantitative assessment of the regulatory provisions of the human body.

The software developed in this work can be used to automate the calculation method of nonlinear analysis as well as to found the basis for the development of expert system evaluation of the functional state of the human body.

The implementation and, in a perspective, the methodic implementation is provided for groups of people with a risk of sudden death, and also for the overload regimes estimation in a group of practically healthy people. The method does not require load tests, and the observation of the state of human cardiovascular systems is realized in the mode of natural functioning. The main perspectives of implementation are: 'health medicine', sports medicine, control of organism response on high psycho-emotional and/or physical load, sudden cardiac death risk estimation.

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