Phase Space-Based Imaging of Mass Data on Instantaneous Cardiac Rhythm

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In this paper we present phase and extended phase spaces of instantaneous cardiac rhythm designed for one of the patients of the Tver Regional Cardiology Health Center. This paper also demonstrates the efficiency of use of the phase spaces for imaging of mass Holter monitoring data.

Keywords: Holter monitoring, instantaneous cardiac rhythm, phase space.

Introduction

According to the World Health Organization (WHO) data as of 2011 reflecting the statistics of global causes of all death events in the universe, the cardiovascular diseases hold a leading position and are 31%.

This statistical data is indicative of the urgency of development of new high-accuracy and effective mathematical and computer aided techniques for cardiac rhythm investigation on the basis of Holter monitoring (HM) and mathematical modeling methods. The critical moment of this program is Holter monitoring-based imaging of mass data on instantaneous cardiac rhythm.

By now, the basic conception of evaluation and prediction of risks of formation of fatal cardiovascular complications is considered to be cardiac rhythm variability (CRV) analysis. One of the upcoming CRV research trends is an instantaneous cardiac rhythm (ICR) analysis. The Holter recording (HR) technique allows obtaining ICR data within several days. Within 24 hours of HR a data set consisting of about 150000 data points can be obtained.

Statement of the Problem. Designations

In the papers [Kudinov, Lebedev, …, 2015; Ivanov, Kudinov, …, 2016] the CRV function, *y(t)*, which most adequately reflects the cardiovascular system dynamics was introduced. Together with the *y(t)*, it is possible to implement a function characterizing an ICR change rate; let us call it IRCR (instantaneous rate of cardiac rhythm) function, *v(t)*. The functions *y(t)* and *v(t)* contain complete information on ICR pattern on the time interval of interest. The numerical values of functions *y(t)* and v(t) provided hereafter are in units of min^{-1} and $min^{-1}sec^{-1}$, correspondingly.

A set of points in R^2 with orthogonal coordinates *y(t)* and *v(t)* form a phase space (PS) of ICR. The functions *y(t)* and *v(t)* determine a phase trajectory (PT) and every its point determines a CRV and, consequently is referred to as a phase point (PP).

Together with the PS of ICR, the report uses an extended phase space (EPS) of ICR which represents a set of points in R^3 with orthogonal coordinates (*y(t)*,*v(t)*,*n(t)*). The function *n(t)* describes a number of PP passages through the (*y(t)*,*v(t)*) point. In this case, the PP in the PS represents the projection of the PP in the EPS on the (*y*,*v*) plane.

We cite the certain type of “EPS - PS of ICR” of one of the patients of the Tver Regional Cardiology Health Center. We take the HR duration which is short enough and equal to 632 sec. With essentially major HR time intervals, the figures for the EPS and the PS of ICR will not be detailed.

The EPS of ICR of the patient of interest is shown in Fig. 4.

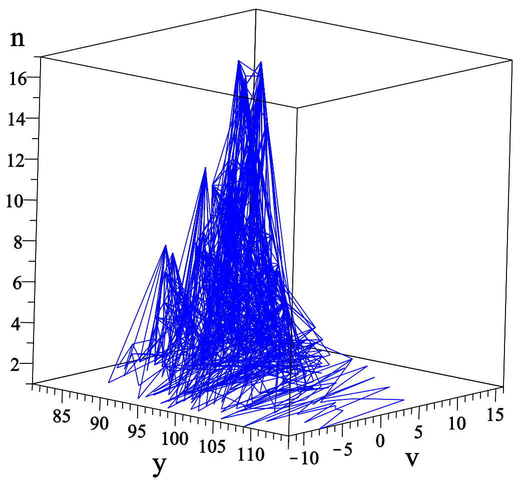

Fig. 1.

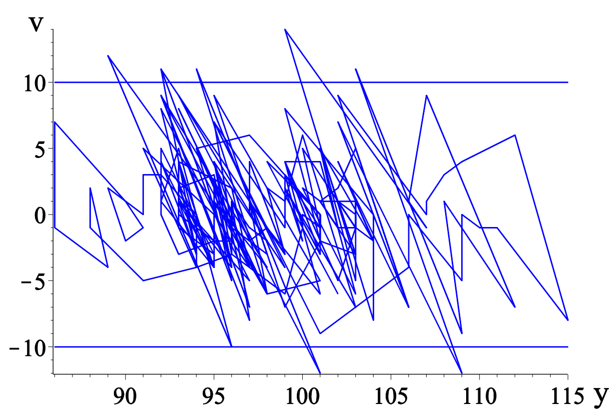

Fig. 2.

From Fig. 1 we can see that the PP in the EPS describes a complex geometric configuration. The PP condensation point corresponds to the peak in Fig. 1 and has coordinates y_m=96, v_m=-1. The PP passes through this point 17 times during the HR time. In the neighbor of this ICR point of the patient of interest we can see the maximum time. It is reasonable to call the cardiac rate of 96 min^{-1} as an intrinsic heart rate of the patient.

The projection of Fig. 1 on the *yv* plane gives the PS of ICR shown in Fig. 2.

The horizontal lines in Fig. 2 separate the PS into three areas. The internal area can be reasonably referred to as a normal instantaneous cardiac rhythm area where $-10 \le v \le 10$. The normal rhythm boundary $|v|=10$ is chosen according to the amount of change of v and separates high value zone $|v|>>1$ and low value zone $|v|\sim 1$. Two other PS areas can be reasonably referred to as an ICR jump (catastrophe) area. From Fig. 2 we can see that the ICR of the patient of interest has only 25 jumps over the observation period of 632 sec.

In order to detect motion of the ICR phase point within the PS in real-time mode, we made an ICR phase point motion animation application. Visualization observation of ICR phase point motion pattern enables to carry out a detailed ICR dynamics analysis, and thus specify the state of cardiovascular system of the patient under examination. In this case, the phase point trajectory has the Brownian pattern and represents a fractal curve.

In Fig. 3 we cite a projection of EPS on the *yn* plane.

From this Figure we can see that besides the PP condensation peak, the ICR has 5 more other condensation points but with approximately half a number of PP passages through these points. The heart rates in these points will be both 5 min^{-1}, 7 min^{-1} greater and 6 min^{-1}, 8 min^{-1}, and 11 min^{-1} less than y_m. This is indicative of a reasonably optimal degree of ICR variability of the patient of interest, which is in turn indicative of a good state of his/her cardiovascular system.

As for the ICR change rates *v(t)*, the corresponding data can be obtained from the projection of the PP in the EPS on the *(y,v)* plane shown in Fig. 4.

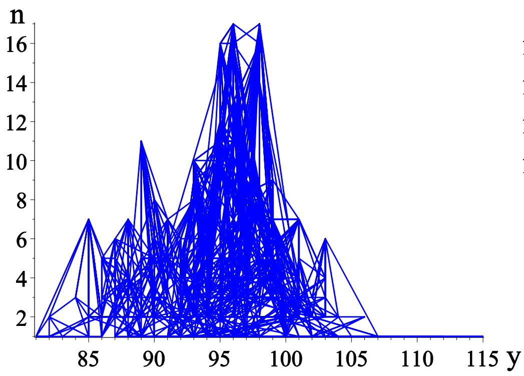

Fig. 3.

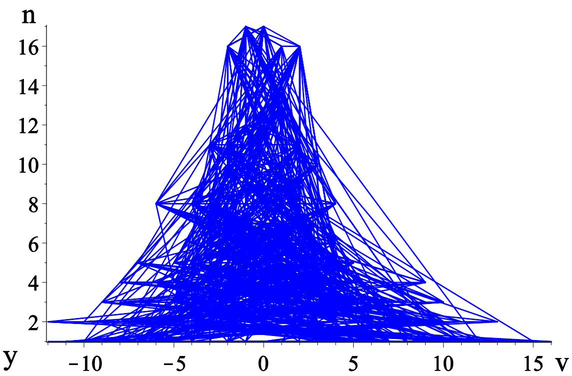

Fig. 4.

Fig. 4 demonstrates a complex pattern of *v(t)* deviation from the mean value $v \approx 0$, whereby the cardiac rhythm is the most stable. We can see that the IRCR deviates from zero much more symmetrically than the ICR. This is indicative of uniformity of rates of ICR rise and decrease. To our opinion, this is one more evidence of a good state of cardiovascular system of the patient.

Conclusion

The research we have conducted is indicative of a true complex mode of behavior of the functions *y(t)* and *v(t)* characterizing the ICR state. We have demonstrated with specific reference the efficiency of study of these functions based on imaging of mass data on ICR with the use of EPS.

References

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