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VISUALISATION OF THE QUANTUM PHASE SPACE OF INSTANTANEOUS HEART RHYTHM

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In this paper we offer an algorithm for quantization of the classical phase space of instantaneous heart rhythm with a constant or in quantization increment of *h*. The process of quantization of the phase space of instantaneous heart rhythm divides the phase space into cells with a finite size of *h*. The primary objective of this approach is visualisation of the quantum phase space of instantaneous heart rhythm. The phase cells of this space are color-coded with different colors depending on the values of their occupation numbers. The estimates showed the sufficiency of use about 10 colors. At that, the informativity level of visualisation of the quantum phase space of instantaneous heart rhythm remains invariant. Color visualisation of the quantum phase space of instantaneous heart rhythm clearly demonstrates that it can be used as a cardiovascular system state marker. We offer a method for description of the quantum phase space of instantaneous heart rhythm which will allow to detect statistical regularities of instantaneous heart rhythm chaos.

Keywords: quantization, quantization constant, phase space, instantaneous heart rhythm, visualisation.

1. Introduction

One of the major problems facing cardiology is representation of 24-hour Holter monitoring (HM) data for analysis of RR intervals in the form combining simplicity and informativity [1-4]. It can be done by means of visualisation of a data set obtained from RR intervals analysis based on the quantum phase space (QPS) of instantaneous heart rhythm (IHR).

The classical phase space (PS) of IHR is a set of states in space R^2 defined by the functions $y(t)$ (IHR) and $v(t)$ (IHR change rate) [5-7]. The function $v(t)$ is the difference derivation $y(t)$ [6]. The functions $y(t)$ and $v(t)$ are constructed according to the data from 24-hour Holter monitoring. To perform IHR analysis, it is necessary to represent the RR intervals data from 24-hour Holter monitoring in the form combining simplicity and informativity. We will image this data set based on the QPS of IHR. Visualisation of the QPS of IHR is representation of digital IHR information in the easy-to-analysis and -monitoring form.

2. Algorithm for Quantization of the Classical PS of IHR

Generally, quantization of the classical PS is understood to be a process of division of the PS into cells with a finite size of h. The h parameter is known as either a constant or a quantization increment. We perform the procedure of IHR PS quantization according to the algorithm:

$$y_i = h\left[yh^{-1}\right], v_i = h\left[vh^{-1}\right], \quad i = 1,2,\ldots N(h), \tag{1}$$

where y, v – the coordinates of a point in the classical PS of IHR, [ ] – the “rounding to the nearest whole number” operator. According to (1), y_i, v_i have the values which are multiples of a quantization constant, that is h.

The set of points with the y_i, v_i coordinates shall be designated as “QPS of IHR”. At that, the QPS of IHR is divided into unit cells with a volume of $\Delta\Gamma=|\Delta y_i\ \Delta v_i| = h^D$, since the PS of IHR creates the fractal set which has dimensions of D [5].

The values of y_i, v_i determine the QPS cells, and their multiplicities determine the occupation number, n_i, of these states. At that, the range space $\{n_i, y_i, v_i\}$ contains full IHR information over the whole time interval of interest.

The phase-space volume of QPS of IHR characterizes the IHR variability and is calculated by the formula:

$$\Gamma_q = h^D N(h). \tag{2}$$

According to (2), the fractal dimension D of QPS of IHR is calculated by the formula:

$$D(h) = \ln \frac{N(h=1)}{N(h)} \Big/ \ln h. \tag{3}$$

Let the quantization constant h for all QPSs of IHR = 1. At a given value of h the structure of QPS of IHR turns out to be informative enough. Hereafter the general cases for $h\neq 1$ will be considered.

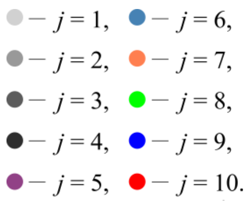
The critical task of our approach is visualisation of the set of states $\{n_i, y_i, v_i\}$. For this purpose we assign different colors to points y_i, v_i of the QPS of IHR depending on the values of occupation numbers. Our estimates show that use of about 10 colors is quite enough.

Let $n_m=max\{n_i\}$. Let the IHR state $\{n_m, y_m, v_m\}$ is marked with "×". It corresponds to the maximum probability of IHR being in this state during HM.

We select colors for the points of the QPS of IHR according to the following algorithm. We divide the n_i range space into J intervals:

$$\left((j-1)/J\right)^{\gamma} < n_i/n_m \leq \left(j/J\right)^{\gamma}, \ j = 1,2,\ldots,J. \tag{4}$$

Let us set the values of n_i meeting the requirements stated in (4) as $n_{i,j}$. Let us assume that γ=1.6, J=10, and assign the following colors to points y_i, v_i of the QPS of IHR with the occupation numbers $n_{i,j}$:



Then we have the following $n_{i,j}/n_m$ ranges:

$$0 < n_{i,1}/n_m \le 0.0251, \qquad 0.0251 < n_{i,2}/n_m \le 0.0761,$$
$$0.0761 < n_{i,3}/n_m \le 0.1457, \qquad 0.1457 < n_{i,4}/n_m \le 0.2308,$$
$$0.2308 < n_{i,5}/n_m \le 0.3299, \qquad 0.3299 < n_{i,6}/n_m \le 0.4416,$$
$$0.4416 < n_{i,7}/n_m \le 0.5651, \qquad 0.5651 < n_{i,8}/n_m \le 0.6998,$$
$$0.6998 < n_{i,9}/n_m \le 0.8449, \qquad 0.8449 < n_{i,10}/n_m \le 1.$$

The optimum choice of intervals and colors should be investigated further.

3. QPS of IHR of the Patients under Examination

Figures 1-4 represent the QPS of IHR of four patients of the Tver Regional Cardiology Health Center (TvRCHC) constructed using the Maple program system according to the data from 24-hour HM.

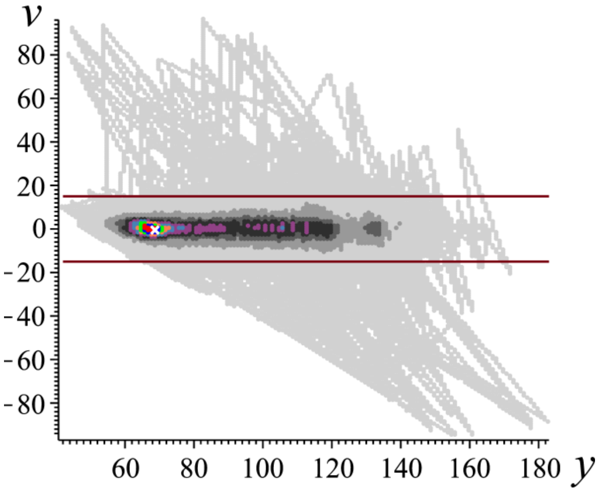


Figure 1. The QPS of IHR of the first patient, × {n_m=69, y_m=-1, v_m=1949}

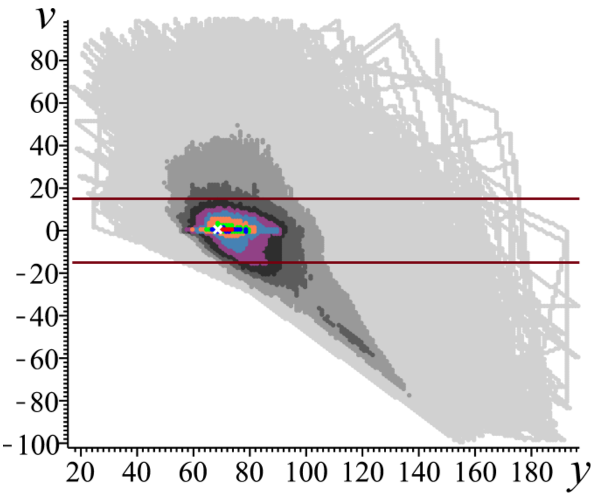


Figure 2. The QPS of IHR of the second patient, × {n_m=69, y_m=0, v_m=2975}

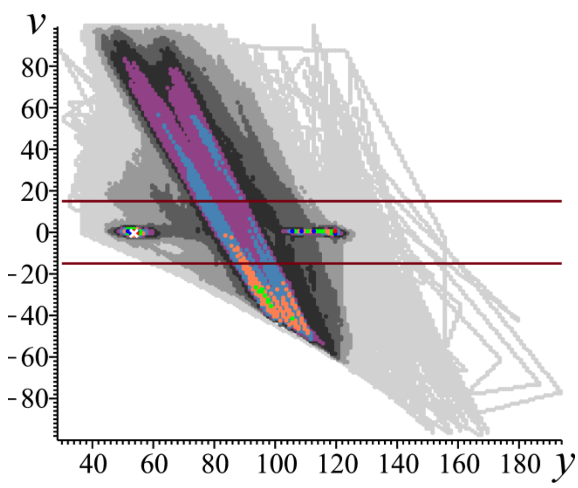


Figure 3. The QPS of IHR of the third patient, × {n_m=54, y_m=-1, v_m=1864}

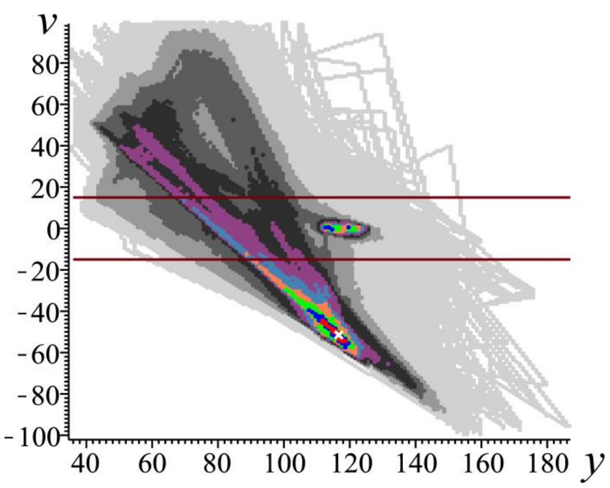


Figure 4. The QPS of IHR of the fourth patient, × {n_m=117, y_m=-52, v_m=2855}

As Figures 1-4 show, the QPSs of IHR are divided into odd-shaped 10 colored bands. In all cases the "×" cells are in the red-colored bands with the maximum probability of presence of phase points in these bands. All the colored bands are clearly-worded geometric structures having defined regularities of their configurations. The geometric structure of these colored bands reflects adequately the cardiovascular system states of the patients under examination.

We represent the diagnoses of the patients under examination: Patient 1 - norm, Patient 2 - Ryan's class 4a ventricular arrhythmia, Patient 3 - Ryan's class 4a ventricular arrhythmia, Patient 4 - Ryan's class 5 ventricular arrhythmia.

The horizontal lines in Figures 1-4 divide the QPS of IHR into three areas; $15<v<15$, $v<-1$, and $v>15$. The first area corresponds to regular IHR, the second and the third areas – to IHR jumps (catastrophes) [8].

For the patient with state “norm”, all color points of the QPS of IHR with the exception of the first grey color $j=1$, reach the regular rhythm area. In case of Ryan's classes 4a and 5 ventricular arrhythmias, the significant amount of cells of the QPS of IHR reaches the IHR jump area. The red-colored areas with the peak values of occupation numbers of states, n_i, in all four cases have the infinitesimal phase-space volume Γ_q of the QPS of IHR: for the first patient – 7, for the second patient – 6, for the third patient – 4, for the fourth patient – 15 dimensionless units. The total Γ_q will be as follows: for the first patient – 11497, for the second patient – 19767, for the third patient – 13997, for the fourth patient – 14570 dimensionless units. Note that the total Γ_q of the patient without cardiac pathology is the minimum one among the examined patients.

4. Conclusion

In this paper, the algorithm for quantization of the classical PS of IHR with a constant or in quantization increment of h was offered. In the process of quantization, the PS of IHR is divided into cells with a finite size of h.

The prime advantage of our approach is color visualisation of the QPS of IHR. The phase cells of this space are color-coded with different colors depending on the values of their occupation numbers. Our estimates showed the sufficiency of use about 10 colors with the invariant informativity level of visualisation of the QPS of IHR. Color visualisation of the QPS of IHR clearly demonstrated its availability as a cardiovascular system state marker.

The proposed method of description of the QPS of IHR made it possible to detect statistical regularities of IHR chaos.

References

[1] R.M. Baevskiy. Prognozirovanie sostoyaniy na grani normy i patologii. M.: Meditsina, 1979, 205 pp.

[2] Baevsky R.M., Petrov V.M., Cornelissen G., Halberg F., Orth-Gomer F., Akerstedt T., Otsuka K., Breus T., Siegelova J., Dusek J., Fiser B. Meta-analyzed heart rate variability, exposure to geomagnetic storms, and the risk of ischemic heart disease // Scripta Medica Facultatis Medicae Universitatis Brunensis Masarykianae. 1997. 70(4–5):201–5.

[3] Irurzun IM, Bergero P, Cordero MC, Defeo MM, LVicente J, EMola E. Non-linear properties of R-R distributions as a measure of heart rate variability // Chaos, Solitons and Fractals. 2003. 16(5):699–708. DOI: 10.1016/S0960-0779(02)00403-4.

[4] A.V. Adashev, A.Yu. Loskutov. Prakticheskie aspekty sovremennyh metodov analiza variabelnosti serdechnogo ritma. M.: Medpraktika–M. 2010, 126 pp.

[5] V.P. Tsvetkov, S.A. Mikheyev, I.V. Tsvetkov. Fractal phase space and fractal entropy of instantaneous cardiac rhythm // Chaos, Solitons and Fractals. 2018. V. 108. pp. 71–76. DOI: 10.1016/j.chaos.2018.01.030.

[6] A.P. Ivanov, A.N. Kudinov, S.A.Mikheev, V.P. Tsvetkov, I.V. Tsvetkov. Phase Space-Based Imaging of Mass Data on Instantaneous Cardiac Rhythm // CEUR Workshop Proceedings. 2016. V. 1787. pp. 271-274. URL: http://ceur-ws.org/Vol-1787/271-274-paper-45.pdf (accessed: 12.03.2018).

[7] Ivanov A.P., Kudinov A.N., Mikheev S.A., Tsvetkov V.P., Tsvetkov I.V. Phase Space of Instantaneous Cardiac Rhythm and Imaging of Big Data // Proceedings of Distributed Computer and Communication Networks: Control, Computation, Communications (DCCN-2016). 2016. V.2. pp. 215-219.

[8] A.P. Ivanov, A.N. Kudinov, D.Yu. Lebedev, S.A.Mikheev, V.P. Tsvetkov, I.V. Tsvetkov. Katastrofy mgnovennogo serdechnogo ritma v modeli multifraktalnoy dinamiki i po dannym holterovskogo monitorirovaniya // Matem. modelirovanie. 2017. V. 29. no. 5. pp. 73-84.