Time Registration and Life Science Data Registration

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Abstract: - The paper is destined for use in medicine, psychology, in man's self-development training, breathing technique's training, in the field of stress resistance, health promotion, strengthening of the capacity for work. We involve new technology for registration of time interval between two consecutive EKG RR intervals (R peaks) or pulse wave peaks, which consist of simultaneous registration of two time intervals: 1) the time between two consecutive R peaks, and 2) time interval from the beginning of registration and beginning of each wholesome R or pulsogram peak. Our new mathematical algorithm allows reconstructing all pulsogram or RR intervalogram, providing full use of time domain and also frequency domain methods.

Key-Words: - Heart rate variability, RR interval, time interval, cubic spline, spline approximation, empty intervals.

1 Introduction

The paper is destined for use in medicine, psychology, in man's self-development training, breathing technique's training, in the field of stress resistance, health promotion, strengthening of the capacity for work; and it relates to the apparatus and methods for detection of the heart rate variability and it's may be used in providing biofeedback during training sessions of organism's vegetative balance and coherence [1]-[4]. The most prominent data analysis method – frequency time domain method needs very precise data acquisition technology, which is difficult to obtain, especially in practical everyday conditions, for example – in gym centers, individual biofeedback devices or apparatus for measurement of blood pressure and pulse. We involve new technology for registration of time interval between two consecutive EKG RR intervals or pulse wave peaks, which consist of simultaneous registration of two time intervals: 1) the time between RR intervals, and 2) time interval from the beginning of registration and beginning of each wholesome R or pulsogram peak. Our new mathematical algorithm allows reconstructing all pulsogram or RR intervalogram, providing full use of time domain methods.

Contrary to the view that under optimal conditions the heart beats sequence should remind the metronome, this is definitely not so [5]. Due to influence of Autonomic Nervous System, affecting the sinus node (nervous center, located in the heart, which activates each of the next cardiac cycle starting after a pause), pulse beats followed each other at different time intervals, and, as a result, the time span between two consecutive heart beats can vary over a wide range – from 400 to 1500 msec. Plotting these following time intervals graphically, we get a wavy line. It is called the Heart Rate Variability (HRV) line. It turned out that this curve is very informative [4]-[12].

When registering a heartbeat, we get a simple series of numbers (intervals between every two consecutive heartbeats in millisecond's, in average 70 numbers during minute, such as, for example, 721, 753, 835, 802, 799, etc.) from which we may derive many different indicators of the activity of vegetative nervous system, and, in addition, each of these numbers are characterized by strongly different physiological or psychological conditions. That is why we see a rapid increase of searches of new algorithms, approbation of new mathematical models.

Any technique that allows you to record an electrocardiogram is valid. As recording equipment does not play important role for the conditions (as it for many other so called psycho physiological methods, for example, galvanic skin response), the technical details of the HRV record is no l onger even object for serious discussions in the scientific literature.

We should start with the fact that the HRV was one of the chief methods used for evaluation of physiological state in aerospace medicine and psychology (it was in the period around years 1950-1980, mainly in Russia [7]. There are many studies that indicate the relationship between emotions and changed SRV indicators. HRV may be used as an indicator of risk prediction after myocardial infarction [5]. Until about 1980ties the only methods of, primary used in direct time regime were time domain methods, where some un-preciosity of data registration may be acceptable, somehow a great amount of very sophistical methods for registration process errors corrections were elaborated [8], [9]. Nevertheless, it was useful practice to simply delete the wrong fragments of registered signals.

The situation changes when the frequency domain method for RR interval analysis enters. Due to sophistical mathematical algorithms used in frequency domain methods, also demands for data acquisition quality remarkably grows up. T he fact is, that even the slightest registration error analysis results already vastly impressed, which could easily lead to complete distortion of the results of the analysis. Detection of atrial fibrillation in HRV signals needs analysis of irregular time series. Standard time domain and spectral method are not sufficient [10]. In paper [12] authors have used modern discrete wavelet transform to find precise heart beat signal. But in this paper as in other mentioted us papers nothing was told and used lost heart beat disappears. In paper [12], as in the papers [5], [6] are used standart deviation in the form $\sigma_x = \sqrt{\sum_{n=1}^{N} \frac{\left(x_n - \overline{x}\right)^2}{N}}$. Really the form is: $\sigma_x = \sqrt{\sum_{n=1}^{N_1} \frac{\left(x_n - \overline{x}\right)^2}{N_1}}$, where the number N_1 is true number of all heart beats. This point is main idea of this our work: to reconstruction all real heart beats.

2 Our approach of data recording

Whereas the frequency and time domain is the essence of each curve against the curve point of beginning, then we decided that it is better to go by road, which consists of 2 s teps independently. First is registration. We traditionally registered one size of place (the time interval between the current and the previous heart beats) in addition to each pulse blow we register also time interval from the beginning to of the strike. And the second – we failed the pulse interval pulsogram registration empty space with the original mathematical algorithm assistance. Our new records show clearness fragment: 782, **16009,** 781, **16790,** 791, **17582,** 811, **18393,** 757, **21460,** 737, **22197,** 731, **2292,** etc. If the fragment is without damage, then the time from the start (with fluctuations approximately 1 milliseconds (ms) range) corresponds to the sum of the length of the interval. It is also here in the demonstration the short numbers are together. If, however, we are significantly mistaken (or even extras stole movement, or any of the artifacts', this idyllic scene changes. We can see the following note fragment: 664,299859,833,300693,797,**301490,777, 306827,700,309765,799,310564**,756,311321.

To carry out analyses of this place. After 299859 (and 299.9 seconds) is the interval to 833 ms (0.8 sec), and it gives the correct next registered number: 300693 (300.7 sec). The same is true of the ensuing interval: sum up 797 ms (0.8 seconds), we get a number – 301490 (301.5 sec). Then come the obvious recorded error. In this model **301490** with subsequent RR interval – 777 ms, we become 302267 (approximately 302.3 seconds), but next notation is: 306827 (approximately 306.8 s ec). This number is completely invalid for future use by the frequency domain methods. A number of our registration time, the 306827 a llows us to solve the problem. But because this is the real time since records began. Schedule this item takes its real location, and pulse curve are not distorted in any way. In previous our paper [3] we have looked in the past time. As mentioned N. Wiener in the book [13]: "To predict the future of a curve is to carry outa certain operetion on i ts past. T he true prediction operator cannot be realized by any constructible apparatus; but there are certain operators which bear it a certain resemblance and are, in fact, realizable by apparatus which we can build." Now we worked idea for the extrapolation in the near future. It means the prognosis in the near future.

3. Our mathematical ideas for mathematical approximation for the empty interval

We have empty segment, which begin with u_0 finished with u_{N+1}. The unknown values (pulse beats) are $u_i, i=\overline{1,N}, N>1$. How can we find these values u_i ?

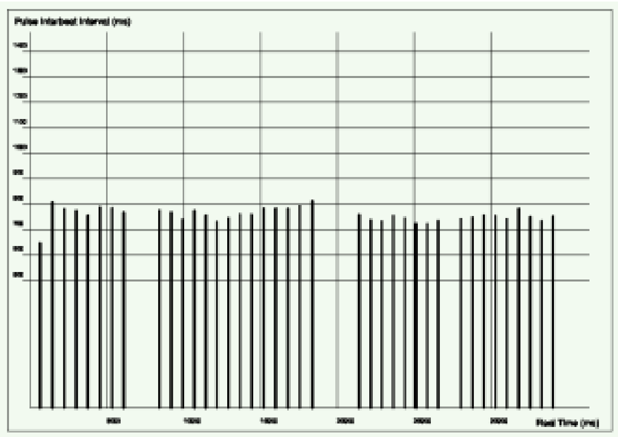

Fig. 1. Heart rate variability fragment with some empty intervals.

In numerical mathematics the traditional way is to approximately this empty interval with spline function [14]. Unfortunately, this problem differs from classical interpolation problem in two points. In numerical mathematics are given the points in which are given the unknown function values. Here we don't have points and don't have the values (heartbeats length). Now this problem can be solved with ideas in the data's from heart rate figure. Here we cannot solve this complex, but we can suggest first simple solution.

The first question is: how many heart beats have we lost? The answer is not clear. The first reason is to make as some middle value of some intervals left and right of this empty interval [3], [4]. This assumption allows us to find $t_i, i=\overline{1,N}$.

4. Spline approximation

The situation with $N=1$ will be looked separately. The values u_0, u_2 are known. Clearly, we find:

$$u_1 = \frac{u_0+u_2}{2}. \qquad (1)$$

Now we looked $N \geq 3$. Firstly, we assume that at points t_i we know the values $u_i = u(t_i)$. The first derivatives we designate of the splines as $S'(t_i) = m_i$. For the one segment $t \in [t_i, t_{i+1}]$ then we have this form of the classical cubic spline [14] - [16]:

$$S(t) = u_i + m_i(t-t_i) + a_{i,1}(t-t_i)^2 + a_{i,2}(t-t_i)^3, i=\overline{0,N}. \qquad (2)$$

Here we have two unknown coefficients $a_{i,1}, a_{i,2}$.

First equation is continuity in next point t_{i+1}:

$$u_{i+1} = u_i + m_i\tau_i + a_{i,1}\tau_i^2 + a_{i,2}\tau_i^3, \quad \tau_i = t_{i+1} - t_i, i=\overline{0,N}. \qquad (3)$$

Second equation is continuity of first derivative in the point t_{i+1}:

$$m_{i+1} = m_i + 2a_{i,1}\tau_i + 3a_{i,2}\tau_i^2, i=\overline{0,N}. \qquad (4)$$

Third equation will be the continuity of second derivative in the point $t=t_i$:

$$2a_{i-1,1} + 6a_{i-1,2}\tau_{i-1} = 2a_{i,1}, i=\overline{1,N}. \qquad (5)$$

We obtain from equations (3), (4) following values for the unknown coefficients:

$$a_{i,1} = 3\frac{u_{i+1}-u_i}{\tau_i^2} - \frac{m_{i+1}+2m_i}{\tau_i},$$

$$a_{i,2} = \frac{m_{i+1}+m_i}{\tau_i^2} + 2\frac{u_i-u_{i+1}}{\tau_i^3}, i=\overline{0,N}.$$

When substituting coefficients $a_{i-1,1}, a_{i-1,2}, a_{i,2}$ in the equation (5) we obtain:

$$\frac{1}{\tau_{i-1}}m_{i-1} + 2\left(\frac{1}{\tau_{i-1}} + \frac{1}{\tau_i}\right)m_i + \frac{1}{\tau_i}m_{i+1} = 3\frac{u_i-u_{i-1}}{\tau_{i-1}^2} + 3\frac{u_{i+1}-u_i}{\tau_i^2}, i=\overline{1,N}. \qquad (6)$$

This form is used in the numerical mathematics and its applications [14]-[16]. In interpolation theory in the points $t=t_i$ is given known interpolation values $u_i = u(t_i)$. In our case, the length of heartbeats is unknown. We solved this system to unknown values m_i. We use approximations:

$$\frac{u_i - u_{i-1}}{\tau_{i-1}} = \frac{m_{i-1} + m_i}{2}, \frac{u_{i+1} - u_i}{\tau_i} = \frac{m_{i+1} + m_i}{2}.$$

The equation (6) gives:

$$\frac{m_{i-1}}{\tau_{i-1}} + \left(\frac{1}{\tau_{i-1}} + \frac{1}{\tau_i}\right) m_i + \frac{m_{i+1}}{\tau_i} = 0, i = \overline{1, N}. \quad (7)$$

Classical cubic spline have continuous second derivative. To construct spline we need two boundary conditions on both ends of interval. Traditionally are given the first or second derivative. On left side for the first and second derivative, we have:

$$m_0 = m_0^{'}, \quad (8)$$

$$2\frac{m_{-1} - 2m_0 + m_1}{t_1 + t_{-1}} = m_0^{''}. \quad (9)$$

Here m_{-1} is the first value before the left side heart rate, the time t_{-1} is for previous heart rate beat. The boundary condition with second derivative we can transfer in following form:

$$m_0 = 0.5m_1 - 0.5m_0^{''}\left(t_1 + t_{-1}\right) + 0.5m_{-1}. \quad (10)$$

Analogous the right side boundary condition is:

$$m_{N+1} = m_{N+1}^{'}, \quad (11)$$

$$m_N = 0.5m_{N+1} - 0.5m_{N+1}^{''}\left(t_{N+2} + t_N\right) + 0.5m_{N-1}. \quad (12)$$

Similarly m_{N+2} is the value after the right side heart rate m_{N+1} and the time moment t_{N+2} is next after right side time. If the empty interval left or right side contains only one heart beat point, then the formula (7) transform to first type boundary condition.

We will solve the system (7) together with boundary conditions (8)-(12) with the elimination method [17], [18]. We write system in the form:

$$A_i m_{i-1} + C_i m_i + B_i m_{i+1} = 0, i = \overline{1, N}. \quad (13)$$

Here

$$A_i = \frac{1}{\tau_{i-1}}, B_i = \frac{1}{\tau_i}, C_i = \frac{1}{\tau_{i-1}} + \frac{1}{\tau_i};$$

$$m_0 = \kappa_1 m_1 + \mu_1, m_{N+1} = \kappa_2 m_N + \mu_2.$$

For the first type boundary conditions, we have such values:

$$\kappa_1 = 0, \mu_1 = m_0^{'}, \kappa_2 = 0, \mu_2 = m_{N+1}^{'}. \quad (14)$$

If we have second type boundary conditions, we have values:

$$\kappa_1 = 0,5, \mu_1 = 0.5\left[m_{-1} - m_0^{''}\left(t_1 - t_{-1}\right)\right], \quad (15)$$

$$\kappa_2 = 0,5, \mu_2 = 0.5\left[m_{N+1} - m_N^{''}\left(t_{N+2} - t_N\right)\right]. \quad (16)$$

Now we can give the algorithm for the elimination method [18]:

$$a_1 = \kappa_1, b_1 = \mu_1, a_{i+1} = \frac{B_i}{A_i a_i + C_i}, b_{i+1} = \frac{A_i b_i}{A_i a_i + C_i},$$

$$i = \overline{1, N}, m_N = \frac{b_{N+1} + a_{N+1}\mu_2}{1 - \kappa_2 a_{N+1}}, \quad (17)$$

$$m_i = a_{i+1} m_{i+1} + b_{i+1}, i = \overline{0, N-1}.$$

Mathematically the sufficiently conditions for the stability of the elimination method are [18]:

$$|C_i| \geq |A_i| + |B_i|, i = \overline{1, N};$$

$$|\kappa_j| \leq 1, j = 1, 2; |\kappa_1| + |\kappa_2| < 2.$$

As we see, the sufficiently conditions are fulfilled. Realized in the algorithm (17) we find the values $m_i, i = \overline{1, N}$.

Now the question is to find the values of lengths of heartbeats. We use the finite difference method [17], [18]:

$$\frac{u_i + u_{i-1}}{\tau_{i-1}} = m_i, u_i = u_{i-1} + \tau_{i-1} m_i, i = \overline{1, N-1}. \quad (18)$$

Really for $i = 1$ we have:

$$u_1 = u_0 + \tau_0 m_0.$$

Values m_0, u_0 are known, we can find the value u_1. The first weakness of this approximation is the finite difference order, which is first order of approximation. The second possibility is to go from the right hand side. In this case we have only first order of approximation:

$$\frac{u_{i+1} + u_i}{\tau_i} = m_{i+1}, u_{i+1} = u_i + \tau_i m_{i+1}, \quad (19)$$

$$i = N-1, N-2, ..., 1.$$

We give practical real heart beat example. For example after two empty interval we have one heart beat and again follow empty interval:

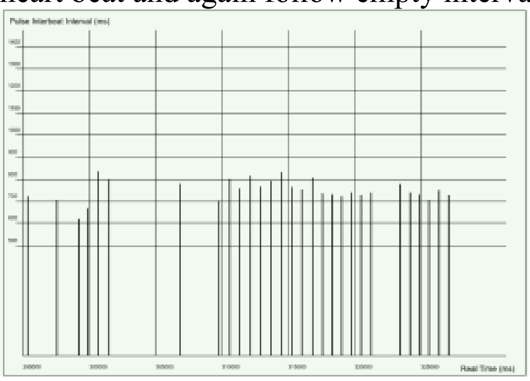

Fig.2. Example with at least two one heart beat between two empty intervals.

We start with $i = 2$ and first type boundary conditions (8), (11):

$$A_1 m_0^{'} + C_1 m_1 + B_1 m_2 = 0,$$

$$A_2 m_1 + C_2 m_2 + B_2 m_3^{'} = 0.$$

We solve both equations to unknown heart beats m_1, m_2:

$$m_1 = \frac{B_1 B_2 m_3^{'} - C_2 A_1 m_0^{'}}{C_1 C_2 - B_1 A_2},$$
$$m_2 = \frac{C_1 B_2 m_3^{'} - A_1 A_2 m_0^{'}}{B_1 A_2 - C_1 C_2}. \quad (20)$$

The value from equations (15) we designate as u_i^l, but from equations (16) as u_i^r.Then as true value, we use arithmetic middle value:

$$u_i = \frac{u_i^l + u_i^r}{2}.$$

We understood that method is first approximation for the reconstruction of the empty interval. We hope to publish improved mathematical method in future. This is good side of such approximation, but weakness of this method is the absence of specific side of structure of heart rate curve character.

5. Conclusion

We have constructed some new form of registration of the time interval between the current and the previous heartbeats and the time from the beginning of the registration process. We h ave some new spline approximation by splines for the reconstruction of lost heartbeats. This allows displaying blank intervals in the drawing. The usage of spline ensures the smoothness of the obtained curve, because the cubic spline has a continuous second derivative. In the future we hope to make extrapolation to look in the sometime intervals ahead.

We express our thanks to the reviewer for the idea to use interpolation of small empty intervals by Bezier approximation [19] instead of cubic splines. This idea will be continued later in our next broader article. With a purpose did the authors use Wiener's book [13], - we are planning to extrapolate this idea in near future.

References:

[1] Aldersons A., Buikis A. Mathematical algorithm for heart rate variability analysis. *Recent Advances in Applied &Biomedical Informatics and Computational Engineering in Systems Applications,* 2011, p. 381-386.

[2] Buikis A., Aldersons A. Training method for promotion of emotional stress reduction, psychological coherence and vegetative balance. *Latvian patent No. 13729*, 2008. Riga, p. 14.

[3] Buikis A., Aldersons A. In depth mathematical algorithm for heart rate variability analysis. *Journal of Multidisciplinary Engineering Science Studies,* 2017. Vol. 3, Issue 1. p. 1262 - 1269.

[4] Aldersons A., Strautina M. Respiratory sinus arrhythmia biofeedback in diaphragm breathing training. *Proceedings of the Latvian Academy of Sciences. Section B: Natural, Exact and Applied Sciences*, 1998, Vol. 52, No. 3/4, p. 194-199.

[5] Heart rate variability. Standards of measurement, psychological interpretation, and clinical use. *Task force of the European Society of Cardiology the North American Society of Pacing Electrophysiology.* Circulation 93: pp.1043-1065, 1996.

[6] Mika P. Tarvainen „Kubios HRV version 2.2“. *USER'S GUIDE, 2014.* University of Eastern Finland. p. 44.

[7] Parin V.V., Baevskij P. M., Volkov Y. N., Gazenko O. G. *Cosmic cardiology.* [Парин В.В., Баевский Р.М., Волков Ю.Н., Газенко О.Г. Космическая кардиология.] Leningrad. (in Russian) Медицина, 1967.

[8] Zhemaitite D.I. Vegetative regulation sinus rhythm for the healthy and patient. *Analysis the heart rhythm.* Vilnius, 1982. p. 22-32.

[9] Iljina S.S., Chernajev A.S., Jefimova I.P., Umanskaja N.E., Zapara V.V. Impact different methods for the analysis heart rate variability in the cardiology. *Vestnik OGU*, 2003. .No. 5. p. 115-120.

[10] Pierzcholski M., Stepien R.A., Stepien P. New nonlinear methods of heart rate variability and diagnostics of artrial fibrillation. *International Journal of*

Biology and Biomedicine, 2011. Issue 4, Vol. 5. p. 201-208.

[11] Smith A.L., Owen H., Reynold K.J. Heart rate variable indices for very short-term (30 beat) analysis. Part 1: survey and toolbox. *Journal Clinic Monitor Computer*, 2013. 27(5). p. 569-576.

[12] ABDEL-Rahman Al-Qawasmi and Khaled Daqrouq. ECG signal enhancement using wavelet transform. *WSEAS TRANSACTIONS on BIOOGY and BIOMEDICINE.* Vol. 7, I ssue2, April 2010. P. 62-70.

[13] Wiener N. *Cybernetics or control and communication in the animal and machine.* Second edition. The M.I.T. Press. Cambridge, Massachusetts. 1985.

[14] Ahlberg J.H., Nilson E.N., Walsh J.L. *The Theory of Splines and Their Applications.* Academic Press, 1967.

[15] Buike, M., Buikis, A. Representation formula for cubic spline with explicit dependence of interpolation function values. *Acta Universitatis Latviensis,* 1992, 575. p. 43-46. (In Russian language)

[16] Buikis A., Buike M. The Conservative Averaging Method: applications, theory and new hyperbolic approximation. *Mathematical and Computational Methods in Applied Sciences. Proceedings of the 3rd International Conference on Applied, Numerical and Computational Mathematics.* Sliema, Malta, August 17-19, 2015. p. 58-67

[17] Quarteroni A., Valli A. *Numerical Approximation of partial differential equations.* Springer, 2008. B erlin Heidelberg.

[18] Samarskii A.A. *The theory of differential schemes.* Marcel Dekker, Inc. New York, Base, 2001.

[19] Wikipedia. Bezier curve.