Method of evaluating the rhythm structure of a cyclic signal through defining the additional countdowns of a discrete function of rhythm

I. V. Lytvynenko

Ternopil Ivan Pul'uj National Technical University;
56, Ruska str., Ternopil, 46000, Ukraine

Received: 11.05.2018 Accepted: 04.06.2018

Abstract

The method of evaluation of additional countdowns of a discrete function of rhythm is being considered by taking into account single-phase values of the countdowns of the simulated cyclic signal, which is rhythmically related to the studied one. Considering the equality of the attributes of cyclicity, additional isomorphic countdowns are chosen in a simulated cyclic signal at all segment-cycles and segment-zones. Then the rhythmic structure is evaluated taking into account the defined additional countdowns. The obtained additional countdowns of the rhythmic structure provide the possibility to evaluate the behaviour of a discrete rhythm function between the countdowns' limits of the segmental structure.

The developed method can be used in automated digital processing systems (of diagnostics and forecasting) of cyclic data: cardiac signals of different physical nature, cyclical economic processes, processes of gas, water and power consumption, processes of surface formations of modern materials for evaluating the countdowns of the rhythmic structure that provides the information relating to the rhythm (pace) escalation in time of the magnitude of time intervals (distances) between single-phase values of the cyclic signal.

The developed method allows solving the problem of evaluating the countdowns of the rhythmic structure through obtaining a rhythmically coupled cyclic signal from a simulated implementation with the initial, studied additional countdowns that correspond to single-phase values in all segments of the cyclic signal. In further research, it is planned to use the obtained information for developing a method for choosing an optimal interpolation polynomial for adaptive interpolation of a discrete function of rhythm on the corresponding segment-cycles or segment-zones.

Keywords: *a cyclic signal, rhythmic structure, evaluation of the rhythm function, segmental cyclic structure, segmental zone structure, segmentation.*

When analyzing cyclic signals in cyclic data processing systems, the question often arises of evaluating their rhythmic structure. In particular, such problems arise after the procedure for segmentation of cyclic signals is accomplished. For example, in automated cardiodiagnostic systems of digital processing of cyclical data, where discretization methods [1], statistical processing [2] and simulation [3] of the cyclic signal are applied. Such tasks can not be solved without a previously estimated rhythmic structure. In particular, the task of evaluating the rhythmic structure of a cyclic signal takes place when performing a morphological analysis of cardiac signals, the analysis of the cardiac rhythm by cardio intervalogram, and the analysis of other cardio signals of a different physical nature. A similar task also arises when processing cyclic economic processes, gas consumption processes, water consumption and energy consumption, as well as when analysing other cyclic signals.

However, in most problems of analyzing cyclic signals, their rhythmic structure is not known, and therefore it is necessary to carry out its preliminary assessment, which makes this task important and relevant for automated systems of cyclic data digital processing. In [4–6] there are described methods for evaluating the rhythmic structure on the basis of piecewise linear, piecewise quadratic interpolation and interpolation by a cubic spline, however, a priori nothing is known about the regularity of the rhythm function variation within the cycles-segments and the segments-zones of the cyclic signal. Therefore, in case of such uncertainty it is naturally to use different approaches to its assessment within the respective segments.

This work is devoted to the developed method for evaluating the rhythmic structure (discrete rhythm function) by determining its additional countdowns for further processing steps (choosing the optimal interpolation method for the discrete rhythm function).

Mathematical model and rhythmic structure

The papers [7, 8] describe a mathematical model of oscillating phenomena and signals in the form of a cyclic function, generalizing the concept of periodic and almost periodic functions for deterministic and

* Corresponding author:
iaroslav.lytvynenko@gmail.com

© 2018, Ivano-Frankivsk National Technical University of Oil and Gas. All rights reserved.

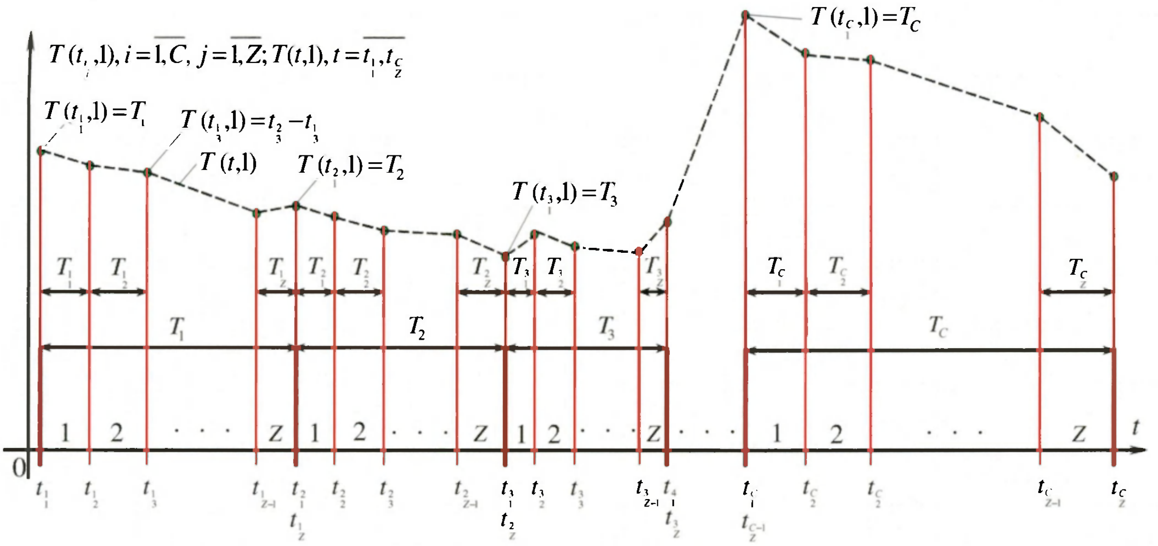


Figure 1 – Schematic representation of the discrete and continuous functions of rhythm for the implementation of a cyclic signal (continuous function of rhythm, piecewise linear, marked with a dotted line)

stochastic cases, in particular, there is described a model of continuous and discrete cyclic random processes with a segmental structure. The paper [7] shows that the cyclic rhythmic structure of any cyclic function is completely described by its rhythm function, which determines the law of variation of time intervals between single-phase values of the cyclic function. To perform the evaluation of the rhythmic structure of the cyclic signals, the segmentation methods [9, 10] are first applied to the cyclic signal under investigation, and the information on the segmental structure is obtained: the segmented cyclic $\mathbf{D}_c=\{t_i, i=\overline{1,C}\}$ or segmented zone $\mathbf{D}_z=\{t_{i_j}, i=\overline{1,C}, j=\overline{1,Z}\}$ structure. For a particular segment structure, there is obtained information about two countdowns for each segment that correspond to the beginning and its end. This information is used to evaluate the rhythmic structure (a discrete function of rhythm).

The rhythmic structure for the case of a segmental cyclic structure of a discrete signal, when $\mathbf{W}=\mathbf{D}$ is defined as follows:

$$T(t_i,n)=t_{i+n}-t_i, \forall i=\overline{1,C}, n\in \mathbf{Z}. \quad (1)$$

The rhythmic structure for the case of a segmented zone structure (a zone-cyclic structure) of a discrete signal, when $\mathbf{W}=\mathbf{D}$ is defined as follows:

$$T(t_{i_j},n)=t_{i+n_j}-t_{i_j}, \forall i=\overline{1,C}, j=\overline{1,Z}, n\in \mathbf{Z}. \quad (2)$$

To evaluate the rhythmic structure $\hat{T}(t_i,n)$, or $\hat{T}(t_{i_j},n)$ it is accepted that $n=1$ since, in practice, we are dealing with the processing of a cyclic signal, as a rule, every subsequent cycle ($n>0$), namely, when $n=1$, for example, taking into account the rhythm function, the cycles following each other, rather than the chosen cycles with a certain step, as for example when $n=2$, etc (Fig. 1).

The problem formulation of the rhythmic structure evaluation by determining its additional countdowns consists in determining the set of countdowns $t_{i,g}\in \mathbf{W}$, $i=\overline{1,C}$, $g=\overline{1,G}$ for the rhythmic structure $\hat{T}(t_i,1)$, $t_i\in \mathbf{W}$, which corresponds to the segmented cyclic structure $\mathbf{D}_c=\{\hat{t}_i, i=\overline{1,C}\}$, according to which $t_i<t_{i,g}<t_{i+1}, t_{i,g}, t_i\in \mathbf{W}$, $i=\overline{1,C}$, $g=\overline{1,G}$. Or it consists in determining the set of countdowns $t_{i_{j,g}}\in \mathbf{W}$, $i=\overline{1,C}$, $j=\overline{1,Z}$, $g=\overline{1,G}$ for the rhythmic structure $\hat{T}(t_{i_j},1), t_{i_j}\in \mathbf{W}$, which corresponds to the segmented zone structure $\mathbf{D}_z=\{t_{i_j}, i=\overline{1,C}, j=\overline{1,Z}\}$ at which $t_{i_j}<t_{i_{j,g}}<t_{i_{j+1}}, t_{i_{j,g}}, t_{i_j}\in \mathbf{W}$, $i=\overline{1,C}, j=\overline{1,Z}, g=\overline{1,G_j}$ where G is the number of additional countdowns on the corresponding cycles-segments, G_j is the number of additional countdowns on the corresponding segments-zones of the rhythmic structure, their number at all segments has to be equal, i.e. $G=\sum_{j=1}^{Z} G_j$. In this case, the set of additional countdowns corresponds to the single-phase values of the cyclic signal on the corresponding segments or, in other words, this set of additional countdowns, for which the isomorphism conditions of the cyclic signal countdowns and the equality of the values by the attribute (attributes) are fulfilled [8, 10]. That is, the conditions (3), (4) are satisfied for countdowns within the segments-cycles and (5), (6) for countdowns within the segments-zones.

for the set $\mathbf{D}_c$, the segmented zone structure is as follows:

$$t_{i_j}\leftrightarrow t_{i+1_j},\ldots;\ t_{i_{j+1}}>t_{i_j},\ t\in \mathbf{W}, i=\overline{1,C}, j=\overline{1,Z}, \quad (3)$$

$$p(f(t_{i_j}))=p(f(t_{i+1_j}))\rightarrow \mathbf{A},\ t\in \mathbf{W}, i=\overline{1,C}, j=\overline{1,Z}, \quad (4)$$

for the set $\mathbf{D}_z$, the segmental cyclic structure is as follows:

$$t_i \leftrightarrow t_{i+1},\ldots;\ t_{i+1} > t_i,\ t \in \mathbf{W}, i = \overline{1,C}, \quad (5)$$

$$p(f(t_i)) = p(f(t_{i+1})) \to \mathbf{A},\ t \in \mathbf{W}, i = \overline{1,C}, \quad (6)$$

where $\mathbf{A}$ is a set of attributes [7].

Method for evaluating the rhythmic structure

In order to understand the problem, we will consider a method for determining additional countdowns of a discrete rhythm function. The essence of the method consists in the following: first, it is necessary to simulate the realization of a rhythmically coupled cyclic signal with the investigated one. Rhythmic connectivity consists in using the same rhythmic structure (a discrete rhythm function) of the cyclic signal $\hat{T}(t_i,1)$, $t_i \in \mathbf{W}$ for a segmented cyclic structure $\mathbf{D}_c = \left\{\hat{t}_i, i = \overline{1,C}\right\}$ or $\hat{T}(t_{i_j},1)$ for a segmented zone structure $\mathbf{D}_z = \left\{\hat{t}_{i_j}, i = \overline{1,C},\ j = \overline{1,Z}\right\}$. The simulation of such an implementation occurs by scaling an independent representative cycle, taking into account the rhythmic structure (1) or (2), the countdowns of which are obtained by the segmentation methods. The first cycle of a cyclic signal, reflecting the features of the cyclic signal under study, is a representative one. After the scaling is carried out, a sequential "stitching" of each cycle into one implementation is made. This method can be used both for a stochastic approach, a mathematical model in the form of a cyclic random process with a segmented structure, and in the framework of a deterministic approach, a mathematical model in the form of a cyclic numerical function with a segmented structure [10].

There is used the method presented in [11] for simulation. Having applied it, we obtain a simulated realization of a cyclic signal $\dot{f}(t), t \in \mathbf{W}$, which is rhythmically associated with the input cyclic signal $f(t), t \in \mathbf{W}$. As noted previously, the simulated and studied cyclic signals have the same rhythmic structure, by scaling an independent representative cycle: the first cycle $f_1(t), t \in \mathbf{W}_1$ of the realization under investigation or the estimation of the mathematical expectation $\hat{m}_\xi(t), t \in \mathbf{W}_1$ (in the case of the stochastic approach when it is known) of the cyclic signal under study $\xi_\omega(t), t \in \mathbf{W}$, taking into account the rhythmic structure (a discrete rhythm function) $\hat{T}(t_i,1)$, $t_i \in \mathbf{W}$ or $\hat{T}(t_{i_j},1)$, $t_{i_j} \in \mathbf{W}$.

Consider the basic mathematical relationship for this stage.

The implementation of a rhythmically coupled signal is simulated in the form (7), for the case of a segmented cyclic structure:

$$\dot{f}(t) = \sum_{i=1}^{C} \dot{f}_i(t), t \in \mathbf{W}, \quad (7)$$

where $\dot{f}_i(t)$ are the i th independent segments-cycles of a rhythmically coupled cyclic signal with an input signal $f(t)$.

The implementation of a rhythmically coupled signal is simulated in the form (8), for the case of a segmented zone structure (zone-cyclic structure):

$$\dot{f}(t) = \sum_{i=1}^{C}\sum_{j=1}^{Z} \dot{f}_{i_j}(t), t \in \mathbf{W}, \quad (8)$$

where $\dot{f}_{i_j}(t)$ are the j th segments-zones of the i th segments-cycles of a rhythmically connected cyclic signal with an input signal $f(t)$.

Since the segmented zone structure is a part of the segmented cyclic one, there are ties between the i th segments-cycles and the j th segments-zones in the i th segments-cycles of the rhythmically coupled cyclic signal:

$$\dot{f}_i(t) = \sum_{j=1}^{Z} \dot{f}_{i_j}(t), i = \overline{1,C}, t \in \mathbf{W}, \quad (9)$$

The domain for the corresponding cycles-segments and the segments-zones have a relationship (10), respectively.

The domain $\mathbf{W}_i$ of the segment that corresponds to the i th cycle is equal to the union of the domains $\mathbf{W}_{i_j}$ of smaller segments-zones that do not intersect:

$$\mathbf{W}_i = \bigcup_{j=1}^{Z} \mathbf{W}_{i_j},$$

$$\mathbf{W}_{i_j} \bigcap \mathbf{W}_{i_q} = \varnothing,\ j \neq q,\ j,q = \overline{1,Z}, i = \overline{1,C}. \quad (10)$$

The domain of the registered/modeled signal $\mathbf{W}$ is equal to the sum of the domains of the cycle segments $\mathbf{W}_i$ or to the sum of domains of smaller segments-zones $\mathbf{W}_{i_j}$ on the cycles that do not intersect:

$$\mathbf{W} = \bigcup_{i=1}^{C} \mathbf{W}_i = \bigcup_{i=1}^{C}\bigcup_{j=1}^{Z} \mathbf{W}_{i_j},$$

$$\mathbf{W}_{i_j} \neq \varnothing, j = \overline{1,Z}, i = \overline{1,C}. \quad (11)$$

Consider the second stage of the algorithm which can be either for the segmented cyclic structure, respectively, the rhythm function $\hat{T}(t_i,1)$, $t_i \in \mathbf{W}$ or for the segmented zone structure, respectively, the rhythm function $\hat{T}(t_{i_j},1)$, $t_{i_j} \in \mathbf{W}$.

In the case of a segmented cyclic structure, a procedure is performed for choosing those countdowns from the simulated implementation $\dot{f}(t)$, which values are equal to the countdowns from the first cycle according to the attribute (4). In this case, the isomorphism condition of the countdowns on the corresponding segments (3) must be fulfilled, or in other words, single-phase samples are chosen regardless of whether a deterministic or stochastic approach is applied to the mathematical model of cyclic signals. In the latter case, the simulated implementation is considered as deterministic, which reflects non-random values on the cycles, since during the modeling we performed scaling of the representative cycle.

From the modeled implementation, the countdowns of the first cycle $\dot{f}_1(t), t \in \mathbf{W}_1$ are sequentially chosen and compared with the counts of the next segments-cycles. Two conditions must be fulfilled:

1) the condition of the attributes equality (equivalence) for the segmented cyclic structure (4), while taking the counts $\tilde{t}_{i,g}$, $g = l$ as additionally determined when there is fulfilled the condition of attributes equality in all segments-cycles.

$$p(\dot{f}_1(t_{1,l})) = p(\dot{f}_2(\tilde{t}_{2,l})) = ... = p(\dot{f}_i(\tilde{t}_{i,l})) = ... = p(\dot{f}_c(\tilde{t}_{c,l})),$$
$$i = \overline{2,C}, l = \overline{1,L}, \quad (12)$$

where $t_{1,l} \in \mathbf{W}_1, \tilde{t}_{i,l} \in \mathbf{W}, \tilde{t}_{i,l} \notin \mathbf{W}_1, i = \overline{1,C}, l = \overline{1,L}$; $\{t_{1,l}\}$ is a set of countdowns of the first cycle $l = \overline{1,L}$; $\{\tilde{t}_{i,l}\}$ is a set of countdowns on the entire realization, except for the first cycle (a representative cycle).

2) the isomorphism condition of the countdowns on the corresponding segments:

$$t_{i,g} \leftrightarrow t_{i+1,g}, ...;\ t_{i+1,g} > t_{i,g},\ t_{i,g} \in \mathbf{W}, i = \overline{1,C}, g = \overline{1,G}. (13)$$

If one of the two conditions is not satisfied at one of the cycles-segments of the simulated cyclic signal, then the countdown $\tilde{t}_{i,g} \neq t_{i,l}$ is not taken into account.

Similarly, the definition of additional countdowns of a discrete rhythm function consists in the choosing of single-phase countdowns, that is, the countdown $\tilde{t}_{i,g}$ is taken as additionally determined when the condition of equality of attributes is fulfilled at all segments-cycles, that is:

$$f_{\phi_{1,g}} = f_{\phi_{2,g}} = ... = f_{\phi_{i,g}} = ... = f_{\phi_{c,g}},$$
$$i = \overline{1,C}, g = \overline{1,G}. \quad (14)$$

If this condition is not fulfilled at least at one segment-cycle, then the countdown $\tilde{t}_{i,g}$ is not taken into account.

After determining all the additional countdowns, the rhythmic structure is evaluated (the values of the discrete rhythm function are determined), taking into account certain additional countdowns:

$$\hat{\dot{T}}(t_{i,g}, 1) = \tilde{t}_{i-1,g} - \tilde{t}_{i,g},\ i = \overline{1,C}, g = \overline{1,G}. \quad (15)$$

In the case of a segmented zone structure, a procedure is performed for choosing those countdowns from the simulated realization $\dot{f}(t)$, which values are equal to the countdowns from the first cycle according to the attribute (6), then the isomorphism condition of the countdowns on the corresponding segments (5) must be fulfilled, or in other words, single-phase samples are chosen.

From the simulated realization, the countdowns from the first cycle $\dot{f}_1(t), t \in \mathbf{W}_1$ are sequentially chosen and compared with the counts of the next segments-cycles and segment-segments, thus two conditions must be fulfilled:

the equality condition of the attributes (equality of values) for the segmented zone structure (6), whereby the countdowns $g = l$, $\tilde{t}_{i_{j,g}}$ are taken, as additionally determined when the equality condition of the attributes is fulfilled in all segment-zones.

$$p(\dot{f}_{1_j}(t_{1_{j,l}})) = p(\dot{f}_{2_j}(\tilde{t}_{2_{j,l}})) = ... = p(\dot{f}_{i_j}(\tilde{t}_{i_{j,l}})) = ... = p(\dot{f}_{c_j}(\tilde{t}_{c_{j,l}})),$$
$$i = \overline{2,C}, j = \overline{1,Z}, l = \overline{1,L}, \quad (16)$$

where $t_{1_{j,l}} \in \mathbf{W}_1, \tilde{t}_{i_{j,l}} \in \mathbf{W}, \tilde{t}_{i_{j,l}} \notin \mathbf{W}_1, i = \overline{1,C}, j = \overline{1,Z}, l = \overline{1,L}$;

$\{t_{1_{j,l}}\}$ is a set of countdowns of the first cycle $l = \overline{1,L}$;

$\{\tilde{t}_{i_{j,l}}\}$ is a set of countdowns at the entire realization, except for the first cycle (a representative cycle).

2) the isomorphism condition of the countdowns at the corresponding segments:

$$t_{i_{j,g}} \leftrightarrow t_{i+1_{j,g}}, ...;\ t_{i_{j+1,g}} > t_{i_{j,g}},\ t_{i_{j,g}} \in \mathbf{W},$$
$$i = \overline{1,C}, j = \overline{1,Z}, g = \overline{1,G}. \quad (17)$$

If one of the two conditions is not satisfied at one of the cycles-segments of the simulated cyclic signal, then the countdown $\tilde{t}_{i_{j,g}} \neq t_{i_{j,l}}$ is not taken into account.

Similarly, the definition of additional countdowns of a discrete rhythm function consists in the choosing of single-phase countdowns, that is, the countdown $\tilde{t}_{i_{j,g}}$ is taken as additionally determined when the condition of equality of attributes is fulfilled at all segments-cycles, that is:

$$f_{\phi_{1_{j,g}}} = f_{\phi_{2_{j,g}}} = ... = f_{\phi_{i_{j,g}}} = ... = f_{\phi_{c_{j,g}}},$$
$$i = \overline{1,C}, j = \overline{1,Z}, g = \overline{1,G}. \quad (18)$$

If this condition is not fulfilled at least at one segment-cycle, then the countdown $\tilde{t}_{i_{j,g}}$ is not taken into account.

After determining all the additional countdowns, the rhythmic structure is evaluated (the values of the discrete rhythm function are determined), taking into account certain additional countdowns:

$$\hat{\dot{T}}(t_{i_{j,g}}, 1) = \tilde{t}_{i-1_{j,g}} - \tilde{t}_{i_{j,g}},\quad i = \overline{1,C}, j = \overline{1,Z}, g = \overline{1,G}. \quad (19)$$

Figure 2 shows the algorithmic support of the developed method for evaluating the rhythmic structure by defining its additional countdowns.

The results of applying the method

We apply the relations obtained above for estimating the rhythmic structure (discrete rhythm function) of cyclic signals, for example, a signal with a segmented zone structure, as a generalized case. Figure 3 shows an example of a cyclic signal (electrocardio signal), and a discrete rhythm function is determined by the segmentation method.

To simulate a rhythmically coupled cyclic signal with the signal given in Fig. 3 *a*, we use the input data: the rhythmic structure (a discrete rhythm function) is given in Fig. 3 *b* and the representative cycle is shown in Fig. 4 *a*.

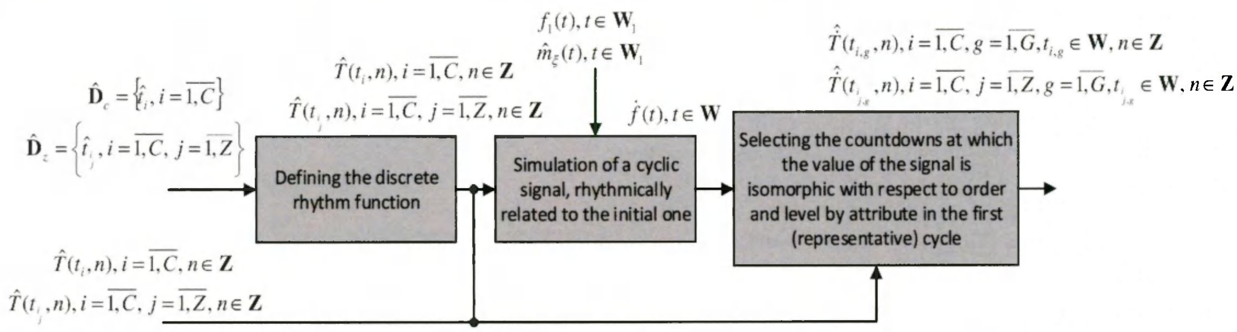
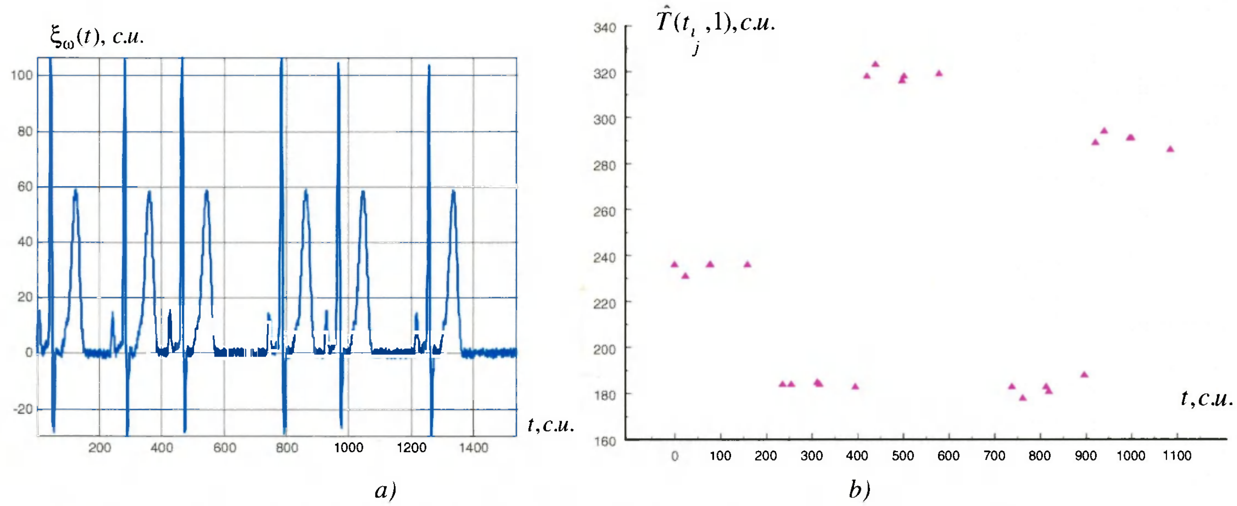
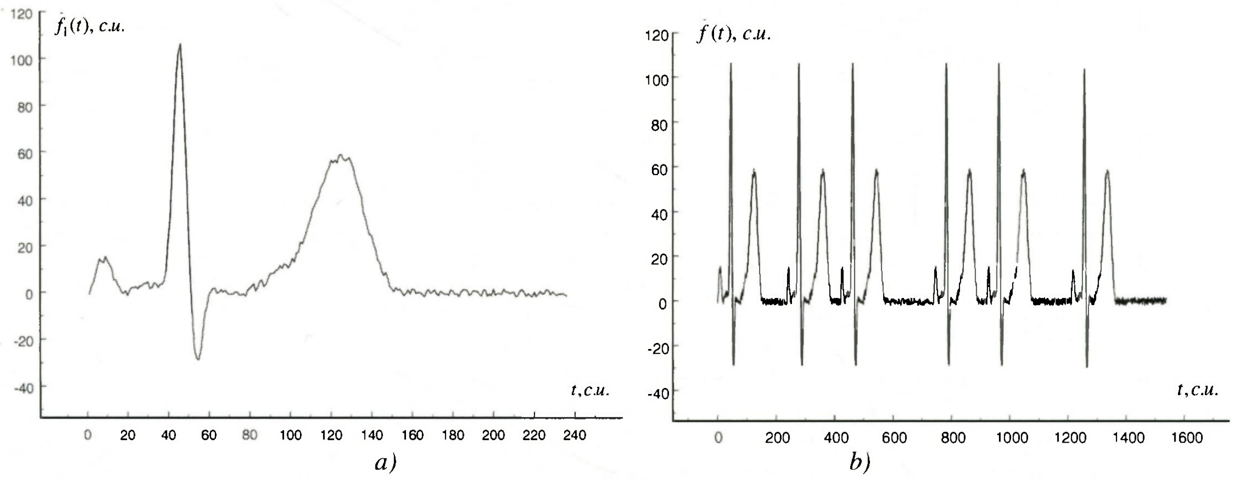


Figure 2 – Structural diagram of the method for evaluating the rhythm structure (of the discrete rhythm function) through defining its additional countdowns



a) realization of the initial electro cardio signal, diagnosis - conditionally healthy person; b) a discrete rhythm function is defined (triangles - countdowns of the discrete rhythm function, the number of countdowns = 24)

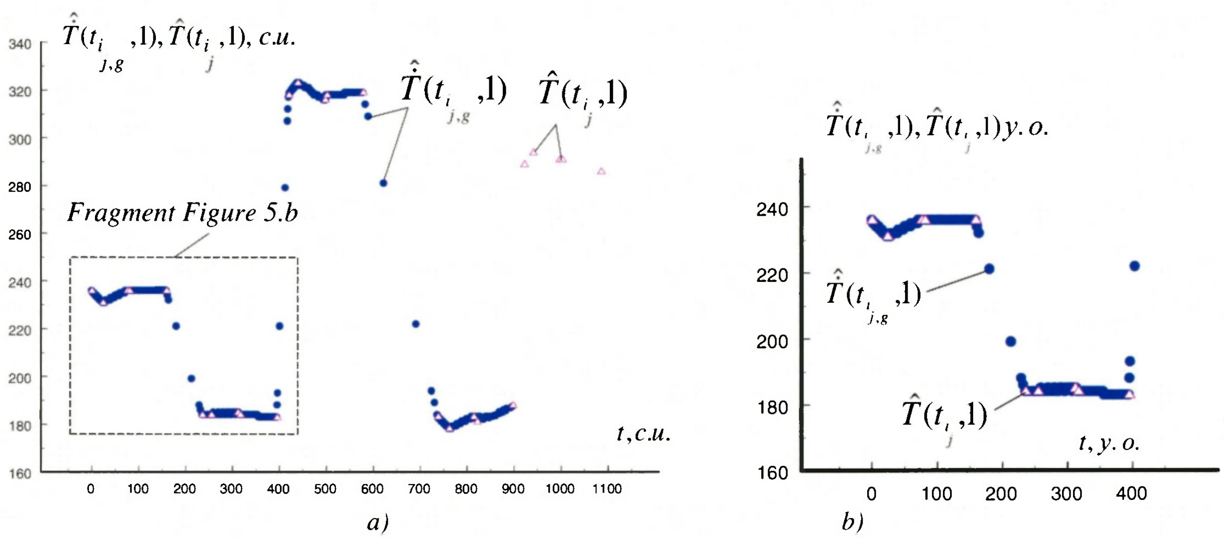
Figure 3 – Realization of the initial cyclic signal and the rhythm structure (discrete rhythm function) is evaluated, the countdowns of which are determined by methods of segmentation



a) the first cycle (representative) of the initial electro cardio signal;
b) realization of a simulated cyclic signal

Figure 4 – The first cycle (representative) of the initial cyclic signal and the realization of the simulated cyclic signal (electro cardio signal), rhythmically related to the initial signal

Analyzing the results obtained, it is necessary to say that the number of received additional countdowns is 713. It is more than in the case of the rhythmic structure obtained by taking the countdowns that give the methods of segmentation equal to 24 (Fig. 5). Thus, this method allows one to get more rhythmic patterns that will be taken into account for the further evaluation of the rhythm function at the corresponding segments. If



a) a discrete rhythm function and the defined additional countdowns of the discrete rhythm function (dots – evaluated additional countdowns of the rhythm function = 713 countdowns; triangles – countdowns of the discrete rhythm function (determined by methods of segmentation), 24 countdowns);
b) an enlarged fragment (Figure 5 a) of defined additional countdowns of the rhythm structure

Figure 5 – Results of the method of evaluating the rhythm structure through defining the additional countdowns of the discrete function of rhythm

we take into account the countdowns of the rhythmic structure and the corresponding values (phases) of the simulated cyclic signal rhythmically associated with the input, then this method can be considered as a method of making a cyclic signal as strictly cyclic, as this postulates the mathematical model. In this case, the sampling rate will not be uniform for such a cyclic signal, and the values, corresponding to the countdowns, will be single-phase. That is, there is performed the equality by the attributes for all values and the isomorphism for all countdowns as provided for in the theory of cyclic functions [7].

Conclusions

The developed method allows us to obtain more countdowns of the rhythmic structure (a discrete rhythm function). Although we obtain more countdowns for the rhythmic structure compared with information about the countdowns that the segmentation methods provide, however, the choice of the optimal interpolation polynomial for estimating the rhythm function remains relevant. In addition, if we take into account the countdowns of the rhythmic structure and their corresponding values (phases) of the simulated cyclic signal, rhythmically associated with the input one, then this method can be considered as a method of reducing the cyclic signal to a strictly cyclic signal as postulated by the mathematical model.

The developed method can be used in automated systems of digital processing (diagnostics and forecasting) of cyclic data: cardio signals of various physical nature, cyclic economic processes, gas processes, water consumption and energy consumption, surface processes of relief formations of modern materials for estimating rhythm (rate) of time intervals (distances) between single-phase values of the cyclic signal.

The developed method makes it possible to solve the problem of evaluating the countdowns of the rhythmic structure by obtaining a cyclic signal, rhythmically coupled with the input one, which is studied by additional countdowns corresponding to single-phase values at all segments of a cyclic signal. In further studies, it is planned to take into account the obtained information for developing the method of choosing the optimal polynomial interpolation for creating the method of adaptive interpolation of the discrete rhythm function at the corresponding segments-cycles or segments-zones.

References

[1] Lupenko, S 2006, 'Features of discretization of cyclic functions', *Measuring and computer technology in technological processes*, no.1, pp. 64–70. [in Ukrainian].

[2] Lytvynenko, Ia 2006, 'Methods of statistical processing of heart signals based on their model in the form of a cyclic random process with zone temporal structure', *Bulletin of the Ternopil State Technical University Ternopil*, vol. 11, no. 4, pp. 189–200. [in Ukrainian].

[3] Lytvynenko, Ia 2011, 'Imitation modeling of interconnected economic processes on the basis of the vector of cyclic rhythmically related random processes', *Electronics and control systems*, no. 2 (28), pp. 133–141. [in Ukrainian].

[4] Lupenko, S 2007, 'The task of interpolation of the rhythm function of a cyclic function with a known zone structure', *Electronics and Control Systems*, no. 2 (12), pp. 27–35. [in Ukrainian].

[5] Lytvynenko, Ia 2016, 'The Method of the Quadratic Interpolation of the Discrete Rhythm Function of the Cyclical Signal With A Defined Segmented Structure', *Scientific Journal of the Ternopil National Technical University*, vol. 84, no. 4, pp. 131–138. [in Ukrainian].

[6] Lytvynenko, Ia 2017, 'The Method of Interpolation by a Cubic Spline of a Discrete Function of the Rhythm of a Cyclic Signal with a Definite Segmental Structure', *Measuring and computing engineering in technological processes*, no. 3, pp. 105–112. [in Ukrainian].

[7] Lupenko, S 2006, *Theoretical bases of modeling and processing of cyclic signals in information systems*: Monograph, Lviv, 343 pp. [in Ukrainian].

[8] Lytvynenko, Ia 2016, 'The Problem of Segmentation of the Cyclic Random Process with a Segmental Structure and the Approaches to Its Solving', *Journal of Hydrocarbon Power Engineering*, vol. 3, iss. 1, pp. 30–37.

[9] Lytvynenko, Ia 2005, 'Statistical method for determining the zone structure of an electro cardiogram in automated diagnostic systems', *Bulletin of the Ternopil State Technical University Ternopil*, vol. 10, no. 3, pp. 165–175. [in Ukrainian].

[10] Lytvynenko, Ia 2018, 'Method of segmentation of determined cyclic signals for the problems related to their processing and modeling', *Scientific Journal of the Ternopil National Technical University*, vol. 88, nNo. 4, pp. 153–169. [in Ukrainian].

[11] Lytvynenko, Ia 2009, 'Simulation of synchronously registered heart signals on the basis of a vector of cyclic rhythmically related random processes in cardiometric problems', *Electronics and control systems.*, no. 4 (22), pp. 141–148. [in Ukrainian].

УДК 004.67

Метод оцінювання ритмічної структури циклічного сигналу за додатковими відліками дискретної функції ритму

Я.В. Литвиненко

Тернопільський національний технічний університет імені Івана Пулюя; вул. Руська, 56, м. Тернопіль, 46000, Україна

Розглядається метод оцінювання додаткових відліків дискретної функції ритму шляхом врахування однофазних значень відліків змодельованого циклічного сигналу, ритмічно пов'язаного з досліджуваним. Враховуючи рівність атрибутів циклічності, вибираються додаткові ізоморфні відліки в змодельованому циклічному сигналі на всіх сегментах-циклах та сегментах-зонах, після цього оцінюється ритмічна структура з врахуванням визначених додаткових відліків. Отримані додаткові відліки ритмічної структури дозволяють оцінити поведінку дискретної функції ритму між відліками меж сегметної структури.

Розроблений метод може бути використаний в автоматизованих системах цифрової обробки (діагностики та прогнозу) циклічних даних: кардіосигналів різної фізичної природи, циклічних економічних процесів, процесів газо-, водо- та енергоспоживання, процесів поверхні рельєфних утворень сучасних матеріалів для оцінювання відліків ритмічної структури, що дає інформацію про ритм (темп) розгортання у часі величини часових проміжків (відстаней) між однофазними значеннями циклічного сигналу.

Розроблений метод дозволяє вирішити проблему оцінювання відліків ритмічної структури шляхом отримання зі змодельованої реалізації ритмічно пов'язаного циклічного сигналу із вхідними досліджуваними додатковими відліками, які відповідають однофазним значенням на всіх сегментах циклічного сигналу. У подальших дослідженнях планується врахувати отриману інформацію для побудови методу вибору оптимального інтерполяційого полінома для адаптивної інтерполяції дискретної функції ритму на відповідних сегментах-циклах чи сегментах-зонах.

Ключові слова: *оцінювання функції ритму, ритмічна структура, сегментація, сегментна зонна структура, сегментна циклічна структура, циклічний сигнал.*