NEW METHODS OF AN ST SEGMENT OF ELECTROCARDIOSIGNAL PARAMETERS ESTIMATION

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Abstract: new noise proof integral approach to estimation of an ST segment of electrocardiosignal morphology parameters is offered. The methods of ST segment parameters revealing in its spectral composition in bases of Legendre polynomials and Walsh functions are designed. It is designed sets of decisive rules for categorization of morphology types of ST segment on base of its spectral coefficientes values in bases of Legendre polynomials and Walsh functions in accordance with criteria established in medical practice. It is developed new method of allocation of ST-segment time-domain interval at real-time mode.

Introduction

In clinical practice of diseases diagnostics connected with infringement of myocardial electrical conductivity (myocardial infarction, ischemia) the ST segment of electrocardiosignal (ECS) analysis has a great importance.

The basic ST segment parameters estimation automatic method, used today, is the method of measurement ECS in significant points and comparison of the received levels with thresholds. The given method has a low noise stability, and under the noise handicapes influence the erroneous decision on features of an ST segment can be made.

The procedure of signal averaging in temporary area during several cardiocycles is used for noise stabilities increase. It has an essential lack - during such averaging the information the presence of short-term episodes of changes in the form of an ST segment (trancient episodes of ischemia) can be lost. So development and research of new methods and algorithms for the estimation of an ST-segment parameters are urgent tasks.

Materials and Methods

The theoretical part of work is constructed on the basis of the mathematical analysis, spectral analysis, theory of approximation of functions, theory of detection of signals and mathematical statistics. The experimental researches were carried out with the use of annotated ECS databases, intended for testing automatic algorithms of ECS processing (European ST-T Database, QT-T Database). The results of researches are received in the program environments Mathcad, Matlab and Delphi.

Results

As the approach to an ST segment morfology parameters estimation the use of integrated criteria, that is spectral coefficientes of a signal in some orthogonal basis, was offered [1].

Analysis of ECSs with different detours from rates allows to present base model ST segment in the manner of sum of three normalized signals-primitives: constant offset Uc_0, linear increasing signal with zero limited by it area Uc_1 and parabolic concave signal with minimum in medium of interval of measurement and zero area under crooked Uc_2 [2] .

Got collection of signals-primitives with corresponding scale factors overlays all requireded morphology types of considered area of signal $U_{ST}(\theta)$:

$$U_{ST}(\theta) = m_0 \cdot Uc_0(\theta) + m_1 \cdot Uc_1(\theta) + m_2 \cdot Uc_2(\theta) \ , \quad (1)$$

there m_0, m_1, m_2 - scaling factors.

The requirements to the orthogonal basis functions have been formulated. They allow to prove a choice of the basis providing revealing of clinical parameters by taking into account of features of a researched signal morfology:

1. The Requirement of localization: in orthogonal basis must be present the spectral component, which amplitude depends only from presence in description of ST-segment morfology only one of the the signals-primitives and does not depend on two others.
2. The Requirement of minimum difficulty of calculations and simplicities of technical realization.

There was is organized study of ST segment spectral presentation in orthogonal bases of harmonic functions, Chebyshev of the first and second kind polynomials, Legendre polynomials and Walsh functions by the way of shaping the basis functions on interval of ST segment existance as on area of orthogonality and calculations corresponding spectral coefficientes. There was is stated that to the best advantage supplied requirements satisfy the bases of Legendre polynomials and Walsh functions.

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Calculation of spectral coefficientes A_n for Legendre polynomials is produced on formula

$$A_n = \int_{-1}^{1} U_{ST}(x) L_n(x) dx = 2\int_{0}^{1} U_{ST}(\theta) L_n(2\theta - 1) d\theta, \quad (2)$$

there $L_n(x)$ – Legendre polynomial order n, orthogonal on interval [-1,1] with single function $h(x)=1$;

for Walsh functions

$$A_n = \int_{0}^{\theta} U_{ST}(\theta) pal_n(\theta) d\theta, \quad (3)$$

there $pal_n(\theta)$ – the Walsh function number n ranked on Paly.

It is stated that zero, first and the second spectral amplitudes in Legendre basis and 0, 1 and 3 - in Walsh basis ranked on Paly characterize, accordingly, degree and sign of offset, direction of slopping and presence of proturberance or concavities (Figure 1 and Figure 1) [2, 3, 4]. Values of given spectral amplitudes possible to consider as morfology parameters - offsets (PO), slopping (PS) and proturberances/concavities (PP/C).

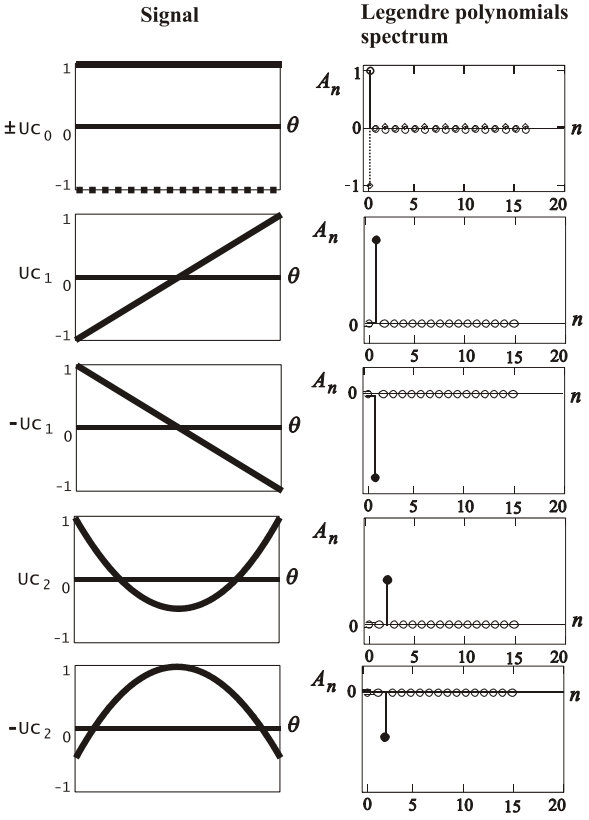

Figure 1: Signals-primitives and its Legendre polinomials spectral coefficientes

Presence of constant coefficients of intercoupling between spectral amplitudes values and scaling factors under corresponding to signals-primitives allows not only qualitative, but also quantitative to value the morphology parameters. The factors of issue each of signals-primitives on corresponding to spectral amplitudes are presented in Table 1.

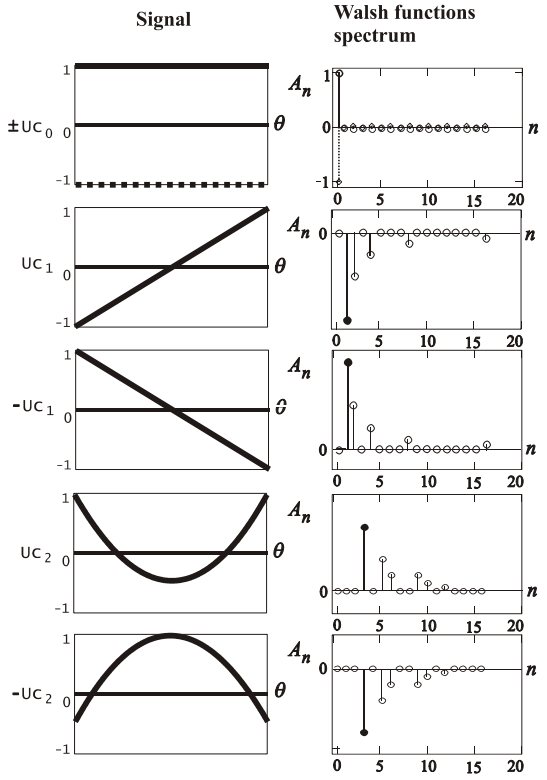

Figure 2: Signals-primitives and its Walsh functions spectral coefficientes

Table 1: Factors of issue

	PO / K_0	PS / K_1	PP/C / K_2
Legendre	A_0/ 1	A_1/ 0,33(3)	A_2/ 0,2
Walsh	A_0/ 1	A_1/ -0,5	A_2/ 0,375

The methods of revealing of an ST segment morfology parameters in its spectral structure in basis Legendre polinomial and Walsh functions has been developed and investigated [5]. In the comparison with standard dot methods, they provide a 6-8 times larger stability to the influence of the noise handicapes on ECS, that raises sensitivity to the low-level changes of the morfology of a signal and the short-term deviations as well. These methods also allow to provide a storage of the information about an ST segment with the minimal set of informatical parameters.

The sets of the decisive rules allowing to make a classification of types of an ST segment morfology according to the requirements, accepted in medical practice, to normal and describing deviations from norm on the base of three spectral coefficients making in Legendre or Walsh bases, displaying clinical main of an ST-segment morfology parameters, have been developed, and the algorithms of classification on the base of the sets as well.

Here select the following codes of form: FST=1 - normal; FST=21 or 22 – slope-descending depression or elevation; FST=31 or 32 - slope-ascending depression or elevation; FST=41 or 42 - concave depression or elevation; FST=51 or 52 - proturberant depression or

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elevation; FST=61 or 62 - horizontal depression or elevation. The sets of the decisive rules are presented in Table 2 (for component in Legendre basis) and in Table 3 (for component in Walsh basis).

Table 2: The sets of the decisive rules (Legendre)

Codes of type of form	A_0	A_1	A_2
1	0	0	0
21	<0	<0	0
22	>0	<0	0
31	<0	>0	0
32	>0	>0	0
41	<0	*	>0
42	>0	*	>0
51	<0	*	<0
52	>0	*	<0
61	<0	0	0
62	>0	0	0

Table 3: The sets of the decisive rules (Walsh)

Codes of type of form	A_0	A_1	A_3
1	0	0	0
21	<0	>0	0
22	>0	>0	0
31	<0	<0	0
32	>0	<0	0
41	<0	*	>0
42	>0	*	>0
51	<0	*	<0
52	>0	*	<0
61	<0	0	0
62	>0	0	0

The real procedure of ST-segment analysis must to include such stages, as allocation of a fiducial point in heart-beat, eliminating the iso-line drift, allocation of time-domain interval, belonging to ST segment, estimation of morfology parameters and categorization of type of morfology. Also are necessary possibility of conservation of information about an ST segment is possible minimum set of parameters and possibility of reconstruction on their base of the main particularities of time-domain form of signal.

It is offerred use the procedure of allocation of a fiducial point on TP segment [6]. In this case fiducial points, selected on electrocardiosignal, simultaneously are discrete samples of the iso-line drift signal [7]. They are represent square-wave pulses modulated on amplitude, following with frequency of heart rate. The filtration method for separation of signal of iso-line drift is possible to use. Chosen signal of driftage is subtracted from source signal.

One of the the main problems, with which happens to to face at estimation of ST-segment morphology parameters, is an exact allocation of givenned area on ECS. The methods of ST segment begin allocation possible to divide into two classes:

1. Founded directly on searching for of ST segment begin JN point.
2. Founded on acceptance for ST segment begin of point, disposed through determined gap of time from R-wave top or begin of QRS-complex.

Searching for of ST segment completion, as a rule, is not realized.

The defect of first class methods is presence of data delay and difficulty of computing procedures. The second class methods are founded on a priori information on possible range of variation of duration of complexes and segments. This class of methods much more simply computationally, allows to process the signal a real-time, but contributes additional inaccuracy, caused by change the frequency of warmhearted reductions and variation of QRS-complex morphology. A mistakes, connected with connection of JN point to R-wave top are significant.

There was is offered method of "QRS-strobing" ST segment signal, combining dignity of ways of mentioned groups and free, in too time, from their defects.

Method of QRS-strobing is founded on that that at summation of first derived energy in driven time-domain window, duration *WW* is equval with duration QRS-complex T_{QRS}, the denominated maximum of function is reached at moment of completion QRS-complex then in point JN. At excess of duration *WW* to T_{QRS} point of maximum convert to "ledge" of constant level by duration, equal duration *WW* subtract QRS-complex duration. At choice of duration of time-domain window equal TST+TQRS will is formed strobe pulse, coinsiding with ST-segment time interval. Given method allows to abandon of searching for fidusial point within QRS-complex. For ECS morphologies variability account are offered to use the dynamic turning of duration of time-domain window, introduction additional control functions and dynamic adaptive thresholds of comparison.

On base of analysis of row of ECS from annotated database European ST-T Database and QT-T Database, intended for check of capacity of work of automatic algorithms, is offered following modification of QRS-strobing method. As main function is used normalized summ of signal first derived modules DWM in time-domain window with adjusted duration:

$$DWM_i = \frac{\sum_{j=i-N+1}^{i} |u_i - u_{i-1}|}{N}, \qquad (4)$$

there u_i – amplitude of ECS sample;
N – number of samples of the signal, fall into time-domain window *WW*, which duration is calculated on formula:
$WW=T_{QRS}+T_{ST}=70\ ms+(56\ ms+0{,}05T_{RR})=A+0{,}05T_{RR}$,
there $A=126\ ms$ – empirical constant.

For increasing of accuracy of determination of moment of excess *DWM* threshold levels and in order to avoid gaps of low-amplitude or "smoothed" QRS-

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complexes procedure of calculation of dynamic adaptive threshold is apply.

Value of threshold level is calculated as follows:

$$DWM_{th\_i}=N_i+q(S_i-N_i), \quad (5)$$

$$N_{i+1}=\begin{cases} pu_i+(1-p)N_i, & u_i < DWM_{th\_i} \\ N_i, & u_i \geq DWM_{th\_i} \end{cases},$$

$$S_{i+1}=\begin{cases} S_i, & u_i < DWM_{th\_i} \\ pu_i+(1-p)S_i, & u_i \geq DWM_{th\_i} \end{cases},$$

there u_i – amplitude of ECS sample, p и q –factors, S_i – slitherring estimation of level of signal, N_i – slitherring estimation of level of noise, DWM_{th_i} - adaptive threshold level compared with DWM on each step.

As a result of processing of ESC row is stated that value of factors for best combination "sensitivity-stability" have formed: p=0,8, q=0,02.

As control functions was used first derivative of signal, threshold of comparison for which forms 5 mV/s that is standard value when finding the point JN on level of signal first derived.

Offered method allows to select ST segment begin with average inaccuracy, not exceeding one interval of time sampling from values, provided in database annotations.

The most further processing of the ST segment signal is concluded in calculation offered integral morphology parameters and estimation of morphology type in accordance with brought decisive rules. There were designed algorithms, realizing offereded methods.

Variants of hardware realization of offereded methods are following devices:

- device for ST-segment allocation. In given device is presented the hardware realization of offereded way of ST segment allocation;

- device for estimation of ST segment parameters [5]. Given device is independent submachine, used for solving problems of estimation of ST segment parameters, at diagnostics of episodes of ischemia for instance.

The set of offered methods is incarnate in hardware-software complex, intended for automatic ECS processing. It is developed software [8], realizing estimation of ST segment parameters in accordance with offereded ways. Given hardware-software realization was used for exploratory whole and can avail also for undertaking the examinations in hospital conditions.

Conclusion

The methods of revealing of an ST segment morfology parameters in its spectral structure in basis Legendre polinomial and Walsh functions has been developed and investigated. In the comparison with standard dot methods, they provide a 6-8 times larger stability to the influence of the noise handicapes on ECS, that raises sensitivity to the low-level changes of the morfology of a signal and the short-term deviations as well. These methods also allow to provide a storage of the information about an ST segment with the minimal set of informatical parameters.

The sets of the decisive rules allowing to make a classification of types of an ST segment morfology according to the requirements, accepted in medical practice, to normal and describing deviations from norm on the base of three spectral coefficients making in Legendre or Walsh bases, displaying clinical main of an ST-segment morfology parameters, have been developed, and the algorithms of classification on the base of the sets as well.

The method of allocation of a time interval belonging to an ST-segment is developed. This method ensures steady work in a real time mode in the conditions of amplitude-temporary parameters variability of ECS waves and complexes.

The hardware and software realizing the set of the offered methods, and allowing to make an authentic estimation of an ST segment parameters has been developed.

The developed methods allow to estimate of an ST segment parameters authentically even within the limits of one cardiocycle. That raises diagnostic and prognostic importance of the results of ECS processing.

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