# METHOD FOR ALLOCATION OF A FIDUCIAL POINT IN EACH HEART-BEAT

A.A. Miheev* and O.V. Melnik*

*Ryazan State Radiotechnical Academy, Ryazan, Russia

mel@rgrta.ryazan.ru
omela111@yandex.ru

**Abstract: New approach to procedure for allocation of a fiducial point in each heart-beat is offered. In base of procedure is prescribed the TP segment of electrocardiosignal, which corresponding to heart electric diastole, analysis. The questions of increasing of noise-immunity of devices, realizing offered method for allocation of a fiducial point considereded.**

## Introduction

The allocation of a fiducial point on electrocardiosignal (ECS), which for beginning of next heart-beat serves, is necessary operation before the further ECS processing. The sequence of fiducial points is used for definition heart-beats duration, their segmentation, the separated ECS elements (waves and complexes) measurement.

The heart-beats duration measurement for given time lag is used in heart rate related diagnosis for estimation of condition of separate functional systems of organism, for determination of organism reactions to different external influences such as stress, receiving the medicinal preparations, physiotherapy etc. The heart-beats duration values are necessary to know when discovery of such changes of cardiogram as arrhythmias, extrasystoles.

Traditionally for allocation of a fiducial point the QRS complex is used. Number of different methods for QRS-complex allocation is developed, which on used solving rule do on the following groups:

- time-domain ECS analysis methods;
- methods founded on frequency-temporary ECS transformations;
- neural network based methods;
- syntax methods;
- mixed methods.

At present the most spreading have got the methods from first enumerated group. This is considerable with uncomplicated technical realization with small reduction of efficiency of QRS-complex allocation and possibility to conduct the real-time ECS analysis.

The lacks caused of a QRS complex morphology variability, shown in R-wave peak splitting, transformation of a complex in QS, qS, qrS, Qr etc are inherent for methods of allocation of fiducial points within the QRS complex region.

Despite of apparent well-known of questions of a fiducial point allocation at the basis of the ECS time-domain analysis methods, the works for developed of more simple and noiseproof methods proceed.

## Materials and Methods

The theoretical part of work is constructed on the basis of the theory of signals detection and mathematical statistics. The experimental researches were carried out with the use of annotated ECS databe, intended for testing automatic algorithms of ECS processing (QT-T Database). The results of researches are received in the program environments MathCAD and MATLAB.

The check of offered method of allocation of a fiducial point realizability was realized by means of program of schemotechnical modeling Micro-Cap and breadboard modeling.

## Results

It is organized visual analysis of different real electrocardiograms, as normal, so and with different detours from rates, given in conditions of hospitals or polyclinics. As a result of analysis is stated that most stable form has the electrocardiosignal area between T and P waves (TP segment). This segment corresponds to electrical diastole of heart and at absence of additive noise and artifact is on iso-line.

The stability of a TP segment morphology can be used for allocation of a fiducial point in each heart-beat. However, insofar stable TP segment morfology, so its duration is variable when the heart rate (HR) changes. Except TP segment at iso-line one more enough extended ST-segment is disposed. With some HR TP-segment duration becomes ST-segment duration less.

For determination of area of possible HR values, under which possible certain to use TP segment for determining at him a fiducial point in each heart-beat, regression analysis of dependency of TP- and ST segments durations from HR is organized [1,2]. For analysis electrocardiograms 30 patients with different detours from rates were displayed. The number of cardiograms for each patient from 10 to 30.


ISSN: 1727-1983 

Figure 1 illustrates the dependency of TP- and ST segments durations from HR. This dependency is adequately described by exponential regression. With provision for confidential intervals for regressions TP- and ST segments on HR, built at level α=0.05, area of surplus of TP segment duration on ST segment duration spreads before HR values 110-130 beat per minute.

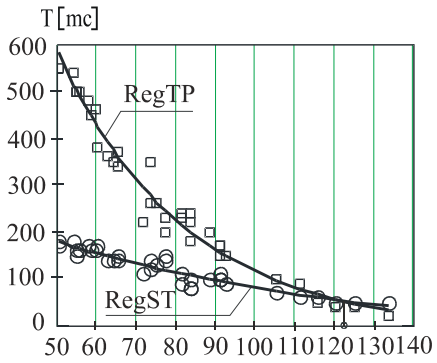


Figure 1: Relationship of ST- and TP segments durations with HR

This results allow to draw a conclusion about possibility of use TP segment for allocation of a fiducial point at most cases, when examination of patients is conducted in polyclinic or hospital, i.e. at comparatively calm conditions even though beside patients is denominated moderate tachycardia.

Before allocation procedure of a fiducial point at TP segment is necessary to execute the following actions. Electrocardiosignal was cleaned from interference of industrial frequency by any known way. If ECS processing is expected the determination of its elements amplitude-temporary parameters, that necessary also to avoid the iso-line drift.

When it is required only select fiducial point in each heart-beat but ECS morphology is not important, for instance, in heart rate measurements when arrhythmias and extasystoles revealing, for eliminating of interference of industrial frequency enough to use a low-pass filter with frequency of cut 10 - 20 Hz. For simplification of procedure of allocation heart-beat begin at TP segment also possible to abandon the operations of iso-line drift eliminating. The possible view of electrocardiosignal beside which necessary to select fiducial point in each heart-beat is shown on Figure 2.

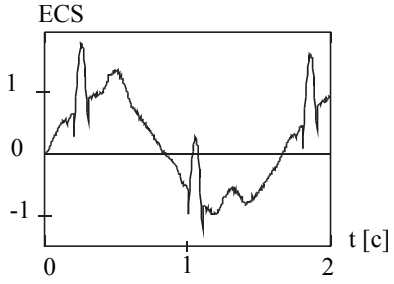


Figure 2: ECS with iso-line drift

For allocation of a fiducial point in each heart-beat at TP segment possible to offer the following actions [3], which are illustrated the scheme on Figure 3 and time diagram on Figure 4.

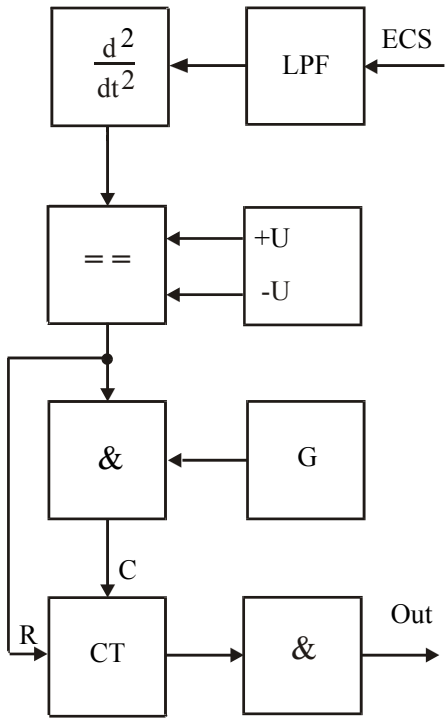


Figure 3: Scheme of allocation of a fiducial point

The low-pass filter (LPF on Figure 3) avoids the industrial frequency interference. Hereinafter ECS with assessed additional low frequency interference (iso-line drift) subject double differentiation (block «$d^2/dt^2$» at Figure 3). This operation is technically realized vastly more simply operations of the iso-line drift eliminating since can be realized on base of taking the differences of second order. Electrocardiosignal shown on Figure 2 after double differentiation is of the morphology shown on Figure 4. It is compared with two threshold levels (Figure 3) one of which is disposed below iso-line (−U) but second above iso-line (+U).

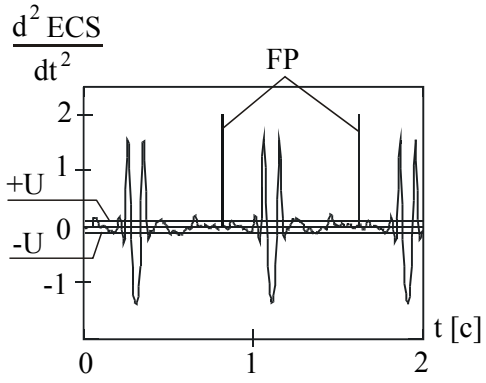


Figure 4: Second derivative from ECS with iso-line drift


ISSN: 1727-1983 

Scheme of comparison of signal with threshold levels (block «= =» at Figure 3) can be build at base of two comparers. At finding of the second derived ECS signal between threshold levels a signal with leaving the scheme of comparison allows the passing through scheme And (&) of pulses from generator of pulsing pulses (G) on counting entry "C" counter (CT). The period of pulsing pulses can be taken equal used in standard electrocardiographs or holter monitors to period of ECS sampling. Source from period of following of pulsing pulses, the number N establish, which can be reached by counter of pulses only on ECS area between T and P waves. On this area a counter haves time to consider given number of pulses N. At achievement of this number on leaving the shaper of supporting point (&), presenting itself scheme And, is formed the pulse (FP on Figure 4), which is a fidusial point. On rest areas ECS signal is beyond the scope of values, limited by threshold levels, an earlier then achievement by counter of amount N, and counter is thrown in initial condition on entry "R".

Usage second derived ECS promotes the reinforcement of quick changing electrocardiosignal areas (the waves) comparatively slowly changing areas (the segments) that allows to reduce the requirements to stabilities of threshold levels.

Threshold levels are possible to choose from the following considerations. Since segment TP corresponds to heart electric diastole then on this area ECS are present only noises (the noise of ECS amplifier or noise of slicing if for the after-treatment analog electrocardiosignal was transformed in a digital). Shall move time-domain window along ECS, duration which several more ST-segment and calculate the power of signal in window.

$$P_{2d} = \frac{1}{To}\int_{t}^{t+To}\left[\frac{d^2U(t)}{dt^2}\right]^2 dt, \qquad (1)$$

there $P_{2d}$ - capacity of a signal second derivative at a time-domain window,
*To* - duration of window.

At passage by a window of a TP segment the signal power determined according to expressions (1) will have the minimal value $P_{min}$, equal to noise dispersion. Considering, what the noise has the normal law of distribution and zero mathematical expectation, it is possible to accept of threshold levels value U=3σ, where $\sigma = \sqrt{P_{\min}}$ - standard deviation. Thus the probability of a presence of noise readout between threshold levels will make 0.9973. This also will determine probability of correct allocation of a fiducial point on a TP segment.

Offered method is set in base of device [4] for determination heart-beat begin, timed with beginning P-wave of ECS. Given device included in magnetotherapeutically device «Almag-BIO», the model-based sample of which is developed and made in "Elatomsky instrumental plant", Russia. The signal, corresponding to P-wave beginning, is used for synchronizing the influence running pulsed magnetic field to patient and the patients biorhythms.

P-wave begin is often used as points of counting out, on which realize synchronizing sequences of heartbeats under their averaging, for instance, for study of late atrial potentials [5]. In connection with urgency of this problem, study was organized [6], allowed to install relationship between required digit capacity of analog-to-digital converter (ADC) and given ECS sample rate.

The essence of study is concluded in the following. It was used the generally accepted P-wave approximation as positive sinusoidal function half-wave [7] or second degrees polynomials [8]. The sinusoidal function amplitude is a P-wave amplitude and period is duplicated interval of P-wave duration. As polynomials most suitable [9] power-mode polynomials (the parabola), Legendre polynomials and Chebyshev of the second kind polynomials, determined at [-1, 1] interval. Given polynomials are described accordingly expressions:

$$P(\Theta) = \Theta^2, \qquad (2)$$

$$L_2(\Theta) = \frac{1}{2}\left(3\Theta^2 - 1\right), \qquad (3)$$

$$T_2(\Theta) = 2\Theta^2 - 1, \qquad (4)$$

there $-1 \le \Theta \le 1$.

Compatible beginning (Θ = –1) and completion (Θ = 1) of polynomials (2),…,(4) accordingly with P-wave beginning and completion, will get last description corresponding to polynomials:

$$PP(\Theta) = a\left(\Theta^2 - 1\right)U_P, \qquad (5)$$

$$PL(\Theta) = b\left[\frac{1}{2}\left(3\Theta^2 - 1\right) - 1\right]U_P, \qquad (6)$$

$$PT(\Theta) = c\left[\left(2\Theta^2 - 1\right) - 1\right]U_P, \qquad (7)$$

there $U_P$ – P-wave amplitude,
*a*, *b*, *c* – factors, providing equality of corresponding polynomials value and P-wave amplitude then Θ=0.

Under began and completions P-wave and polynomials factors overlapping have following values: *a*= –1, *b*= –1/2, *c*= – 2/3 and all polynomials (5),…, (7), describing P-wave, are reduced to type

$$U(\Theta) = -U_P\left(\Theta^2 - 1\right). \qquad (8)$$

Relative variable Θ is connected with current time t on interval of P-wave existence by correlation


ISSN: 1727-1983 

$$\Theta = 2\left(\frac{t}{T_P} - \frac{1}{2}\right), \qquad (9)$$

there $T_P$ – P-wave duration,
$0 \le t \le T_P$.

With provision for (8) and (9) P-wave signal description with specified polynomials will be of the form of

$$UP(t) = \frac{4t}{T_P}\left(1 - \frac{t}{T_P}\right)U_P. \qquad (10)$$

P-wave description as positive sinusoidal function half-wave is of the form of

$$US(t) = \sin\left(\pi\frac{t}{T_P}\right)U_P. \qquad (11)$$

The method of maximum second derived use for determination of ECS waves borders usually. If signal is presented digitally, that is used the maximum of differences of the second order. For reliable separation P-wave begin, differring from true begin no more than for one period of sampling ECS, maximum value of differences of the second order must be not less two steps of ADC sampling. Step of sampling is defined known correlation

$$\Delta = \frac{Uo}{2^R}, \qquad (12)$$

there $Uo$ – ADC referred voltage,
$R$ – number of ADC position.

Real ECS always contains noise forming, which tightens the requirements to digit capacity of ADC. This fact necessary to take into account then chooses ADC digit capacity.

Considering, what the noise acting to ECS has the normal law of distribution and zero mathematical expectation and dispersion $\sigma^2$, there $\sigma$ – standard deviation. Will take amplitude of noise $A=3\sigma$.

Defining maximum values of differences of the second order from (10), (11) and considering (12), as well as influence of noises, possible get the expressions, linking required number of ADC position with given period of ECS sampling.

At approximations by second degrees polynomials will get

$$RP \ge \log_2\left\lceil\frac{2Uo}{U_P\frac{4T_d}{T_P}\left(1 - \frac{T_d}{T_P}\right) - A}\right\rceil, \qquad (13)$$

there $T_d$ – period of ECS sampling,

]x[ – means that got at fission a number is rounded before nearest greater whole value.

Then approximations as positive sinusoidal function half-wave we will get

$$RS \ge \log_2\left\lceil\frac{2Uo}{U_P\pi\frac{T_d}{T_P} - A}\right\rceil. \qquad (14)$$

The allocation of fiducial point in each heart-beat exactly on TP segment opens the new possibilities on removal (correction) of ECS iso-line drift.

Most wide-spread methods of correcting of the iso-line drift at present founded on spline-approximations and filtrations by high-pass filters (HPF). To note that inaccuracy of approximation is meticulous that is to say in principal incurable. Accuracy of its reconstruction grows worse when increase the frequency of change the signal of iso-line drift, and at achievement of half of repetition rate of fiducial point equal heart rate (HR), reconstruction becomes impossible. The ST segment parameters are distorted in the second event since frequency spectrum of iso-line drift, as a rule, nearly completely complies with ST-segment frequency spectrum.

Since TP segment corresponds to heart electric diastole, that ECS samples, taken on TP segment, are practically samples of iso-line drift. At studies [10] have shown that if present ECS samples, chosen on TP segment and accepted as fiducial point in each heart-beat, in mode of composite form pulse signals (CFPS) [11] then in spectrum of iso-line drift discrete signal possible to suppress N first spectral forming (spectral zones) with frequencies $F_d$, $2F_d$,…, $NF_d$, there $F_d=1/T_d$ – the ECS sampling rate. Component in zero spectral zone are forming signal of iso-line drift, and can be chosen by means of low-pass filter. Moreover follows to emphasize that signal on LPF output is exactly signal of iso-line drift, rather then its approximation, as in the event of spline-approximations. The absence in CFPS spectrum of N first spectral component allows to select the signal of iso-line drift which frequency can achieve HR and even exceed it. The following subtraction of recalled signal of iso-line drift from source ECS frees the last from additional low frequency influence which is a iso-line drift.

Such approach to correcting of iso-line drift is realized in device [12].

**Conclusions**

The offered approach to allocation of a fiducial point in each heart-beat provides the following advantages:


ISSN: 1727-1983 

- independence of a fiducial point allocation algorithm from the ECS elements morfology variability, in particular QRS complex;
- simple algorithm and the simple technical realization of allocation of a fiducial point in each heart-beat, in this connection raises efficiency of its allocation;
- the allocation of a fiducial point previous to all basic ECS elements, allows on the basis of knowledge of electrocardiosignal morphology to identify all its elements correctly;
- the allocation of a fiducial point at an ECS segment, appropriate electrical heart diastole, allows to offer the new approaches to elimination of iso-line drift.

## References

[1] MIHEEV A.A., ZUIKOVA O.A. (2004): 'Heart-beat beginning selection', *The bulletin of arrhythmology (Vestnik Aritmologii)*, **35**, Exhibit C, p.191

[2] VARNAVSKY A.N., MELNIK O.V., MIHEEV A.A. (2005): 'Method for selection of a fiducial point in each heart-beat', *Biomedical technology and radioengineering*, 2005, **1-2**, pp. 36-39

[3] RF Patent 2219828 (2003), A61B 5/02. Method for heart-beat beginning allocation and device for its realization/ O.A. ZUIKOVA, A.A. MIHEEV // Discoveries. Inventions. 2003.

[4] RF Patent 2237432 (2004), A61 B5/0452. The device for heart-beat beginning allocation / O.A. ZUIKOVA, A.A. MIHEEV // Discoveries. Inventions. 2004.

[5] PROSTAKOVA T.S., AKASHEVA D.U., IVANOV G.G. (1996): 'Late atrial potentials', *Cardiology*, 1996, **11**, pp. 95 -100

[6] MIKHEEV A.A. (2004): 'Correlation between capacity of analog-to-digital converter and sampling frequency in the determination of the initial point of P wave of electrocardiosignal', *Biomedical Engineering*, 2004, **6**, pp. 279-282

[7] LEBEDEV V.V., KALANTAR V.A., ARAKCHEEV A.G., KORADO I.V. (1997): 'Tested signal for check of measurements algorithms in electrocardiografic automatic systems', *Biomedical Engineering*, 1997, **3**. pp. 40, 41

[8] LEBEDEV V.V., KALANTAR V.A., ARAKCHEEV A.G. (1998): 'Algorithms of measurement ECG waves duration', *Biomedical Engineering,* 1998, **5**, pp. 6-14

[9] ANGO A. (1967): 'Mathematics for electro- and radioengineer', (Nauka, Moscow), p. 780

[10] MELNIK O.V., MIHEEV A.A., NECHAEV G.I. (2005): 'Iso-line shift of electrocardiosignal selection', *Biomedical technology and radioengineering*, 2005, **1-2**, pp. 26-30

[11] KARASEV V.V., MIHEEV A.A., NECHAEV G.I. (1996): 'Measuring systems for revolvinging nodes and mechanisms', (Energoatomizdat, Moscow), 176 p. (pp. 76-92)

[12] RF Patent 2251968 (2005), A61 B 5/0402. Method of eliminating iso-line of electrocardiosignal shift and device for its realization/ A.A. MIHEEV, G.I. NECHAEV // Discoveries. Inventions, 2005.


ISSN: 1727-1983 