

## Evaluation of Coherence of T wave in Different Leads

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### Introduction

T-wave changes are one of the most common abnormalities noted on an ECG. Changes in the T-wave may be a normal variant in some healthy individuals, or related to age, body configuration or other conditions. T-wave abnormalities may also be caused by virtually any type of cardiovascular disorder [1].

Analysis of two synchronous time series can be done using statistical or analytical methods. Statistical analysis is well developed and used, e.g. spectral analysis and cross-correlation [2,3]. Meanwhile, analytical methods are quite a new area. Previous studies have shown the unsuitability of statistical methods for cardiosignals [4].

This paper introduces several characteristics to evaluate intrapersonal coherence: relations of the same ECG parameter  $AT_1$  (amplitude of T-wave) in two different leads. Therefore, two time series were cointegrated into one matrix time series. For further investigation matrix analysis was applied.

In this study comparison of matrix time series eigenvalues and other proposed characteristics is made with the aim to evaluate homogeneity of repolarisation processes in myocardium for increased heart work during physical load.

### Theoretical Background

Intrapersonal concatenation between two different human body systems or coherence of system parts were explored by many scientists: complexity of systems [5, 6], motor synergy [7], graphical investigation of coherence [8]. These studies have shown that in certain cases concatenation of two processes may reveal much more information than data themselves.

The methodology of two numeric time series investigation is presented when values of elements are

determined [9]. Using mathematical methods for investigation it is necessary to form two synchronous time series  $(x_n; n = 0, 1, 2, \dots)$  and  $(y_n; n = 0, 1, 2, \dots)$ ;  $x_n$  and  $y_n$  are real-valued terms representing ECG measurement data. In this case  $x_n$  and  $y_n$  stand for  $AT_1$  parameters of two different lead ECG signals. The matrix time series can be constructed as follows:

$$A_n := \begin{bmatrix} a_n & b_n \\ c_n & d_n \end{bmatrix}, \quad (1)$$

where  $a_n := x_n$ ,  $b_n := x_{n-1} - y_{n-1}$ ,  $c_n := x_{n+1} - y_{n+1}$ ,  $d_n := y_n$ . Other mathematical relationships can be used to form these series. Before evaluation of the characteristics describing cohesion of ECG parameters some numerical parameters of second order matrices  $A_n$  must be introduced:

$$\text{Tr}A_n := a_n + d_n \text{ (trace of matrix } A_n \text{)}, \quad (2)$$

$$\text{dfr}A_n := a_n - d_n \text{ (difference)}, \quad (3)$$

$$\text{cdp}A_n := b_n \cdot c_n \text{ (co-diagonal product)}. \quad (4)$$

From these initial parameters follow characteristics which have more applicative sense:

$$\text{dsk}A_n = (\text{dfr}A_n)^2 + 4\text{cdp}A_n \text{ (discriminant)}, \quad (5)$$

$$\lambda_n = \frac{1}{2}(\text{Tr}A_n \pm \sqrt{\text{dsk}A_n}), \quad (6)$$

where  $\lambda_n$  are respectively I and II eigenvalues of matrix  $A_n$ . A new proposed characteristic derived from ones above is

$$\gamma_n = \text{dfr}A_n \pm \sqrt{\text{dsk}A_n}. \quad (7)$$

Discriminant may be negative. To calculate the square root the following complex function is used (consider (6) and (7))

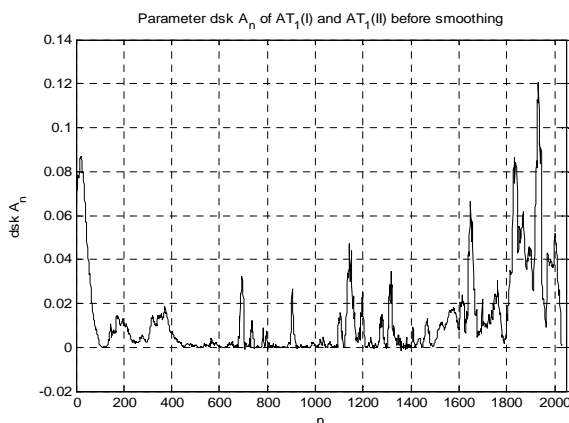
$$\omega_k = \sqrt{z} = \sqrt{r} \left( \cos\left(\frac{\varphi_0}{2} + \pi k\right) + i \sin\left(\frac{\varphi_0}{2} + \pi k\right) \right), \quad (8)$$

where  $r$  – the absolute value of the complex number;  $\varphi_0 = \arg z$ ;  $k = 1, 2$ . If the final result is complex then the absolute value for simplicity of visualization is taken.

## Results

The T wave amplitude in 12 leads of continuous electrocardiogram signal during bicycle ergometer stress test was investigated. Physical load at first stage was 50W for few minutes for initial worm up. At next stage the worm up load increased till 100W, again for few minutes (usually it takes 2-3 min.) and the third stage was 300W for men or 200W for women till the appearance of fatigue features and the stop of investigation. After stop of investigation sportsmen were sitting still for five minutes. The all investigation usually takes from 15 to 25 minutes depending on the sportsman physical abilities. The heart need to overcome different stages of adaptation during hard physical load. The intrinsic functional adaptation features and their homogeneity can be investigated using cointegration of two time series.

The parameters  $dsk$ ,  $\lambda^+$  and  $\gamma^+$ , calculated from two time series (e.g., amplitude of T wave in I-st standard lead and amplitude of T wave in II-nd standard lead) cointegration in some way are associated with their relation ( $\varepsilon$ ). When  $\varepsilon$  (relation) is stronger,  $Y$  ( $1/\varepsilon$ ) is going to 0, when relation is weaker,  $Y$  increases [5]. For qualitative evaluation of changes of different parts of the heart two adjacent leads (but not the same localization, I-st and II-nd standard leads, which could be related with the left heart ventricle) and two more outstanding leads I-st standard and V2 leads (I-st lead is more related with the left heart, V2 lead more with right heart) were investigated. During investigation were recorded about 2000 heart cycles.  $Y$  reflects  $1/\varepsilon$ , X axis is number of cardio cycle.



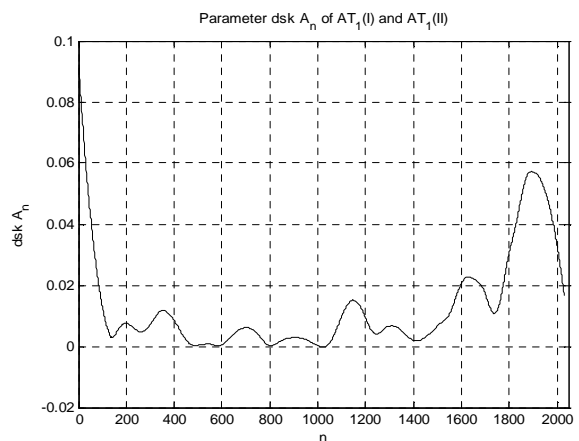
**Fig. 1.** Dynamics of two adjacent leads relation, parameter  $dsk$  before smoothing

In order to reduce noise and correct baseline local weight scatterplot smoothing (LOESS) method is applied

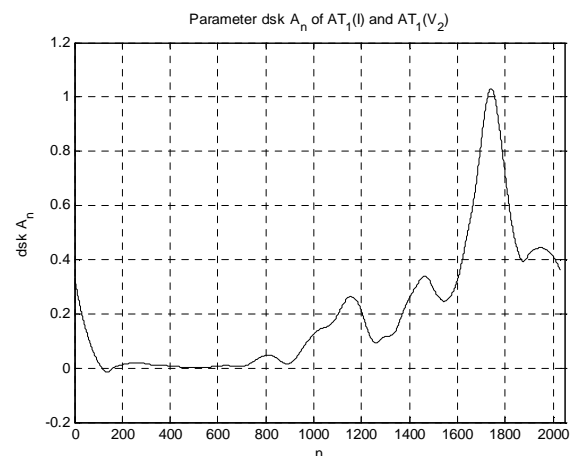
[10]. LOESS is (somewhat) more descriptively known as locally weighted polynomial regression. At each point in the data set a low-degree polynomial is fit to a subset of the data, with explanatory variable values near the point whose response is being estimated. The polynomial is fit using weighted least squares, giving more weight to points near the point whose response is being estimated and less weight to points further away. The value of the regression function for the point is then obtained by evaluating the local polynomial using the explanatory variable values for that data point. The LOESS fit is complete after regression function values have been computed for each of the  $N$  data points. Many of the details of this method, such as the degree of the polynomial model and the weights, are flexible. The weight function used for LOESS is the tri-cube weight function:

$$w(x) = \begin{cases} (1 - |x|^3)^3, & \text{for } |x| < 1, \\ 0, & \text{for } |x| \geq 1. \end{cases} \quad (9)$$

The smoothing parameter  $q$  determines how much of the data is used to fit each local polynomial.  $q$  is a number between  $(d+1)/N$  and 1, with  $d$  denoting the degree of the local polynomial and  $N$  total number of data points. In our case  $q = 0.25$ .



**Fig. 2.** Dynamic of two adjacent leads relation, parameter  $dsk$



**Fig. 3.** Dynamic of two more outstanding leads relation, parameter  $dsk$

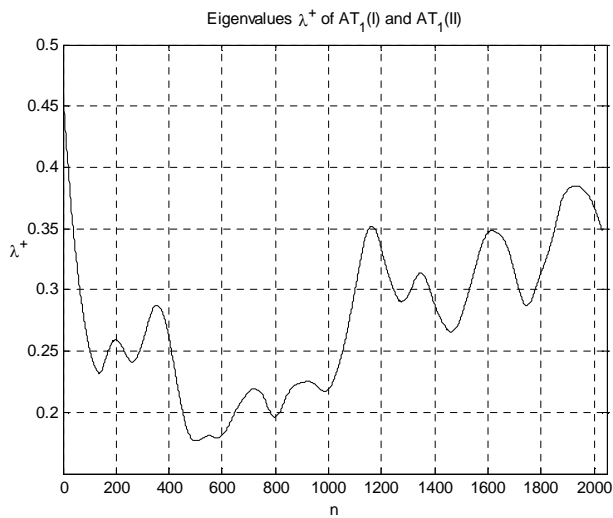


Fig. 4. Dynamic of two adjacent leads relation, parameter  $\lambda^+$

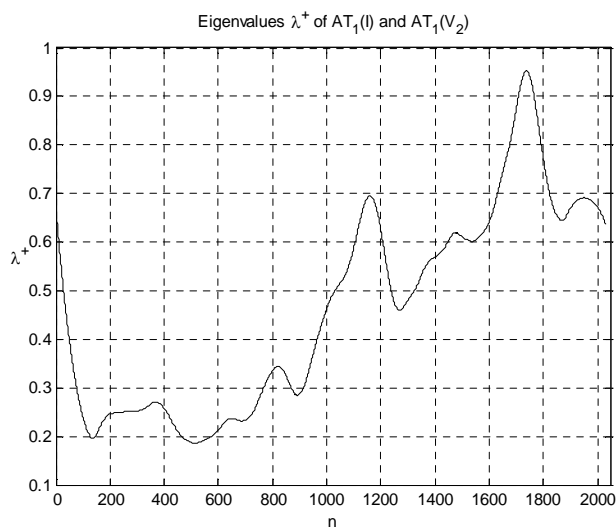


Fig. 5. Dynamic of two more outstanding leads relation, parameter  $\lambda^+$

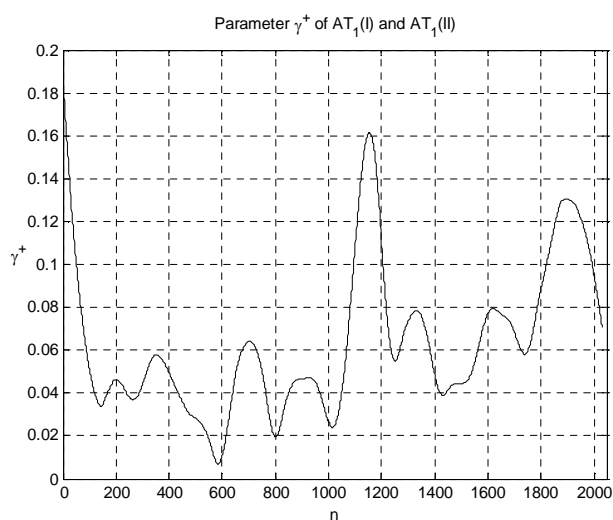


Fig. 6. Dynamic of two adjacent leads relation, parameter  $\gamma^+$

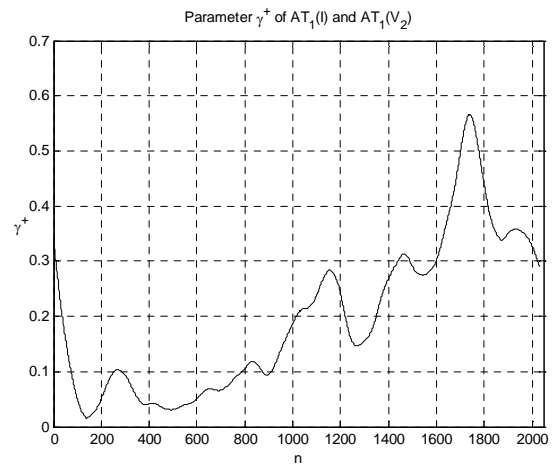


Fig. 7. Dynamic of two more outstanding leads relation, parameter  $\gamma^+$

## Conclusions and future works

The high interconnections in both sets of leads during physical load were found. The relation was more expressed for adjacent leads. The continuously changing picture of heart repolarisation feature, which could be related and reflects different metabolic rate in different parts of the heart during different stages of load was observed. It means that at all complexity of heart in different stages of adaptation to load have dynamic character and this character is meaningfully fluctuated. The limits of such fluctuations for healthy persons as well as for patients are still not known, but it could be very important parameter for evaluation of appearing pathology in heart or even in all body. The investigations in this area will be preceded.

These observations might be useful for diagnostic purposes evaluating the effect of activity for athletes etc.

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**R. Šmidkaitė, Z. Navickas, L. Bikulciene, A. Vainoras, V. Poškaitis.** Evaluation of Coherence of T wave in Different Leads // *Electronics and Electrical Engineering*. – Kaunas: Technologija, 2009. – No. 5(93). – P. 113–116.

Electrocardiogram (ECG) is one of the most general, informative and widely used means for diagnosis of heart diseases. Previous studies have shown that in certain cases concatenation of two processes may reveal much more information than data themselves. This paper introduces several characteristics to evaluate intrapersonal coherence: relations of the same ECG parameter  $AT_1$  (amplitude of T-wave) in two different leads. Therefore, two time series were cointegrated into one matrix time series. For further investigation matrix analysis was applied. The information revealed by several matrix characteristics was compared visually. Different tendencies of concatenation were noticed, specified by leads and load. Intrapersonal analysis is to be extended to interpersonal in further studies. III, 7, bibl. 10 (in English; summaries in English, Russian and Lithuanian).

**P. Шмидтайте, З. Навицкас, Л. Бикулчене, А. Вайнорас, В. Пошкайтис.** Оценка связи между Т-зубцами в электрокардиограммах человеческого сердца // *Электроника и электротехника*. – Каунас: Технология, 2009. – № 5(93). – С. 113–116.

Электрокардиограмма является одним из наиболее доступных средств исследования работы человеческого сердца. Кроме того, кардиограмма является наиболее информативным и приемлемым источником при исследовании сердечных заболеваний. Во многих случаях больше полезной информации можно получить не только при рассмотрении одиночных величин разных сигналов, а при исследовании связи между этими сигналами. В этой работе исследуется связь между амплитудами Т-зубцов разных дериваций. Оценка взаимосвязи между двумя временными рядами, которые описывают значения параметров  $AT_1$ , производится при коинтеграции этих временных рядов в один матричный временной ряд. Информативность некоторых характеристик сравнивается между собой графически. Были замечены важные тенденции изменения связи между разными парами дериваций при разных физических нагрузках сердца пациента. В дальнейшем будут исследованы особенности связей между кардиограммами не только интраперсонального, но и интерперсонального характера. III, 7, bibl. 10 (на английском языке; рефераты на английском, русском и литовском яз.).

**R. Šmidkaitė, Z. Navickas, L. Bikulčienė, A. Vainoras, V. Poškaitis.** Elektrokarđiogramos T dantelio sąsajų vertinimas // *Elektronika ir elektrotechnika*. – Kaunas: Technologija, 2009. – Nr. 5(93). – P. 113–116.

Vienas įprasčiausių, informatyviausių ir plačiausiai taikomų tyrimų širdies būklei nustatyti yra širdies elektrokardiograma (ECG). Tam tikrais atvejais daugiau informacijos pateikia ne pavieniai signalai, o jų tarpusavio ryšiai. Šiame darbe nagrinėjami sąryšiai tarp skirtingų derivacijų T dantelio amplitudžių. Sąsajos vertinamos dvi laiko eilutes, atitinkančias  $AT_1$  parametrų reikšmių sekas, sutraukiant į vieną matricių eilutę. Kelių pasirinktų matricinių charakteristikų informatyvumas grafiškai lyginamas tarpusavyje. Buvo pastebėtos svarbios skirtingų derivacijų porų sąryšių kitimo tendencijos. Tolesniuose darbuose planuojama tirti ne tik intrapersonalines, bet ir interpersonalines sąveikas. II, 7, bibl. 10 ( anglų kalba; santraukos anglų, rusų ir lietuvių k.).