Wireless Vital Signals Monitor for Patients with Cardiovascular Diseases and Sportsmen

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Abstract

The wireless vital signals monitoring system has been developed. It aids to monitor patients with cardiovascular diseases (CVD) and sportsmen. The system consists of wireless electrocardiogram (ECG) and motion signals recording and transmitting device to personal computer and software for signal analysis and evaluation of human functional state. The feedback and warning means has been developed.

The new method for assessment of interpersonal and inter parameter concatenation during monitoring of vital signals has been developed. Assessment of inter parameter concatenation permitted to reveal some new features of heart functionality when ECG monitoring was performed during percutaneous transluminal coronary angioplasty (PTCA) and physical stress examination.

1. Introduction

Cardiovascular diseases (CVD) are the loading source of death in Europe, mainly for people older than 65 [1]. The Holter systems are used for long term monitoring of patients with CVD. However, the Holter systems are unable transmit automatically information at the moment when abnormal cardio activity is present.

Many people worldwide are engaged in physical training or jogging and there is a constant increase of tools available for control of human health and physical training. Usually the heart rate monitors are used for that purposes [2]. However, it is important not only to control heart rate frequency during physical exercise, but also to evaluate functional status of a person and particularly adaptability of cardiovascular system, as well as estimate amount of performed work in order to make optimal planning of intensity and duration of training. The main task of the work was to develop the wireless vital signals monitoring system and new method for assessment interpersonal and inter parameter concatenation for patients with CVD and sportsmen.

2. Methods

2.1. Architecture of wireless vital signals monitoring system

Figure 1 illustrates the architecture of developed multi-tier vital signals monitoring and warning system.

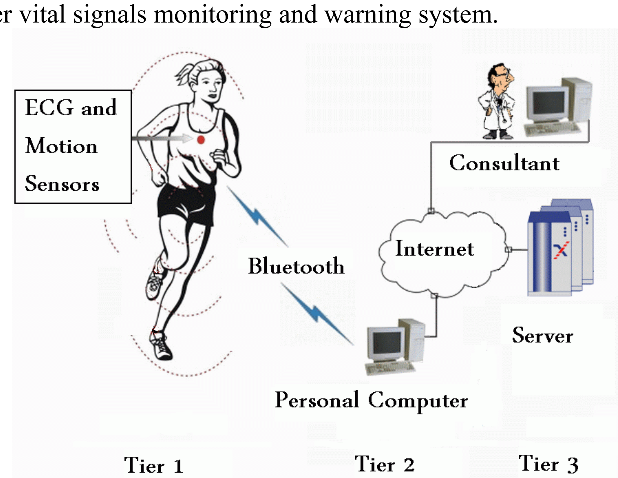

Figure 1. Architecture of ECG and motion signals monitoring system.

A pivotal part of the developed system is tier 1 – ECG and motion sensors with Bluetooth transmitter to personal computer. 3 channel ECG sensor is used for monitoring heart activity and 3-axis accelerometer motion sensor is used to discriminate the human status and estimate his level of activity. The second tier is the personal computer with communication means and software for on-line data analysis, transmitting warning signals for patient and monitoring data through Internet to consultant and server. The third tier is intended for consultant with off-line data analysis software and optimized service of healthcare or sport medicine professionals.

2.2. The new method for assessment interpersonal and inter parameter concatenation

The interpersonal influence of several athletes is important factor for winning or loss in sportive contests. The methods for investigation of interpersonal influence are not widely developed and this estimation is problem of today in science and practice. The results of the Institute of HeartMath (USA) [3] show that for investigation of this influence the most usable are processes of the heart action. The methodology of two numeric time series investigation is presented when values of elements are determined.

Using mathematical methods for investigation of interpersonal influences it is necessary to form two synchronous numerical time series $(x_n; n = 0,1,2,...)$ and $(y_n; n = 0,1,2,...)$ which represent exploratory object. Here x_n and y_n are real numbers and its represent results of some measurements. Usually it is electrocardiogram signals (or some parameters of signals) of two associated persons (for instance, married couple or two prizefighters). Let two numerical time series $(x_n; n = 0,1,2,...)$ and $(y_n; n = 0,1,2,...)$ be given. Then the matrix time series $(A_n; n = 0,1,2,...)$ can be formed. Here $A_n := \begin{bmatrix} a_n & b_n \\ c_n & d_n \end{bmatrix}$ and coefficients $a_n := x_n$, $d_n := y_n$, $b_n := \alpha(x_{n-1} - y_{n-1})$, $c_n := \beta(x_{n+1} - y_{n+1})$ when parameters α, β are at choice dependent on properties of time series $(x_n; n = 0,1,2,...)$ and $(y_n; n = 0,1,2,...)$. So, in this case four time series $(a_n; n = 0,1,2,...)$,... $(d_n; n = 0,1,2,...)$ and one matrix time series $(A_n; n = 0,1,2,...)$ are obtained. Of course these series can be formed using other mathematical relationships. Different methods for analysis of obtained series can be used [4,5]. For investigation of matrix time series the numerical characteristics of second order matrices and main components of matrices A_n were used:

1. $\mathrm{Tr}A_n := a_n + d_n$ (trace of matrix A_n),
2. $\mathrm{dfr}A_n := a_n - d_n$ (difference),
3. $\mathrm{cdp}\,A_n := b_n \cdot c_n$ (co-diagonal product),
4. $B_n := \begin{bmatrix} \frac{\mathrm{dfr}A_n}{2} & b_n \\ c_n & -\frac{\mathrm{dfr}A_n}{2} \end{bmatrix}$ (main component of matrix A_n).

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

5. $\mathrm{dsk}\,A_n = (\mathrm{dfr}A_n)^2 + 4\,\mathrm{cdp}\,A_n$ (discriminat),
6. $\det A_n = \frac{1}{4}\left((\mathrm{Tr}A_n)^2 - \mathrm{dsk}\,A_n\right)$ (determinant),
7. $\lambda_n = \frac{1}{2}\left(\mathrm{Tr}A_n + \sqrt{\mathrm{dsk}\,A_n}\right)$ (I eigen value of matrix A_n),
8. $\mu_n = \frac{1}{2}\left(\mathrm{Tr}A_n - \sqrt{\mathrm{dsk}\,A_n}\right)$ (II eigen value matrix A_n), etc.

The various relationships between obtained numerical characteristics hold true. For instance, $\lambda_n + \mu_n = \mathrm{Tr}A_n$; $(\lambda_n - \mu_n)^2 = \mathrm{dsk}A_n$; $\lambda_n \cdot \mu_n = \det A_n$; $(\lambda_n - \mu_n)^2 - (\mathrm{dfr}A_n)^2 = 4\mathrm{cdp}A_n$; $\mathrm{dfr}A_n = \mathrm{dfr}B_n$; $\mathrm{dsk}A_n = \mathrm{dsk}B_n$; $A_n = \frac{1}{2}(\mathrm{Tr}A_n)E + B_n$; $B_n^2 = \frac{\mathrm{dsk}A}{4}E$, when E is eigen matrix.

Two important types of matrices in matrix analysis are important. The matrix $\boldsymbol{I}$ is called idempotent (matrix of stable power), if $I^2 = I$ and the $\boldsymbol{N}$ - nilpotent (matrix losing power), if $N^2 = \mathbf{0}$, where $\mathbf{0} := \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}$.

For instance, the main component B_n is nilpotent if $\mathrm{dsk}A_n = 0$, and the matrices $I_n := \frac{1}{2}E + \frac{1}{\sqrt{\mathrm{dsk}\,A_n}}B_n$ and $E - I_n$ are idem potent if $\mathrm{dsk}A_n \neq 0$.

If discriminants of matrices A_n become to zero then matrices A_n from idempotent become to nilpotent. Mathematically, if the limits $\mathrm{dsk}A_n \to 0$, $b_n \to \overline{b}, c_n \to \overline{c}$, satisfying condition $\overline{b} \cdot \overline{c} \leq 0$ exists, then $B_n \to \begin{bmatrix} \pm\sqrt{|\overline{b} \cdot \overline{c}|} & \overline{b} \\ \overline{c} & \mp\sqrt{|\overline{b} \cdot \overline{c}|} \end{bmatrix} := \overline{B}$ and $\overline{B}^2 = \mathbf{0}$. It shows that chosen time series $(x_n; n = 0,1,2,...)$ and $(y_n; n = 0,1,2,...)$ become similar and its describe more associated interpersonal system. The sequence of idempotent matrices $\left(\sqrt{\mathrm{dsk}A_n}\cdot I_n; n=0,1,2,...\right)$ if the limit transitions $|\lambda_n-\mu_n|\to 0$, $\sqrt{\mathrm{dsk}A_n}\cdot I_n\to\overline{B}$ exists can be formed, and this sequence shows evolution of matrix sequence $(A_n; n=0,1,2,...)$. When functional complexity of any structures are analyzed the most important problem is evaluation of inter element links and interaction between them. In 1983 V. I. Arnol'd presented the methods for assessment the dynamic characteristics of such interaction [6] but usage of those methods is problematic in case of living objects because many troubles start up in formalizing of physiologic processes. Methods for visualization of interaction of human physiologic processes have been developed in HeartMath Institute (USA) [3].

3. Results

Authors of presented study proposed the mathematic algebraic procedure for concatenation of physiologic processes in the heart, and it permits directly and quantitatively asses the interdependence of two processes. The developed procedure was applied in ECG monitoring of patients with coronary artery disease (CAD) during percutaneous transluminal coronary angioplasty (PTCA), as well as during physical stress examination of healthy persons. Figures 2,3,4,5 illustrate the typical cases of concatenation between ECG parameters. Supposedly the chosen duration of JT interval is pertained with velocity of metabolic processes, duration of QRS complex reflects the velocity of excitation and T wave pertains with quality of hemodynamics in myocardium. During PTCA at the end of revasculization (figure 2) we could observe qualitative increase of independency between JT and DQRS, and it is related with improved excitation of the myocardium.

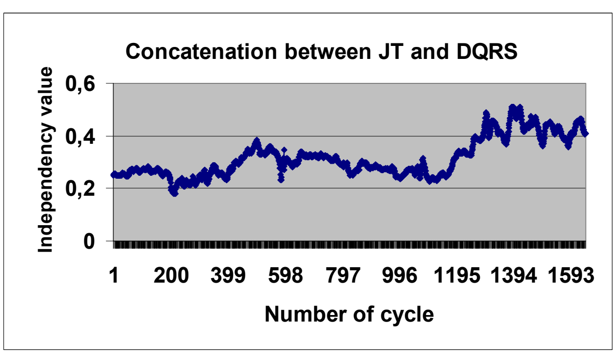

Figure 2. Sample of concatenation of ECG parameters (JT – interval between end of QRS complex and end of T wave; DQRS - duration of QRS complex) during PTCA procedure of patient with CAD.

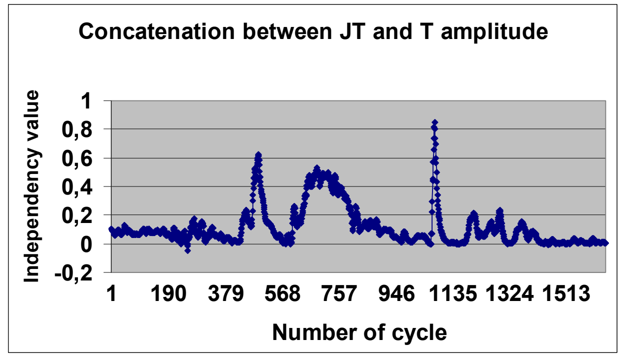

Figure 3. Sample of concatenation of ECG parameters (JT – interval between end of QRS complex and end of T wave and T wave amplitude) during PTCA procedure of patient with CAD.

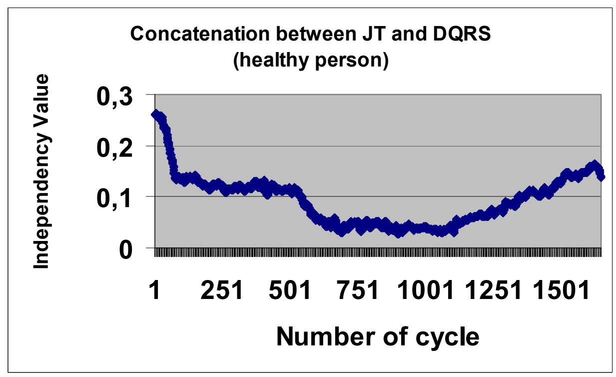

Figure 4. Sample of concatenation of ECG parameters (JT – interval between end of QRS complex and end of T wave; DQRS - duration of QRS complex) during physical stress test of healthy person.

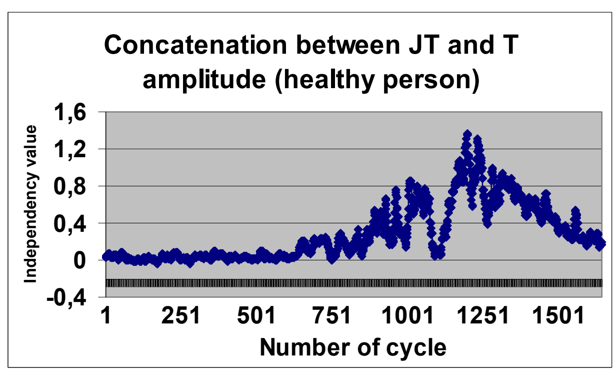

Figure 5. Sample of concatenation of ECG parameters (JT – interval between end of QRS complex and end of T wave and T wave amplitude) during physical stress test of healthy person.

During physical load the sympathy nervous system is dominated and the concatenation between JT and DQRS apparently increases (in opposite – independency decreases), and after load during recovery period the opposite dynamics of concatenation could be observed (figures 4,5).

It is interest to know that even during load the concatenation between JT and T wave amplitude started to decrease as concerns with local inadequate hemodynamic influence to cardiologic processes

Analysis of changes in heart rate (HR) during the performance of locomotion of various intensities showed that the same physical task requires a different energy costs in dependence on the environmental conditions. Cross-country conditions, i.e. mountain and more twists required the more mobilization of cardiovascular system as to perform the task and the bigger changes in HR was observed. If during the jogging at the stadium HR was 112.6±4.8 b/min. during the performance of the same task at cross-country conditions was 123.6±4.9 b/min. (*difference between these values was significant, $p<0,05$*). The results obtained during the study showed that the type of locomotors task has an influence on assessment of mobilization of cardiovascular system during the walking and running as well. The type of activity constitutes important information and it was evident from the data obtained during the comparison of values of relative power assessed by accelerometers during the various locomotors task. In the present study, it is confirmed that the amplitude of the body's accelerometer signal is related mostly to vertical swings at each step, walking and running as well. The present investigation also confirmed the large inter-individual variation of acceleration while performing the same physical activity.

4. Discussion and conclusions

The main results of work are: developed wireless device of monitoring system, created software of data analysis in real time, proposed the mathematic algebraic procedure for concatenation of physiologic processes in the heart. The developed procedure was applied in ECG monitoring of patients with coronary artery disease (CAD) during percutaneous transluminal coronary angioplasty (PTCA), as well as during physical stress examination of healthy persons.

Proposed method and values of concatenation between various processes could serve as indicators of human functional state and also could be applied for assessment of interpersonal functional concatenation.

Results of the present study confirmed that the amplitude of the body's accelerometer signal is related mostly to vertical swings at each step, walking and running as well. The present investigation also confirmed the large inter-individual variation of acceleration while performing the same physical activity.

Acknowledgements

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