Monitoring of Condition of the Cardiovascular System by Means of Mobile Phones Using ECG Noise Variance

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***Abstract*— A technology is offered for monitoring of condition of the cardiovascular system based on the analysis of ECG noise variance. ECG noise variance is shown to be a carrier of useful information on hidden pathological processes in the cardiovascular system. Use of mobile phones with application of the offered technology of analysis of cardiosignals will allow real-time warning of patients about crises related to cardiovascular diseases.**

***Keywords*— noise variance; cardiovascular system; ECG; cardiosignal; monitoring; mobile phone**

I. Introduction

Reduction in price and size of computer equipment paved new ways to monitor state of health, an example of which is Holter monitor offered by the American biophysicist Norman Holter in 1949 [1]. Holter monitor continuously records ECG in the course of 24 hours for its subsequent analysis by a cardiologist. The shortcoming of Holter monitor is its inability to process ECG signals for continuous monitoring of condition of the cardiovascular system. Condition of the cardiovascular system is not therefore determined on-line but only after a certain amount of time, with a cardiologist being involved.

To eliminate the above-mentioned shortcoming, researchers in the field of cardiologic equipment are developing devices that process cardiosignals on-line, which makes it possible to alert a patient to significant deviations from normal parameters of his ECG. However, such alert is frequently late. For this reason, researchers work on possibility of performing monitoring of the cardiovascular system based on ECG parameters that correlate with the latent period of origin of pathology, which will allow informing patients of serious malfunction of the cardiovascular system before it starts. Solving of this problem is covered in the present paper.

II. State-of-the-Art

The Japanese company Nihon Kohden presents a wireless system of monitoring by means of Nihon Kohden transmitter and the central station that receives data of a large number of patients, or by means of Nihon Kohden [2] telemetry system. The condition of a patient and measuring of vital signs are monitored every single second.

Belgian company IMEC [3] developed a mobile ECG system that works paired with Android OS based smartphones. The device is linked to the apparatus via wireless connection with low power consumption. Standard Bluetooth connection consumes too much energy, so scientists had to develop a replacement. ECG interface is based on the standard Secure Digital Input Output (SDIO) applied in Google phones. The essence is in receiving a lasting picture of the patient's cardiac rhythm; all you need to do is to attach several sensors to the body and enable monitoring. The system will allow sending medical statistics by SMS or e-mail. There is also an option of tracking down the location of the patient via GPS, which is very useful for rapid response if cardiogram leaves much to be desired. The basic part of the interface has been 'borrowed' from the Linux nucleus, which makes the appearance of versions ported to devices working with this OS possible. The system is not mass produced, so it is not present in the market yet.

Italian company "Ates Medica Device" developed "Easy ECG Mobile", a mobile telemedical ECG system [4]. Easy ECG Mobile system consists of mobile ECG recorders and the central stations. Mobile recorder (MR) allows registering, visualizing, saving ECG records and sending ECG records to the central station. MR is a compact and easy-to-control device consisting of two units: "Easy ECG Pocket" digital ECG amplifier and the control unit. Easy ECG Pocket records ECG and sends it in the digital form to the control unit via wireless connection. The control unit is a communicator (a PDA with mobile phone) equipped with "Mobile ECG" application. Devices are interconnected via Bluetooth. The control unit receives ECG signals registered by means of Easy ECG Pocket, visualizing and saving it in memory. After that the record can be sent to the central station by pressing one single button. The record is transmitted via the Internet in several seconds and via wireless local area network practically instantly. The system is mass produced at the present time.

The German company "Custo Med GmbH" [5] developed "Custo Tera" system that allows performing continuous monitoring of the cardiovascular system by means of ECG. The electric activity of the heart is recorded on a Holter ECG over a period of usually 24 hours, at least 18 hours. During the

This work was supported by the Science Development Foundation under the President of the Republic of Azerbaijan – **Grant No. EIF-2011-1(3)-82/09/1**

recording process data are registered in a recorder and are then evaluated by analyzing software in the PC. Holter ECG systems have been successfully developed and sold worldwide by Custo Med for 20 years already. The new Custo Tera Holter ECG concept has been implemented in close cooperation with the users in hospitals and physicians' offices. Even the basic version offers all functions that make it possible to create a validated Holter ECG report within the shortest time. [6]

The Swedish company "Ericsson" developed "Ericsson Mobile Health" (EMH) system. EMH is a system for remote monitoring of the condition of the cardiovascular system and designated for measuring of medical parameters of both adults and children. The system provides comfortable access to measuring of a number of parameters, including ECG, blood pressure, pulse rate. EMH consists of the patient's set, the server unit and the application. The patient's set includes one or more medical sensors, an individual communications device and additional accessories (battery charger, batteries and sensor accessories). The communications device is the center of the patient's set, which receives measurement data from the sensors via Bluetooth technology and sending them to the server unit of the system via mobile network. Physicians view patients' data by means of web applications developed for various purposes and ensuring connection with the server unit. EMH 3.0 is mass produced by Ericsson at the present time. [7]

The Israeli company "Aerotel Medical Systems" is one of the world leaders in the production of modular mobile units designed for transmission of important medical data by means of phone, mobile phone and other electronic communication devices. The company offers Aerotel Heartline™ system for ECG monitoring. The products include the full range of personal devices with 1 to 12 channels for data transmission via phone, which are used for remote diagnostics or first aid. Registered ECG signals are sent via phone to the medical center, where they are received by the special "Heartline" computer station and the results are displayed on the screens. [8]

The Russian company "Cardiocode Ltd" developed and presented "Cardiocode" monitoring system in 2005. Apart from cardiosignals, the equipment measures and analyzes rheosignals. That distinctive feature allows one to determine the condition of the cardiovascular system of patients and detect a wide range of pathological processes in advance. According to the manufacturer, the system is unique. In 2009, the company presented the mobile version of the system. Mobil Cardiocode is easy to use. Putting on the light device that looks like an ordinary wristlet, a patient can read the information on the condition of his heart at home with pressing of a button. The data are sent to from the device to the Call Center, where they are instantly deciphered and studied by experts. If the situation is critical, an operator contacts the patient and takes further qualified action. [9]

III. Problem Statement

It follows from the above-mentioned that most of the mobile system for monitoring of the condition of the cardiovascular system available on the market are not actually mobile in the proper sense of the word, as they require additional data processing in stationary conditions. Besides, monitoring in most of the existing mobile systems is based on parameters, which are insensitive to hidden pathological processes in the cardiovascular system.

Thus, mobile means for monitoring of the cardiovascular system existing today have the following shortcomings:

- inability to detect pathology at the stage of origin
- inability of assess the condition of the cardiovascular system on spot without sending data to the server through communication channels for further processing

The present paper offers a solution for eliminating the above-mentioned shortcomings by applying algorithms of noise monitoring for processing of ECG signals.

IV. Noise Variance as a Carrier of Useful Information

[10] has suggested using noise variance as a carrier of useful information about the condition of an object or a system and offered an algorithm for calculation of noise variance [10, p.110]:

$$D_\varepsilon = \frac{1}{N}\sum_{i=1}^{N}\left(\overset{\circ}{g}(i\Delta t)\overset{\circ}{g}(i\Delta t) + \overset{\circ}{g}(i\Delta t)\overset{\circ}{g}((i+2)\Delta t) - 2\overset{\circ}{g}(i\Delta t)\overset{\circ}{g}((i+1)\Delta t)\right) \tag{1}$$

where $\overset{\circ}{g}(i\Delta t)$, $\overset{\circ}{g}((i+1)\Delta t)$ and $\overset{\circ}{g}((i+2)\Delta t)$ are values of centered cardiosignals in successive time points $i\Delta t$, $(i+1)\Delta t$ and $(i+2)\Delta t$ respectively.

The distinction of algorithm (1) is the adequate selection of sampling frequency that depends on the spectral composition of noise. As it is demonstrated in [11], effective sampling frequency at calculation of ECG noise variance is about 40 Hz.

V. Technology of Monitoring of the Cardiovascular System

The concept of monitoring of the cardiovascular system based of ECG noise variance has been suggested by Prof. Telman Aliev in [10, pp. 189-192]. We have used this concept to develop a system equipped with ADS1298RECGFE-PDK programmable controller [12] operated by Windows XP OS.

The process of measuring ECG signals is as follows. Electrodes are attached to three points of a patient's body skin (first channel electrode to the right wrist; second channel to the left wrist; zero electrode in between the left wrist and the left elbow). By means of those electrodes, the controller reads and digitizes electric potentials of the above-mentioned points with the set frequency (from 500 Hz to 32 kHz), after which digital ECG signal is sent to the computer and written in an XLS file.

Further, the software application specially developed by us reads results of readings of ECG signals from the XLS file and calculates noise variance using algorithm (1) with effective frequency (40 Hz [11]).

At the present time, software for processing of digitized ECG signals is being adapted to Windows Mobile mobile phones. Use of mobile phones with application of the offered technology of analysis of cardiosignals will allow real-time warning of patients about crises related to cardiovascular diseases.

VI. Results of Calculation of ECG Noise Variance

ECG were taken in two age groups (each consisting of 3 persons) during several days. Patients of the first group ("S", "Y" and "N") were in the age range of 20 to 25. Patients of the second group ("E", "Z" and "A") were in the age range of 50 to 65. Signal was read in the course of 10 seconds on the average with frequency 500 Hz and 8,000 Hz. Results of calculation of ECG noise variance for each patient are given in Tables I-IV.

TABLE I. Results of Calculation of D_ε for Patients of the First Group at Sampling Frequency of ECG Signal 500 Hz

No.	D_ε (S), µV	D_ε (Y), µV	D_ε (N), µV
1	0.004045	0.002879	0.001740
2	**0.007058**	0.003741	0.001708
3	0.004974	0.002994	0.001951
4	0.003734	**0.001626**	0.002078
5	**0.003613**	0.002175	0.001972
6	0.004991	0.003127	0.001390
7	0.005720	0.003693	0.000809
8	0.003829	0.003443	0.001083
9	0.003766	0.004738	**0.000536**
10	0.005252	0.005193	**0.005017**
11	0.005302	**0.006431**	0.001345
12	0.004268	0.003361	0.001819
13	0.003698	0.003593	0.001201
14	0.005250	0.004914	0.001038
15	0.005028	0.003327	0.000560
$\overline{D_\varepsilon}$	0.004702	0.003682	0.001616

TABLE II. Results of Calculation of D_ε for Patients of the First Group at Sampling Frequency of ECG Signal 8 kHz

No.	D_ε (S). µV	D_ε (Y). µV	D_ε (N). µV
1	0.003688	0.004364	0.002182
2	**0.005548**	0.003131	**0.000924**
3	0.005419	0.002826	0.002826
4	0.003601	0.003929	**0.003929**
5	0.004500	0.003679	0.003679
6	0.003859	**0.001432**	0.001014
7	0.004658	0.001935	0.000999
8	0.003863	0.001793	0.000967
9	0.004278	0.002364	0.001028
10	0.003245	0.002453	0.001799
11	0.004678	0.003565	0.001978
12	0.004247	**0.004749**	0.002447
13	0.005247	0.003538	0.001040
14	0.004980	0.003753	0.000981
15	**0.003141**	0.004268	0.001441
$\overline{D_\varepsilon}$	0.004330	0.003185	0.001815

Tables 1-4: $\overline{D_\varepsilon}$ is the average value of noise variance D_ε of ECG signal; extreme values of noise variance D_ε for each patient's ECG are marked in bold.

Tables 1-4 show that despite the obvious spread of values of noise variance D_ε, average values of the mentioned parameter in the whole monitoring period at sampling frequencies 500 Hz and 8,000 Hz practically match (see Table 5).

TABLE III. Results of calculation of D_ε for patients of the second group at sampling frequency of ECG signal 500 Hz

No.	D_ε (E), µV^2	D_ε (Z), µV^2	D_ε (A), µV^2
1	**0.005452**	**0.009463**	0.027343
2	0.008653	0.014834	0.036513
3	0.006305	0.015601	0.027570
4	0.007105	0.018453	**0.025923**
5	**0.009323**	0.014854	0.030133
6	0.007578	0.015272	0.040542
7	0.006856	**0.023722**	**0.043397**
$\overline{D_\varepsilon}$	0.007325	0.016028	0.033060

TABLE IV. Results of calculation of D_ε for patients of the second group at sampling frequency of ECG signal 8 kHz

No.	D_ε (E), µV^2	D_ε (Z), µV^2	D_ε (A), µV^2
1	0.006615	0.021725	0.032414
2	0.007466	0.023414	0.028708
3	0.007303	0.013816	0.043349
4	**0.006141**	**0.011037**	0.026177
5	0.006445	**0.025371**	**0.025100**
6	**0.010944**	0.013950	**0.051143**
7	0.007486	0.015574	0.049632
$\overline{D_\varepsilon}$	0.007486	0.017841	0.036646

TABLE V. Results of comparison of average values of noise variances for each patient

Name	ν, Hz	$\overline{D_\varepsilon}$, µV^2	σ, %
S	500	0.004702	8.2
	8,000	0.004330	
Y	500	0.003682	14.5
	8,000	0.003185	
N	500	0.001616	11.6
	8,000	0.001815	
E	500	0.007325	2.2
	8,000	0.007486	
Z	500	0.016028	10.7
	8,000	0.017841	
A	500	0.033060	10.3
	8,000	0.036646	

Table 5 demonstrates that average values of noise variance deviate no more than by 10-15% depending on the frequency. Besides, deviation can be both positive and negative, which indicates that sampling frequency of ECG signal within the range of 500 to 8,000 Hz produces no significant effect on the results of calculation of noise variance by introducing extra instrumental interference.

As it follows from Fig. 1, despite the spread of values of noise variance D_ε, individual stable limits of values of the given parameter is observed for each patient.

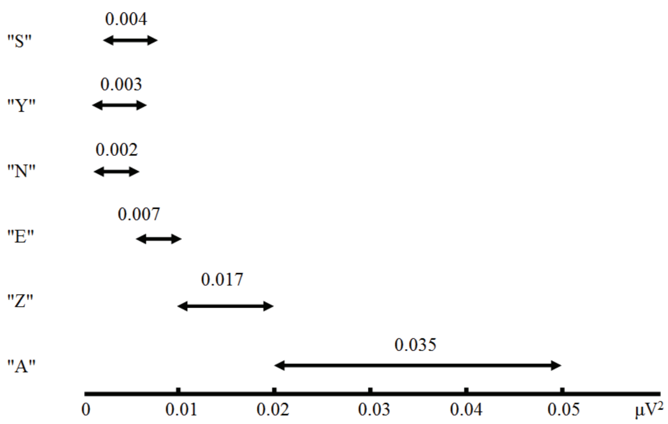

Figure 1. Comparison of spread of values of noise variance D_ε of different patients (average values of noise variance for each patient are given above value ranges).

VII. Conclusions

Analysis of the results of calculation of ECG noise variance allows one making the following conclusions:

- Calculated value of noise variance does not depend on the initial sampling frequency. Influence of instrumental interference on the value of variance is therefore insignificant
- Average value of noise variance is individual for each patient. Its value and change dynamics can therefore characterize the condition of the cardiovascular system and predict the dynamics of development of hidden pathological processes

References

[1] Holter monitor, www.en.wikipedia.org/wiki/Holter_monitor
[2] Nihon Kohden, www.nihonkohden.com
[3] IMEC, www2.imec.be/be_en/press/imec-news/ecgpatch.html
[4] Easy ECG Mobile, www.atesdevice.it/site/ecg/ecgmobile.html
[5] Custo Med GmbH, www.customed.de/index.php?ip=217
[6] Custo Tera Holter ECG, www.customed.de/index.php?ip=233
[7] Ericsson Mobile Health, www.ericsson.com/hr/ict_solutions/e-health/emh/
[8] Aerotel Medical Systems, www.aerotel.com/en/products-and-solutions/heartline-ecg-monitoring.html
[9] Cardiocode, www.cardiocode.ru/en/
[10] T.Aliev. Digital Noise Monitoring of Defect Origin. Springer, London (2007), 223 p., www.springer.com/engineering/signals/book/978-0-387-71753-1
[11] N.F. Musayeva, N.E. Rzayeva, U.E. Sattarova. Technology of monitoring of the beginning of pathophysiological processes in the cardiovascular system. Transactions of Azerbaijan National Academy of Sciences, vol. XXXI, No.6, 2011, pp. 162-167, www.science.az/cyber/journal/2011/6-23.pdf (in Russian)
[12] Texas Instruments: ADS1298RECGFE-PDK, www.ti.com/tool/ads1298recgfe-pdk