The Mobile ECG and Motion Activity Monitoring System for Home Care Patients

S Korsakas[1], J Lauznis[2], A Vainoras[1], Z Markovitch[3], L Gargasas[1], I Markovitcha[4], Z Navickas[5], R Ruseckas[1]

[1]Institute of Cardiology of Kaunas University of Medicine, Kaunas, Lithuania
[2]Integris Ltd, Riga, Latvia
[3]Riga Technical University, Institute of Computer Control, Riga, Latvia
[4]Latvia Institute of Cardiology, Riga, Latvia
[5]Kaunas University of Technology, Kaunas, Lithuania

Abstract

The basic idea of this work was to develop user-friendly mobile wireless ECG and motion activity recording device, software for real time signal analysis and warning system based on ordinary or pocket PC and designed for home care patients with cardiac risk.

The mobile patient device includes 3 channel ECG front-end recorder, 3-axis accelerometer and Bluetooth module. Feedback signaling to patient is provided with sound, vibration and light or their combination.

The software makes input signals pre-processing, recognition and measurement of ECG parameters, calculates breathing frequency from the ECG signals and evaluates patient activity from the motion signals in the real time. Finally monitoring system makes a decision about patient state changes from the calculated parameters using the convolution of Mealy and Moore automata, and in case of appearance of dangerous situation sends the warning signal to patient and analysis results to physician on duty.

1. Introduction

There are many heart diseases, where a long term real time ECG monitoring is necessary. Usually this procedure could be done only in the hospital, sometimes with unpredictable duration and with the same taking out the potential patient from his common every day media. At the same time, if there is no other necessity for staying in the hospital, this procedure could be carried out by individual himself at home. It could be useful also during rehabilitation time for patient self-control and in several e-health conceptions [1-2]. Existing systems in the market for this purpose are designed to be used by medical staff in the hospitals, have special requirements and are not suitable for use in non-hospital environment by patients [3-4], and for this reason the EUREKA project HEART GUARD was started [5]. The main task of the project was to develop the personal wireless ECG and motion activity transmitting device and warning system for long term monitoring of home care patients with cardiac risk.

2. Methods

2.1. System architecture and hardware

The system architecture design includes definition of system components and implementation requirements, specification of requirements for each unit, specification of interactions inside the system including data transfer standards. The basic scheme of the HEART GUARD system is presented in Figure 1. It consists of two parts: the mobile monitoring system of home care patients and the remote consulting system for physicians. In this project we were concentrated on developing the mobile ECG and motion activity monitoring and warning system for home care patients.

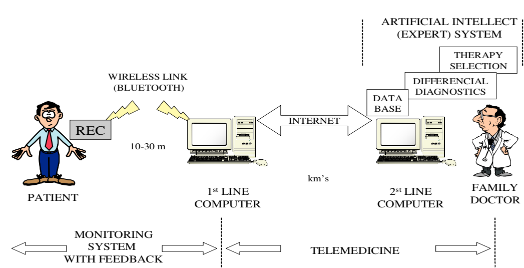

Figure 1. HEART GUARD system architecture.

The hardware of monitoring system was developed. It consists of wireless ECG and motion activity recording and transmitting device. The block diagram of patient mobile device is presented in Figure 2. It includes 3 channel ECG front-end recorder with baseline correction, 3-axis accelerometer and Bluetooth module with antenna.

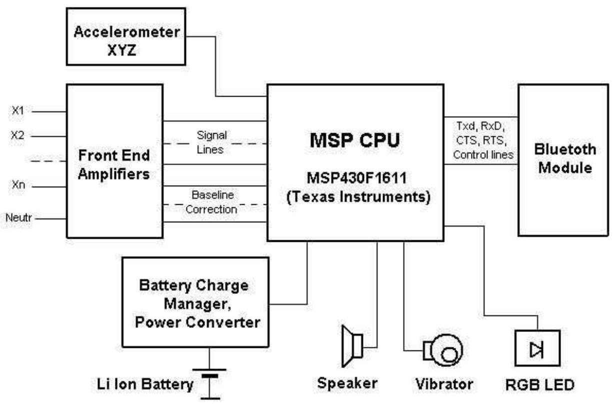

Figure 2. The block diagram of patient mobile device.

Unit is powered from Li Ion battery. Feedback signaling to patient is provided with sound, vibration and light or their combination. Acquired ECG and motion data are packed in 256 byte blocks and transmitted to PC for analysis. Receipt conformation and feedback signal, if required, is sent back to the device after each block.

2.2. Algorithm for evaluation of patients monitoring parameters

Data stream during monitoring we described using the convolution of Moore and Mealy automata [6,7,8]. We have developed decision algorithm for monitoring system using presented in Figure 3 structure of Moore (M_r) and Mealy (M_l) automaton convolution.

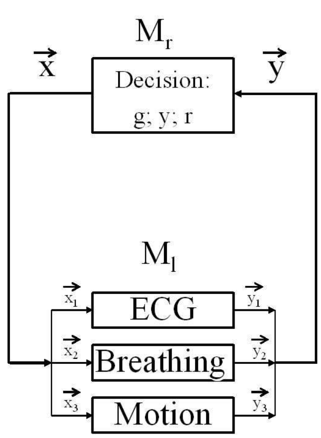

Figure 3. The structure of decision algorithm.

Data from ECG, breathing and motion activity parameters obtained and evaluated by Mealy automaton, later are analyzed by Moore automata, and in case of appearance of dangerous situation the warning signal is sent to the patient or physician. In every ten seconds the state of automaton convolution is changed, after new data volume is coming.

The criteria for evaluations of ECG data are presented in Table 1 and for breathing and motion activity evaluation are shown in Table 2.

Table 1. The evaluation criteria of ECG parameters.

For heart rate (HF):				
HFi;	i = **1**	**2**	**3**	**4**
[bpm]	0-40	40-100	100-140	140 and more
HF"i ;	i = **1**	**2**	**3**	
	the same	higher	less	
ΔHF	± 25%	> 25%	< 25%	
ΔHF is set in preferences				
For QRS complex duration (DQRS):				
DQRSi;	i =**1**	**2**	**3**	
[ms]	70-100	100-120	120-140	
DQRS"i;	i =**1**	**2**	**3**	
	the same	longer	shorter	
ΔDQRS	± 20%	> 20%	< 20%	
ΔDQRS is set in preferences				
For ST segment amplitude in any of three ECG leads:				
STi;	i =**1**	**2**		
	0-0,1mV	> 0,1mV		
could be set in preferences as **ε**				
Σ/STi/";	i =**1**	**2**	**3**	
	the same	bigger	less	
ΔΣ/STi/;	0-0,1mV	> 0,1mV	< 0,1mV	
ΔΣ/STi/; is set in preferences				

Evaluation of processes is made according to the value of parameters and their changes, so every parameter has two "sided" evaluations (M_l). Such approach let us more carefully follow the changes in patients state from one side and not to pay attention when changes appear only in one process and is not supported by the changes in other (M_r). Thus let us avoid false positive decisions in patient state evaluation. The state of Moore and Mealy automaton convolution reflect the state of patient inclusive it's main functional features in every day life.

Main principle of ECG data evaluation in (M_l) is presented in Table 3. In the first column different types of evaluated cardiocycles are presented according to their own parameters from Table 1. At first, evaluated ECG parameters are combined to evaluate the type of cardiocycle (Table 3), than on the next step the sequence of cardiocycles is evaluated and the decision ECG_g or ECG_y or ECG_r is appeared (Table 4).

Table 2. The criteria for evaluation of breathing and motion activity data.

Evaluation of breathing frequency (Kv):				
Kvi;	i =**1**	**2**	**3**	**4**
[bpm]	0-6	6-10	10-20	>20
Kv"i ;	i =**1**	**2**	**3**	
	the same	higher	less	
ΔKvi	± 25%	> 25%	<25%	
ΔKvi is set in preferences				
Motion activity processes (Acs):				
Body state:				
Acsi;	i =**1**	**2**	**3**	
	supine	upright	urgent alarm	
Acs"i;	i =**1**	**2**	**3**	
	the same	stands up	lie-down	
Evaluation of movement (M):				
Mi;	i =**1**	**2**	**3**	
	stationary	small	high	
Mi";	i =**1**	**2**	**3**	
	the same	higher	less	
ΔMi is set in preferences				

Table 3. The decision rules for ECG parameters evaluation in every cardiocycle.

Cycle type	DQRS 1	DQRS 2	DQRS 3	ST 1	ST 2	HR 1	HR 2	HR 3	HR 4
$S^{1,0}$	1			1		1	1	1	1
$S^{1,1}$	1				1	1	1	1	1
$S^{2,0}$		1		1		1	1	1	1
$S^{2,1}$		1			1	1	1	1	1
$S^{3,0}$			1	1		1	1	1	1
$S^{3.1}$			1		1	1	1	1	1

Table 4. The main decision made by Moore automaton.

Conditions	1	2	3
EKG_g	1		
EKG_y		1	
EKG_r			1
B_g	1		
B_y		1	
B_r			1
I_g	1		
I_y		1	
I_r			1
Green	x		
Yellow		x	
Red			x
Next 10s	x	x	x

The made evaluations by (M_l) are combined with evaluations of other processes and common decision for all situation is made by (M_r).

Used Moore and Mealy automaton convolution help us to combine the analysis of different physiologic processes in one data stream analysis algorithm.

3. Results

3.1. The pilot samples of patient device

The first pilot samples of patient monitoring device were designed using different components. The first version of device was constructed using front-end amplifiers LT1112, microcontroller C8051F006, 3-axis accelerometer MMA-7260Q and Bluetooth Zeevo module. The next version of device was constructed using MSP from Texas Instruments 430F1611 and Bluetooth Ezurio module. The sample of monitoring device for registration ECG and motion data is shown in Figure 4.

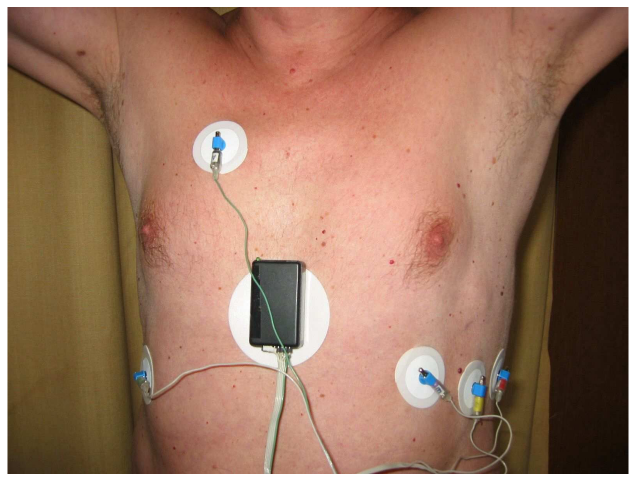

Figure 4. The sample of patient device for registration 3 ECG leads and 3-axis accelerometer signals.

The protocol of data changes with PC was developed. The samples of monitoring device were tested according to standard IEC 60601-2-49:2001.

3.2. Software of the monitoring system

The software for input and on-line analysis of ECG and motion activity signals was developed. The software performs: data input from the recording device via Bluetooth and store it in the PC memory, data pre-processing (noise reduction, artifact suppression), recognition of P-QRS-T complexes, measurement of P-QRS-T parameters and calculation the breathing frequency from ECG data. At the same time the software evaluates the patient position (standing, lying, sitting) and calculates motion power from the accelerometer signals. The screenshot of 3 leads ECG, 3 channel of motion signals and calculated parameters in real time is presented in Figure 5.

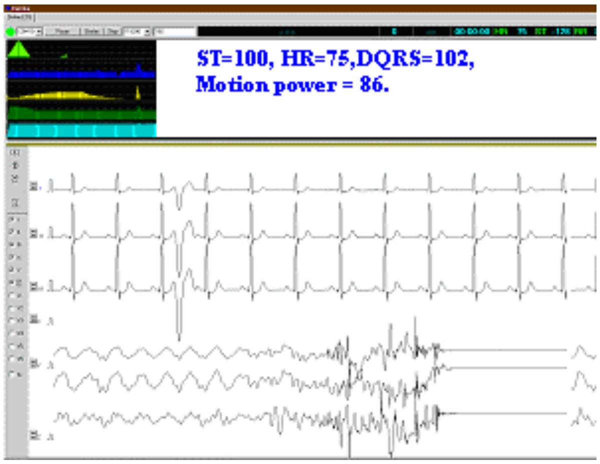

Figure 5. The screenshot of input signals and calculated parameters in real time.

Finally the software of monitoring system makes a main decision about patient state changes from the calculated parameters described upper using Moore and Mealy automata algorithm. According to received analysis results the software forms warning signals (green, yellow, red) to patient. In case of appearances of dangerous situation for patient, the software sends the results of analysis to physician on duty. The software is created by using plain C++ and can run on different PC platforms.

4. Discussion and conclusions

The presented work reflects three main positions: developed hardware of monitoring system, proposed decision algorithm and created software.

The developed hardware of monitoring system consists of 3 lead ECG and 3 channel motion activity signals recording and wireless transmitting device. The developed device meets the requirements of standard IEC 60601-2-49:2001.

We have showed that the patient functional state variation and dynamics could be formalized and mathematically described by the convolution of Mealy and Moore automata. We have investigated some constructions of automaton. After that research we concluded that the convolution of Mealy and Moore automaton is the simplest and easiest way to describe investigated processes. Moore automaton can represent ruling part, Meally automaton – executive part of processes. The presented model is changeable – we can easily add new components (subautomaton, states, functions) and describe the information streams in more details. This model could be applied for the automation of diagnosis or could help to organize the feedback between patient functional state and applied influence.

The created software performs the monitoring data analysis in real time. It allows in case of appearance of dangerous situation for patient to send the warning signal to patient and the results of analysis to physician on duty.

Acknowledgements

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References

[1] Braga F, Forlani C, Signorini MG. A knowledge based home monitoring system for management and rehabilitation of cardiovascular patients. Computers in Cardiology 2005;32:41-4.

[2] Gonzalez R, Jimenez D, Vargas O. WalkECG: A mobile cardiac care device. Computers in Cardiology 2005;32: 371-4.

[3] BIOCONTROL – BioEvent. http:/www.von-berg-medizingeraete.de.

[4] EKG-Monitoring-Card Vitaphone 100 IR. http;//www.vitaphone.de

[5] Mobile personal ECG monitor. http://www.eureka.be/inaction/AcShowProject.do/id=3489

[6] Berskiene K, Aseriskyte D, Navickas Z, Vainoras A. Development of Information System for E – health using Mealy and Moore automata. Mathematics and mathematical modelling. Kaunas: Technology, 2005;1:48-54.

[7] Zvironiene A, Navickas Z, Rindzevicius R.. Telecommunication systems analysis using the convolution of Moore and Mealy automata. Electronics and Electrical Engineering. Kaunas: Technology, 2005;59:18-23.

[8] Zvironiene A,.Navickas Z,.Rindzevicius R. The expression of the Telecommunication system with an infinite queue by the convolution of Moore and Mealy automata. Proceedings of the 27th International Conference on Information Technology Interfaces, Croatia 2005:669-72.

Address for correspondence

Stasys Korsakas
Sukileliu 17, LT50009 Kaunas,
Lithuania
stakor@medi.lt