

Personal Monitor for Evaluation of Human Functional State

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Introduction

In Europe, the cardiovascular diseases (CVD) are leading source of sudden death, causing about 45 percent of all deaths [1]. The goal of the health care is empowering the citizens to fight CVD by means of a preventive lifestyle and an early diagnosis of CVD. In many cases for CVD diagnosis a long-term real time vital signals 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. 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. The first researches of developing the home telemonitoring systems for heart failure assessment appeared 3-4 years ago [2-5].

The main aim of this work was to develop the algorithms and software for personal monitor of human functional state evaluation. The first task was to develop the software for continuous (on-line) analysis of monitored vital signals (ECG, motion activity) and the generation of real time objective feedback to patient. The second task was to develop the software for comprehensive (off-line) analysis of storage data during long-term (24 hours) patient monitoring.

The functionality of software of personal monitor

The developed personal monitor (Fig. 1) consists of 3 ECG lead and 3 channel motion signal recorder with Bluetooth module on board, ordinary Bluetooth ready PC [6] and two packages of software. The first software

package is intended for on-line analysis of vital signal and the second one – for comprehensive off-line analysis of stored patient data during monitoring.

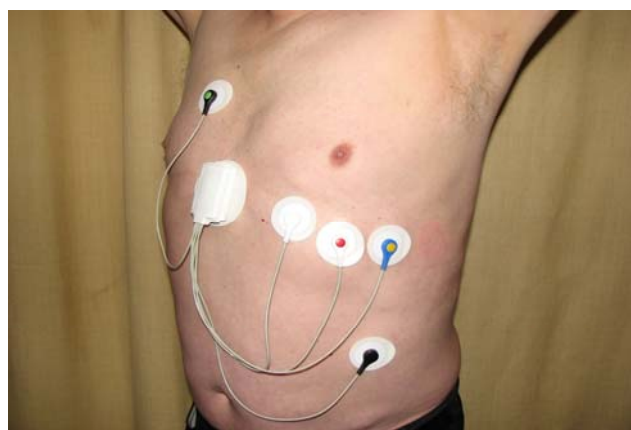


Fig. 1. The prototype of patient personal monitor for registration of 3 ECG leads and 3-axis accelerometer (inside box) signals

The following functions are performed by on-line analysis software package:

- input and visualization of vital signals from personal monitor on the PC via Bluetooth interface (Fig. 2);
- storage of input data on the PC for later comprehensive off-line analysis;
- detection of QRS complex, calculation of heart rate (HR), measurement of QRS duration and ST wave values in all three ECG leads, visualization of calculated parameters on the PC screen (Fig. 3);
- determination of patient position (horizontal or vertical), evaluation of patient activity (Fig.10, bottom graph) and detection of “patient markers” from the accelerometer data;
- calculation of respiration frequency from the ECG data (Fig. 6);

- evaluation patient functional state of calculated and measured parameters using Moore and Mealy automata algorithm [6] and generation of warning signals (green, yellow, red) to patient;
- in case of appearances of dangerous situation for patient, transmission the results of analysis to physician on duty.

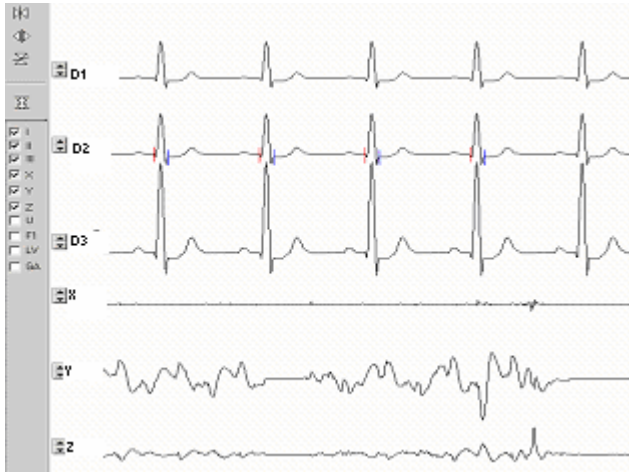


Fig. 2. Sample of visualization of input data: 3 ECG leads (upper curves) and 3 channel motion signals (bottom curves)

A new ECG system for monitoring consisting of five electrodes and three ECG leads has been proposed (Fig. 1): the first electrode is placed in the position of standard lead V1, the second – V4, the third – V5, the fourth – V6, and fifth indifferent electrode is placed below the chest. The three ECG leads D1, D2, D3 (Fig. 2) are formed: $D1 = \Phi1 - \Phi2$, $D2 = \Phi1 - \Phi3$, $D3 = \Phi1 - \Phi4$, where $\Phi1, \Phi2, \Phi3, \Phi4$ are potentials, recorded in 1, 2, 3 and 4 points. The last three curves in the underside of Fig.2 represent the intensity of body movement in horizontal (x), vertical (y) or transversal (z) directions.

HR	Δ HR	QRSd	Δ QRSd	STa	Δ STa	Position	Respiration	Time
89	0	92	0	-268	-1	H	12	16:42
89	0	92	0	-268	0	H	12	16:42
90	1	92	0	-268	0	H	12	16:43
89	-1	94	1	-271	-1	H	12	16:44
89	0	92	-1	-271	0	H	12	16:44
89	0	92	0	-271	0	H	12	16:45
89	0	92	0	-271	0	H	12	16:46
89	0	92	0	-271	0	H	14	16:46
90	1	92	0	-271	0	H	14	16:47
89	-1	92	0	-268	1	H	14	16:48

Fig.3. Sample of representation of calculated (in real time) parameters

In the first column of parameters table (Fig.3) the heart rate (HR), estimated from current RR interval and in the second – the difference of HR (Δ HR), estimated from current and previous RR interval are presented; in the third column the duration (in ms) of current QRS complex (QRSd), and in fourth – the difference of duration between current and previous QRS complex (Δ QRSd) are presented; in the fifth column the amplitude (in μ V) of deviation of current ST segment from baseline (STa) and

in sixth - the difference of amplitude between current and previous ST segment (Δ STa) are presented. In the seventh column the patient position (in sample horizontal – H), determined by 3-axis accelerometer is indicated. The eighth column is intended for indication of respiratory frequency (times per minute), determined from ECG data, and in the last column the time of recording of analyzed signals is presented.

The real time software for personal monitor is created by using plain C++ and can run on different PC platforms.

Evaluation of breathing function from ECG data

There is a big interest to have as much as possible information from the processes which could be recorded in simple noninvasive way. An ECG is such a process, and in spite of the fact that ECG seems quite well investigated process, the investigators in the world are looking for new information on ECG. One of the trials is find the methods for evaluation the lungs function according to ECG changes that are influenced by breathing. It is well known effect, when during the deep breathing the heart rhythm frequency increases at inspiration phase and decreases during expiration phase. It means that heart rate is influenced by regulatory systems and directly through the changing pressure in breast. It seems that evaluation of breathing according heart rate change is enough simple task, but unfortunately, it is rarely used in clinical practice. The reason of such situation could be explained by relation of heart rhythm variability on the frequency of the heart – the increasing frequency causes the decreasing of dispersion.

With the aim to check these features, 28 female students from Kaunas University of Medicine during their every day life for 24 h and during their aerobic fitness training were investigated by using personal monitor. The points for evaluation all day activity were taken in the morning, an hour after they wake up, at evening at about 7-8 p.m. and at night, about 2-3 a.m. (Fig.4, upper curve).

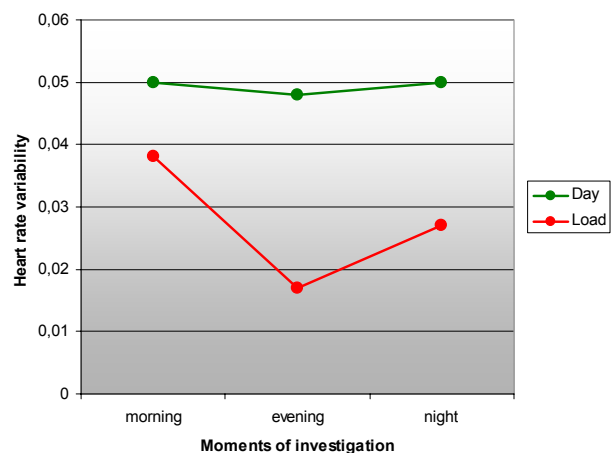


Fig. 4. Changes of heart rate variability during day time and fitness activity

During training also three points during warm up, during maximal activity, and during recovery have been taken (Fig.4, bottom curve). It is easy to see that during the day time, when heart rate changes are not so meaningful,

the changes of heart rate variability ($V_a = SD/mean$) are marginal also, but during aerobic fitness training the variability drops down significantly, and in this case evaluation of breathing becomes problematic. Another problem is disturbances of heart rhythm, when the sequence of heart beats is damaged seriously.

In aim to increase the accuracy of breathing frequency evaluation we have a try to find other phenomena on ECG which could reflect the breathing process. A heart throwaway about 100 ml of blood during every beat. When reaching the lungs blood decreases the resistance of breast. On ECG it is seen as change of R wave amplitude. An augmentation of load causes the increase of blood volume, and the changes of R wave must increase too. For the same students the changes of R amplitude in the same situations – during day (Fig.5, bottom curve) and during aerobic exercise (upper curve) have been evaluated. As was expected, during load the variability of R wave increased, and it means that usage of this parameter could improve the accuracy breathing estimation, as compared with such when for this purpose the heart rate is used.

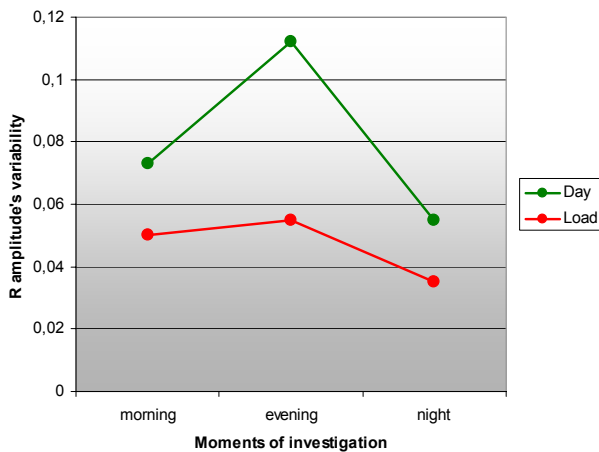


Fig.5. Changes of R wave amplitude variability during day time (bottom curve) and aerobic exercise (upper curve)

According to information obtained from individual detailed investigation of R wave amplitude changes, algorithm for calculations of breathing frequency have been developed. The first step is to choose interval in which the frequency will be calculated, for example, from 10s to 30s, and to choose longer interval is not possible, because some sudden breathing problems could be missed. In chosen interval the QRS complexes are detected and R wave amplitude, as well as RR intervals (interval between two adjacent QRS complexes) measured (Fig. 6a). In chosen interval the mean value of R amplitude and RR interval are calculated. The ratio of individual parameter to the mean for every beat is calculated also. With accuracy ε in chosen interval the maximal and minimal values of R wave amplitude and RR intervals are detected. Intervals between detected maximal and minimal values are calculated and the means both are obtained. These mean values represent the frequency of breathing (Fig. 6b). Testing of algorithm during load has showed a good agreement with real situation. Surely, only frequency of breathing poorly represent the breathing process, and the volume of breathing is needed as well, but this will be aim for next stages of investigation.

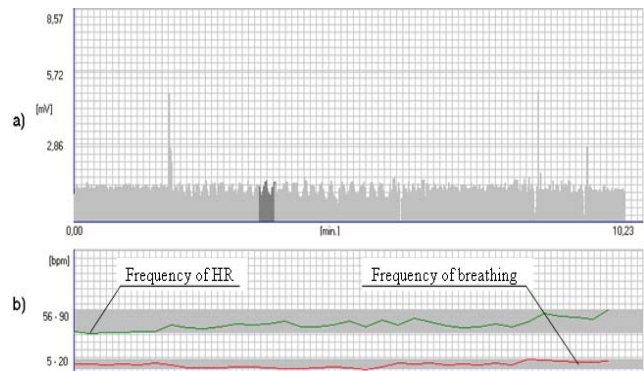


Fig.6. Changes of heart rate and breathing frequency

Comprehensive analysis of stored patient monitoring data

The on-line patient monitoring program always records ECG and motion activity data to PC hard disk. These data are intended for analysis by using mathematical and expert methods, and results are assigned for medical staff. For this purpose the off-line software of comprehensive analysis of storage patient monitoring data was developed. The off-line software performs the next functions:

- recognition and measurement of ST segment changes, JT interval duration, RR interval duration and visual representation in a time domain;
- QRS complex detection and classification to determined classes (Fig. 7);
- representation of monitoring data and events in time domain, select the event environment, measure magnitude and duration (Fig. 8);
- calculation R and S wave's magnitudes values sets dispersion, JT and RR time intervals relation and presentation visual results in Poincare diagram and time domain format);
- using R wave's magnitudes and RR time intervals sets, calculation of respiration frequency and presentation it in visual time domain format (Fig. 9, upper curve);
- determination of patient position (horizontal or vertical), evaluation of patient activity (Fig. 9, bottom curve) from the accelerometer data;
- forming of final document of patient monitoring results (Fig.10).

After the recognition of QRS complex the marks of onset and offset of it are defined, the measurement of QRS duration and determination of it shape is performed, and classification of QRS to five classes is accomplished: normal beats (N), supraventricular beats (S), ventricular beats (V), fussion beats (F), pacemaker beats (Q), and unclassified complexes (U) forms the last group (Fig. 7, upper part). In the middle part of Fig. 7, the number of QRS complexes in every class is presented. Besides, the user (physician) could manually overview the results of classification (Fig.7, bottom part).

In Fig. 8 (bottom part) the time scale is presented, and user could identify the moments of time, when and what the arrhythmic events took place.

Fig. 9 (upper curve) shows the averaged breathing rate, detected from oscillations of R wave during inspiration and expiration. In hundredth second the patient was asked to breath frequently, and developed algorithm gave a correct result, and real results coincided well with such, obtained by program. The bottom curve shows the result of developed power, when patient was asked do the intensive exercises at seventieth second of investigation. In the final protocol of investigation (Fig. 10) and in its starting part the statistics of found rhythm disorders is

presented: the total monitoring time, star time of investigation, the total number of found heart beats, and among them – number of abnormal ventricular and supraventricular heart beats with ratio (in percent) to all beats. Bellow the maximal and minimal HR values are presented and results of detailed analysis of detected arrhythmic events is supplied. In bottom part of Fig.10, the trend of ST segment displacement (in μV) STa from baseline during all period of investigation could be observed.

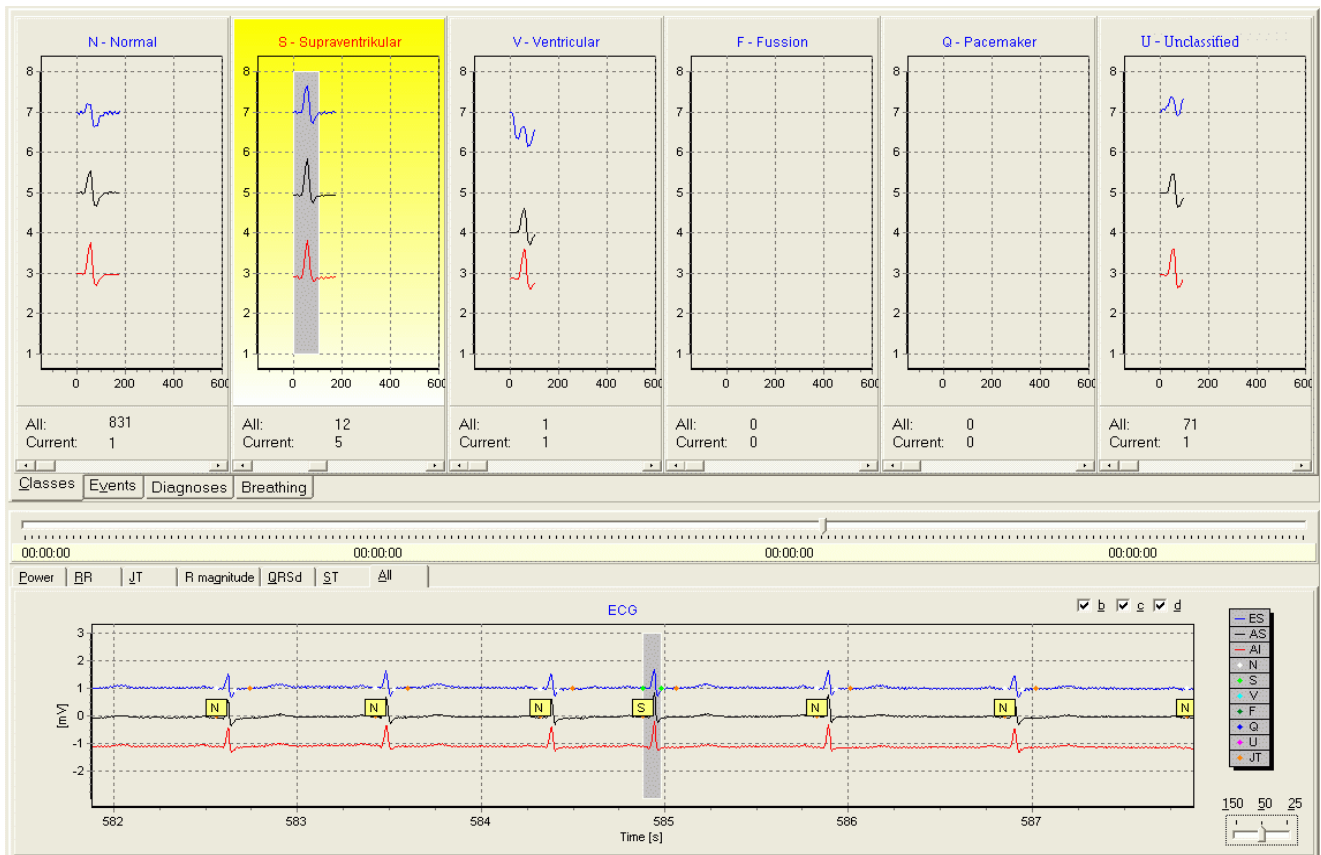


Fig. 7. Sample of classification of QRS complexes

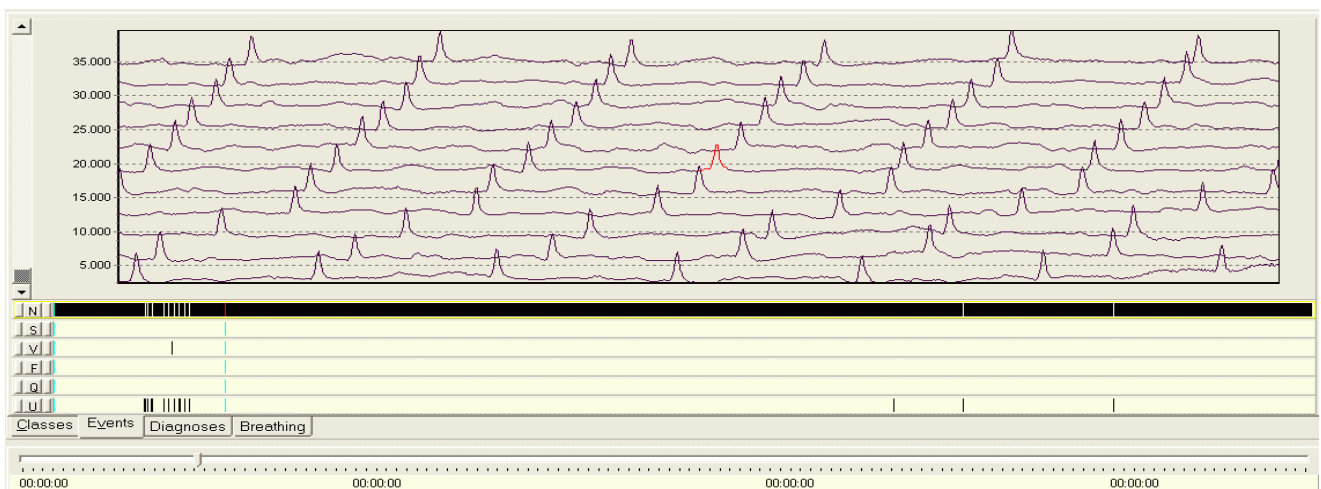


Fig. 8. Sample of presentation of arrhythmic events

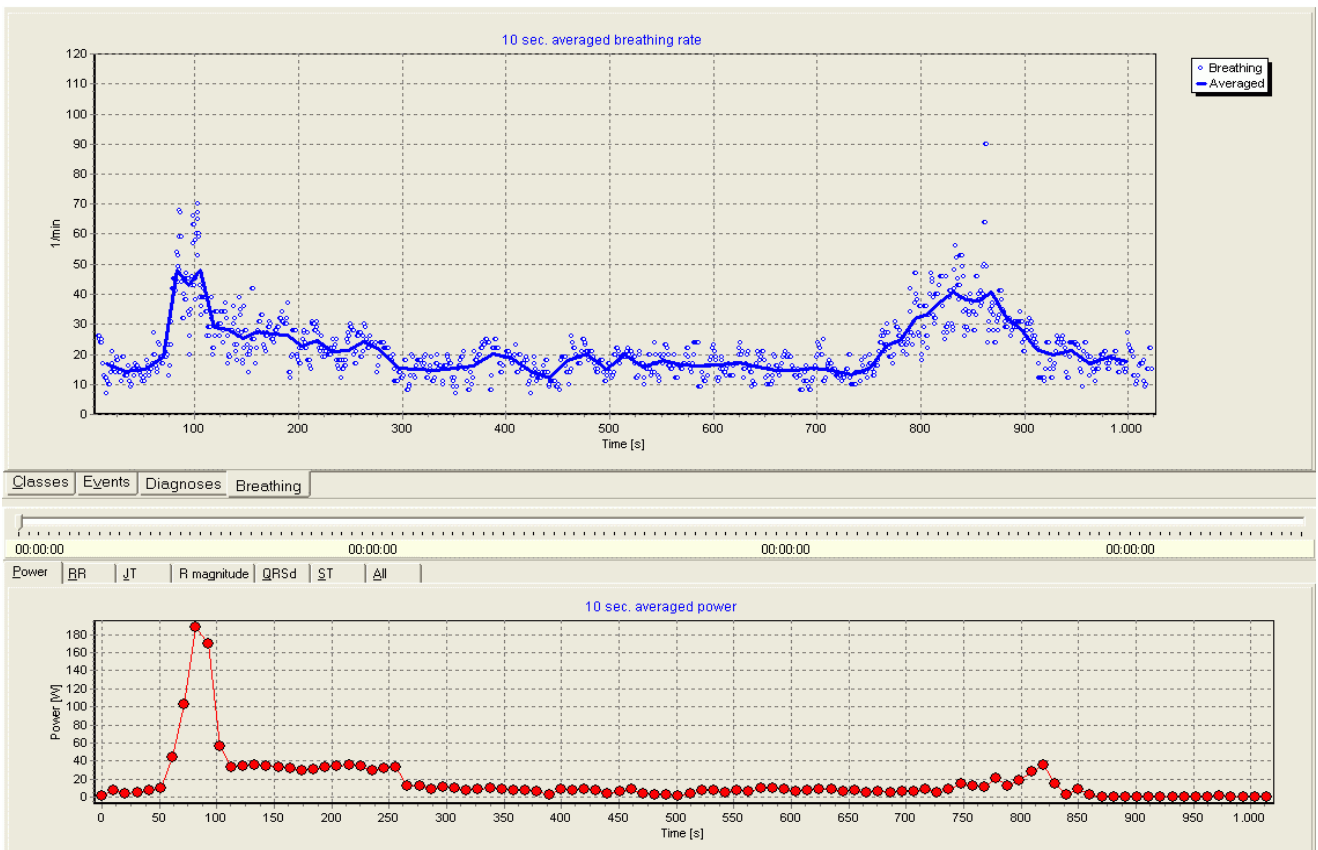


Fig. 9. Results of evaluation of breathing rate (upper curve) and patient activity, represented as developed power (W) (bottom curve)

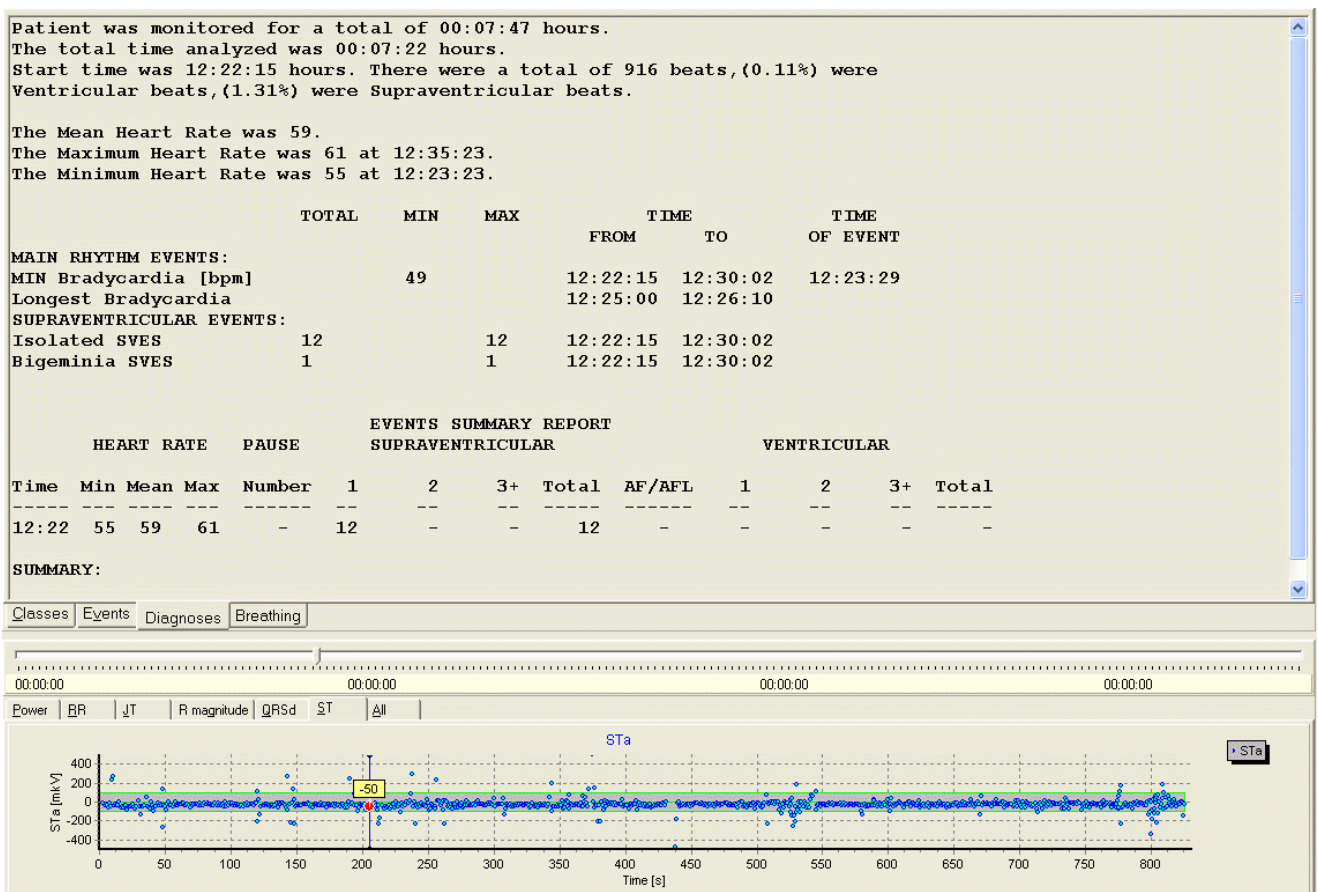


Fig.10. Final results of patient monitoring

The off-line software package is created by using plain C++ and it is working in the WINDOWS environment with the PC PENTIUM-IV 3GHz processor about 5 sec for data record 1 hour duration and 6 channels by 500Hz sampling rate.

In the nearest future the developed personal monitor with patient functional state evaluation software will be tested according IEC 60601-2-47:2001 using standard data bases.

Conclusions

1. The developed personal monitor with two packages of software for vital signal analysis performs to improve heart failure diagnostics.

2. The investigations of breathing frequency evaluation from ECG parameters during physical load showed the good agreement with real situation.

3. The developed personal monitor with software for patient functional state evaluation is required to test according standard IEC 60601-2-47:2001 for monitoring heart failure patients at home conditions.

Acknowledgements

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S. Korsakas, A. Vainoras, L. Gargasas, V. Jurkonis, R. Ruseckas, V. Miškinis, R. Jurkonienė, A. Vitartaitė. **Personal Monitor for Evaluation of Human Functional State** // *Electronics and Electrical Engineering*. – Kaunas: Technologija, 2007. – No. 6(78). – P. 61–66.

The aim of this work was to develop algorithms and software for personal monitor of human functional state evaluation. Two software packages were developed: one – for continuous on-line analysis of monitored vital signals (ECG, motion activity) with the generation objective feedback to patient and second - for comprehensive off-line analysis of storage data during long-term (24 hours) patient monitoring for diagnostic purposes. The method of breathing frequency evaluation from ECG parameters was developed. One investigation for sportsmen during physical load showed the good agreement with real situation. The developed personal monitor with software for patient functional state evaluation is required to test according standard IEC 60601-2-47:2001 for monitoring heart failure patients at home conditions. Ill. 10, bibl. 6 (in English; summaries in English, Russian and Lithuanian).

C. Корсакас, А. Вайнорас, Л. Гаргасас, В. Юрконис, Р. Русецкас, В. Мишкинис, Р. Юрконене, А. Витартайте. **Персональный монитор для оценки функционального состояния человека** // *Электроника и электротехника*. – Каунас: Технология, 2006. – № 6(78). – С. 61–66.

Целью исследования было разработка алгоритмов и программного обеспечения для персонального монитора для оценки функционального состояния человека. Были разработаны два пакета программного обеспечения: первый предназначен для прямого анализа мониторируемых сигналов (ЭКГ, активность движения) и формирования сигнала тревоги пациенту, второй предназначен для детального анализа долго регистрируемых (24 ч.) сигналов, накопленных в компьютерной памяти для диагностических целей. Разработана методика для оценки частоты дыхания из ЭКГ, проверка которой показала, что вычисленная частота для спортсменов во время физической нагрузки хорошо совпала с настоящей. Персональный монитор с программным обеспечением для оценки функционального состояния человека подготовлен для тестирования по требованиям стандарта IEC 60601-2-47:2001 и использованию его для наблюдения кардиологических больных в домашних условиях. Ил. 10, библи. 6 (на английском языке; рефераты на английском, русском и литовском яз.).

S. Korsakas, A. Vainoras, L. Gargasas, V. Jurkonis, R. Ruseckas, V. Miškinis, R. Jurkonienė, A. Vitartaitė. **Asmeninis monitorius, skirtas žmogaus funkcinėi būsenai įvertinti** // *Elektronika ir elektrotechnika*. – Kaunas: Technologija, 2007. – Nr. 6(78). – P. 61–66.

Darbo tikslas – sukurti asmeniniam stebėjimo įrenginiui žmogaus funkcinės būklės vertinimo algoritmus ir programinę įrangą. Buvo sukurti du programinės įrangos paketai: vienas skirtas stebimųjų signalų (EKG ir judėjimo aktyvumo) tiesioginei analizei ir pavojaus pacientui signalams generuoti, antras – ilgalaikio stebėjimo (24 val.) signalų, sukauptų kompiuterio atmintyje, išsamiai analizei diagnostikos tikslais. Sukurta kvėpavimo funkcijos vertinimo iš EKG parametrų metodika, pagal kurią sportininkų kvėpavimo dažnis, nustatytas fizinio krūvio metu, gerai sutapo su tikruoju. Asmeninio stebėjimo įrenginys kartu su programine įranga, skirta žmogaus funkcinėi būsenai vertinti, ruošiamas testuoti pagal standarto IEC 60601-2-47:2001 reikalavimus, kad jį galima būtų naudoti kardiologiniams pacientams stebėti namuose. Il. 10, bibl. 6 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).