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Autonomous Monitoring of the Main Set of Parameters of the Cardiovascular System

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A hardware–software system for autonomous monitoring of the main set of parameters of the cardiovascular system is described. Its main difference from conventional monitoring systems of domestic or foreign manufacture is that a single monitor is used for analysis of all the main physiological parameters of the cardiovascular system.

An increase in the efficacy of therapy can be achieved by comprehensive monitoring of the state of health followed, if necessary, by early diagnosis and adequate medical care of detected disorders. Thus, development of modern information systems and software for computer-assisted monitoring of the cardiovascular system (CVS) becomes an important task.

Available Holter monitors provide monitoring of several characteristics of the CVS, such as ECG, arterial pressure (AP), etc. However, monitoring of the functional state of the CVS should be based on comprehensive analysis of basic physiological parameters as well as statistical and spectral parameters of biological processes and signals. In addition, nonlinear monitoring methods have been introduced by the European Society of Cardiology and the North American Society of Pacing and Electrophysiology because the biological self-organization processes are nonlinear and often have fractal structure [1].

To comprehensively monitor the state of the CVS, an autonomous hardware–software system for Holter monitoring was developed at the Institute of Engineering Physics and Radio Electronics, Siberian Federal University [2] (Fig. 1). The system is based on an MKM-09 recorder.

The main difference of the developed hardware–software system from domestic and imported analogs is that it provides comprehensive analysis of the basic physiological parameters of the CVS (cardiac rhythm and its anomalies, cardiac electrical signal (CES), background cardiac electrical signal, pulsation wave, pulsation wave propagation time, vascular tension, arterial pressure). Cardiac rhythm and cardiac rhythm variability represent the state of the regulatory systems of the human body; CES, the state of the electrical conduction system of the heart; pulsation wave, the state of the vascular system; background cardiac electrical signal, the state of the myocardial system; pulsation wave propagation time, the state of vascular tension. Combined analysis of CES and the pulsation wave provides quantitative estimates of blood flow rate and noninvasive monitoring of CVS parameters.

Fig. 1. Hardware–software system for monitoring of hemodynamics based on the MKM-09 recorder.

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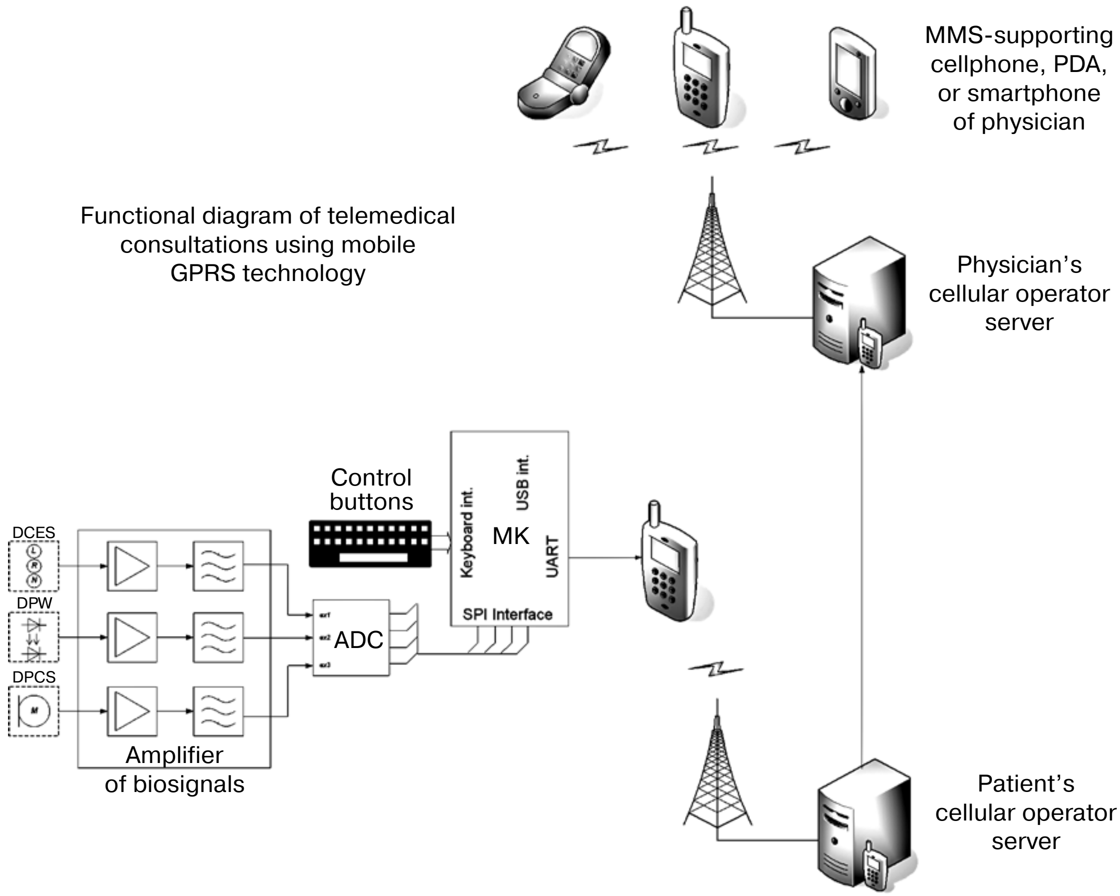


Fig. 2. Implementation of hardware–software system for CVS monitoring on the basis of E-mail, Internet, and GPRS technologies.

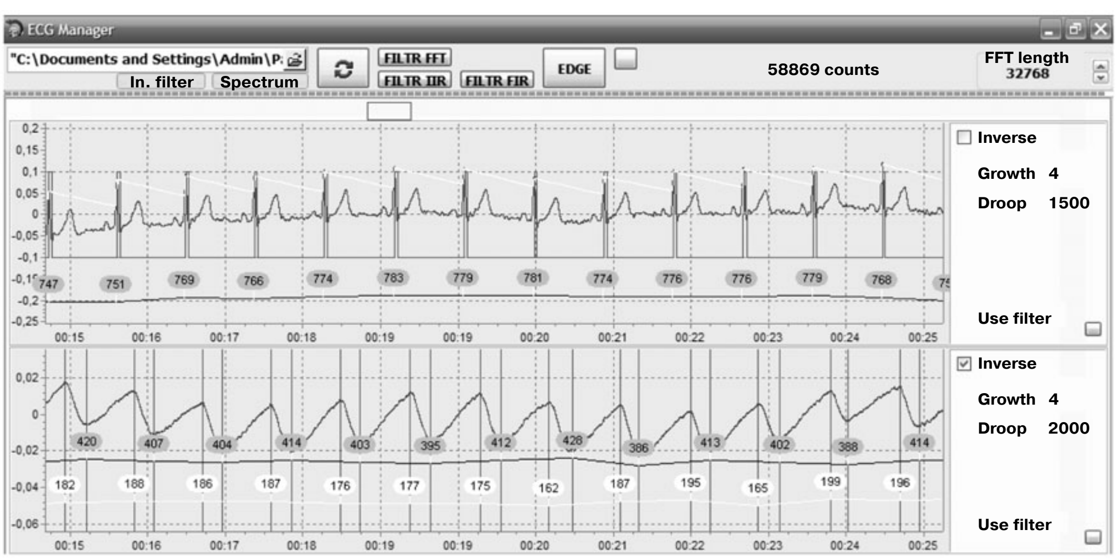


Fig. 3. Combined record of ECG and pulsation wave and measurement of pulsation wave propagation time in systolic phase (top line) and diastolic phase (bottom line) using the MKM-09 recorder.

The hardware–software system based on the MKM-09 recorder also provides remote transmission of monitoring data via intra- and inter-hospital computer networks (E-mail, Internet, GPRS systems). Biological signals from the MKM-09 are transmitted to a PC via an MMS card or USB interface. Upon processing, the data is presented as a graphical file. Then the file is transmitted as an MMS message to the physician in charge using the computer network. The USB interface allows on-line monitoring (power supply is provided by the PC). The structure of the hardware–software system based on the MKM-09 recorder is shown in Fig. 2.

Individual monitoring implemented in modern infrastructure provides effective diagnosis of the state of the CVS. In recent years, measurement of the pulsation wave propagation rate became widely used for monitoring of arterial vascular tone [3]. Vascular elasticity decreases with age, thereby increasing the pulsation wave propagation rate. This noninvasive method provides continuous monitoring of the pulsation wave propagation time by

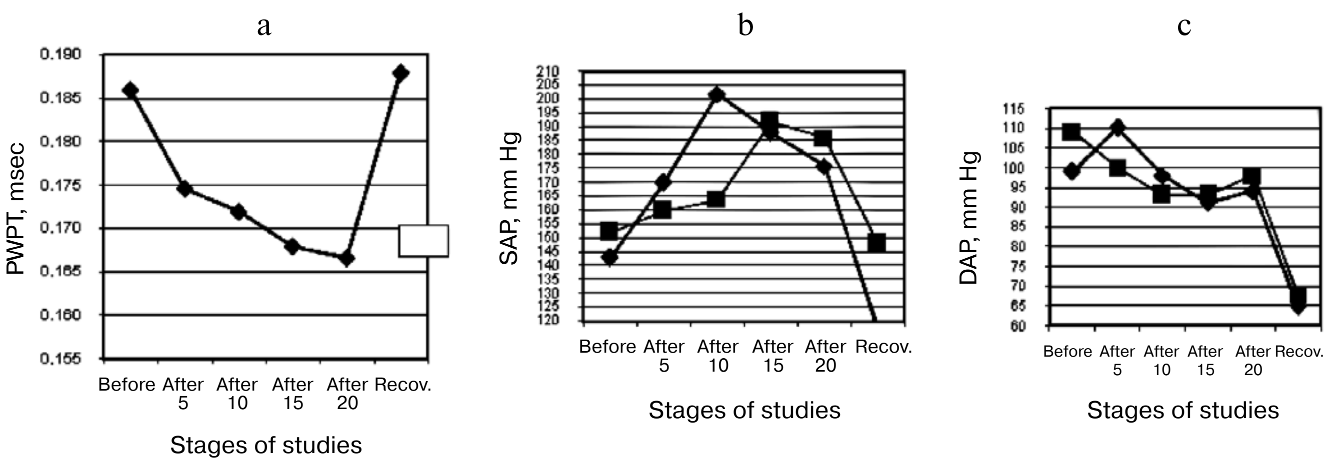


Fig. 4. a) Curves of pulsation wave propagation time (PWPT) measured using the MKM-09 monitor; curves of (b) systolic and (c) diastolic AP measured using the BPLab and A&D Medical monitors.

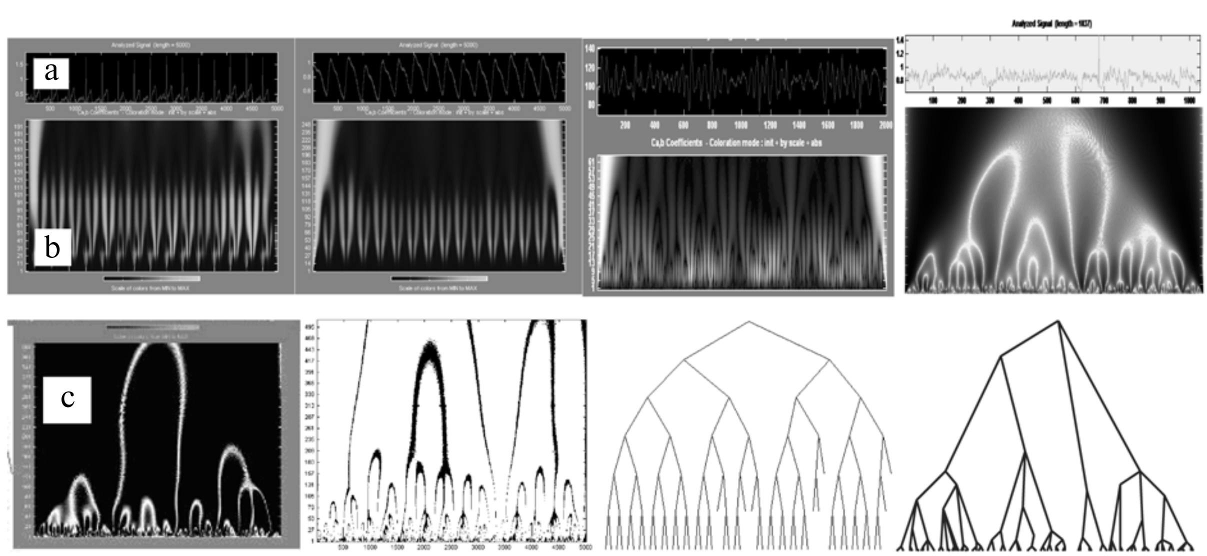
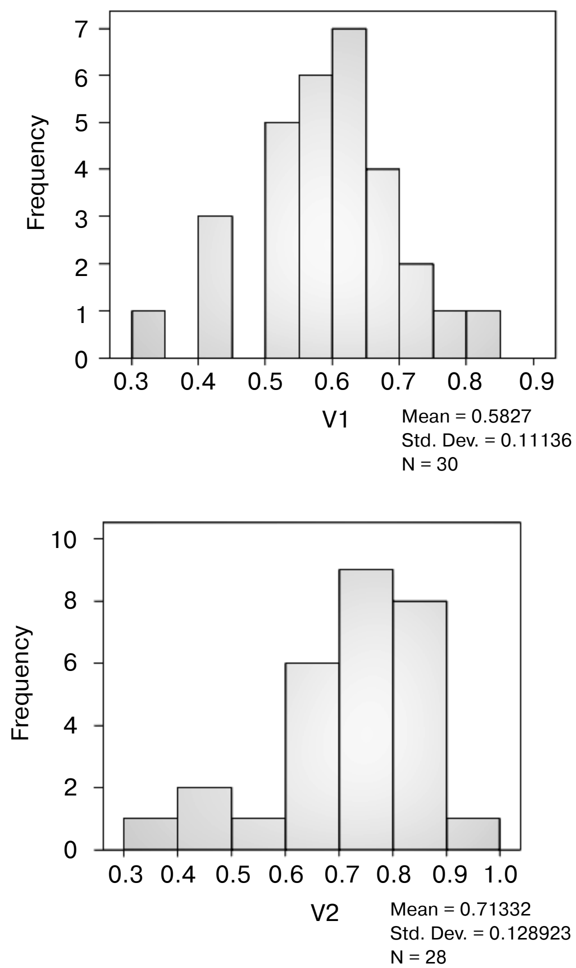


Fig. 5. a) Background cardiac electrical signal, ECG, pulsation wave, cardiointervalogram (CIG); b) wavelet analysis; c) their skeleton functions (Cayley trees).



	N	M	σ
V1	30	0.592	0.111
V2	28	0.713	0.128

Fig. 6. Estimate of renormalization invariance of CES, background cardiac electrical signal, pulsation wave, and cardiac rhythm.

TABLE 1. Pulsation Wave Scaling

i/j	0.8	0.661	0.631	0.64
1	0.656	0.727	0.791	0.803
2	0.714	0.937	0.789	0.8
3	0.333	0.84	0.8	0.75
4	0.8	0.761	0.75	0.83
5	0.65	0.625	0.555	0.76
6	0.615	0.8	0.84	0.631
7	0.75	0.5	0.666	0.5
$\overline{Sc}$	0.646	0.670	0.686	0.714
σ	0.08	0.057	0.035	0.01

TABLE 2. Cardiac Electrical Signal Scaling

i/j	1	2	3	4	5
1	0.55	0.56	0.45	0.69	0.57
2	0.66	0.61	0.77	0.53	0.31
3	0.57	0.59	0.61	0.42	0.54
4	0.62	0.65	0.51	0.82	0.75
5	0.65	0.62	0.68	0.55	0.61
6	0.75	0.53	0.41	0.67	0.53
$\overline{Sc}$	0.62	0.59	0.57	0.61	0.55
σ	0.027	0.016	0.046	0.05	0.053

TABLE 3. Cardiointervalogram Scaling

Number of cross-section	CIG skeleton scaling
1	0.6
2	0.55
3	0.56
4	0.64
5	0.67

measuring the time interval between the R wave and the excitation of the sensors attached to fingers, toes, and earlobes. The pulsation wave propagation time (ΔT) is determined from the positions of the R wave peak and the maximum and minimum of the pulsation wave. It is measured in systolic (τ_s) and diastolic (τ_d) phases (Fig. 3).

Correlation of the pulsation wave propagation time with AP is observed in load tests (Fig. 4a). Measurement of the pulsation wave propagation time and AP using, respectively, the MKM-09 monitor (Fig. 4a) and the BPLab and A&D Medical monitors (Fig. 4b) shows this correlation to be inverse. The measured values of the pulsation wave propagation time can be converted to milliseconds; AP, to mm Hg.

The software of the hardware–software system based on the MKM-09 recorder provides nonlinear analysis of test results based on wavelet transform. Fractal self-organization of biological systems is based on the principle of scale invariance [3]. The fractal array construction can be represented geometrically by a Cayley tree plotted in an ultrametric space [4].

In the renormalization invariance estimate, the skeleton functions of the wavelet transform reveal the Cayley tree structure of the analyzed process (Fig. 5c), while scaling of these functions is used to test their scale invariance. In the normal state of the human body, the distribution of scalings of biological signals and processes is normal (Fig. 6) and close to the golden ratio of ~0.618 (Tables 1-3).

Conclusion

High morbidity from cardiovascular diseases requires development of individual monitors of the CVS. Combined detection of CES, background cardiac electrical signal, and pulsation wave allows monitoring of vascular tone and its response to environmental factors. This method of monitoring does not require expensive equipment and can find wide application in practical medicine.

Nonlinear analysis of the test results provides objective evaluation of normal and pathological states of the human body. The skeleton functions of the wavelet transform reveal the structure of the process of interest, whereas the scaling procedure determines the degree of scale invariance of the process, which can be considered as a criterion of the normal functional state of the patient's health.

REFERENCES

1. Heart Rate Variability Standards of Measurement, Physiological Interpretation, and Clinical Use: North American Society for Pacing and Electrophysiology [Russian translation], IKT, St. Petersburg (2001).
2. G. M. Aldonin, Dat. Sist., No. 1, 40-44 (2008).
3. G. M. Aldonin, Robustness in Nature and Technology [in Russian], Radio i Svyaz', Moscow (2003).
4. A. I. Olemskii and A. Ya. Flat, Usp. Fiz. Nauk, **163**, 6-9 (1993).