A seismocardiography system and a possibility of its use for diagnosis of internal organs diseases using seismocardiogram information analysis

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Abstract. The work is devoted to the development of a cardioseismometer system for obtaining a seismocardiogram for informational analysis of seismocardiographic signals and diagnosis of internal organs diseases on their basis. The cardioseismometer system allows measuring angular velocity projections and the vector of apparent acceleration recorded on the chest due to the mechanical movement of the heart, calculation of heartbeat acceleration vector - magnitude and direction relative to the reference coordinate system. The most informative and available for high-precision measurement parameters of seismocardiographic signals are selected, which are compared to the parameters of the electrocardiograms measuring model used to diagnose diseases. The conclusion was made about the possibility of using the dynamics of the seismocardiographic signal main parameters for informational analysis to diagnose diseases of internal organs. Experimental research results are given.

1. Introduction

The accumulated experience of studying the variability in the main parameters of serially registered electrocardiosignals indicates that electrocardiosignals have all the properties of the signals, and the heart has all the signs of information organ. In this regard, V. M. Uspensky first substantiated and proposed the theory of information function of the heart [1, 2], and then on its basis, a technology of electrocardiosignals information analysis that has no analogues in the world practice was developed [2, 3]. Through experience in the use of technology, it was established that at the time of electrocardiosignals generation by the sinus node the programs of norms and various diseases are laid in them by amplitude, frequency and phase modulation of the main ECG parameters. Specific code templates for more than 30 of the most common and life-threatening diseases of the internal organs were obtained. On their basis, a diagnostic system "Screenfax" was created and tested, that has a long experience of more than 15 years, the use of which is detailed in the monograph [4].

The most important of this experience is the fact that the information analysis of electrocardiosignals allows for the first time to carry out with high reliability the diagnosis of internal organs diseases at any stage of development, including the initial formation stage. Diagnosis of diseases at the initial stage of
formation opens the possibility of organizing and conducting primary personalized prevention and preventive treatment to prevent the final stage fraught with life-threatening complications development. The absence of primary targeted specific prevention of the internal organs diseases is current importance problem of modern medicine. In particular, that fact explains the high reserving frequency of these diseases among the population despite the evident successes of diagnosis, but only at the final stage of their development, when therapeutic measures are not so effective, and complications are life-threatening.

An essential element of "Screenfax" diagnostic system is electrocardiograph providing electrocardiogram (ECG) capturing acceptable for the information analysis. Electrocardiographs that are widely used in medical practice are unsuitable for this purpose. Biophysical explanation of the electrocardiograph requirements allows formulating of necessary technical electrocardiograph parameters to implement technologies for electrocardiosignals information analysis [4, 5]. Further improvement of the electrocardiograph should be associated with the improvement of the element base.

Taking into account that the heart generates cardiosignals of different physical nature (electrical, magnetic, hydrodynamic and mechanical) which carry the same information improvements in their registration devices are of interest. In particular, seismocardiography system that is capable of registering seismocardiogram (SCG) reflecting the mechanical effect of the heart on the chest during its contraction in the form of seismic cardiopulses. We have assumed that the mechanical heart action with pulse nature may have the properties of signals (seismocardiosignals) with the possible use of them for information analysis.

The purpose of the study: the development of a seismocardiography system with state-of-the-art components and software for its capturing and processing, methods of main seismocardiogram parameters measuring, comparison with the dynamics of the same ECG signal parameters and reveal the possibility of their use for the diagnosis of internal organs diseases.

While a person moves and breathes, the orientation of body changes relative to the plane of the local horizon and accordingly the orientation of seismocardiography sensor measuring axes changes, that leads to distortion of the accelerometer signals due to the influence of free fall acceleration on the accelerometer data. So there is a task of measuring the orientation angles of the accelerometers sensitivity axes relative to the plane of local horizon and carrying out algorithmic compensation of the body movement.

The coordinate system associated with the seismocardiography system is shown in the figure 1, it is formed by the following axes: X-axis is directed from right shoulder to left, Y-axis is directed to the head, Z-axis is perpendicular to the XY plane and complements the coordinate system to the right.

2. Seismocardiogram signal processing algorithm
A seismocardiogram signal processing algorithm is based on a measurement model for processing an electrocardiogram that was proposed by Uspensky [6, 7].

In the process of research, a rational scheme for constructing a seismocardiogram capture was chosen and experimental samples were made [8, 9]. Figure 2 shows a picture of a seismocardiogram capture device.

The method for determining the single heart beat cycle in the seismocardiogram consists of the following sequence of accelerometers and gyroscopes signals processing. The measurements of apparent acceleration projections on the axis of the instrumental coordinate system, analog-to-digital conversion of signals and primary filtering, compensations of zero shifts and accelerometers sensitivity errors are performed. In addition, projections of the angular velocities on the axis of the instrumental coordinate system are calculated and zeros offset and gyroscopes sensitivity errors are compensated. The rotation matrix of the instrumental coordinate system relative to the reference one is calculated and then an estimation of orientation angles (roll, pitch, yaw) is performed.
This calculation is based on the angular velocities projections and apparent accelerations. After that, the value of heartbeat self-acceleration vector, its modulus and angles $\alpha$ (the angle of heartbeat acceleration vector deviation from the horizontal plane) and $\beta$ (angular orientation of the heartbeat acceleration vector relative to the $Y_b$ axis, that is directed to the head) are calculated.

The algorithm of seismocardiogram signal processing takes into account the interrelation of coordinate systems: instrumental and reference.

The result of processing of the apparent accelerations measured projections and angular velocities in the instrumental coordinate system are the modulus of the self-acceleration vector of the heartbeat, that is registered on the chest, and the angles of its orientation relative to the orthogonal coordinate system associated with the human body.

3. Experimental research

An experimental simultaneous ECG and SCG capturing was performed. Time synchronisation between signal capturing was not less than 25 microseconds.

Accelerations spectrum measured on the chest is shown on the figure 3. The results have shown that micromechanical accelerometer, in addition to low-frequency microvibrations, measures the entire spectrum of acoustic, infra-sound and infra-low frequencies. The primary sources of noise and microvibrations are compressors, ventilation, vehicles, pipelines, working machines, equipment. Production and transport noises contain infrasonic components that are not recorded by conventional measuring instruments, are not audible and have high levels of sound pressure. At the same time, the frequency spectrum of the seismocardiogram is very close to the spectrum of low-frequency sound and low-frequency microvibrations. This phenomenon complicates the task of precise seismic cardiac cycle measuring and its selection against the background of external disturbances. The appearance of a seismocardiogram does not depend strongly on the presence of additional noise components, however, as our research have shown, the amplitude variability depends on the presence of infrasonic noise during the measurement.

Figure 5 shows an electrocardiogram and a seismocardiogram (SCG), recorded with special software for the diagnosis according to the combined method of electro-seismocardiography [10]. As can be seen from the figure, a regularity is observed between ECG and SCG signals amplitude so a seismocardiogram can act as an additional source of cardiac signal parameters for information analysis.

Figure 6 shows a segment of seismic cardiac cycle acceleration module that corresponds to the time when the mitral valve is closed with the points: MC – mitral valve closure, IM – isovolumic movement, AO – aortic valve opening, IC – isotonic contraction, RE – peak of rapid ejection.

An estimation of ECG and SCG parameters variability was performed both for amplitude $R_n$ and time intervals $T_n$ between peaks corresponding to the heart contraction as shown on the figure 4. The upper plot on the figure 7 shows a comparison of time intervals $T_n$ variability calculated as $T_{n-1} - T_n$, solid plot represents $T^{SCG}_n - T^{SCG}_{n-1}$ for SCG along the Z-axis, while dashed line represents...
$T_n^{ECG} - T_{n-1}^{ECG}$ for ECG. As can be seen from the graph, there is a coincidence between ECG and SCG time intervals increments, that confirms the assumption made in the introduction about the same nature of mechanical and electrical heart activity.

![Figure 3. Seismocardiogram spectrum](image)

![Figure 4. Intervals $T_n$, $R_n$](image)

![Figure 5. An example of simultaneously recorded ECG and SCG](image)

![Figure 6. Acceleration module corresponding to a single cardiac cycle](image)

The lower graph on the figure 4 shows an example of ECG and SCG amplitude $R_n$ variability calculated as $R_{n-1} - R_n$. As can be seen from this graph, the coincidence of these variabilities is not so evident as for $T_n - T_{n-1}$, this problem is under our investigation now. One of the reasons of that may be errors in automatic SCG peaks detection (SCG signal is different from ECG: it has many extremums, the algorithm for their detection is not so simple as for ECG), but for a large number of intervals, the dynamics of ECG and SCG variability in $R_n$ increments coincides.

Diagrams of $T_n$ and $R_n$ increments were obtained by the representation of their values in the form of a flat curve connecting the points with coordinates $(T_n - T_{n-1}, R_n - R_{n-1})$. Figures 8 and 9 show examples of such diagrams. They are different for different people, the authors suggest that their appearance also carries some information about the health state.

4. Conclusion
The application of electrocardiogram information analysis technology in medical practice can be the technical basis for diagnosing diseases of internal organs at the stage of their initiation and the initial stage of development. Prevention and preventive treatment at this stage will prevent the development of final diseases stage that is dangerous for human life with its complications and help to improve the health of the population. The results of comparative analysis of main electrocardiograms and
The conducted research has shown that:

- It is possible to register the variability of the main seismocardiographic pulse, corresponding to the contraction of the heart ventricles, time intervals between these pulses and the dynamics of acceleration vector due to cardiac contraction.

- There is a parallelism in the dynamics of similar parameters for electrocardiogram and seismocardiogram signals, that indicates the prospect of seismocardiogram usage in the diagnostic systems based on information analysis of cardiovascular signals of different physical nature.
The absence of electrodes and electrode cables for seismocardiogram registration gives it a certain advantage over the electrocardiograph if it is necessary to register the cardiogram in non-standard conditions. Experimental studies have confirmed the correctness of chosen cardioseismometer schematic design solutions and algorithms of its work.

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References
[1] Uspensky V M 2008 Information Function of the Heart. Theory and Practice of the Internal Organs Diseases Diagnosis Using the Electrocardiogram Information Analysis (Moscow: Economics and information) (In Russian)

[2] Uspensky V M 2008 Information function of the heart Clin. Med. 86(5) pp 4-13

[3] Uspenskiy V M Information function of the heart. A measurement model 2011 Proc. of the 8-th Int. Conf. Measurement (Slovakia) pp 383-386

[4] Uspensky V M 2016 Information Function of the Heart. Theory and Practice of the Internal Organs Diseases Diagnosis Using the Electrocardiogram Information Analysis (Moscow: Planeta) (In Russian)

[5] Uspensky V M 2011 Information function of the heart. Biophysical substantiation of technical requirements for electrocardioblock registration and measurement of electrocardiosignals parameters acceptable for information analysis to diagnose internal diseases Proc. Joint Int. IMEKO TC1+ TC7+ TC13 Symp. (August 31–September 2, 2011, Jena, Germany) urn:nbn:de:gbv:ilm1-2011imeko-024:6

[6] Patent RU2407431 (C1) — 2010-12-27 Uspenskij V M A Method for Internal Organs Diseases Diagnosis
https://worldwide.espacenet.com/publicationDetails/biblio?II=0&ND=3&adjacent=true&locale=en_EP&FT=D&date=20101227&CC=RU&NR=2407431C1&KC=C1#

[7] Patent RU2159574 (C1) — 2000-11-27 Uspenskij V M, Kravchenko Ju G, Pavlovskij K P and Averbakh Ju I Device for Performing Express Diagnostic of Internal Organ Diseases and Oncopathological Disorders
https://worldwide.espacenet.com/publicationDetails/biblio?II=0&ND=3&adjacent=true&locale=en_EP&FT=D&date=20001127&CC=RU&NR=2159574C1&KC=C1#

[8] Achildiev V M, Basarab M A, Bedro N A, Soldatenkov V A, Evseeva Y N, Gruzevich Y K, Konnova N S and Levkovich A D 2018 Cardioseismometer unit based on micromechanical sensors Proc. of the 25-th Saint Petersburg Int. Conf. on Integrated Navigation Systems (ICINS) pp 1-10

[9] Levkovich A, Achildiev V, Soldatenkov V, Basarav V, Bedro N, Gruzevich Y, Evseeva Y, Konnova N and Komarova M 2018 Seismocardiography system based on micromechanical sensors Proc. Int. Conf. IIERI on Medical Physics, Medical Engineering and Informatics (Basic Clin. Pharmacol. Toxicol.) 123 (Denmark:Wiley) pp 9-10

[10] Achildiev V M, Basarab M A, Bedro N A, Soldatenkov V A, Gruzevich Y K, Evseeva Y N, Konnonova N S, Levkovich A D and Uspensky V M 2018 Electroseismocardiography system consisting of a high resolution electrocardiograph and a seismocardiography system based on micromechanical sensors Proc. 4th Int. Conf. “Electronic component base and microelectronic modules” of the Int. Forum "Microelectronics-2018" (Moscow: Technosphera) pp 514-6 (In Russian)