Application of an automated complex resistance and phase difference measuring method for rheographic studies of human cardiovascular system

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Abstract. The structure of an automated system for measuring the complex resistance of the human body and the phase difference is proposed. It is used in the rheographic method for diagnosing human cardiovascular system diseases using a multilevel microcontroller structure. The metrological analysis of the automated system made it possible to achieve an increase in the measurement accuracy both by reducing the methodological and instrumental components of measurement errors. The relative basic measurement error does not exceed ± 0.5%.

1. Introduction

The relevance of the human cardiovascular system study is conditioned by a sharp increase in diseases associated with it and high mortality from them. There are several methods and well-known instruments for non-invasive measurement of the human body parameters, in particular the cardiovascular system. One of these methods is rheography [1]. Using this method, the following parameters of the cardiovascular system can be measured: blood volume (OS) for the recorded areas, cardiac contractile ability (SPS), determined by the amplitude of the systolic wave on the thoracic differential rheogram, stroke volume of the heart (VOS), reduction in heart rate (HR) is determined by processing rheograms (contractions per minute), blood minute volume (MCV), blood volume index or blood volume (TC) of a region, and several dozen other parameters of a person's cardiovascular system.

Such an informative method of medical research confirms the relevance of improving its principles and measurement methods in order to increase their accuracy by conducting metrological analysis. This method allows you to examine large vessels of the human circulatory system for clogging with blood clots. To do this, it is required to place at least four electrodes on one limb (two input and two output) on the upper and lower parts of the limb.

2. The structure of the software and hardware rheographic complex system

The authors have developed an automated information system and a system for complex resistance and phase difference measuring for studying the human cardiovascular system parameters (Figure 1) [2]. The central node in it is the master microcontroller, which controls the slave microcontrollers via the I²C interface [3, 4]. Slave microcontrollers (of which there can be up to 127 units in the system) generate a digital signal of various frequencies, which is fed to a digital-to-analog converter (DAC).
There it is converted into an analog signal with a given frequency and amplitude. The signal frequency can be adjusted by the user from 1 to 100 kHz. It is known that the rheography method works only at frequencies up to 100 kHz, since the complex impedance reactive component weakens at frequencies above 10 kHz, and at frequencies above 100 kHz it has no effect [5]. The received analog signal enters the stage of operational amplifiers (OA) and through the electrodes passes through the human body, where at the receiving electrode the signal goes to the receiving stage OA, where it is amplified. Then, the amplified signal passes through a low-pass filter (LPF) and enters the input of a digital-to-analog converter (ADC), from where the value of the difference between the input and output voltage of a signal of different frequencies is formed in the registers in the slave microcontroller. Data is transmitted over the I²C interface to the master microcontroller from each slave microcontroller. The host microcontroller processes the received packets and transmits them via the USB interface to a personal computer (PC) for displaying the obtained complex resistance and phase difference values in the dialog menu.

![Block diagram of the proposed rheographic complex.](image)

The results obtained from medical practice and scientific developments show that at the moment a multichannel measuring system manifests itself best in the method of the human body composition impedance analysis. In this regard, the use of several devices of the same type, the control of which will be based on the I²C data bus, will provide a multichannel mode of simultaneous measurements with a minimum arrangement of devices in a miniature device [6, 7].

The use of the multichannel measurement mode provides a more accurate heart rate and stroke volume calculation by averaging the data obtained in different parts of the human body. The use of the device multichannel operation mode will be useful when carrying out surgical operations on the limbs, on different body parts to let the surgeon have information about the amount of blood flowing through the vessels in parallel with the control of the patient's pulse in front of him. In emergency situations, this method is able to calculate the volume of blood in case of closed extremities injuries, which does not enter the injured area if blood flow is impaired.

The use of external operational amplifiers can reduce matching errors. The main purpose of the external interface is to expand the ADC dynamic range by bringing the voltage offset of the output measuring signal to the input OA, and to reduce the output impedance of the measuring circuit, since it is added to the measured one and can introduce a significant error [8].
3. Functioning of the measuring complex

The control of the rheographic hardware-software complex and the measurement results processing is carried out according to the method, which is implemented in software using a PC, master and slave microcontrollers [5, 9]. The master microcontroller contains a control program that controls the slave microcontrollers, sends control signals to each of them, and receives the obtained values. Then it transfers them to the PC. In this case, the leading microcontroller transmits the obtained results of the complex resistance calculation to the program dialog box on the PC. The slave microcontrollers generate voltage signals at different frequencies to measure the complex impedance of the human body part and process the measured values of the voltage passing through the human body to calculate the complex resistance and phase difference. An integrated transducer of the impedance spectral composition in a wide frequency range is built on the basis of a slave microcontroller, in which the active (R) and reactive (X) components of the impedance Z are calculated for each frequency, from which the impedance modulus is then calculated:

$$|Z| = \sqrt{R^2 + X^2}$$

and its phase:

$$\varphi = \arctg \left( \frac{X}{R} \right),$$

and packets of the received data on the complex resistance and the difference of the phase value are formed for transmission to the master microcontroller. In turn, the main component of the complex resistance is $X_c$ – the capacitive resistance of the human body. It is determined by the formula:

$$X_c = \frac{1}{2f\pi C}$$

where $f$ – probing signal frequency, $C$ – capacity of the human body. The inductive component contribution to the final measured impedance is extremely small.

Measurement of the phase difference between the probe current source signal and the recorded signal allows to formalize the effect of the skin resistance capacitive component on the impedance through the measured signal mathematical processing, which helps to reduce the error of measurement results.

By the calculated difference in the blood volumes readings through the measured areas at the same test signal frequency and the same pulse, one can judge about the weakening of the blood flow. This value will depend on the blood vessel length, the degree of clogging with blood clots, the vessel elasticity [9, 10]. The implementation of this technique will make it possible to formulate conclusions about the state of large blood vessels, which, in fact, is an alternative to such generally accepted diagnostic methods as computed tomography and magnetic resonance imaging [12].

4. Conclusion

The structure of an automated system for the human body complex resistance and the phase difference measuring is proposed. It is used in the rheographic method for diagnosing human cardiovascular system diseases with an error of no more than ± 0.5%. The measurement results allow to indirectly calculate such parameters as the stroke volume of the heart, the amount of blood rolled through the vessels, etc. Processing and display of the results obtained using the automated system can be displayed in graphical and tabular form, as well as stored in a database for further research.

An increase in the measurement accuracy is also achieved by improving the hardware implementation and the method of the human body conductivity multifrequency measurement, followed by the capacitive parasitic component of the measured signal calculation.

References

[1] Malakhov A I, Tikhomirov A N, Shchukin S I, Kobelev I A, Kobelev AV, Belenkov Yu N, Shakaryants G A and Kozhevnikova M V and Kaplunova V Yu 2016 Electroimpedance
Methods of Investigation of Cardiac Activity *Journal Cardiology* 56 (12) 33–39

[2] Golubkov P E, Pecherskaya E A and Karpanin O V and Kraynova K Y 2018 Automated system for bioimpedance measuring *Proc. International Conference of Young Specialists on Micro/Nanotechnologies and Electron Devices* pp 641–644

[3] Tsai B, Birgersson E, Birgersson U 2018 Mechanistic multilayer model for non-invasive bioimpedance of intact skin *Journal of Electrical Bioimpedance* 9 31–38

[4] Artamonov D V, Baranov V A, Pecherskaya E A, Pushkareva A V and Tsypin B V and Fimin A V 2019 Application of a Hyper-Complex Impedance Model for Indirect Measurements of Materials Parameters of Functional Electronics *Proc. International Conference of Young Specialists on Micro/Nanotechnologies and Electron Devices* pp 760–764

[5] Kawala A, Khoma V and Zmarly Y D and Sovyn Y 2008 Use of Wavelet Transform for Qualification of Rheograms Characteristic Points *Journal Plezegland Elektrotechniczny* 84 (3) 132–133

[6] Leonov S D, Obrazcov S A and Troickiy Y V 2011 A Bioimpedance Meter Measuring both Active and Reactive Components *Journal Biomedical Engineering* 45(4) 128–131

[7] Podyacheva E , Zemlyanukhina T and Shadrin L and Baranova T 2020 Features of Hemodynamics of Pulmonary Circulation During the Diving Reflex *Journal Biological Communications* 65 (3) 244–251

[8] Didenko V I and Ivanov A V 2009 A Metrological Approach to the Investigation of the Quantization Noize of Delta-Sigma ADCs *Measurement Techniques* 52 (5) 521–527

[9] Righetti X and Thalmann D 2010 Proposition of modular I2C-Based wearable Architecture *Proc. 15th IEEE Mediterranean Electrotechnical Conference “MELECON”* pp 802–805

[10] Dobrynina L A, Gnedovskaya E V, Shabalina A A, Sergeeva A N and Kravchenko M A and Nikolaeva N S 2018 Biomarkers and mechanisms of early vascular damage *Journal of Neurology and Psychiatry* 12 (2) 23–32

[11] Balkanov A S ,Gaganov L E and Stashuk G A and Sherman L A 2008 To the mechanism of edema around malignant brain glioma *Vestnik rentgenologii i radiologii* 4–6 55–58

[12] Zakharova N E, Danilov G V, Potapov A A, Pronin I N, Alexandrova E V, Kravchuk A D, Oshorov A V, Sychev A A and Polupan A A and Savin I A 2019 The prognostic value of MRI-classification of traumatic brain lesions level and localization depending on neuroimaging timing *Zhurnal Voprosy Nejrokhirurgii Imeni N N Burdenko* 83(4) 46–55