Software designed to digitize transitional characteristics when conducting bioimpedance studies on a biological object

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Abstract. The essence of the article is to develop a method for the formation of descriptors intended for neural networking classifiers of medical risks based on the analysis of transition processes in the biomaterial in the in vivo experiment. The essence of the proposed method is to form the test effects of the probing current on the anatomical areas with anomalous electrical conductivity and obtaining the amplitude-phase-frequency characteristics of the impedance of the biomaterial to which the test effect was carried out. The coordinates of the Cowl's graphic were used as descriptors. Cowl's graphic was obtained on the basis of the conversion of Carson counts of the transition process in a quadrupole, the element of which is the impedance of the studied biomaterial. A sequence of unipolar rectangular pulses was supplied to the inlet of the quadrupole. It is shown that the linear model of the biomaterial impedance allows you to obtain descriptors based on its amplitude-phase-frequency characteristics, taking into account the dissipative properties of the biomaterial. The receipt of the Cowl's graphic model with its dissipative properties, allows you to build medical risk classifiers for socially significant diseases.

1. Introduction

Any risk of worsening health and reducing the life expectancy of a person is a medical risk requiring its assessment. Nowadays the risks of oncological, cardiovascular and infectious diseases are most common [1, 2, 3, 4]. For timely and high-quality diagnosis of medical risk, it is necessary to use the decision-making support subsystems (DMSS) as part of the information system. This is due to the fact that the diagnosis of medical risk requires simultaneous screening of a large population group in order to detect oncological, cardiovascular diseases, viral infections [3, 5, 6]. In [7, 8, 9, 10], it was shown that diagnostic systems can be built on the basis of the methodology of bioimpeant studies based on changing the values of electrical conductivity in bioactive points (BAP). Conducted studies in [11, 12, 13, 14, 15] revealed the effects of weak currents on BAP.

The most effective method is based on the construction of the Cowl's graphic. This method is based on the amplitude-phase-frequency performance (APFP) of a two-pole equivalent to the impedance of the biomaterial included in the zone of the probing current source [11]. It should be noted that when conducting biimepered studies, it is necessary to comply with the requirements of the morphological homogeneity and intact of biomaterial. Since the frequency range of the probe current is quite large, and the movement step on this range should be sufficiently small to take into account the dissipative properties of the biomaterial impedance, the measurement process requires a long time. Therefore, to implement the above requirements becomes problematic.

Thus, to determine the impedance of the biomaterial Z (jω), it is necessary to set the rect(t).
where the \( A \)-amplitude of the \( \text{rect}(t) \), pulse, \( \tau \)-duration of the \( \text{rect}(t) \), \( T \) - the pulse period \( \text{rect}(t) \), \( N \) is the pulse number \( \text{rect}(t) \). In the sequence, \( n = 1, 2, ...N \).

Thus, the Cowla's graphic for biomaterial can be determined by one transition characteristics of the four-pole or a set of transition characteristics with averaging them in time or by frequency.

2. Materials and methods
Taking into account the analysis and results of the work obtained in [3, 15, 16, 17] for bioimpedence studies on a biological facility, a software and hardware complex (SHC) was also designed and tested. Devices included in the designed SHC, and the tasks performed by them are shown in Figure 1.

![Diagram of the SHC](image)

**Figure 1.** Block diagram of the SHC

Connection with bio-object is carried out by using the probe. A module of high-speed SHC with USB 2.0 interface - E20-10 manufactured by CJSC L-Card (http://www.lcard.ru) was used as a conversion unit. It should be noted that the pack allows not only to digitize, but also to visualize the transition process according to the specified parameters.

3. Results and discussion
The RAD STUDIO XE8 with the existing L-Card library (Liscari Lcome) was used as the software development environment. The choice of this environment is due to the availability of the use of ready-made applications for working with ADC, DAC and the ability to visualize various information data with their subsequent scaling.

The developed software product implements the main functions using four modules, the interaction circuit which is presented in Figure 2.

![Diagram of interaction of software product modules](image)

**Figure 2.** Scheme of interaction of software product modules
The first MainF module (Fig. 2) is the main module of the software product, which is designed to organize the operation of the interface with the input parameter entry module, view the data obtained during the execution of experiments (data display is implemented as graphs). It transmits control to other software product modules, as well as communicates with the L-Card module.

The functioning of the second DigitalThread module (Fig. 2) implements interaction with the ADC and DAC.

The software was developed in the Delphi Rad Studio XE 8 environment using libraries in module 3 (Lisbari and Lcome).

The fourth TViewChar module (Fig. 2) is designed to display the transitiona\[\text{(2)}\]l characteristics.

When modeling the transient characteristics in BAP, the biomaterial is represented by an equivalent scheme of the passive RC-two-pole proposed by Cowla \[3, 13, 14\].

The transitional characteristic is the reaction of the linear system on the Heaviside step function and is one of the energy characteristics of the BAP \[3\]. The operator resistance Z (S) of the two-pole is determined according to the formula \[3\]:

\[
Z(s) = \frac{R + R_s + sR_sR_C}{1 + sR_sC}
\]  

Heaviside’s pulses are formed by the E20-10 module and are fed to the biomaterial from the exit of the DAC, and the transition process is observed on the \(R_T\) resistor, on which the voltage transmitted to the computer is formed. The impedance of the biomaterial is determined by the law of Ohm:

\[
Z = \frac{U_{ax} - U_{anex}}{I_{RT}},
\]  

where the \(U_{ax}\) is the voltage at the inlet of the four-pole, the \(U_{anex}\) - the voltage at the outlet of the four-pole, \(I_{RT}\) - the current in the \(R_T\) resistor equal to the biomaterial. Considering that \(I_{RT} = U_{anex}/R_T\) and believing that \(\text{Re} Z >> R_T\), we get:

\[
Z = \frac{U_{ax}(t)}{U_{anex}(t)} \cdot R_T
\]  

If there are \(n\) discrete samples on the measuring circuit at the output of the circuit \(U_{anex}[n] (n=0, \ldots N-1)\), then the discrete conversion of the Fourier of the output signal is:

\[
U_{anex}[m] = \sum_{n=0}^{N-1} U_{anex}[n] e^{-j\frac{2\pi nm}{N}}.
\]  

In this case, the spectral characteristics of the four-pole is defined as:

\[
S[m] = \sum_{n=0}^{N-1} U_{anex}[n] e^{-j\frac{2\pi nm}{N}}
\]  

where \(M=N-1\) is the number of discrete samples of APFP, \(m=1 \ldots M, \Delta t\) - sampling step \(U_{anex}(t)\).

To build a Cowla's graphic (APFP) of biomaterial, it is necessary to move from the spectral characteristics of the four-pole to the biomaterial impedance.

\[
Z[j\omega] = \frac{R_T}{S[j\omega]}
\]  

For the \(m\)-th point of the Cowla's graphic:

\[
Z[m] = \frac{\Delta t \cdot M \cdot R_T}{2 \cdot \pi \cdot m} \sum_{n=0}^{N-1} U_{anex}[n] e^{-j\frac{2\pi nm}{N}}
\]  

Impedance is a comprehensive value and depends on the frequency. Therefore, it is characterized by a Cowla's graphic, which is a set of points on the complex plane - the coordinates of the complex vector Z, each of which corresponds to a certain test voltage frequency.
To build the Cowla's graphic, it is necessary to go to the coordinate system (ReZ, ImZ), replacing the exponent with trigonometric functions of the Euler, according to the formula:

\[ e^{-\frac{j2\pi n}{N}} = \cos\left(2\pi \frac{m \cdot n}{N}\right) - j \cdot \sin\left(2\pi \frac{m \cdot n}{N}\right) \]  \hspace{1cm} (9)

The algorithm for constructing the Cowla's graphic was developed and implemented on the basis of transition samples, based on the values of the values of the real and impedance of the biomaterial impedance on the frequency system for \( R_T = 1000 \) Ohms, shown in Figure 3.

![Figure 3](image3.jpg)

**Figure 3.** Dependence of the real and imaginary parts of the biomaterial impedance on the frequencies

The process of obtaining the data by means of the L-Card to search for the BAP is implemented on the basis of the algorithm shown in Figure 6. In the first block of this algorithm, the user is set to the sampling frequency \( \Delta, \Delta e \) [0.15 kHz, 10 MHz], the frame size of the frame \( T \), which corresponds to the time interval and determined as a product of the number of counts by the size of the sampling step. In the second block, the value of constant voltage is established, affecting the biomaterial \( U, U_e \) [0, 3.5V], as well as the initial and final time of research.

When digitizing data, we obtain two channels: the first corresponds to the values of the transition characteristic, and the second values of the DAC (Figure 4).

![Figure 4](image4.jpg)

**Figure 4.** Interfaces of the visualization mode software product

4. Conclusion
The process of digitizing the transition characteristic on the bio-object is given. To control the dynamics of the electrical properties of the biomaterial, it is advisable to use the currently vehicle characteristics of the biomaterial in the anomalous electrical conductivity zones obtained by reversible linearly changing voltages.
The advantages of the SHC designed are as follows:
- it allows not only to digitize, but also to visualize the transition process according to the specified parameters.
- the simplicity of work using SHC does not require any additional training;
- scaling graphs occurs automatically, which makes it possible to detailed viewing the process of obtaining transitional characteristics;
- the method of formation of descriptors, which will be used for neural networks of medical risks, based on the analysis of transition processes in the biomaterial in the experiment in vivo.

In the future, the developed SHC will provide the ability to work with previously saved files, and a procedure for changing the possibilities of visualization, which contributes to a detailed study of transitional characteristics. An important prospect of the development of this SHC may be the establishment of risks of infectious diseases, which can help with primary diagnosis in a pandemic. This system can be used for additional diagnostics in hospitals or commercial organizations providing medical services.

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