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Software of information-measuring system for electric impedance tomography of biological objects

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Abstract. This article describes the development of software for an electrical impedance tomography device that solves the problems of controlling the acquisition unit, primary processing and transmission of measurement data, their further processing on a personal computer, reconstruction, visualization and saving of results. Software modules are defined, algorithms for their functioning are developed, and their block diagrams are shown. An algorithm for the interaction of electrical impedance tomography device software modules with each other has been developed. A graphical interface for the device software has been developed. An algorithm for interaction with EIDORS software has been developed.Criteria for experimental testing of the functioning of the developed software have been developed, and possible errors in the operation of each module have been identified.

1 Introduction

Electrical impedance tomography (EIT) is a medical imaging method characterized by a large number of computational operations, which requires the use of the computing power of at least a personal computer. The market for ready-made software for EIT is represented by proprietary solutions from manufacturers of EIT devices with limited compatibility, which also do not allow fine-tuning of the research process, which imposes significant restrictions on the use of such software in scientific research.
In this regard, the task arises of developing software to ensure full compatibility with our further hardware developments of the EIT.

The software of the information-measuring system for electrical impedance tomography of biological objects, EIT software [1-3], must solve the following problems:
- management of EIT device;
- visualization of the results of measuring potentials φ_i on the surface of the biological object (BO);
- processing the results of measuring potentials φ_i on the surface of the BO;
- saving measurement results in the form required for the program for reconstruction and visualization of the internal structure of the BO;
- the ability to change the parameters of the measurement process.

- reconstruction and visualization of the spatial distribution of conductivity in the BO with saving of the results [4].

Thus, the EIT software consists of the following modules:

- module of initialization and establishment of initial parameters (MIP);
- device control module (DCM);
- module for processing measurement results (MPMR);
- module for reconstruction and visualization (MRV).

2 Results and discussion

An algorithm for functioning of the EIT software has been developed. The block diagram of the functioning of the algorithm [5] is presented in Figure 1.

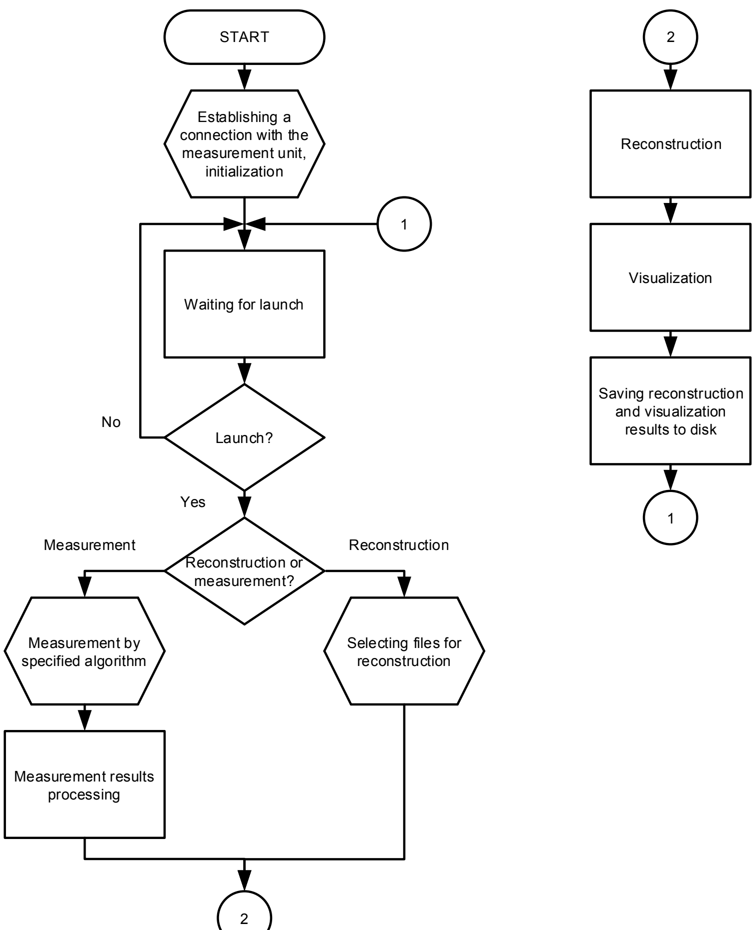

Fig.1. Block diagram of the functioning algorithm of the EIT software

After the program starts, the initial values of the software parameters are set and a connection is established with the EIT device. Next, the program waits to be launched. After pressing the start button, the required action is checked. If it is necessary to perform a reconstruction based on the available data, the program accesses the MRV module, displays the visualization result and goes into launch standby mode. If it is necessary to reconstruct the distribution for the BO connected to the device, the software accesses the DCM module and starts the process of obtaining data to reconstruct the conductivity distribution according to a given algorithm. The result of measuring the potential φ_i is transmitted to the MPMR module, where they are processed and transferred to the MRV module. After visualizing the reconstruction results, the program saves the reconstruction and visualization results and waits for the next launch.

2.1 Description of the main software modules

In MIP device parameters are set (gain of the analog input path K_{in}; ADC conversion frequency f_{ADC}; control signal source; shape, amplitude $U_{A\mathrm{cont}}$, frequency f_{cont} of control signal U_{cont}) and parameters for measuring the potential amplitude φ_{iA} (experiment brief description; algorithm for obtaining data for reconstructing the conductivity distribution), a path is set for saving the measurement results and reconstruction results. DCM generates control commands for EIT software to carry out the measurement process in accordance with the specified algorithm and measurement parameters. MPMR processes the results of measuring the potential φ_i and saves them into a text file prepared for the program for reconstruction and visualization of the internal structure of the BO. Based on the measurement results and measurement parameters, MRV reconstructs and visualizes the internal structure of the BO.

2.2 Development and description of a detailed algorithm for the functioning of each module of the EIT software. Functional block diagram

The MIP module stores variables and initial settings. The following options are available:
- gain of the analog input path K_{in};
- ADC frequency f_{ADC} [6];
- frequency f_{cont}, shape and amplitude $U_{A\mathrm{cont}}$ of the control voltage for the device current source CS;
- source of control voltage U_{cont} (DAC [7] or external generator);
- path to the folder for storing measurement results;
- a comment with a brief description of the experiment (for example, a description of the location and type of heterogeneity in the BO).

The DCM module operates as follows. If the built-in DAC is used as a source of the control signal, then the parameters of the control signal (frequency f_{cont}, shape and amplitude $U_{A\mathrm{cont}}$) are read from the MIP. Based on these data, a data array is formed containing a sampled control signal U_{cont}. The sampling frequency of the control signal is equal to the sampling frequency of the DAC f_{DAC}. Next, taking into account the parameters of the MIP module, the DAC is initialized and launched. An array describing the control signal is written to the DAC buffer, from which data is streamed to the DAC output. Next, code D is output to the digital lines of the MK, containing the address code of the switch K for connecting the electrodes E_i according to a given algorithm for obtaining data to reconstruct the conductivity distribution.

After connecting the electrode E_i to the common point, and the electrode E_{i+1} to the CS, the process of measuring the potentials φ_i on the surface of the BO starts. Taking into account the parameters of the MIP module, the ADC is initialized. During initialization , parameters such as the number n of the electrode E_i , the gain of the analogue input path K_{in}, and the ADC frequency f_{ADC} are set. Streaming ADC data input into the ADC buffer is started. The number of potential measurement results φ_i that contains information about 5 periods of change in potential φ_i at the ADC input is read from the ADC buffer. The sampling result from the ADC buffer is transferred to the MPMR module. The memory occupied by the ADC buffer is released, and the ADC is stopped. The contents of the DAC buffer are updated. All described actions are repeated from connecting the electrodes to the CS and the common point until stopping the ADC for the next pair of electrodes specified in the data acquisition algorithm for reconstructing the conductivity distribution. The described actions are repeated until the specified algorithm is implemented. The DAC is stopped and control is transferred to the MPMR module. The block diagram of the operating algorithm of the DCM module is presented in Figure 2.

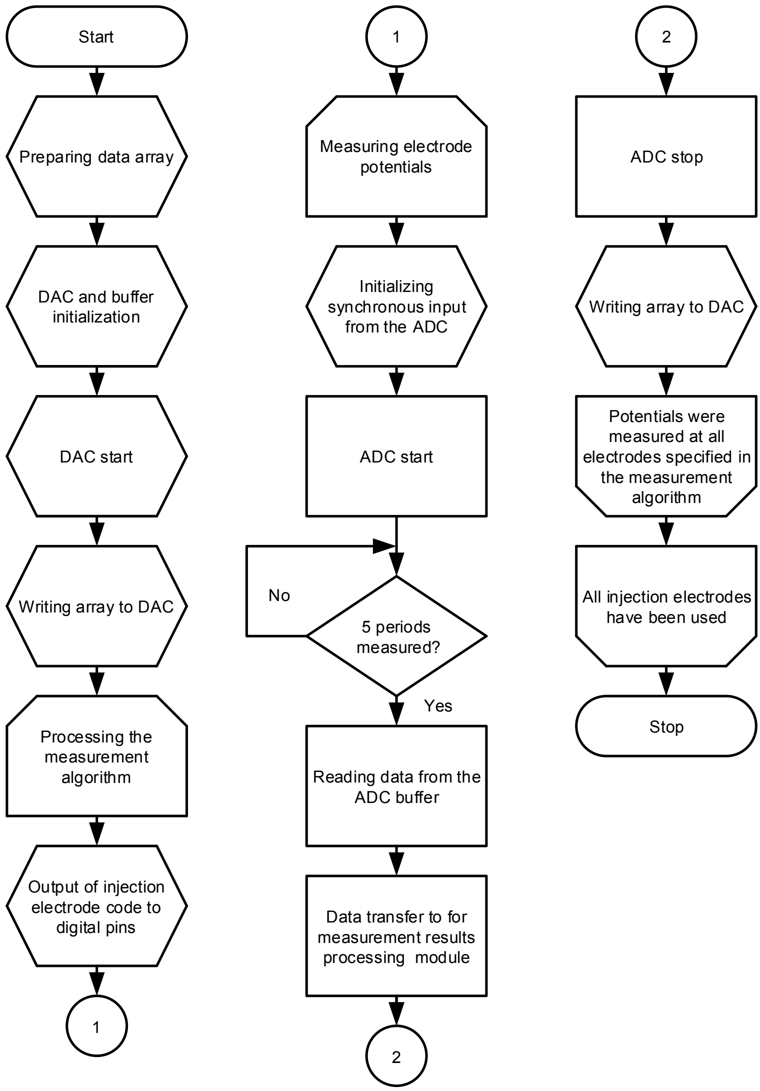

Fig.2. Block diagram of the operation algorithm of the DCM

The MPMR module converts measurement results from ADC codes into voltage, taking into account the calibration coefficients K_{cal}. Based on information about 5 periods of potential change φ_i on the electrode E_i for each configuration of injecting and measuring electrodes, the amplitude value of the potential φ_{iA} is calculated. Based on the resulting array of amplitude values of the potential φ_{iA}, the MPMR module prepares a data file for reconstructing the conductivity distribution in the BO, which is saved along the path stored in the MIP. In this case, the file name is formed from the time and date of the measurement. The data file contains a comment with information about the structure of the experiment, including the shape, amplitude *I* and frequency *f* of the injected current. The block diagram of the MPMR operation algorithm is presented in Figure 3.

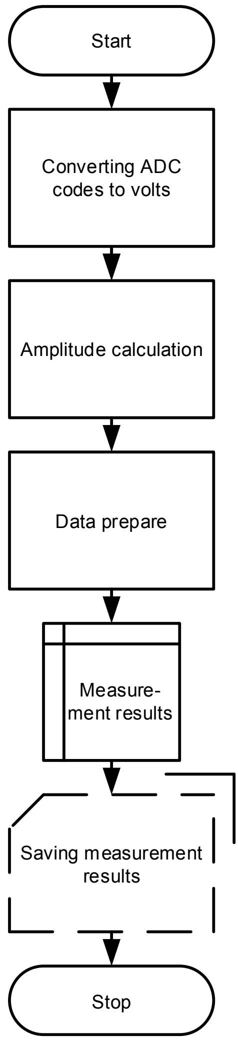

Fig.3. Block diagram of the MPMR operation algorithm

The MRV module transmits the path to the data for reconstruction to the reconstruction and visualization program through the console. The program is implemented using *EIDORS software* [8] in the *Octave* environment [9].

2.3 Development and description of an algorithm for the interaction of software modules of the EIT device with each other. Interaction block diagram

A block diagram of the interaction of EIT device software modules is shown in Figure 4. The MIP module prepares the launch of the EIT device software. DCM reads the parameters of the data acquisition process for reconstruction and visualization of the conductivity distribution in the BO (brief description of the experiment; algorithm for obtaining data for reconstruction of the conductivity distribution, gain of the analogue input path Kin; ADC frequency f_{ADC}; control signal source; shape, amplitude U_{Acont}, frequency f_{cont} of the control signal U_{cont}) from the MIP and controls the operation of the EIT device. The results of measuring 5 periods of change in potential φ_i on the electrode E_i for each configuration of injecting and measuring electrodes are transferred to the MPMR module. Upon completion of the work of the DCM, the control will be reorganized by MPMR. The path to the data file and measurement parameters are read from the MIP. Upon completion of the work, control is transferred to MRV.

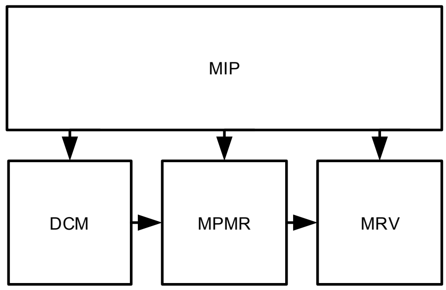

Fig. 4. Block diagram of interaction between EIT software modules

2.4 Development and description of the EIT software interface

A graphical interface [10] of the EIT device software has been developed. The screen form is shown in Figure 5. The interface is divided into 2 parts - the main panel and the settings panel. The main panel is shown in Figure 5(a). The settings panel is shown in Figure 5(b).

The main panel contains control buttons, indicators and charts. The "*Meas*" button starts the measurement process, the "*Rec&Vis*" button starts the process of reconstruction and visualization of the conductivity distribution in the BO. Switch "*Input/Output*" allows to measure the control voltage U_{cont} at the input of the CS. In the line "*Module name*" the name of the connected L-Card I/O board [11] is displayed. In the line "Measurement time, ms" at the end of the measurement process, the time in milliseconds spent on obtaining data for reconstruction and visualization of the conductivity distribution in the BO is displayed. The indicator "Intermediate measurement results/Control signal" displays intermediate measurement results of 5 periods of change in potential φ_i on the electrode E_i for the current configuration of the measuring and injection electrodes, or 5 periods of control voltage U_{cont} at the *CS* input. Between the "Intermediate measurement results/Control signal" indicator and the "Final measurement results" indicator there is a scale that fills as you approach the end of the data collection process for reconstruction and visualization of the internal structure of the BO. The "Final measurement results" indicator displays data for reconstruction and visualization of the internal structure of the BO - the amplitude value of the potential φ_{iA} for each configuration of injecting and measuring electrodes described in the data acquisition algorithm. The "Measurement time, ms" indicator should display the time t that has elapsed since the start of the data collection process for reconstruction and visualization of the BO conductivity distribution and until the software results are saved.

The settings panel contains controls. *Gain* control sets the gain of the analogue input path K_{in}. Possible positions of the control element are from 1 to 4. Value 1 corresponds to $K_{in} = 1$ (measurement range ±10 V). Value 2 corresponds to $K_{in} = 4$ (measurement range ±2.5 V). Value 3 corresponds to $K_{in} = 16$ (measurement range ±0.625 V). Value 4 corresponds to $K_{in} = 64$ (measurement range ±0.15625 V). The control element "ADC frequency, kHz" sets the ADC conversion frequency f_{ADC}. Frequency change limits 1 Hz – 200 kHz. The control element "Control voltage frequency, kHz" sets the frequency f_{cont} of the control signal U_{cont}.

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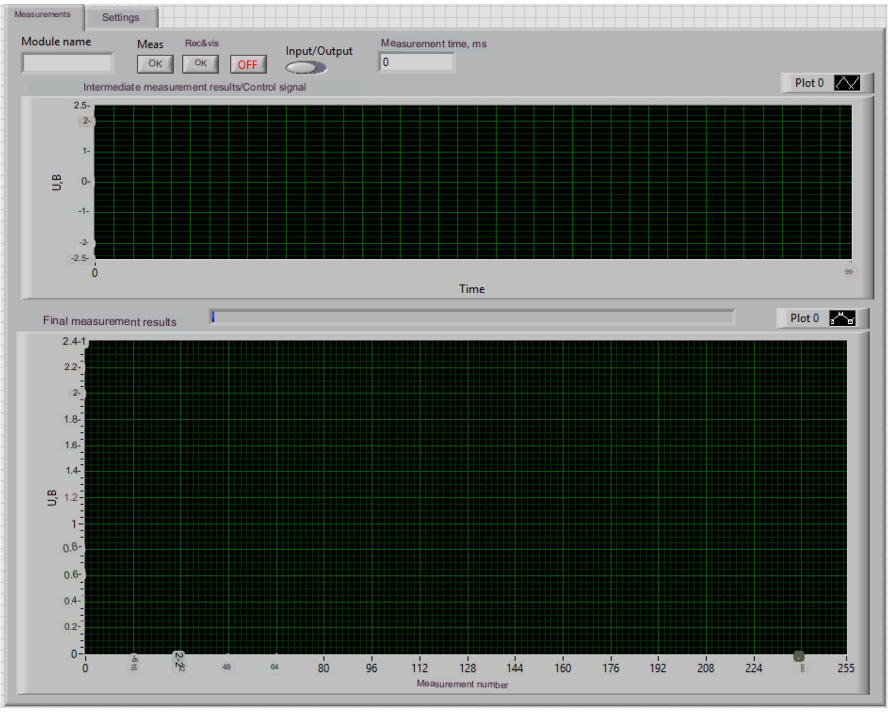
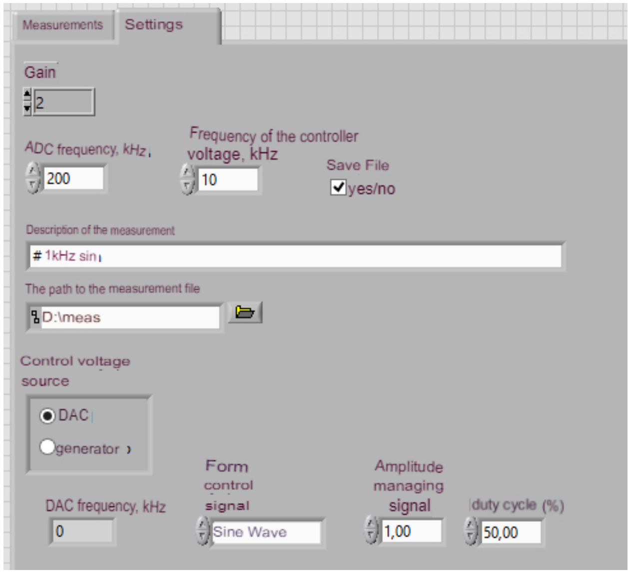
Variation range 1 Hz – 20 kHz. The “Save file” control allows you to disable saving the results of measuring the amplitude value of the potential φ_{iA} and the results of reconstruction and visualization of the internal structure of the BO. If there is a checkmark, saving is carried out. The “Measurement Description” control element allows you to leave a comment describing the experiment being carried out, which will be added when saving the measurement results of the amplitude value of the potential φ_{iA} and the results of reconstruction and visualization of the internal structure of the BO. The “Path to measurement file” control allows you to specify the path to the folder to save the results. The “Control voltage source” switch allows you to select the source of the control signal U_{cont} - an external generator or a built-in DAC. The “DAC frequency, kHz” indicator shows the current sampling frequency of the DAC f_{DAC}. The “Control signal shape” control element allows you to select the shape of the control signal U_{cont} from 4 proposed options - sine wave (*Sine Wave*), triangular signal (*Triangle Wave*), sawtooth signal (*Sawtooth*) and rectangular pulses (*Square Wave*). The control element “duty cycle, %” sets the duty cycle of rectangular pulses. Range is 1 – 99%. The control element “Amplitude of control signal, V” sets the amplitude U_A of the control signal U_{cont}. Range of change 0 – 4.5 V.



a)



b)

Fig.5. Main front panel (a) and settings panel (b)

2.5 Description of the interaction algorithm with EIDORS

Interaction with EIDORS is done by launching the console version of *Octave* from *LabVIEW* [10]. After launching in *Octave* in console mode, the MRV module transmits information about the path to the data files and calls a **.m* file with the text of the program for reconstruction and visualization of the distribution of the internal structure of the BO. The program is written using *EIDORS* libraries and functions. The result of the program is an image of the internal structure of the BO. The image is displayed in a separate window. An example of the displayed window is shown in Figure 6.

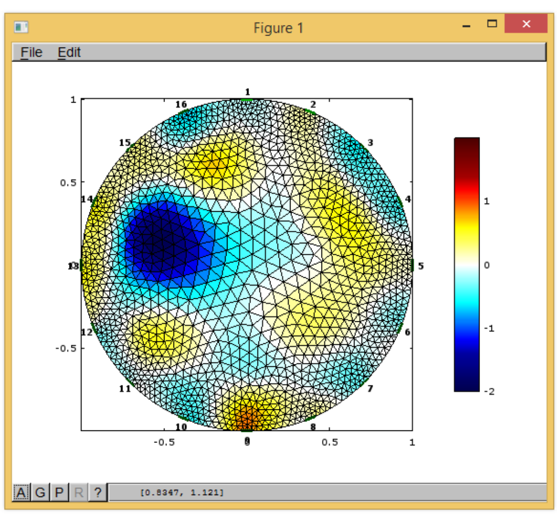


Fig.6. Example of a window with the result of visualization of BO internal structure reconstruction

2.6 Description of the research algorithms

At the moment, the following measurement algorithm has been implemented. Electrode E_1 is connected to the common point, electrode E_2 to *CS*. The potentials $\varphi_1..\varphi_{16}$ are measured on the electrodes $E_1..E_{16}$ relative to a common point. Next, electrode E_2 is connected to the common point, electrode E_3 to *CS*. The potentials $\varphi_1..\varphi_{16}$ are measured on the electrodes $E_1..E_{16}$ relative to a common point. And so on until electrode E_{16} is connected to the common point, and electrode E_1 to *CS*. Based on these data, the potential difference $\Delta\varphi_i = \varphi_i - \varphi_{i+1}$ between adjacent electrodes is calculated. EIT device allows you to connect *CS* to any of the 16 electrodes E_i and measure the potential φ_i relative to a common point on any of the 16 electrodes E_i. In this way, it is possible to calculate the potential difference $\Delta\varphi_i$ between any pair of electrodes.

2.7 Description of algorithms for setting parameters, saving experiment results, displaying the measurement process, displaying results, and other algorithms for the functioning of the software

The results are saved as follows. When the MPMR module is launched, a table of string type variables is formed in RAM. The first line of the table is a comment on the experiment and the measurement time. Next are descriptive lines for the Octave environment, containing the following information: array name, type, number of rows and columns. This information forms the file header. Next are the measurement results converted from a numeric type to a string type. The separator is the transition sign to the next line. The end time of the measurement is read in the format DD:MM:YYYY:HH:MM:SS. This string variable is the name of the file being created. The path to the folder for saving the results is read from the corresponding variable in the MIP module. Based on this information, a text file with the extension *.dat is created.

Interaction with EIDORS occurs as follows. The software calls the Windows command line, which runs the console version of Octave. The console version includes commands for reading specified data files and running a *.m file containing a program for reconstructing and visualizing the spatial distribution of conductivity in the BO.

Measurement parameters are set using the controls on the front panel of the EIT software.

2.8 Software requirements assessment

The minimum system requirements for EIT software are summarized in Table 1.

Table 1. Minimum system requirements

CPU	Pentium 4 (or equivalent) or higher
RAM	1 GB
Screen resolution	1024x768 pixels
O.C.	Windows 7 SP1 and higher
Free disk space	5 GB
I/O board driver	lusbapi3 and higher
Pre-installed software	Octave3.8.0; EIDORS 3.7.1

2.9 Checking the functionality of software modules

Checking the functioning of the MIP is carried out by monitoring the setting of the initial parameters: gain of the analogue input path K_{in} (default 2); ADC conversion frequency f_{ADC}

(default 200 kHz); frequency f_{cont} of control signal U_{cont} (default 10 kHz); the "Save file" control is set to "yes"; control signal shape of U_{cont} (default "*Sine Wave*"); amplitude U_{Acont} of the control signal U_{cont} (default 1 V). If there is an error in establishing communication with the EIT device, the message "Device not detected" is displayed and the software is terminated. Checking the correct installation of the control signal U_{cont} is possible by pressing the "*Meas*" button with the "*Input/Output*" switch in the "*Input*" position. After this, the control signal U_{cont} will be generated at the output of the DAC. The generated signal will be connected to the Y1 input of the ADC. The result of measuring 5 periods of the control signal U_{cont} will be displayed on the "Intermediate measurement results/Control signal" indicator.
The DCM check is carried out based on the presence of measurement results and their form. Possible errors are summarized in Table 2.

Table 2. Errors during operation of the DCM module

Error	Message text	Software actions
DAC initialization error	"DAC initialization error"	Completing the program
DAC startup error	"DAC startup error"	Completing the program
Errors in outputting the code of switches K to digital pins	"Digital output error"	Completing the program
ADC initialization error	"ADC initialization error"	Completing the program
ADC startup error	"ADC startup error"	Completing the program
Error reading data from ADC buffer	"Error reading data from ADC buffer"	Completing the program
ADC stop error	"ADC stop error"	Completing the program

To assess the correct implementation of the algorithm for obtaining data for reconstruction and visualization of the internal structure of the BO, a special load consisting of 16 precision resistors of the same value (R = 220 ± 0.01 Ohm) is connected to the device. One terminal of resistors R is connected to one of the electrodes E_1 .. E_{16}, the second terminals are connected to each other. When starting a measurement on a given load, for every 16 points on the measurement results graph there should be one point with a value of 0.25±0.1 V, followed by a point of 2.3±0.1 V, the remaining points should have a value of 1.3±0.1 V.
The performance of the MPMR is determined by the presence of measurement results on the graph and a file with measurement results in the specified path. If there are no results, you need to check the connections in the device.
The performance of the MRV is determined by the presence of the reconstructed image. If there are errors while running Octave, messages are displayed with the error text issued by the Octave environment. For example:
"error: load: unable to find file %meas_path%/file.dat
error: called from:
error: %Octave-path%\recons_and vis.m at line 17, column 1".

2.10 Checking the functionality of the software graphical interface

The functioning of the elements of the main panel of the graphical interface is checked by evaluating the result of interaction with the panel elements. After pressing the "*Meas*" button, the process of obtaining data for reconstruction and visualization of the conductivity distribution in the BO should start. When the "*Input/Output*" switch is in the "*Input*" position, the "Intermediate measurement results/Control signal" indicator should display 5 periods of the control signal U_{cont}, the parameters of which (shape, amplitude U_{Acont} and frequency f_{cont} of control signal U_{cont}) are specified in the settings panel. When the "*Input/Output*" switch is in the "*Output*" position, intermediate measurement results of the potential φ_i for the current configuration of the injection and measuring electrodes should appear on the "Intermediate measurement results/Control signal" indicator. As the images change on the "Intermediate measurement results/Control signal" indicator, the measurement progress visualization scale and the "Final measurement results" indicator should begin to fill. By pressing the "*Rec&Vis*" button, the process of reconstructing the conductivity distribution in the BO should start. After 20±5 seconds, a window with the results of visualization of the reconstruction results will appear. The "*OFF*" button ends work with the software. If the program is launched successfully, in the line "*Module name*" the name of the connected *L-Card* I/O board should appear . Upon completion of the measurement process, the time *t* should appear in the line "Measurement time, ms" , elapsed from the moment the data collection process was started for reconstruction and visualization of the BO conductivity distribution and until the results of the programs were saved. The time is displayed in milliseconds. Depending on the frequency of the injected current, the time *t* should be in the range from 18 to 40s.

Checking the functioning of the elements of the graphical interface settings panel. When changing the value of the "*Gain*" switch, the limits of the vertical scale of the "Final measurement results" indicator of the main panel should change. When changing the value in the line "Control voltage frequency, kHz", "Control signal shape" or "Control signal amplitude, V", the corresponding parameter of the control signal U_{cont} at the DAC output must change. Change on the top graph of the main panel can be checked by pressing the "*Meas"* button with the *"Input/Output"* switch in the "*Input*" position on the "Intermediate measurement results/Control signal" indicator.

3 Conclusion

Software for the EIT device has been developed to solve the problems of controlling the unit for collecting, processing and transmitting measurement data, processing it, reconstructing it, visualizing it and storing it. Software modules are defined (module for initialization and setting of initial parameters, module for controlling the unit for collecting, processing and transmitting measurement data, module for processing measurement results, module for reconstruction and visualization), algorithms for their functioning are developed, and their block diagrams are presented. An algorithm for the interaction of software modules of the EIT device with each other has been developed, and a block diagram of this algorithm is presented. A graphical interface for the EIT device software has been developed. An algorithm for interaction with EIDORS software has been developed. System requirements for the developed software have been determined.

Criteria for experimental verification of the functioning of the developed software have been developed, possible errors in the operation of each module and the processing of these errors by the software have been identified.

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