

Problems of Development of Continuous Multi-Belt Monitoring in Electroimpedance Tomography on the Basis of Data Acquisition System with LabVIEW Software

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Abstract: The study describes the problems of implementation of the method of multi-belt electrical impedance tomography based on the L-Card data acquisition system with software developed in the LabVIEW graphical programming environment. The limitations of associated hardware component as well as steps to eliminate them also described. As a result, a program for managing the data acquisition and transmission device for multi-belt electrical impedance tomography was developed and allows continuous long-term monitoring.

Key words: Data acquisition systems, I/O card, multi-belt electrical impedance tomography, implementation, LabVIEW, long-term monitoring

INTRODUCTION

Known method of medical imaging Electrical Impedance Tomography (EIT) (Aleksanyan *et al.*, 2016, 2017). One of the significant advantages of this method in comparison with other widely used methods of medical imaging (magnetic resonance imaging, X-ray computed tomography, etc.) is the possibility of continuous monitoring during any desired period of time. On a continuous monitoring based functional EIT (Frerichs *et al.*, 2004) which allows to investigate the dynamic processes in the human body (for example, breathing or blood circulation). This study presents the main problems of the implementation of continuous monitoring by the EIT method based on L-Card solutions in the LabVIEW graphical programming environment.

MATERIALS AND METHODS

A block diagram of the multi-belt electrical impedance tomography device is proposed, shown in Fig. 1 where the BO is the Biological Object on which measurements are made, MU is the Measurement Unit, MC1, ..., MCn are the electric potential recording devices for each belt.

Consider the design of the MC1 device for collecting and transmitting data for electrical impedance tomography of biological objects from a separate patient belt. It contains an Electrode Block (EB) 3, injecting current generator 4, a voltage measuring block 5 on passive measuring electrodes and a Microprocessor Block (MCB)

6. The injecting current generator 4 consists of Current Source (CS) 7 and multiplexer unit (BMG) 8 and the output of the CS is the input of BMG. Voltage measurement unit 5 consists of a Multiplexer Unit (BMU) 9 and analog-to-digital converter 10 and the output of the BMU is the input of the Analog-Digital Converter 10 (ADC), the output of the ADC is connected to the measuring input of the MCB. The outputs of the MCB are connected to the control inputs of the BMG and BMU and the EB contains electrodes and a common electrode and is made in the form of independent electrode belts connected simultaneously to the BMG and BMU. The MCB is configured to control the CS, BMG and BMU as well as monitor the quality of mounting of each electrode, primary mathematical processing of the measurement data, exchange data with the Personal Computer (PC) 2 (Aleksanyan *et al.*, 2015) (Fig. 2a).

On the basis of the structural scheme, a functional diagram of a data acquisition and transmission device for electrical impedance tomography was developed (Fig. 2b).

The quality of the results of conduction variation field reconstruction taken by the EIT method directly depends on the stability of current I passing through the BO during data acquisition to form one tomographic image as well as on the measurement error of potential differences ΔF on the BO surface. Therefore, it is advisable to use ADC/DAC modules. The researchers chose the ADC/DAC USB module L-Card E-502 (Anonymous, 2018). This module is included in the Russian State register of measuring instruments and has

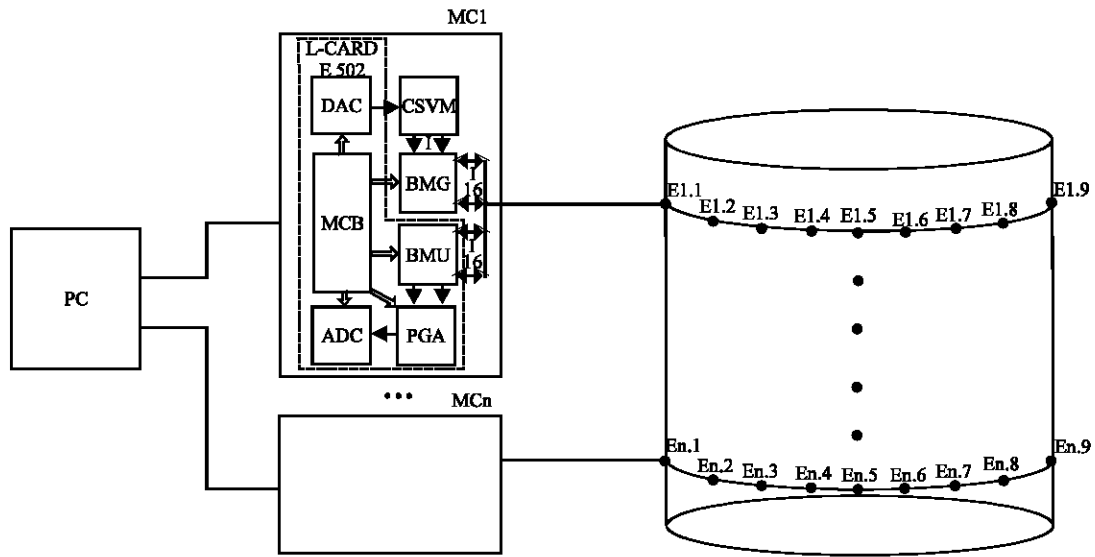


Fig. 1: Block diagram of the device multi-belt electrical impedance tomography

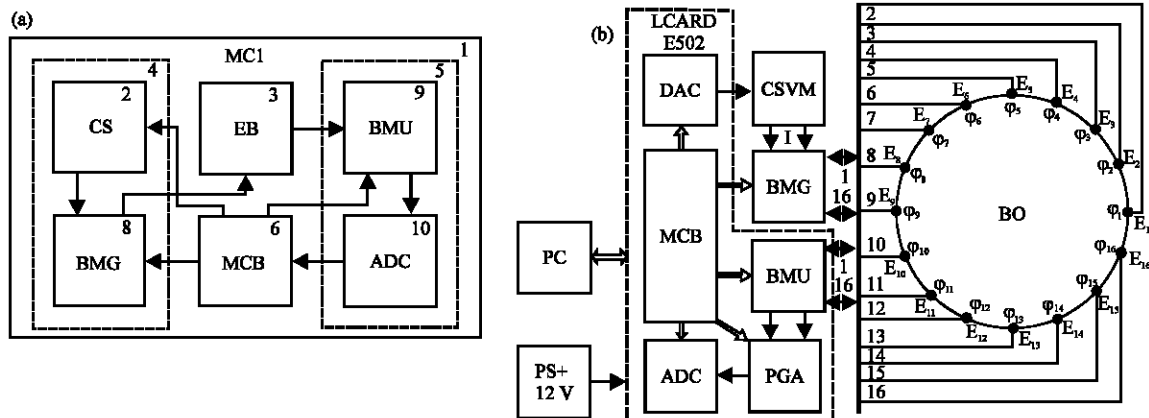


Fig. 2: Structure: a) Function and b) Diagrams of data acquisition and transmission channel for electrical impedance tomography

on its board everything necessary to implement the EIT Method: ADC c multiplexer unit for 16 differential channels and programmable differential amplifier, DAC and digital outputs, USB interface and galvanic isolation of the interface part and the data acquisition/output part. The main technical characteristics of the board are summarized in Table 1.

Thus, the E-502 board makes it possible to measure the potential difference from various electrodes of the, control BMG and control the shape, frequency and amplitude of the current at the CS output using the voltage at the DAC output as well as interact with the PC. In addition, the SDK for working with the board supports working with the development environment and the platform for running LabVIEW programs.

Evdokimov *et al.* (2007) which has rich capabilities for the implementation of virtual instruments and processing of measurement signals.

Development of the electrical impedance tomography data collection and transmission device management program: The implementation of continuous long-term monitoring implies that all actions on the transfer of control actions, the receipt, transmission and processing of measurement information as well as EIT reconstructions must be carried out in real time, i.e., the time for complete processing of one set of measurement information should not exceed the time it was received. At the same time, the time for obtaining one set of measurement data should be minimal and be significantly

Table 1: Main technical characteristics of the E -502 I/O board

Parameters	Values
ADC bit depth	16
ADC sampling frequency (MHz)	2
Measurement range of input signal (V)	±10; ±5; ±2; ±1; ±0.5; ±0.2
Limits of permissible reduced error of measuring DC voltage (%)	Not more than 0.2
Input impedance at differential input (MΩ)	Not <40
Common mode rejection ratio (dB)	Not <70
Resistance to overloads of the input measuring signal of DC Voltage (V)	±15
Bit width	16
DAC sampling rate (MHz)	1
Range of change of the output signal (V)	±5
Total number of digital TTL-compatible general-purpose inputs (pcs)	17
Maximum frequency of synchronous input (MHz)	2
Total number of TTL-compatible digital outputs (pcs)	16
Maximum frequency of synchronous output (MHz)	1
USB 2.0 data transfer rate (High Speed) (Mbit/sec)	160
Power supply (V)	+8, ..., +30
Galvanic isolation of USB and measuring circuits	Present

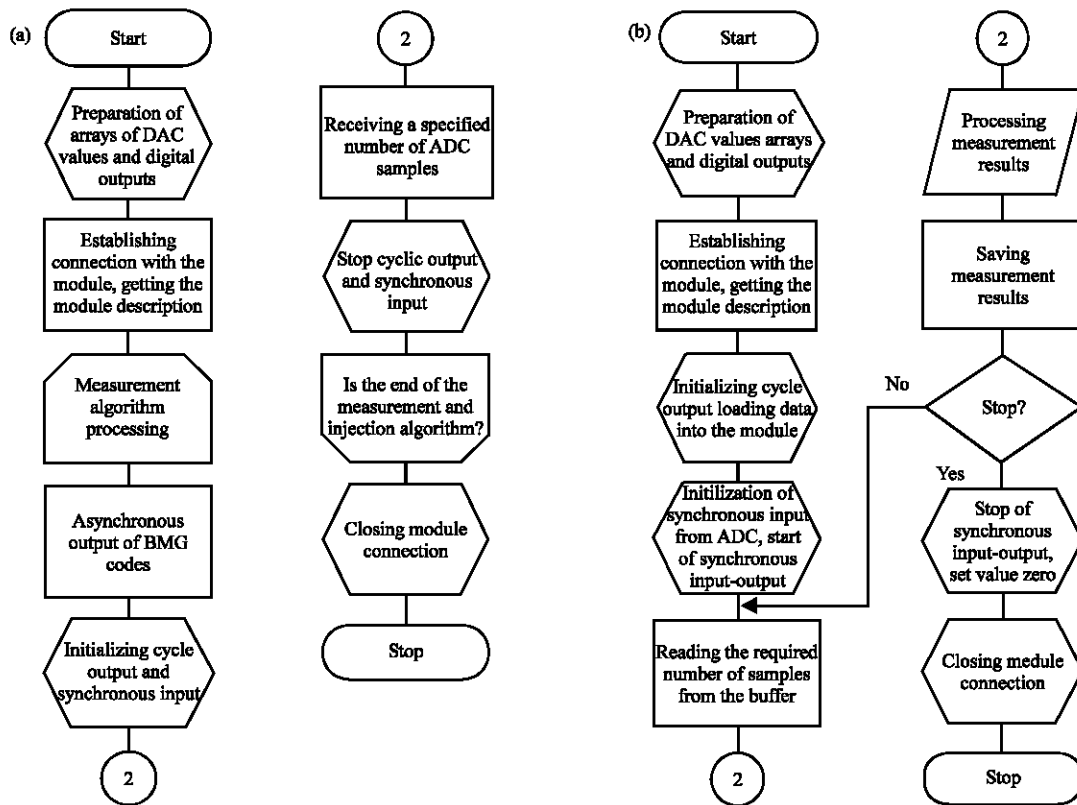


Fig. 3: A block diagram of the I/O card control algorithm: a) Version 1 and b) Version 2

less than the period of flowing biological processes (i.e., it is necessary to minimize the change in conductivity in BO during the acquisition of one set of measurement data).

In general, to implement the EIT method, it is necessary to connect CS to a given pair of electrodes and measure the potential difference between another given pair of electrodes. It simultaneously uses the output of the control signal of the Current Source Voltage

Management unit (CSVM) to the DAC, the output of the digital control codes of the BMG and the BMU as well as the input of data from the ADC. L-Card E-502 supports the following modes of operation (Anonymous, 2018) (Fig. 3):

- Synchronous input
- Synchronous stream output
- Cyclic output
- Asynchronous output

By default, after switching on, all channels are in asynchronous mode of operation. In this mode when you call the asynchronous I/O function, a single input/output of the specified information is performed and the delay from the function call to the data measurement for input or setting the specified value for the output is not exactly defined. In synchronous mode, data transfer at a specified frequency, that is the time between adjacent measurements or the output of neighboring readings is determined. With synchronous input, the module performs measurements with a specified frequency and transmits data through an interface to a buffer from which it can be queried at any time. Similarly, for synchronous output, the module reads data from the buffer as needed and displays the read samples with a given frequency. Cyclic output is a variant of synchronous output; in this mode, the signal from the buffer is cyclically outputted without the need for further paging.

For input, ADC readings, digital input values are available. For the output, the samples of the first channel of the DAC, the samples of the second channel of the DAC and the values of the digital outputs are available. Each of these channels can operate in both synchronous and asynchronous mode. In addition, each channel can be configured individually, that is you can perform, for example, asynchronous input of digital lines with the synchronous streaming collection from an ADC or output a signal in a synchronous stream to one DAC channel mode while in the other set the values asynchronously. The only exception is that it is impossible to perform asynchronous input from the ADC with the synchronous data collection from digital inputs.

Thus, to implement the EIT method, it is necessary to use synchronous streaming input from the ADC, cyclic output to one DAC channel and asynchronous output to digital outputs. Block diagram of the module control program L-Card E-502 for obtaining measurement information for EIT is shown in Fig. 3a.

RESULTS AND DISCUSSION

Problems in the implementation of program management devices the data collection and transmission of electrical impedance tomography: Implementation of control algorithm for I/O board L-Card E-502 developed in the LabVIEW graphical programming environment allows to obtain a set of measurement data (256 measurement periods 5-difference changes and the potential at the frequency of the injected current 20 kHz) for EIT for ~40°C which is unacceptable for the functional implementation of the method EIT. Such a duration of research is due to the fact that the initialization process of the ADC/DAC as

well as stopping streaming I/O takes from 100-300 msec. In this case, the initialization process should be carried out for each pair of measuring electrodes, since, the switching of the BMU is performed when the ADC is initialized. When initializing the synchronous input, you can specify the switching order of the switches, however, in this case, the sampling rate of the ADC is divided equally between all the BMU states and drops to 125 kHz at 16 electrodes. Although, in this case it is possible to reduce the time for obtaining measurement information for EIT to ~1 sec, however, the sampling frequency does not allow the injected current to be used with a theoretical frequency of more than 62.5 kHz (Marks, 2009). At the same time for ~1 sec, one full cycle of cardiac activity occurs in the body, therefore, the conductivity does not remain constant during the measurement.

Thus, the required at least one BMU, controllable similarly to BMG. The block diagram of the control algorithm is shown with an external BMU in Fig. 2b. This implementation of the data acquisition and transmission control program for EIT allows us to receive 208 measurements of 5 periods of change of potential difference at a frequency of injected current of 20 kHz in 52 msec (~19 frames per sec) and an increase in the frequency of injected current reduces the time to receive one set of measurement information to such that it is necessary to increase the number of measured periods of change in potential difference. Otherwise, the time for processing the measurement information and for reconstructing the field of change in conductivity begins to exceed the time for obtaining one set of measurement information for EIT reconstruction. For perception comfort, the researchers of the maximum frequency of data acquisition for EIT reconstruction is limited to 25 frames per sec.

In this implementation, the use of asynchronous digital output control codes BMU and BMG is impractical. The use of synchronous output to digital outputs allows you to rigidly determine the switching time of the BMG and BMU which simplifies the further processing of the measurement information.

Shift register management with digital outputs on the E-502 card: In the case of the 16-electrode data acquisition and transmission system for electrical impedance tomography, 16 channel analog multiplexers are used (for example, DG406 manufactured by Vishay Siliconix). To control such multiplexers, 4 address inputs are required. Each of the BMU and BMG contains two multiplexers controlled separately. Therefore, 16 digital pins of the L-Card E-502 are required. It is also required to translate the multiplexer outputs into a high-impedance

Table 2: Array of states of digital outputs

Operations	RCLK	SRCLK	SER	SRCLR
Reset internal register values	0	0	0	0
Allow write to internal buffer	0	0	0	1
Output of the 8th data bit (A3 of multiplexer 2)	0	0	0	1
Record the 8th data bit (A3 of multiplexer 2)	0	1	0	1
Output of the 7th data bit (A2 of multiplexer 2)	0	0	0	1
Record the 7th data bit (A2 of multiplexer 2)	0	1	0	1
Output of the 6th data bit (A1 of the multiplexer 2)	0	0	0	1
Record the 6th data bit (A1 of multiplexer 2)	0	1	0	1
Output of the 5th data bit (A0 of multiplexer 2)	0	0	0	1
Record of the 5th data bit (A0 of multiplexer 2)	0	1	0	1
Output 4th data bit (A3 of multiplexer 1)	0	0	1	1
Record the 4th data bit (A3 of multiplexer 1)	0	1	1	1
Output of the 3rd data bit (A2 of multiplexer 1)	0	0	1	1
Record the 3rd data bit (A2 of multiplexer 1)	0	1	1	1
Output of the 2nd data bit (A1 of the multiplexer 1)	0	0	1	1
Record the 2nd data bit (A1 of the multiplexer 1)	0	1	1	1
Output of the 1st data bit (A0 of the multiplexer 1)	0	0	1	1
Record the 1st data bit (A0 of the multiplexer 1)	0	1	1	1
Output data from the internal register output buffer	1	0	0	1

state outside the measurement process to eliminate the effect of IT on the patient’s body. This requires the use of another digital output. Thus, it is necessary to expand the number of digital outputs of the L-Card E-502. For this, shift registers are used. Unfortunately, the SDK for working with the L-Card E-502 does not contain ready-made solutions for working with shift registers, therefore, it is required to create a subroutine for forming an array of states of digital outputs that implements the process of writing data to the register.

The researchers used the 8-bit shift register SN74HC595 from Texas Instruments. One shift register per pair of multiplexers is used. Each register has 5 control inputs: SRCLK clock input, SER serial data input, OE high-resistance switching input pin, RCLK synchronization control input pin, SRCLR register reset input. Transition of pins to the high-resistance state and reset of the register values is performed simultaneously in the BMU and BMG, so, you can use 8 digital outputs instead 10 to control the BMG and BMU using shift registers. An example of an array of digital output states for the shift register SN74HC595 for connection 1 (0000 value of the A3..A0 address pins) and 16 (1111 value of the A..A 0 address pins) electrodes are presented in Table 2.

Thus, 19 cycles of synchronous output on the L-Card E-502 digital outputs are spent on switching one pair of measuring and injecting electrodes. During this time, the ADC generates 38 samples which must be excluded from the analysis.

CONCLUSION

The use of universal input/output systems for analog and digital signals in a PC allows to implement a device for

collecting and transmitting data for electrical impedance tomography with high metrological characteristics in the shortest possible time. This study describes some of the ways to circumvent bordering th architecture I/O board and its software. The use of LabVIEW also allows you to significantly speed up the software development process due to the rich possibilities of interaction with the data acquisition system and the processing of measurement information.

The result was implemented as a program control device in the data collection and transmission to electrical impedance tomography, allows continuous monitoring long lead with frequency imaging the internal structure of 10-25 frames per sec depending on the frequency of the injected current I. When the device is no interframe delay. The device is implemented on the basis of the I/O board L-Card E-502, the control program is implemented in the LabVIEW graphical programming environment.

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