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Wareable mobile measuring device based on electrical tomography

Abstract. *In this article, we describe modelling of an advanced system of electrical tomography for biomedical applications. The collection of tomographic data must be as fast as reliable, in order to take into account the algorithms of reversing the tomography with almost real-time update. To provide a high-level application programming interface using standard communication protocols and execute user-level programs. System architecture and prototype designs for biomedical electrical tomography are presented. Details of the implementation are explained for two prototype devices: a separate FPGA / microcontroller chip and a hardware microprocessor containing a system that contains a microprocessor, peripherals and an FPGA system. The algorithms of electrical reconstruction of impedance tomography have been tested. New results of the reconstruction of the numerically simulated phantom were presented. The calculations were made for the defined model by solving the inverse problem.*

Streszczenie. *W tym artykule opisujemy modelowanie systemu zaawansowanej platformy tomografii elektrycznej do zastosowań biomedycznych. Zbieranie danych tomograficznych musi być tak szybkie, jak niezawodne, aby uwzględnić algorytmy odwracania tomografii z niemalże aktualizacją w czasie rzeczywistym. Aby zapewnić interfejs programowania aplikacji wysokiego poziomu przy użyciu standardowych protokołów komunikacyjnych i wykonywać programy na poziomie użytkownika. Przedstawiono architekturę systemu i projekty prototypów dla biomedycznej tomografii elektrycznej. Szczegóły implementacji objaśniono dla dwóch prototypowych urządzeń: oddzielnego układu FPGA / mikrokontrolera i mikroprocesora sprzętowego zawierającego układ, który zawiera mikroprocesor, urządzenia peryferyjne i układ FPGA. Przetestowano algorytmy elektrycznej rekonstrukcji tomografii impedancyjnej. Przedstawiono nowe wyniki rekonstrukcji symulowanego numerycznie fantomu. Obliczenia zostały wykonane dla zdefiniowanego modelu poprzez rozwiązanie problemu odwrotnego. (**Przenośne mobilne urządzenie pomiarowe oparte na tomografii elektrycznej**).*

Keywords: — Electrical Tomography; Image Reconstruction; Biomedical Signals.
Słowa kluczowe: tomografia elektryczna; rekonstrukcja obrazu, sygnały biomedyczne.

Introduction

The platform consists of a data collection device and an aggregation and processing mechanism to generate useful information for diagnosis or for initial monitoring of physiological changes in the body [2-6,13-18]. The tomographic platform will enable the monitoring of physiological processes using the observed changes in electrical conductivity. Considering surface and subsurface information and using hybrid algorithms, new insights can be explored more closely, for example: physiological changes can be related to a specific pathology, the patient's health status can be estimated or a more accurate assessment of drug therapy effects can be provided. The information generated by the platform will be used in diagnostics in order to facilitate the interpretation of patients' medical condition [1.7-12].

Electrical tomography (ET) for biomedical purposes presents structural differences in the general electrical impedance tomography (gpEIT):

- Strengthening is limited by international medical standards regarding current level and frequency. In gpEIT, the current and frequency can be as high as devices and region of interest (ROI) can resist.
- The impression should be transferred with the help of electrodes on the surface of the skin. In gpEIT, the electrodes can be inserted into the ROI or ROI area and can be immersed in an EIT tank filled with electrolytic fluid.
- The stimulation / sensing of data collection and tomographic reversal must be as fast as possible to ensure visualization of the monitored patient in real time. In gpEIT, fast data acquisition and real-time visualization are optional.
- Biological soft / hard tissue is a complex multi-scale matter (colloids -> cells -> tissues -> organs -> body). In gpEIT ROI is often made of simple materials.
- The rhythm and dynamics of the human body modify the surface / volume of organs, e.g. in the case of lung or heartbeat monitoring, but also in the case of tissue inflammation, muscle contraction / muscle elongation among many other dynamic processes. In gpEIT, ROI is mostly considered a static object.

System architecture

The main module is an integral part of the mobile measuring device. Its functionality includes: acquisition of measurement data, initial processing of measured data, calibration of active electrodes, transfer of measurement data to the web-server system and power supply of the entire system. The digital part of the main module is in progress. The analogue part will be created in the next two weeks. The patient is equipped with a measuring device with a sensor system. Two signal classes are considered:

- electrical biopotentials: ECG, EMG, bio-impedance,
- other available signals: temperature, humidity, etc.

The signals are processed in the Analog Front-End analog module. Essentially, its task is to amplify the weak signal to the level required by the analog-to-digital converter (ADC) to ensure the desired quality of the digital signal. In addition, the module should provide pre-filtering of the signal. Then the digital signal is processed by the FPGA. The architecture of the system is shown in the diagram Fig. 1. The bio-interface of the sensor / actuator is a grid measuring n elements, i.e. Electrodes. Digital Signal Processing Device - device for digital processing of medical tomography signals.

Its basic functionalities include:

- controlling an analog switch, switching the injection / measurement function,
- reading and processing of signals (measurement results) in parallel,
- generating a signal for excitation.

The analog switch module will be responsible for switching the excitation signal or reading to / from the corresponding electrodes. Our concept is based on the use of a dedicated system consisting of an FPGA system, a microcontroller, a communication module and a computer with an operating system.

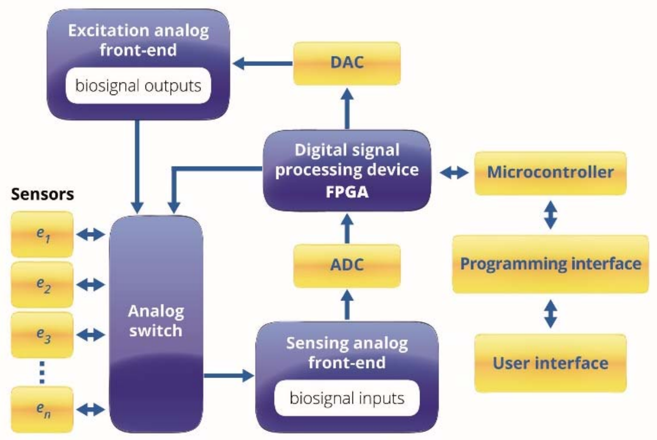


Fig. 1 Block diagram of the measurement system.

Measurement belt

The dominant solution when it comes to the electrode bearing system in EIT systems is the belt. The tape is fastened in a strictly defined position. At the moment, the measuring tape consists of two elastic belts connected together by means of the Velcro system, respectively a main belt with a width of 10 cm, which is responsible for fastening the belt on the chest and an inner belt 315 with a width of 4 cm with signaling electrodes. The inner belt has a length of 1 m and is equipped with 16 electrodes. This means that the electrodes are placed around the chest every 6 cm. The designed device measures both ECG and ET signals. Test ECG rubber electrodes were made. The results did not differ from the Ag / AgCl electrodes.

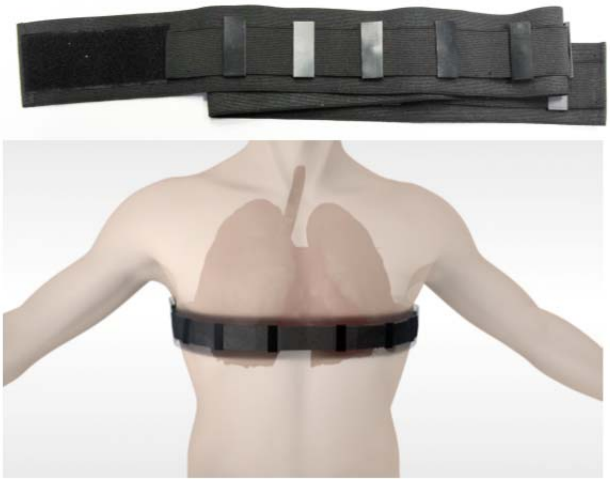


Fig.2 A photo of a measuring strip with installed measuring electrodes and a visualization of its location on the chest.

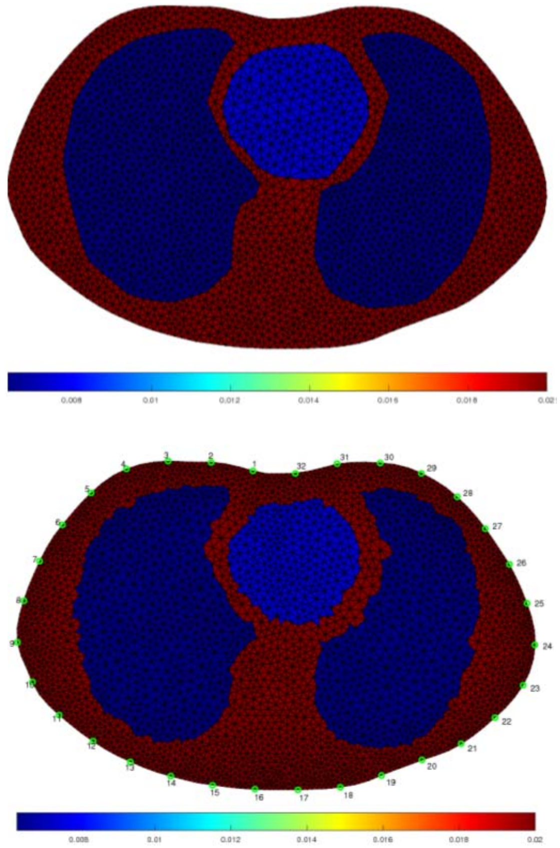
For EIT measurements in medical applications, the electrode / skin interface is critical to achieving good results. In clinical trials, it most often uses electrodes made of silver or silver chloride (Ag / AgCl). They provide excellent signal quality, but they have a serious disadvantage. To ensure good contact with the electrode and skin, use a special gel. However, it dries over time, causing a significant deterioration in the quality of the contact. Therefore, it should be replaced every few hours. In addition, the use of these electrodes usually requires patient preparation, i.e. the attachment sites must be shaved and disinfected with alcohol. The result is that these electrodes are not suitable for long-term use. In the case of our system, which is intended to monitor lung and heart function in long-term and outpatient settings, we must consider other options that will not require the use of gel while ensuring a signal quality comparable to that for Ag / AgCl. I'm talking about so-called dry electrodes. In general, dry electrodes can be divided into two groups: rigid and flexible electrodes. Rigid electrodes are usually made of metal, which provides good electrical properties, e.g. silver, aluminum, gold, titanium or stainless steel. They work well when the mounting site is attached and the patient does not move during the test. In our tomography, we must use flexible electrodes. Their main advantage is that they adapt much better to the shape of the body, and due to the greater adhesion they reduce the impact of patient movements on the measured signal (Figures 2 and 3).

Fig.3.Measuring system based on textile electrodes with signal cables.

Methods and results

Two models of chest measurements were adopted:

- The first one consists of 32 unequal electrodes and areas to approximate the shape of the heart and lungs.
- The second consists of 26 electrodes and areas imitating organ shapes. Electrodes from the first model were selected which were not in the armpits sections. 26 electrodes are understood as the corresponding electrodes from the first model with indexes: 1, 2, (...), 7, 11, 12, (...), 22, 26, 27, (...), 32.



a)

b)

Fig. 4 Original model created on the basis of a 3D scan of the grid to the inverse problem.

a)

b)

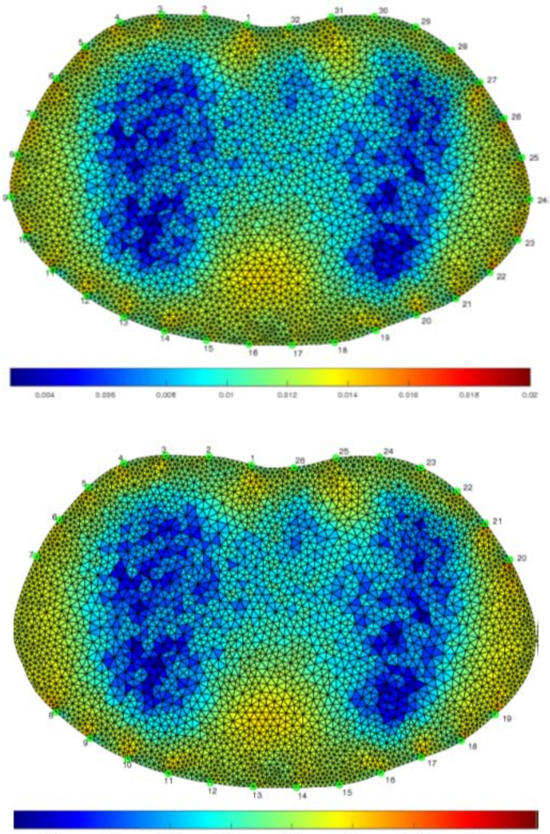
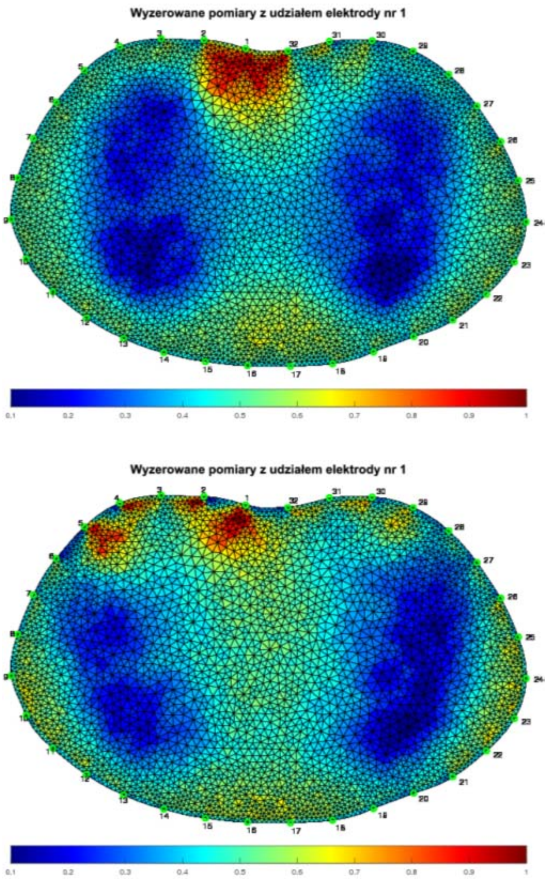


Fig. 5 Reconstructions with the first model (top) and the second model (bottom).

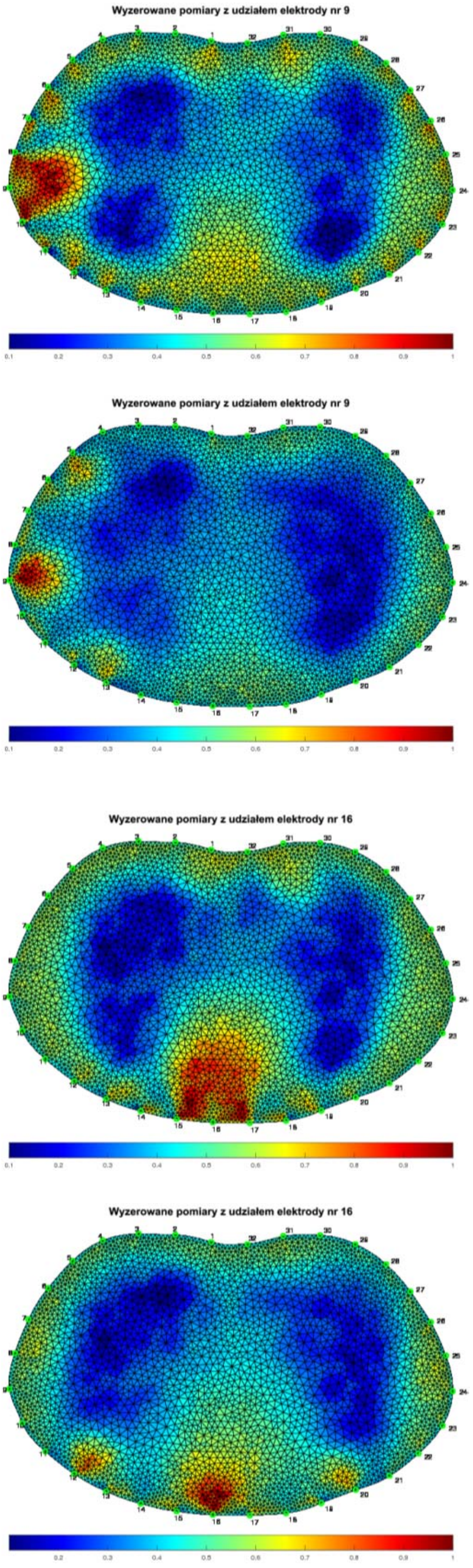
a)

b)


Wyzerowane pomiary z udziałem elektrody nr 1

Wyzerowane pomiary z udziałem elektrody nr 1

c)


Wyzerowane pomiary z udziałem elektrody nr 9

Wyzerowane pomiary z udziałem elektrody nr 9

Wyzerowane pomiary z udziałem elektrody nr 16

Wyzerowane pomiary z udziałem elektrody nr 16

d)

e)

f)

Fig. 6 Reconstructions for selected electrodes without contact for two simulations.

The shapes of the organs and the model of the chest are visible in Fig. 4 (above). Using the shapes (polygons limiting the organs) we get a net without smooth transitions between the interior of the model and the boundaries of the organs (grid to the opposite problem). Visible imperfections of such approximated organs are shown in Fig. 4 (bottom). For the first model, we obtain reconstructions of Fig. 5 (above) and for the second model we obtain the reconstruction presented in Fig. 5 (bottom).

Removal of the electrodes from the area of both armpits in the model results from the experimental data, which shows that the electrodes from these sites most often cause problems, i.e. during the patient's movements their impedance increases significantly.

Two types of measurement methods were considered:

- 0, 16, [0,1] - the excitation electrodes are 16, the n-first angle between 1 and 17 electrode, and the measurements are collected from the electrodes adjacent to the omission of the current electrodes for a given projection angle.
- 0,4, [0,4] - stimulation electrodes are distant by 4, and measurements are collected from electrodes located 4 apart from each other, omitting excitation electrodes.

These patterns of excitation have been considered because the former is one of the more frequently accepted, while the other is the pattern. Fig. 6 shows exemplary reconstructions with randomly chosen electrodes that have no skin contact for the previously described simulations. The first column of the drawings shows reconstructions using the first simulation, the second column uses the second simulation. Reconstructions were made on the basis of the first model (32 equidistant electrodes).

Conclusion

The article shows an advanced system of electrical tomography for biomedical applications. The tomographic data collection has to be as fast as reliable, to take into account the algorithms of reversing tomography with almost real-time update. To provide a high-level application programming interface using standard communication protocols and execute user-level programs. System architecture and prototype designs for biomedical tomography are presented. The platform consists of a data collection device and an aggregation and processing mechanism to generate useful information for diagnostic purposes or to pre-monitor physiological changes in the body. The tomographic platform will enable the monitoring of physiological processes using the observed changes in electrical conductivity. Physiological processes that cause changes in the electrical conductivity of the body can be monitored using hybrid algorithms. The applied algorithms of electrical reconstruction of impedance tomography solve the problem inverse with adequate accuracy.

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