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IDEA OF ELECTRICAL TOMOGRAPHY SYSTEM FOR MONITORING LUNG VENTILATION

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Abstract. *In many applications of electrical tomography, such as monitoring the lungs of unconscious intensive care patients, data acquisition on the entire boundary of the body is impractical. The boundary area available for electrical tomography measurements is restricted. Physiological processes that produce changes in the electrical conductivity of the body can be monitored by hybrid algorithms. This paper presents the architecture of the system based on electrical tomography.*

Keywords: inverse problem, finite element method, electrical impedance tomography

IDEA SYSTEMU TOMOGRAFII ELEKTRYCZNEJ DO MONITOROWANIU WENTYLACJI PŁUC

Streszczenie. *W wielu zastosowaniach tomografii elektrycznej, takich jak monitorowanie płuc pacjentów podlegających intensywnej opiece medycznej, zbieranie danych na całej powierzchni ciała jest niepraktyczne. Dostępne obszary dla pomiarów tomografii elektrycznej są ograniczane. Procesy fizjologiczne, które wywołują zmiany w przewodnictwie elektrycznym w organizmie mogą być monitorowane za pomocą algorytmów hybrydowych. W artykule przedstawiono architekturę systemu opartego na tomografii elektrycznej.*

Słowa kluczowe: zagadnienie odwrotne, metoda elementów skończonych, tomografia impedancyjna

Introduction

This paper presents the architecture of the system collecting data and analyzing medical data by electrical impedance tomography (EIT) [10–13, 16, 17] and electrical capacitance tomography (ECT) [14, 18]. To develop new technology and equipment for an in vivo human body screening and examination is the aim of this concept. The system will operate using the advanced analog-digital device for high-speed recording and high-sensitivity measurement. It will be able to distinguish very small changes of electrical parameters. In current medical research, it is noted that electrical properties of tissues differ depending whether they are healthy or altered. In this solution, it will be possible to externally examine such properties of various parts of the human body. The solution will allow to image dynamic processes taking place inside internal organs by simultaneous reconstruction of electrical permittivity and conductivity. The system will allow to monitor lung ventilation, lung blood flow, cardiac output and lung pathological changes of ill patients. Images obtained will be of moderate resolution, yet anatomical structures will be possible to identify with reasonable confidence. This new equipment will provide more accurate, reliable and early disease diagnosis, which will lead to improvement of clinical decisions and their outcomes. Proposed system will be able is to assist during medical procedures in which no potentially detrimental analysis methods such as X-ray, high power magnetic field or contrasts should be used. Therefore, those procedures will become much safer for patients.

Respiratory diseases are very common nowadays. Their development in both, acute and chronic cases is determined with multiple factors (e.g. environmental pollution, stress). Early diagnostics or constant non-ambulatory monitoring is, unfortunately, not possible. System will consist of dedicated mobile device for registering heartbeat electrical potentials as well as lungs ventilation. It will support process of diagnostics and monitoring of patients' condition in cases of:

- Acute respiratory distress syndrome.
- Chronic obstructive pulmonary disease.
- Bronchoconstriction.
- Pneumonia.
- Pulmonary hypertension.
- Obstructive sleep apnea.
- Pneumothorax.
- Cardiac hemodynamics.
- Aortic insufficiency.
- Hypertension.
- Ischemic heart disease.

Numerical algorithms were based on the level set methods and Gauss-Newton method [5, 7–9, 15].

1. Electrical Tomography

Electrical tomography is an extremely ill-posed inverse problem and high resolution imaging would require unpractically accurate current injection, voltage measurement, low noise levels, and large number of electrodes attached to the boundary of the object. In electrical impedance tomography, electrical currents are injected into an object using a set of electrodes attached on the boundary of the object and the resulting electrode potentials are measured. The conductivity of the object is reconstructed as a spatially distributed parameter based on the known currents and measured potentials. Electrical tomography is an imaging technology in which the electrical conductivity of a body is estimated as a spatially distributed parameter based on measurements of electrical currents and. In absolute imaging, the conductivity distribution is estimated using a single set of potential measurements, where the conductivity is modeled. Applications of EIT include monitoring of heart and lungs. Several medical solutions have been proposed including lung function monitoring of intensive care patients. In medicine, the injected currents are small and harmless to the patient. Almost real-time imaging with tens of frames per second can be achieved with devices small enough to reside by the bedside. This makes electrical impedance tomography attractive especially for constant monitoring. The accuracy of the positioning of the electrodes on the boundary is also a concern as well as that in two-dimensional imaging the injected currents are not confined to travel on the plane determined by the electrodes [1–6].

The electromagnetic field induced by applying a current density to the surface of the body is governed by Maxwell's equations. At low frequencies and small field strengths the electromagnetic properties of living tissue allow these to be simplified to the conductivity equation:

$$\nabla \cdot \left(\gamma(x,y)\nabla u(x,y)\right) = 0, \qquad (x,y) \in \Omega \tag{1}$$

where, Ω denotes a bounded region in the plane, γ denotes the conductivity of the body, and u the electric potential.

2. System idea

A prototype of multimodal tomographic system for medical applications will be created by building a hardware prototype and preparing dedicated software which will analyze medical images using the topological methods and artificial intelligence algorithms and their hybridization. It will result in much better quality of the image reconstruction than in current solutions.

Figure 1 presents the idea of the electrical tomography measurement system. There was designed Lungs Electrical Tomography System (Fig. 4), 3D model of pulmonary (Fig. 2), the EIT measurement belt (Fig. 3) and active electrodes (Fig. 5). The idea of hardware and software system id presented in Fig. 6-8.

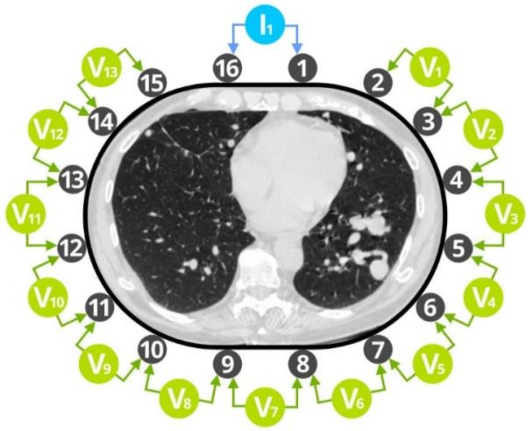

Fig. 1. The idea of the measurement system

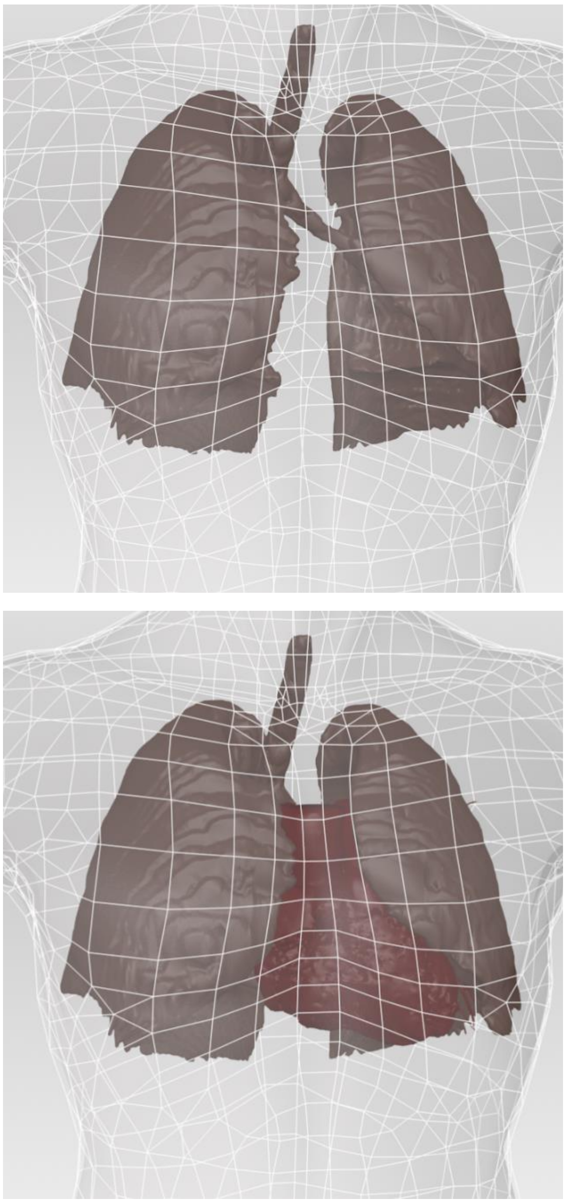

Fig. 2. The model of pulmonary

Fig. 3. The EIT measurement belt

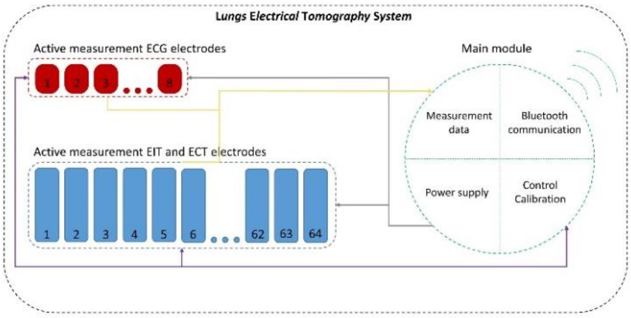

Fig. 4. Lungs Electrical Tomography System

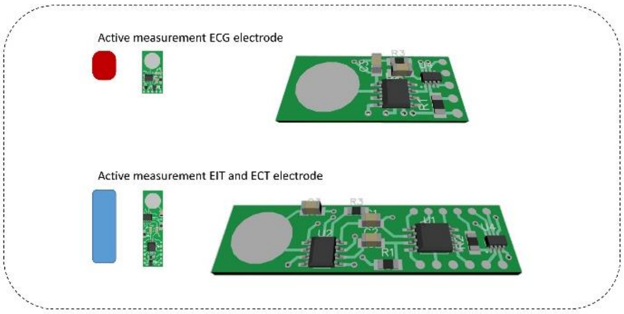

Fig. 5. Active electrodes

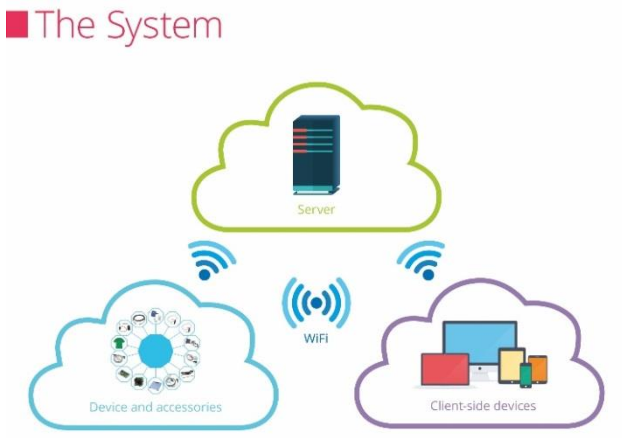

Fig. 6. The idea of system

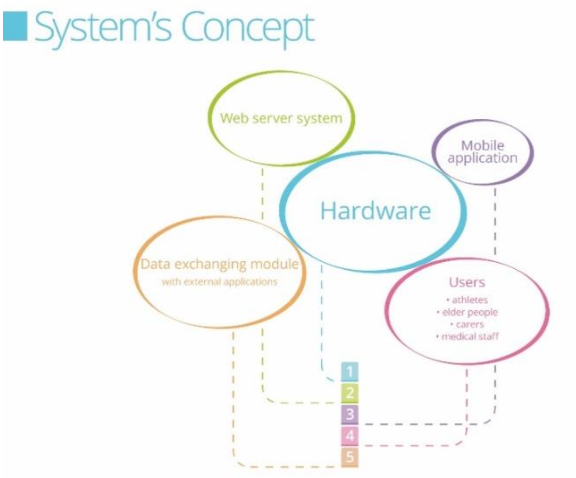

Fig. 7. The concept of solution

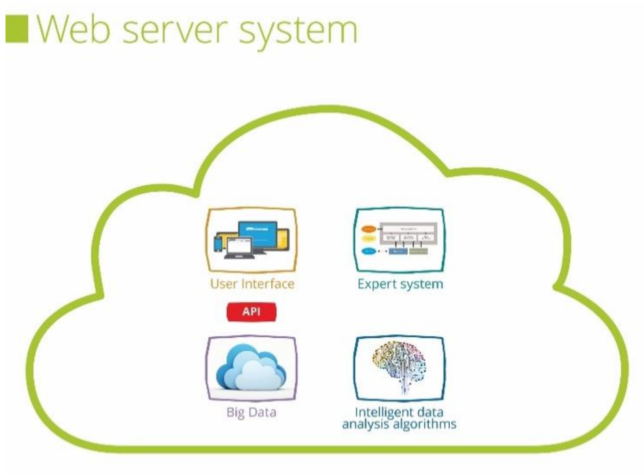

Fig. 8. Web server system

3. Results

Examples show lung imaging without a change of the thorax shape. This test case was done to produce a reference case of lung imaging comparing the image reconstruction between the Gauss-Newton method and the level set method.

In clinical situations, the thorax shape varies due to breathing and changes of the patient position during the measurements. For this reason, we simulate a more realistic case in lung shapes.

Figure 9 and 12 present the geometrical model lungs I and II with 16 electrodes, where (a) the initial model, (b) the reconstructed by Gauss-Newton method, (c) zero level set function, (d) differences between the initial object and the final solution, (e) the reconstructed by the level set method. Figure 10 and 11 present the objective function for the tested models.

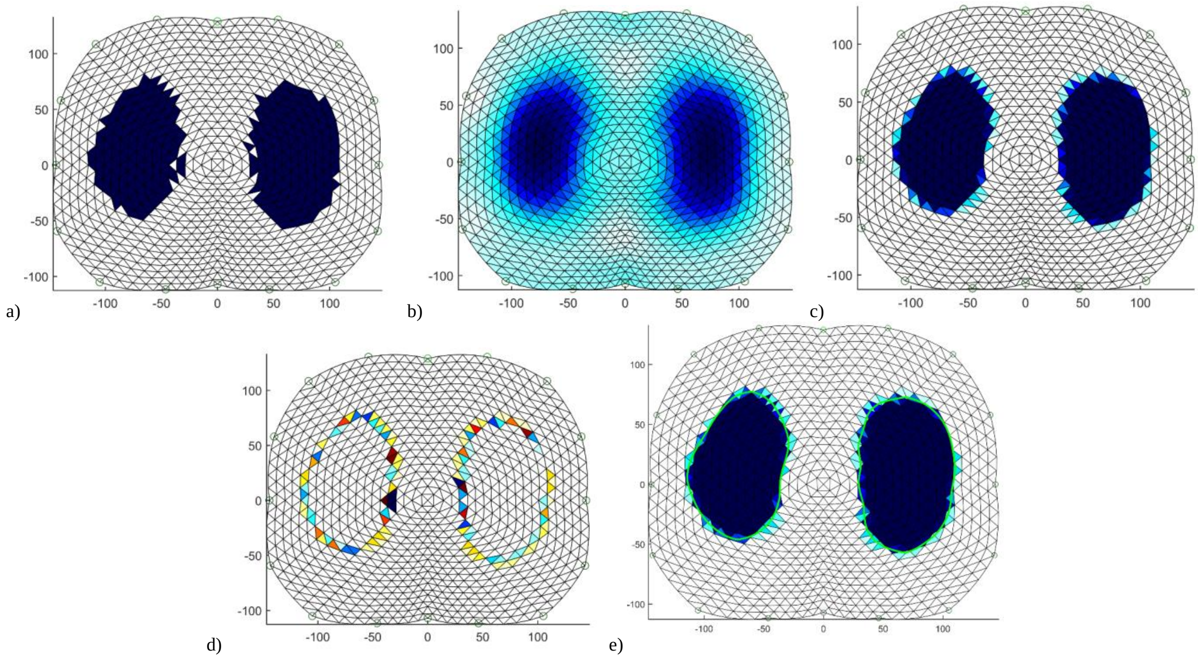

Fig. 9. The geometrical model lungs I with 16 electrodes: a) the initial model, b) the reconstructed by Gauss-Newton method, c) zero level set function, d) differences between the initial object and the final solution, e) the reconstructed by the level set method

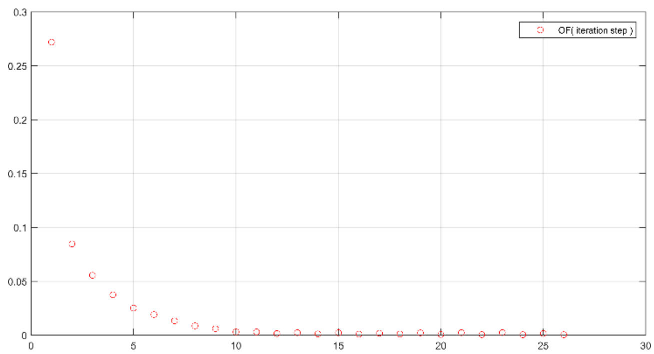

Fig. 10. The objective function for the model in Figure 9

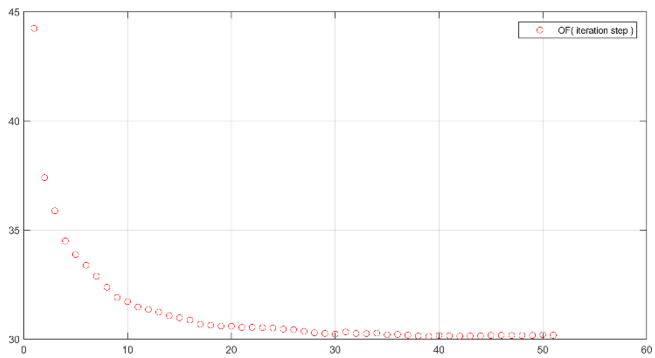

Fig. 11. The objective function for the model in Figure 11

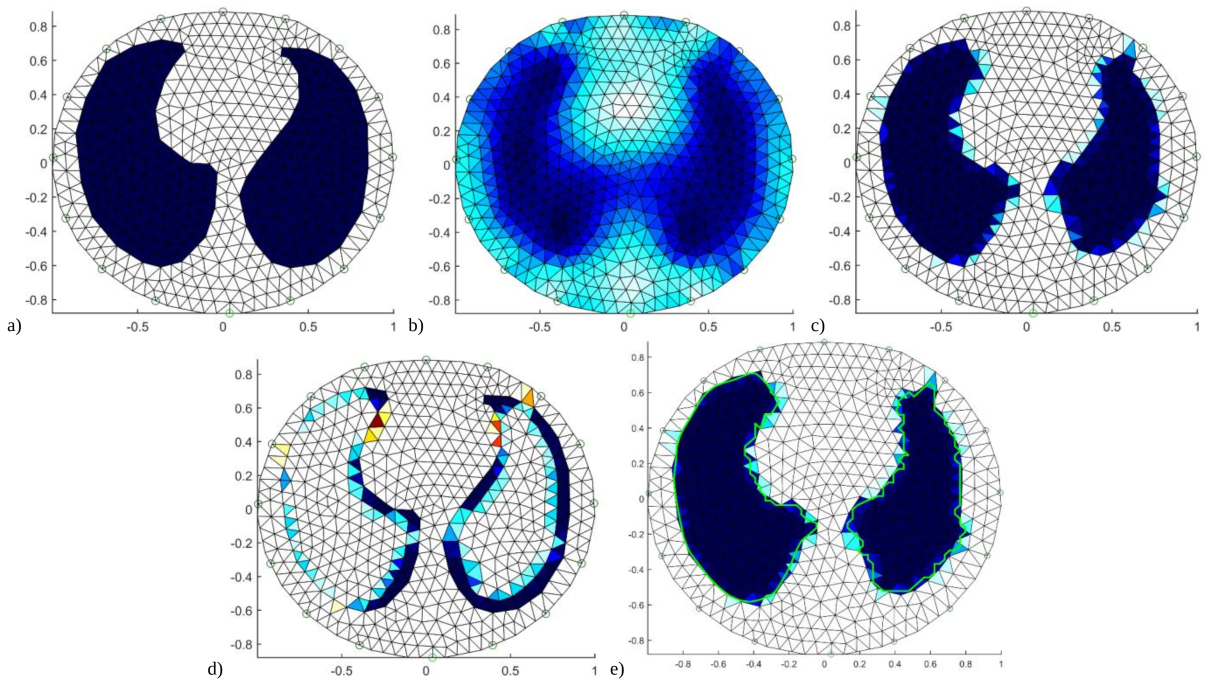

Fig. 12. The geometrical model lungs II with 16 electrodes: a) the initial model, b) the reconstructed by Gauss-Newton method, c) zero level set function, d) differences between the initial object and the final solution, e) the reconstructed by the level set method

4. Conclusion

In this paper, there was proposed an approach to EIT image reconstruction in cases where the Gauss-Newton and level set methods were implemented. In the proposed approach, the conductivity after the change is represented as a linear object. There was presented the architecture of the system based on electrical tomography.

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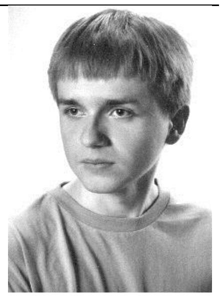

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