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Application of multi-source data for process analysis in electrical tomography

***Abstract**. The article presents the use of multi-source data to analyse processes in electric tomography. Tomography is a technique for imaging the inside of an examined object based on measurements taken at its edge. Depending on the technological specifics, you can see both advantages and disadvantages in terms of accuracy, frequency and resolution of reproduced images. Electric tomography is an imaging technique that uses different electrical properties of different types of materials. The collected information is processed by an algorithm that reconstructs the image. Solving the inverse problem, we obtain the distribution of material coefficients in the studied area. Image reconstruction methods in this work were based on machine learning.*

***Streszczenie.** Artykuł przedstawia zastosowanie danych wieloźródłowych do analizy procesów w tomografii elektrycznej. Tomografia jest to technika obrazowania wnętrza badanego obiektu na podstawie pomiarów wykonanych na jego krawędzi. W zależności od specyfiki technologicznej można zobaczyć zarówno zalety, jak i wady w zakresie dokładności, częstotliwości i rozdzielczości odtwarzanych obrazów. Tomografia elektryczna jest techniką obrazowania, która wykorzystuje różne właściwości elektryczne różnych rodzajów materiałów. Zebrane informacje są przetwarzane przez algorytm, który rekonstruuje obraz. Rozwiązując odwrotny problem, uzyskujemy rozkład współczynników materiałowych w badanym obszarze. Metody rekonstrukcji obrazu w tej pracy oparte zostały na uczeniu maszynowym.. (**Zastosowanie danych wieloźródłowych do analizy procesów w tomografii elektrycznej**).*

Keywords: electrical impedance tomography, electrical capacitance tomography, machine learning.
Słowa kluczowe: elektryczna tomografia impedancyjna, elektryczna tomografia pojemnościowa, uczenie maszynowe.

Introduction

Industrial tomography solves the inverse problem that the optimization, identification or synthesis process. Such problems are difficult to analyze [1-5]. They do not have clear solutions. Knowledge of the process can make image reconstruction more resistant to incomplete information [6-9]. There are many numerical methods [10-26].Tomography enables the analysis of processes taking place in the facility without interfering with them [27-30]. It enables better understanding and monitoring of industrial processes and facilitates real-time process control. Figure 1 shows the structure of the system using an electric tomograph with image reconstruction.

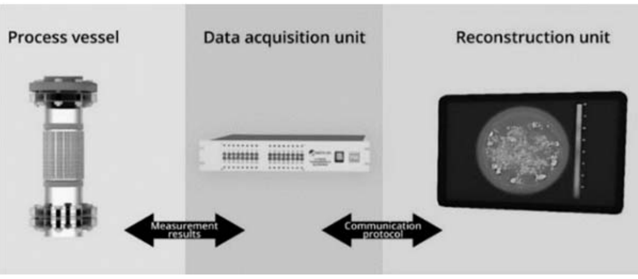


Fig. 1. The idea of system structure with a hybrid tomography scanner with flow measurement, image processing in the cloud computing.

Methods

Electrical tomography is an imaging technique that uses different electrical properties of materials. In this method, the current source is connected to the tested object, and then the voltage distribution on its edge is measured (Fig, 2). The collected information is processed and reconstructed by a specific algorithm. The basic theory can be obtained from Maxwell's equations.
A complex 'admittivity' can define as follows:

(1) $$\gamma = \sigma + \mathrm{i}\omega\varepsilon$$

where ε is the permittivity, σ is the electrical conductivity, ω is the angular frequency.

Potential distribution in a heterogeneous, isotropic area:

(2) $$\nabla \cdot (\gamma \nabla u) = 0,$$

where u is the potential.
Where the capacitance or resistance dominates, the equation factor should be simplified to the form:

(3) $$\nabla \cdot (\sigma \nabla u) = 0 \quad for \ \frac{\omega\varepsilon}{\sigma} \ll 1 \quad \text{(ERT)}$$

(4) $$\nabla \cdot (\varepsilon \nabla u) = 0 \quad for \ \frac{\omega\varepsilon}{\sigma} \gg 1 \quad \text{(ECT)}$$

By resolving the inverse problem, a distribution of material coefficients in the studied area is obtained [31-36]. In electric capacitive tomography, the source of information is the electrical capacity between the electrodes located on the edge of the tested object (see Fig. 3). A very important feature of measurement in the case of capacitive tomography is the lack of need for physical interaction of the sensor with the tested medium, thanks to which this method is non-invasive; this means that it does not interfere with an ongoing industrial process. Another advantage of this measuring technique is the rapid collection of measurement data.
The inverse solution of the problem is achieved:

(5) $$\varepsilon = S * C$$

where: ε – permittivity matrix; C – capacity matrix; S – sensitivity matrix

Inverse problem can be solved with, for example using the Landweber algorithm:

(6) $$\varepsilon_{k+1} = \varepsilon_k + \alpha * S^T * (S * \varepsilon_k - C_m)$$

where: C_m- measured capacity matrix; ε_{k+1} – permittivity matrix, current iteration; ε_k – permittivity matrix, previous iteration; α – coefficient

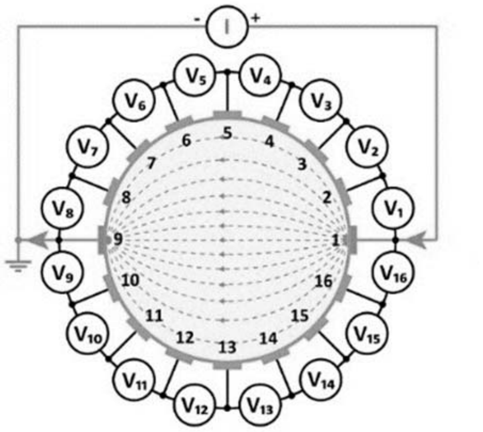


Fig. 2. Measurement model in electrical impedance tomography – opposite method.

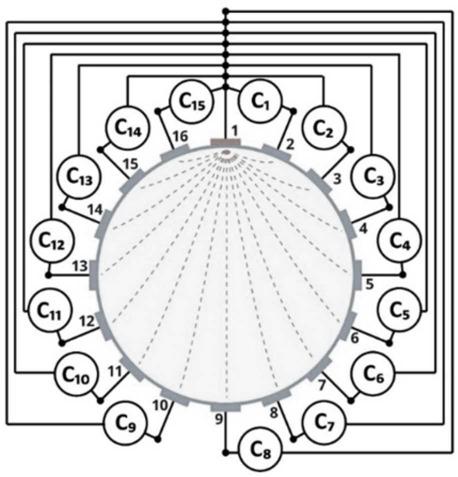
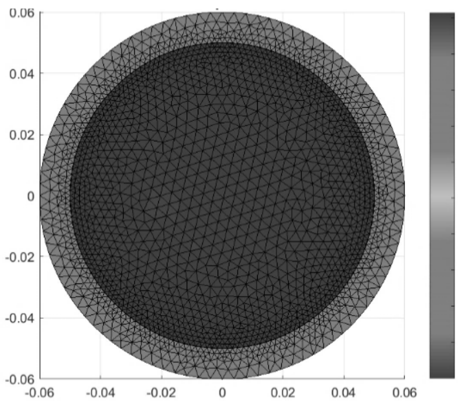


Fig. 3. Measurement model in electrical capacitance tomography.

Results

The individual methods were analyzed on several examples where there are a large number of smaller objects, which is of great importance in tomography. Figure 4 shows the image reconstruction by ECT (LARS method). The image reconstruction by Elastic net for ECT and EIT present in Fig. 5. Figure 6 present the mage reconstruction by multiply Neural Networks. The image reconstructions by hybrid models present Fig 7 and 8.

a)



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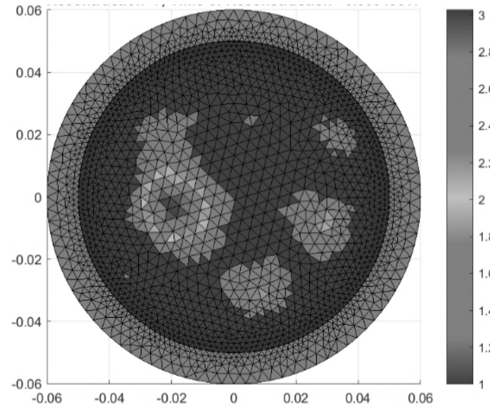
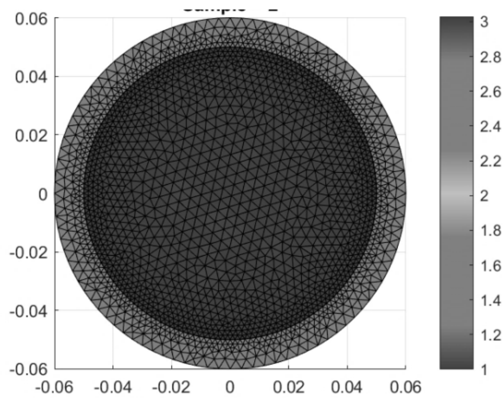


Fig. 4. Image reconstruction – ECT model: (a) pattern, (b) Lars.

a)



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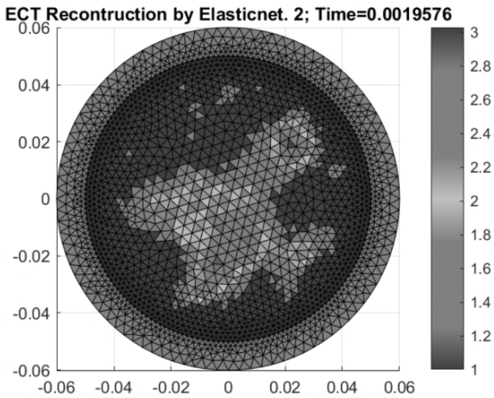


c)

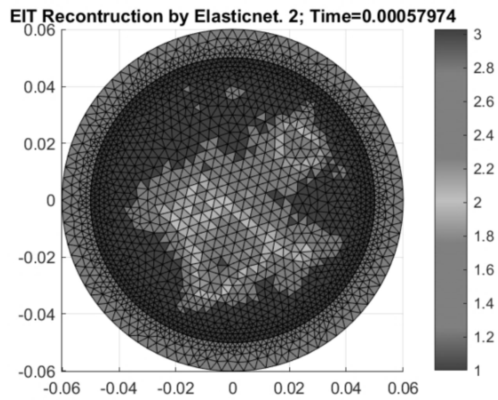
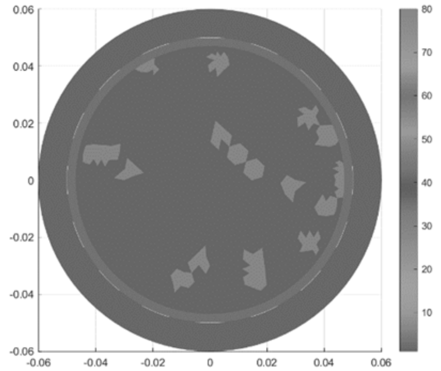


Fig. 5. Image reconstruction by Elastic net: (a) pattern, (b) ECT, (c) EIT.

a)



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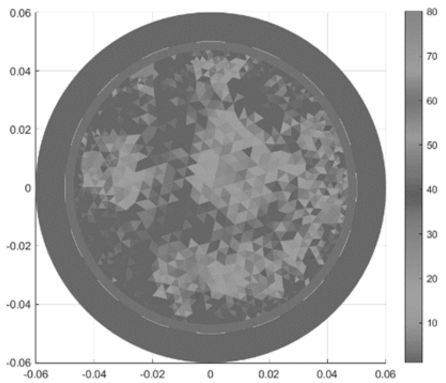
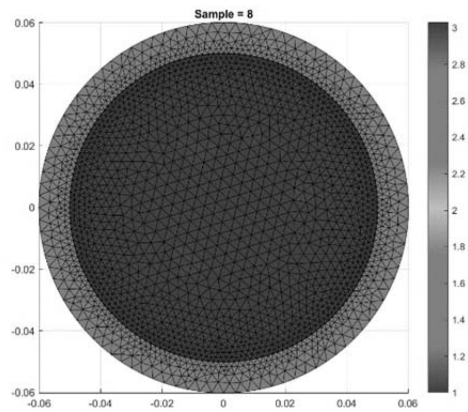


Fig 6. Image reconstruction – EIT model: (a) pattern, (b) multiply Neural Network.

a)



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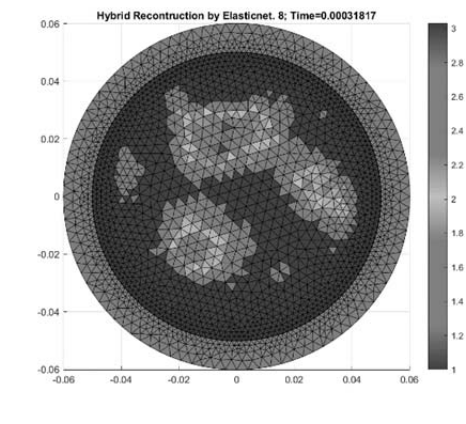
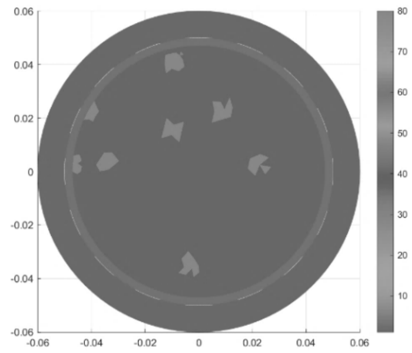


Fig. 7. Image reconstruction – hybrid model: (a) pattern, (b) Elastic net

a)



b)

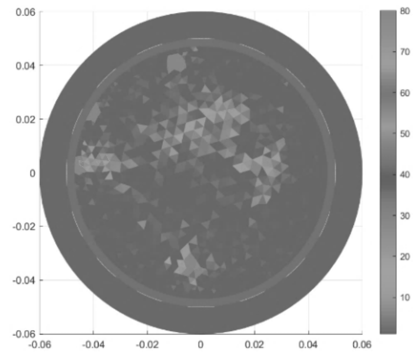


Fig. 8. Image reconstruction – hybrid model: (a) pattern, (b) multiply Neural Network.

Conclusion

The paper presents the application of multi-source data for the analysis of processes in industrial tomography. There is no ideal method for reconstructing and analyzing data, methods and models must be properly selected depending on the problem to be solved. Research focused mainly on developing methods and measurement models for data analysis and reconstruction using electric tomography. To solve the inverse problem, Gauss-Newton methods with Laplace regularization, Gauss-Newton methods with Tikhonov regularization, LARS and elastic net were used. The reconstruction results of individual algorithms were compared with various measurement models. The results obtained show the resolution of spatial data, which gives the possibility of visual analysis of processes occurring in the object. Deterministic methods have a bigger problem with the reconstruction of small objects. The best results were achieved with the use of machine learning using the elastic net and LARS methods. Neural networks largely depend on the training set, with a large training set, especially for smaller objects, they are quite effective. Further work will focus on improving methods of image reconstruction using deep learning and the development of measuring devices for both tomographies.

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