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Analysis of geospatial areas using electrical resistance tomography

***Abstract**. The article presents an analysis of geospatial areas using electrical resistive tomography. Tomography can be used to calculate conductivity by measuring potential differences in a flood embankment. The problem is that each material has unique conductivity. This method collects data on the edge of the tested area, by which the conductivity distribution in the tested object is determined. An inverse problem has been resolved to visualize the properties of the object being tested. The optimization of the objective function uses so-called regularization based on total variation regularization. The best results were obtained by the Gauss-Newton method with Laplace regularization.*

***Streszczenie.** W artykule przedstawiono analizę obszarów geoprzestrzennych z wykorzystaniem elektrycznej tomografii rezystancyjnej. Tomografię można wykorzystać do obliczenia przewodności poprzez pomiar różnic potencjałów w wale przeciwpowodziowych. Problem polega na tym, że każdy materiał ma niepowtarzalną przewodność. Ta metoda zbiera dane na brzegu badanego obszaru, za pomocą których określa się rozkład przewodności w badanym obiekcie. Rozwiązano problem odwrotny w celu wizualizacji właściwości testowanego obiektu. W optymalizacji funkcji celu zastosowano tak zwaną regularyzację opartą na regularyzacji całkowitej zmienności. Najlepsze wyniki uzyskano metodą Gaussa-Newtona z regularyzacją Laplace'a. (**Analiza obszarów geoprzestrzennych z wykorzystaniem elektrycznej tomografii rezystancyjnej)**.*

Keywords: electrical resistance tomography, inverse problem, image reconstruction.
Słowa kluczowe: elektryczna tomografia rezystancyjna, zagadnienie odwrotne, rekonstrukcja obrazu.

Introduction

All reconstruction methods (TV regularization and Gauss-Newton method) indicate that there is an area with very low specific conductivity just below the earth's surface. The best results (the smallest percentage error and the largest correlation coefficient) were obtained by the Gauss-Newton method with Laplace regularization [1]. The conductivity distribution on the tested surface is continuous. The choice of a regularization parameter has a very strong impact on the convergence of the objective function optimization algorithm [2-18].

Electrical resistivity tomography (ERT) is an imaging technique that uses various electrical properties of the environment. In this method, the power source is connected to the object, and then voltage drops at its edge are measured. Based on the collected measurements, the image inside the object is reconstructed. To this end, forward and inverse problems are solved. To solve a forward problem, the finite element method is most often used. Electric tomography has a relatively low image resolution. Difficulties in obtaining high resolution result mainly from a limited number of measurements, non-linear current flow through the given medium and too low sensitivity of measured voltages depending on changes in conductivity inside the area.

Electrical resistance tomography is often used interchangeably with the EIT, especially in environmental and process solutions. ERT is a technique that gives the best results in detailed imaging of soil geological properties. The electrical properties of the soil depend to a large extent on such hydrological properties of rocks and soils as the formation of porosity and water saturation. In addition, this technique is sensitive to temporary temperature changes caused by the introduced steam, air flows, temperature changes or the movement of liquid contaminants. The soil environment in which pipelines and other steel structures are laid has a fundamental impact on the corrosion processes that these structures undergo. Thus, when designing the pipeline route and its cathodic protection installation, it is necessary to determine the degree of corrosion hazard of the soil medium on particular sections of its course. This issue is equally important for existing constructions. This method uses the differentiation of the ground center in the field of constant electric current. By means of a suitable geometrical system of recessed electrodes, it is possible to connect the medium in the current circuit, and then its parameters are measured (voltage and current). As a result of the inverse problem solution, the conductivity distribution in the tested area is obtained.

Image reconstruction in electrical resistive tomography

This study contains examples of image reconstruction [19-46] related to soil structure analysis. Numerical calculations were made using a proprietary application. This application works in the MATLAB environment and is intended for analyzing the condition of levees. In the considered case, the following methods of optimizing the objective function were used:

- Gauss-Newton method with Tikhonov regularization (GN-T),
- Gauss-Newton method with Laplace regularization (GN-L),
- regularization based on total variation function (TV).

Figure 1 shows the geometric model of the examined area along with an example of an internal disorder. The model consists of 511 020 tetrahedrons. It was used only for the purpose of numerical simulation of the data frame. Electrical voltages between specific pairs of electrodes are shown in Figures 2, 3 and 4.

The following markings were used: $\mathbf{U}$ - data frame (measuring voltages), $\boldsymbol{\sigma}_{\text{rec}}$ - proper conductivity which is the solution to the inverse problem

$\mathbf{U}(\boldsymbol{\sigma}_{\text{rec}})$ - voltages calculated on the basis of specific conductivity $\boldsymbol{\sigma}_{\text{rec}}$

The quality of the reconstruction Is determined by the percentage error:

$$\text{PE} = \frac{\| \mathbf{U}(\boldsymbol{\sigma}_{\text{rec}}) - \mathbf{U} \|_2}{\| \mathbf{U} \|_2} \cdot 100\%$$

The correlation coefficient between the voltages $\mathbf{U}$ and $\mathbf{U}(\boldsymbol{\sigma}_{\text{rec}})$ was calculated based on the formula:

$$\text{PCC} = \frac{\sum_{j=1}^{N}\left([\mathbf{U}]_j - \langle\mathbf{U}\rangle\right)\left([\mathbf{U}(\boldsymbol{\sigma}_{\text{rec}})]_j - \langle\mathbf{U}(\boldsymbol{\sigma}_{\text{rec}})\rangle\right)}{\sqrt{\sum_{j=1}^{N}\left([\mathbf{U}]_j - \langle\mathbf{U}\rangle\right)^2}\sqrt{\sum_{j=1}^{N}\left([\mathbf{U}(\boldsymbol{\sigma}_{\text{rec}})]_j - \langle\mathbf{U}(\boldsymbol{\sigma}_{\text{rec}})\rangle\right)^2}}$$

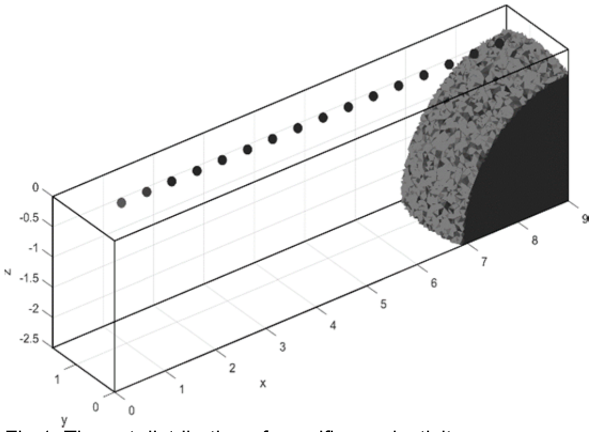

Fig.1. The set distribution of specific conductivity.

Numerical calculations results

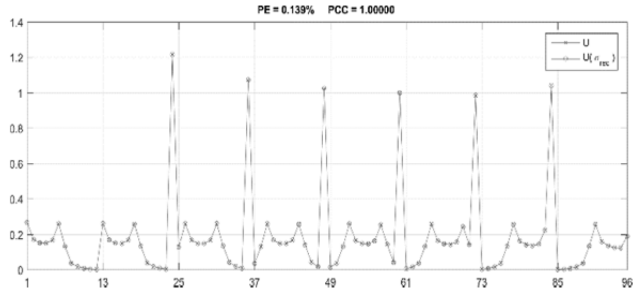

Fig. 2. Electrical voltages - GN-T method.

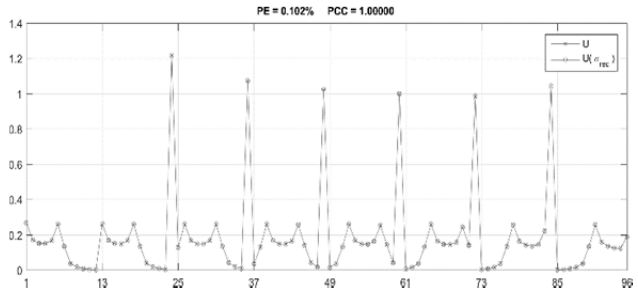

Fig. 3. Electrical voltages - GN-L method.

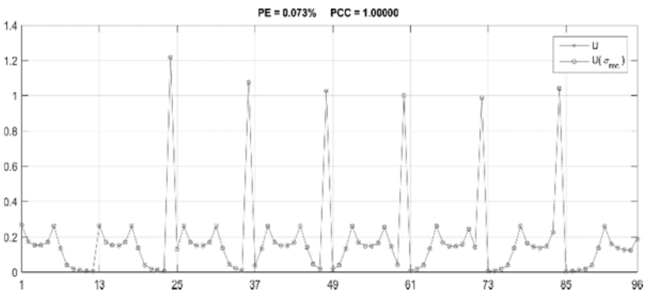

Fig. 4. Electrical voltages - TV method.

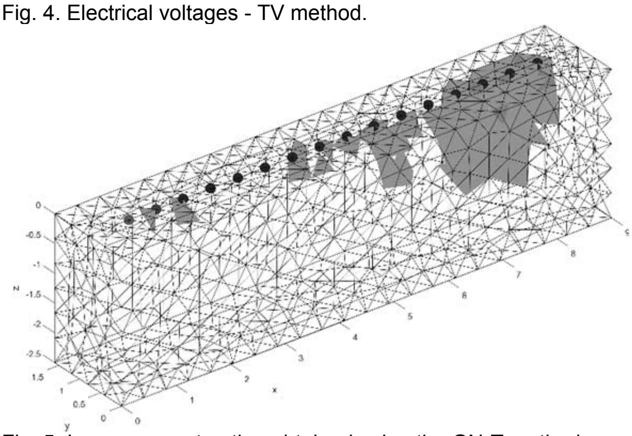

Fig. 5. Image reconstruction obtained using the GN-T method.

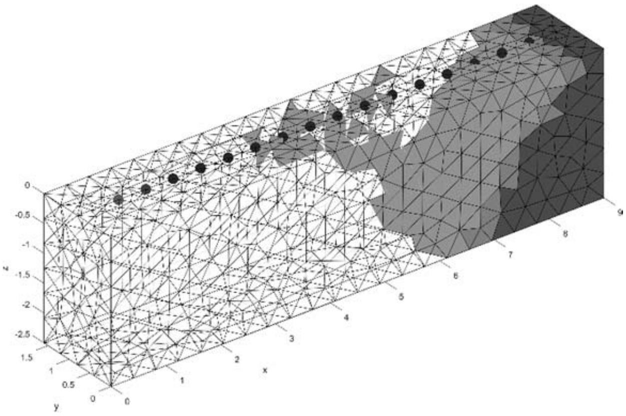

Fig. 6. Image reconstruction obtained using the GN-L method.

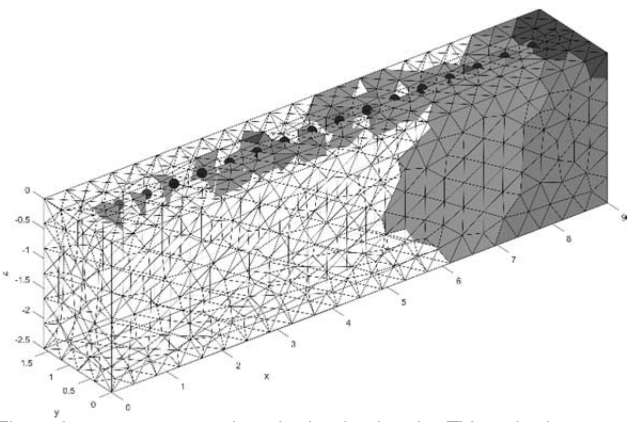

Fig. 7. Image reconstruction obtained using the TV method.

Table 1. Parameters of the finite element mesh used during image reconstruction.

Number of electrodes	16
Electrode Type	point
Number of Nodes	917
Number of finite elements	3200

All presented reconstructions were determined on the basis of a non-negative data frame (electrical voltages). The best results were obtained in the case of the Gauss-Newton method with Laplace regularization and in the case of regularization based on the total variability of the function. In the considered case, the Gauss-Newton method with Tikhonov regularization did not allow an accurate determination of the structure of the examined object (Fig. 5-7).

Table 2. Detailed reconstruction parameters.

Parameter	Method	Value
reconst_type	Gauss-Newton + Tikhonov regularization	'absolute'
	Gauss-Newton + Laplace regularization	'absolute'
	TV regularization	'absolute'
solve	Gauss-Newton + Tikhonov regularization	@inv_solve_gn
	Gauss-Newton +	@inv_solve_gn

	Laplace regularization	
	TV regularization	@inv_solve_abs_pdipm
RtR_prior / R_prior	Gauss-Newton + Tikhonov regularization	@prior_tikhonov
	Gauss-Newton + Laplace regularization	@prior_laplace
	TV regularization	@prior_TV
hyperparameter	Gauss-Newton + Tikhonov regularization	1.0E-3
	Gauss-Newton + regularyzacja Laplace'a	1.0E-3
	TV regularization	1.0E-3
max_iterations	Gauss-Newton + Tikhonov regularization	3
	Gauss-Newton + Laplace regularization	3
	TV regularization	5

Table 3. Parameters characterizing the quality of the reconstruction.

	GN-T	GN-L	TV
PE	0.1392%	0.1016%	0.0731%
PCC	1.0000	1.0000	1.0000

Conclusion

The work presents image reconstruction using electrical resistive tomography. The main advantage of this solution is obtaining a more detailed arrangement of components in the flood embankment. The presented method collects data on the edge of the examined area, with the help of which the conductivity distribution in the examined object is determined. In order to visualize the properties of the tested object, the inverse problem is solved. The optimization methods used allow for correct image reconstruction determination. This means that you can thoroughly analyze the structure under study. Proper coordination of the regularization factor has a significant impact on the convergence of the algorithm. The best result (the smallest percentage error and the largest correlation coefficient) was obtained by the Gauss-Newton method with Laplace regularization.

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