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doi:10.15199/48.2020.04.22

Moisture analysis of building walls using tomographic measurements

***Abstract**. The article presents the analysis of building walls humidity by means of tomographic measurements. The use of modern tomographic techniques allows for spatial assessment of humidity levels. The proposed application solves the inverse problem in electrical tomography. The measuring system contains special electrodes for measuring humidity. The application includes a number of different methods of image reconstruction, such as the level set methods, LARS, or elastic net.*

***Streszczenie.** W artykule przedstawiono analizę wilgotności ścian budynków za pomocą pomiarów tomograficznych. Zastosowanie nowoczesnych technik tomograficznych pozwala na przestrzenną ocenę poziomu wilgotności. Proponowane zastosowanie rozwiązuje zagadnienie odwrotne w tomografii elektrycznej. System pomiarowy zawiera specjalne elektrody do pomiaru wilgotności. Aplikacja obejmuje szereg różnych metod reonstrukcji obrazu, takich jak metoda zbiorów poziomicowych, LARS, czy elastic net. (**Analiza wilgotności ścian budynków za pomocą pomiarów tomograficznych**).*

Keywords: electrical tomography, sensors, inverse problem.
Słowa kluczowe: tomografia elektryczna, sensory, zagadnienie odwrtone.

Introduction

The article presents the reconstruction of the image obtained using the NX EIT wall system prototype [1]. The application is designed to analyze the humidity of the walls. It includes many methods to solve the inverse problem in electrical impedance tomography (EIT). In the considered case, methods of problem optimization are used [2-15]: To solve the inverse problem, several methods based on deterministic, topological and machine learning methods were implemented. [16-46].

Methods

The subject of the analysis in this study are image reconstructions of a selected data frame obtained using a program created in MATLAB. The said application is used to analyze the humidity of the walls. It includes a number of different methods to solve the inverse problem in electrical impedance tomography (EIT).

Electric field potential (satisfies the generalized Laplace equation, which in the Cartesian coordinate system is clearly written as:

$$\frac{\partial}{\partial x}\left(\sigma\ \frac{\partial \phi}{\partial x}\right)+\frac{\partial}{\partial y}\left(\sigma\ \frac{\partial \phi}{\partial y}\right)+\frac{\partial}{\partial z}\left(\sigma\ \frac{\partial \phi}{\partial z}\right)=0$$

The above equation is solved with appropriate boundary conditions.

In the case under consideration, the following methods were used to optimize the objective function:

- Gauss-Newton method with Tikhonov regularization (GN-T)
- Gauss-Newton method with Laplace regularization (GN-L)
- regularization based on total function variation (TV)
- contour level method (LSM + GT + FEM)
- Elastic Net regularization (EN)
- artificial neural networks (ANNs)

Electrical voltages measured between specific electrode pairs are shown in Figures 1 to 6. The following markings were used:

$\mathbf{U}$ - data frame (measuring voltages)

$\mathbf{U}$ - 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 U and U (σ_rec) was calculated based on the formula:

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

Results

The list of finite element mesh parameters for numerical calculations is presented in Table 1. The results of image reconstruction and distribution of electrical voltages are shown in Fig. 1-8. Tables 2 and 3 show the parameters and quality of the reconstruction.

Table 1. List of finite element mesh parameters.

Spatial dimensions	2
Number of electrodes	16
Electrode Type	point
Number of Nodes	1588
Number of finite elements	2908

Table 2. List of reconstruction parameters for deterministic methods.

Method	Regularization parameter	The number of iterations
GN-T	1.0E-2	20
GN-L	1.0E-2	20
TV	1.0E-2	15
LSM+GT+FEM	not applicable	250

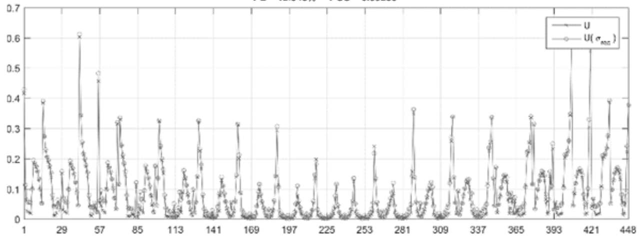


Fig. 1. Electrical voltages - GN-T method.

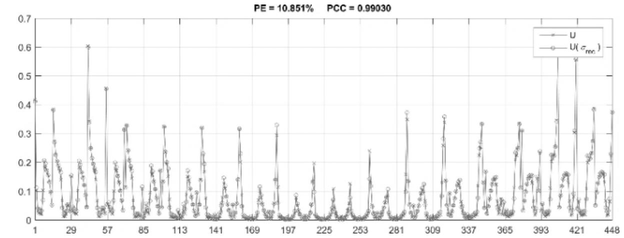


Fig. 2. Electrical voltages - GN-L method.

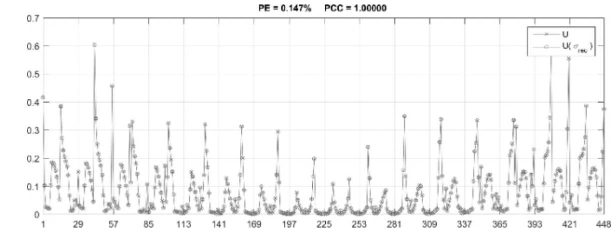


Fig. 3. Electrical voltages - TV method.

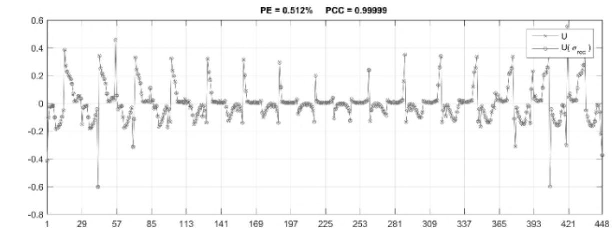


Fig. 4. Electrical voltages - LSM.

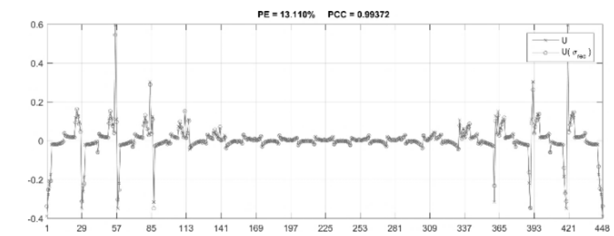


Fig. 5. Electrical voltages - EN.

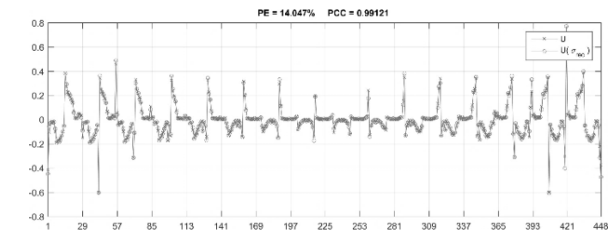
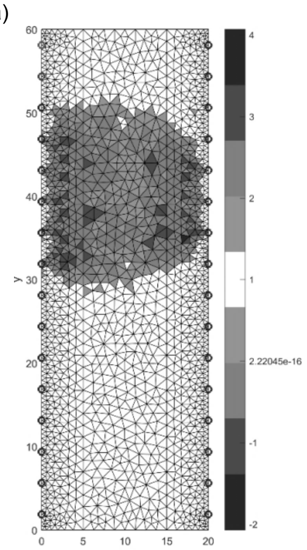
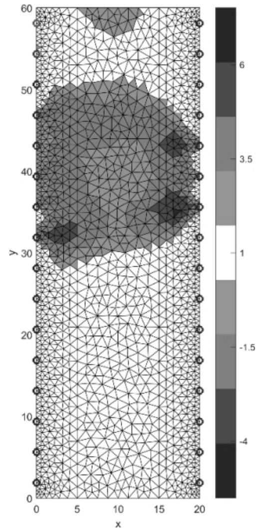


Fig. 6. Electrical voltages - ANNs.

a)



b)



c)

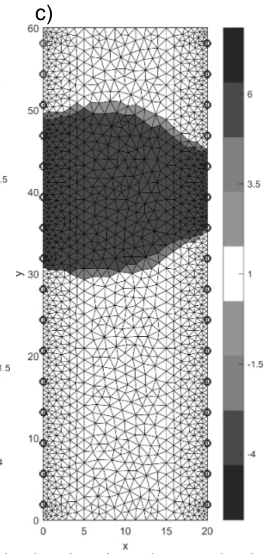
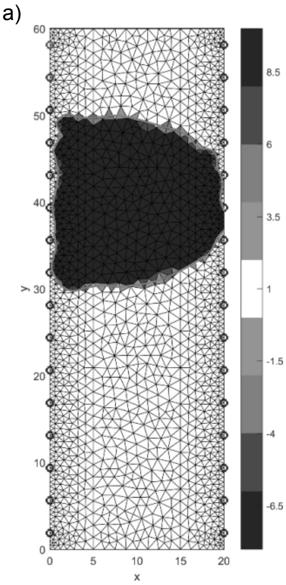
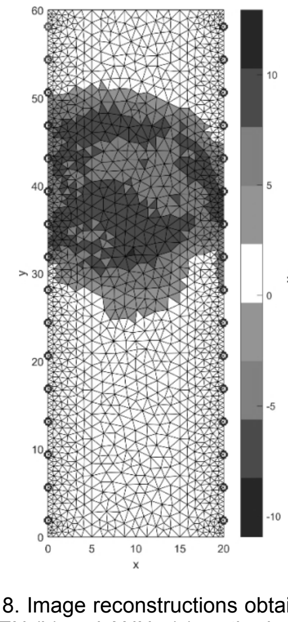


Fig. 7. Image reconstructions obtained using the methods: GN-T (a), GN-L (b) and TV (c). The area marked with navy blue is characterized by increased conductivity (high humidity).

a)



b)



c)

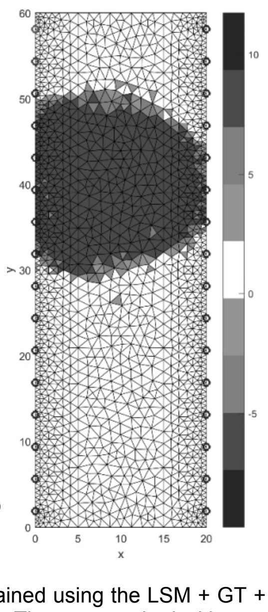


Fig. 8. Image reconstructions obtained using the LSM + GT + FEM (a), EN (b) and ANNs (c) methods. The area marked with navy blue is characterized by increased conductivity (high humidity).

Table 3. Parameters determining the quality of the reconstruction.

	GN-T	GN-L	TV
PE	12.3452%	10.8514%	0.1469%
PCC	0.9924	0.9903	1.0000
	LSM+GT+FEM	EN	ANNs
PE	0.5119%	36.0784%	14.0470%
PCC	1.0000	0.9330	0.9912

Conclusion

The article presents a system for assessing the humidity level of buildings using electric tomography. The use of modern tomographic techniques allows for spatial assessment of humidity levels. The proposed application solves the opposite problem. The measuring system contains special surface electrodes. The solution includes a number of different methods for image reconstruction, such as level set method, total variation, neural networks, or elastic net.

The optimization methods used allow for correct image reconstruction determination. Thus, it is possible to precisely indicate the location of an area with increased humidity. The best results (the lowest percentage error and the largest correlation coefficient) were obtained in the case of the TV and LSM + GT + FEM methods. The reconstruction obtained using the statistical method (EN) is subject to a relatively large percentage error. It is related to the specificity of the data set, on the basis of which the coefficients of the linear model were determined. It should be noted that the relationship between electrical voltage and conductivity is non-linear. In addition, in the considered case, the ratio of wet conductivity to dry conductivity is quite large and is 10 - the linear approximation may not function satisfactorily.

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