Numerical Algorithms and Measurement Systems in Practical Implementation of Electrical Impedance Tomography

Tomasz Rymarczyk, Przemysław Adamkiewicz
Department of Research and Development
NET-ART, Lublin, Poland
Department of Computer Science, UCEA, Lublin, Poland
e-mail: tomasz@rymarczyk.com

Jan Sikora
Electrotechnical Institute, Warszawa, Poland
Lublin University of Technology, Lublin, Poland
e-mail: sik59@wp.pl

***Abstract*— This paper presents a nondestructive method of brick wall dampness testing in real building structures and a new method of testing flood embankment dampness. We used a setup made of specially built laboratory models to determine the moisture level of test brick walls and flood embankments. The topological method and the gradient technique were used with the optimization approach. The finite element method was used to solve the forward problem. The proposed algorithm was initialized by using one step methods and topological sensitivity analysis. We constructed the forward model and we solved the inverse problem in order to visualize moisture inside objects. Practical examples of using the Electrical Impedance Tomography are also presented.**

Keywords-image reconstruction; inverse problem; level set method; finite element method; electrical impedance tomography.

I. INTRODUCTION

This paper presents a new method examining the flood embankment dampness and the brick wall dampness using the electrical impedance tomography [5][9][10]. Numerical methods of the shape and the topology optimization were based on the level set methods [2][3][4] and the gradient methods [15]. The discussed technique can be applied to the solution of inverse problems in the electrical impedance tomography. New algorithms to identify unknown conductivities were implemented. The purpose of the presented method is to obtain a better image reconstruction than gradient methods.

One of the major pathologies in historic buildings is the existence of dampness. Moisture transfer in walls of old buildings, which are in direct contact with the soil, leads to a migration of soluble salts responsible for many building problems. Building porous materials (e.g., brick or concrete), both natural and manufactured, have pores (like a sponge) and the moisture can be pulled up against gravity (capillary effect). Figure 1 shows an example of a damp historical wall. The dampness raising from the soil is a problem in old buildings, especially without adequate horizontal and vertical insulation of foundations. The moisture creates a danger not only to the walls, but also to human health. It promotes progress of rheumatic disorders and formation of fungus on the walls. Fungus can cause allergies and many other diseases. There are many different drainage systems (watertight barriers, injection of hydrofuge products, etc.). Regardless of the method, it is very important to continuously monitor the status of dampness during the drying process. In the case of historical buildings of great cultural importance, the use of destructive measurements is prohibited by conservation specialists. The traditional techniques used to deal with this kind of problem proved to be ineffective, justifying the need to find a new approach [1].

Figure 1. Historical damp wall. Examples of excessively damp brick walls in historical buildings.

Numerical methods of shape and topology optimization methods were based on the level set representation and the shape differentiation and there were topology changes possible during the optimization process [11][12]. Level set methods have been applied very successfully in many areas of the scientific modelling, for example in propagating fronts and interfaces [6][7][8]. Therefore, they are used to study shape optimization problems. Instead of using the physically driven velocity, the level set method typically moves the surfaces by solving the Hamilton-Jacobi equation (2). These approaches based on shape sensitivity include the boundary design of elastic.

In Section II, we present some information about electrical impedance tomography. Section III discusses

 ISBN: 978-1-61208-419-0

models of numerical methods. Section IV shows the numerical results and the paper concludes in Section V.

II. Electrical Impedance Tomography

The Electrical Impedance Tomography (EIT) is a technique of imaging the distribution of conductivity inside the tested object from measurements of the distribution of potentials on the object's surface. In Figure 2, the object is a brick wall with dampness rising from the ground.

The test results obtained by the nondestructive impedance tomography method are compared with the results obtained by numerical simulations. We prepared two prototype measuring systems. One is a low cost EIT tomography system containing 16 electrodes for measuring damp brick wall on one side. The second one is a full EIT system with 32 electrodes for testing on both sides of a wall.

The forward problem in EIT is described by Laplace's equation [9]:

$$\nabla \cdot (\gamma \nabla u) = 0, \qquad (1)$$

where γ denotes conductivity. Symbol u represents electrical potential.

III. Models

Nondestructive methods do not require that samples be taken from the wall, which is their advantage over the destructive methods.

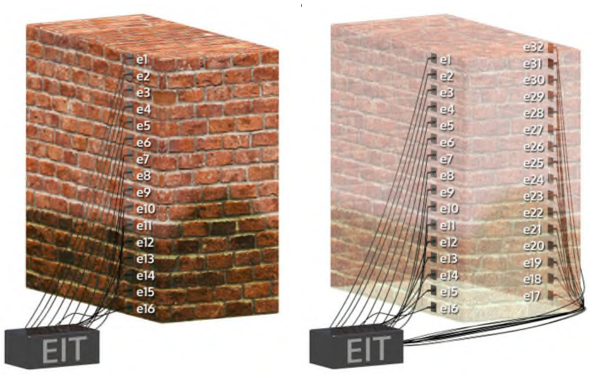


Figure 2. Measurement EIT systems with 16 electrodes and 32 electrodes on the damp brick wall.

Figure 3. Surface electrodes on the damp brick wall.

Among the nondestructive methods, the most popular are electric and nuclear methods, particularly, the electric resistance method, the dielectric method, the microwave method, and the neuronal method [1]. But, in the case of nondestructive methods, the dampness measuring instruments must be calibrated in order to determine the correlation between their indications and the weight concluded dampness of the tested material. In this paper, the electrodes can be easily attached to the tested object. The level set method and the gradient technique were based on shape and topology optimization to solve the inverse problem in the electrical impedance tomography. Such task can be considered as application of the electrical impedance tomography.

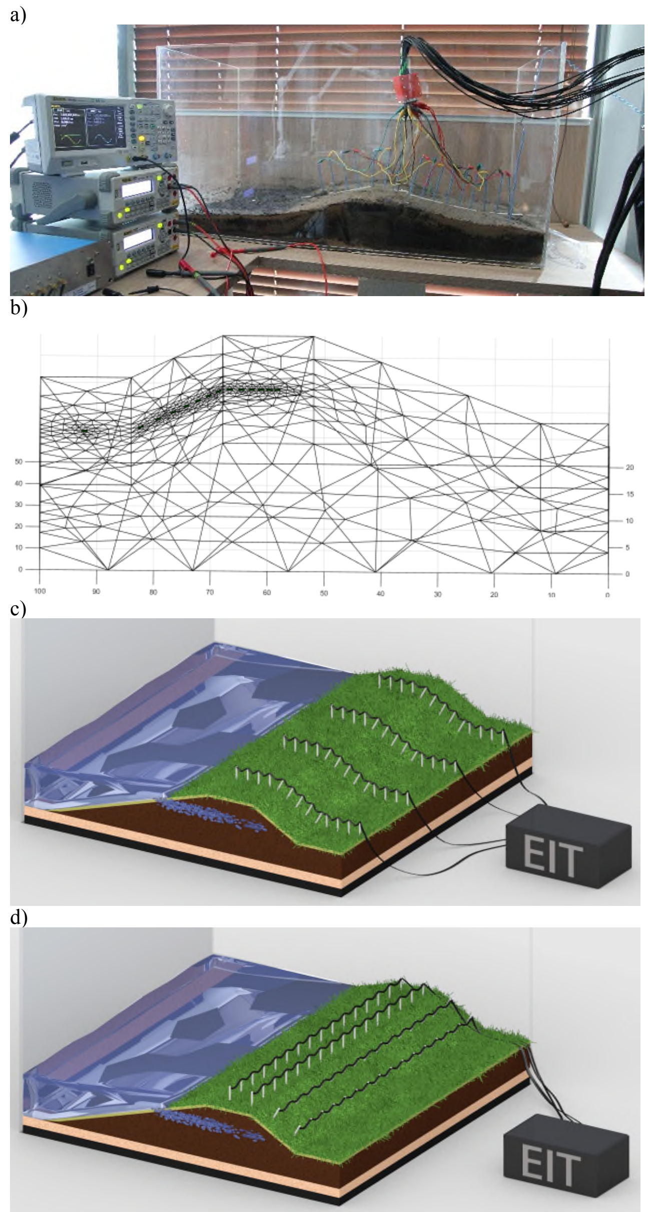


Figure 4. The geometrical laboratory models of the flood embankment: a) the laboratory model, b) the discretization model, c) the first model of measurement, d) the second model of measurements.

The object is a brick wall with dampness rising from the ground in Figure 2. Surface electrodes can be easily attached to the wall (see Figure 3) by special conductive glue. We used an electrical impedance tomography device with multiplexer to make measurements.

The flood embankment system is given in Figure 4. The laboratory model (a) presents the measurement system with multiplexer and 16 electrodes. The discretization model (b) was based on the finite element method (using to solve the forward and inverse problem). The first model (c) collects measurements perpendicularly to the flood embankment. The second model (d) performs measurements parallel to the tested object.

IV. Numerical Methods

Numerical methods of the shape and the topology optimization were based on the level set representation and the shape differentiation and were made possible topology changes during the optimization process.

The motion is seen as the convection of values (levels) from the function ϕ with the velocity field $\vec{v}$. Such a process is described by the Hamilton-Jacobi equation [7]:

$$\frac{\partial \phi}{\partial t} + \vec{v} \cdot \nabla \phi = 0. \tag{2}$$

Here, $\vec{v}$ is the desired velocity on the interface, and is arbitrary elsewhere. Actually, only the normal component of $\vec{v}$ is needed ($v_n \equiv \vec{v} \cdot \vec{n} \equiv \vec{v} \cdot \nabla \phi / |\nabla \phi|$), so (2) becomes:

$$\frac{\partial \phi}{\partial t} + v_n \left| \nabla \phi \right| = 0. \tag{3}$$

Let λ be the adjoint function satisfying [5]:

$$-\Delta\lambda = u - u_m. \tag{4}$$

The material derivative $\dot{u}(x)$ is given by [5]:

$$\dot{u}(\vec{r}) \equiv \lim_{t \to 0} \frac{u_t(\vec{r} + t\vec{v}(\vec{r})) - u(\vec{r})}{t}, \tag{5}$$

where $(x,y) \in \Omega_t$. The shape derivative is following [5]:

$$u'(\vec{r}) \equiv \lim_{t \to 0} \frac{u_t(\vec{r}) - u(\vec{r})}{t} = \dot{u}(\vec{r}) - \vec{v}(\vec{r}) \cdot \nabla u(\vec{r}). \tag{6}$$

The steepest descent direction $\vec{v}$ is given by:

$$\vec{v} = -(\nabla u \cdot \nabla \lambda)\, \vec{n}. \tag{7}$$

In next step the level set function is updated:

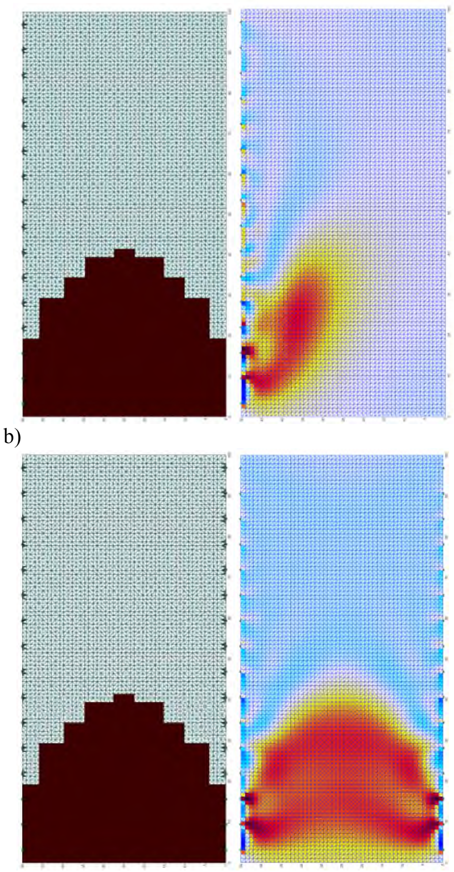
$$\phi^{k+1} = \phi^k - \left(\nabla u^k \cdot \nabla \lambda^k\right) \left|\nabla \phi^k\right| \Delta t, \tag{8}$$

For the minimization problem, iterative coupling of the level set method and the topological gradient method have been proposed. Both methods are gradient-type algorithms, and the coupled approach can be cast into the framework of alternate directions descent algorithms. One step methods and topological algorithms were used to solve this problem.

V. Results

The test results were obtained by using the EIDORS software [14] in Figure 5. We prepared two prototype measuring systems. The first of them is the EIT tomography system that contains 16 electrodes for measuring damp brick wall on one side.

a)



b)

Figure 5. Geometrical model of the investigated dumped wall with (a) 16 and (b) 32 electrodes.

a) b) c)

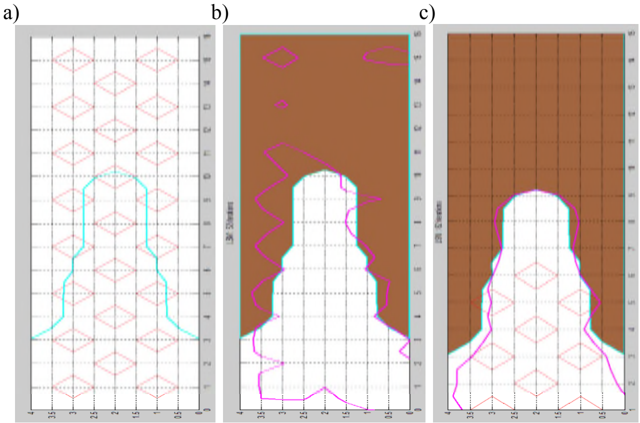


Figure 6. The image reconstruction by the level set method: (a) the original objects and the zero contour, (b) the reconstructed object with one side of the wall, (c) the reconstructed object with both side of the wall.

The latter is a full EIT system with 32 electrodes for testing on both sides of a wall. Figure 2 shows exemplary numerical reconstruction of moisture in the damp wall by the Gauss Newton one step method. Figure 6 presents the image reconstruction by the level set method.

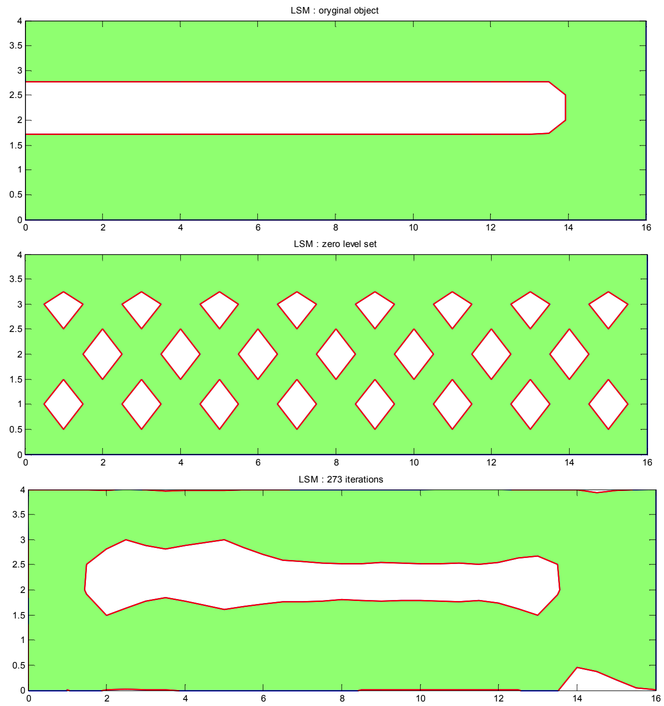


Figure 7: The image reconstruction - the original objects with the measurement system, the zero level set function, the reconstructed object.

Surface potential measurements are performed at different angles of projection whereby the information needed to determine an approximate distribution of conductivity inside the object is obtained. In the example reported below, the conductivity of searched objects is known. The representation of the boundary shape and its evolution during an iterative reconstruction process is achieved by the level set method. The forward problem was solved by the finite element method. Figure 7 shows the process of the image reconstruction with the zero level at initial step is represented by a lot of objects. The picture shows the original object and the reconstruction after 273 number of iterations. The process of reconstruction seems to be the correct one, because the region border is located nearly the real object edges.

VI. CONCLUSION AND FUTURE WORK

A new nondestructive method of the flood embankment dampness and the brick wall dampness was tested by the electrical impedance tomography. Numerical methods of the shape and the topology optimization were based on the gradient techniques and the level set representation. The presented methods have been applied very successfully in many areas of the scientific modelling. These approaches were based on sensitivity analysis. An efficient algorithm for solving the forward and inverse problems would also improve a lot of the numerical performances of the proposed methods. In modeling of the problem in the electrical impedance tomography, it is required to identify unknown conductivities from near-boundary measurements of the potential. Future work will be based on an implementation of artificial intelligence algorithms to solve the inverse problem.

REFERENCES

[1] J. Hoła, Z. Matkowski, K. Schabowic, J. Sikora, K. Nita, and S. Wójtowicz, "Identificationof Moisture Content in Brick Walls by means of Impedance Tomography", COMPEL, Vol. 31, Issue 6, 2012, pp. 1774-1792.

[2] S. Osher and R. Fedkiw, "Level Set Methods and Dynamic Implicit Surfaces", Springer, New York 2003.

[3] J. A. Sethian, "Level Set Methods and Fast Marching Methods", Cambridge Univeristy Press, 1999.

[4] G. Allaire, F. De Gournay, F. Jouve, and A. M. Toader, "Structural optimization using topological and shape sensitivity via a level set method", Control and Cybernetics, vol. 34, 2005, pp. 59-80.

[5] K. Ito, K. Kunish, and Z. Li, "The Level-Set Function Approach to an Inverse Interface Problem", Inverse Problems, vol. 17, no. 5, 2001, pp. 1225-1242.

[6] S. Osher and J. A. Sethian, "Fronts Propagating with Curvature Dependent Speed: Algorithms Based on Hamilton-Jacobi Formulations", Journal of Computational Physics, vol. 79, 1988, pp. 12-49.

[7] S. Osher and R. Fedkiw, "Level Set Methods: An Overview and Some Recent Results", Journal of Computational Physics, vol. 169, 2001, pp. 463-502.

[8] S. Osher and F. Santosa, "Level set methods for optimization problems involving geometry and constraints. Frequencies of a two-density inhomogeneous drum", Journal of Computational Physics, vol. 171, 2001, pp. 272-288.

[9] T. Rymarczyk "Using electrical impedance tomography to monitoring flood banks", International Journal of Applied Electromagnetics and Mechanics 45, 2014, pp. 489–494.

[10] T. Rymarczyk, P. Tchórzewski and J. Sikora, "Topological Approach to Image Reconstruction in Electrical Impedance Tomography", ADVCOMP 2014, ISBN: 978-1-61208-354-4, Rome, Italy, August 24 – 28,2014, pp. 42-45.

[11] J. Sokolowski and A. Zochowski, "On the topological derivative in shape optimization", SIAM Journal on Control and Optimization, vol. 37, 1999, pp. 1251–1272.

[12] C. Tai, E. Chung, and T. Chan, "Electrical impedance tomography using level set representation and total variational regularization", Journal of Computational Physics, vol. 205, no. 1, 2005, pp. 357–372.

[13] T. Rymarczyk, J. Sikora, and B. Waleska, "Coupled Boundary Element Method and Level Set Function for Solving Inverse Problem in EIT", Proc. 7th World Congress on Industrial Process Tomography, Sep. 2013, pp. 312-319.

[14] A. Adler and W. Lionheart, "Uses and abuses of EIDORS: An extensible software base for EIT", Physiol. Meas., 27, 2006, pp.:25-42.

[15] S.F. Filipowicz, T. Rymarczyk, J. Sikora, "Level Set Method for Inverse Problem Solution In Electrical Impedance Tomography", XII International Conference on Electrical Bioimpedance & V Electrical Impedance Tomography, 2004, pp.: 519-522.