Detect Dampness in Building Walls by Solving the Inverse Problem in Electrical Impedance Tomography

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Abstract. The paper presents a measurement system based on electrical tomography. It will be an innovative solution for an evaluation study of the level of dampness of the walls and the condition of the building. Both in terms of the measuring method as the reconstruction algorithm. The application of modern tomographic techniques in conjunction with topological algorithms will allow to perform a non-invasive and very accurate spatial assessment of the dampness level. The authors of this paper propose a new kind of connection with the use of imaging techniques hybrid solution with surface electrodes.

Keywords. Electrical Impedance Tomography, Inverse Problem, Hybrid Methods

Introduction

One of the major causes of pathologies in historic buildings all over the world is the presence of moisture, particularly rising damp. Moisture transfer in walls of an old buildings, which are in direct contact with the soil, leads to a migration of soluble salts responsible for many building problems [2,7,12-14]. The moisture can be pulled up against gravity (capillary effect). Every technique has its advantages, drawbacks and conditioning allowing it to be used only in particular circumstances [8,10]. Using indirect methods (thermographic camera) there is a possibility of determining water concentration only on wall surface or in its subsurface area. This fact poses a fundamental problem in case of thick barriers, because moisture inside any wall is usually few percent higher than near its surface. 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 damp wall. Rising damp from the soil is a problem in old buildings, especially without adequate horizontal and vertical insulation of foundations. 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 (dry as watertight barriers, injection of hydrophuge products, etc.). Regardless of the method it is very important to continuously monitor the status of damp during the drying process. Proposed hybrid method, in
which assessment of building materials’ dampness is an indirect evaluation based on another physical feature, will result in a possibility of conducting multiple measurements without the slightest damage to the examined object. Figure 1 shows damp wall.

Figure 1. Examples of excessively damp brick walls.

1. Models and measurement system

Electrical tomography is an imaging technique for detecting the internal conductivity distribution of an object by voltage measurements taken by an exterior electrode [1,5-6,15-20]. Numerical methods of the shape and the topology optimization were based on the level set representation and the shape differentiation. There were made possible topology changes during the optimization process. Level set methods, Total Variation and Gauss-Newton methods have been applied very successfully in many areas of the scientific modelling such as the wall dampness [3,4,11]. These approaches were based on shape sensitivity include the boundary design of the elastic interface. The finite element method has been used to solve the forward problem. The proposed solution algorithm is initialized by using the topological sensitivity analysis. Shape derivatives and material derivatives have been incorporated with the level set method to investigate shape optimization problems.

The gradient of the potential distribution ($u$) is related to electric field strength by:

$$E = -\nabla u$$  \hspace{1cm} (1)

Assuming there are no current sources or sinks within the region of interest then from Ampère’s law:

$$\nabla \cdot J = 0$$  \hspace{1cm} (2)
Typical problem in EIT requires the identification of the unknown internal area from near-boundary measurements of the electrical potential. It is assumed that the value of the conductivity is known in regions whose boundaries are unknown. The forward problem in EIT is described by Laplace’s equation:

\[ \nabla \cdot (\gamma \nabla u) = 0, \]  

(3)

where \( u \) is potential and \( \gamma \) is conductivity.
Function $u$ is taken under Dirichlet condition in boundary points adjacent to electrodes and Neumann condition on remaining part of the boundary. Problem can be reduced to determination of the minimum value of the functional:

$$I[u] = \frac{1}{2} \int_{\Omega} \gamma |\nabla u|^2 dxdy. \quad (4)$$

Figure 2 presents the cross and neighboring measurement methods of boundary potential data collection illustrated for a cylindrical volume conductor and 16 equally spaced electrodes using in electrical impedance tomography.

The scheme of the algorithm to minimize the objective function is presented in Fig. 3. The system consisted of four layers, as shown in Fig. 5.
Figure 6. The project of measurement system with the special construction of electrodes.

Figure 7. A wall with laboratory measurement system.
The data was acquired from tomographic devices as time series datasets. In this stage MQTT protocol was used to pass the data from the source to the analytical system. The data flow was replicated into two flows: the first one was sent to the database system (for this purpose NoSQL Cloudant database system was used) and the second one was sent to the analytical system for further analysis. The aim of such operation was to process data in real time as well as to keep raw historical data for additional offline analysis (Fig. 4). Figure 6 shows the project of measurement system with the special construction of surface electrodes. A complete electrode consists of three modules: a specific electrode, a PCB with a contact socket and a fastening system. Mechanically, the modules are connected to each other by means of two sleeves placed one inside the other. The test results obtained by the non-destructive impedance tomography method are compared with the results obtained by numerical simulations. A wall with laboratory measurement system is presented in Fig. 7.

2. Numerical Results

Figure 8 shows the image reconstruction of the wall brick for 16 electrodes by the Gauss-Newton method and the Gauss-Newton Level Set Method (hybrid method). Figure 8. The geometrical model of the investigated dampened wall with 16 electrodes—the line measurement: (a) the initial model, (b) reconstructed using the Gauss-Newton method, (c) reconstructed using the hybrid method.

Unknown structures are marked by the solid line; the damp area was marked with a brown block. This picture presents the geometrical model of the investigated dampened wall with the line measurement. Figure 9 shows the geometrical model 3D with 2 x 2 x 8 electrodes of the image reconstruction: (a) model, (b) Total Variation, (c) Gauss-Newton method. Figure 10 presents the geometrical model 3D with 1 x 2 x 16 electrodes.
Figure 9. The geometrical model 3D with $2 \times 2 \times 8$ electrodes – the image reconstruction: (a) model, (b) Total Variation, (c) Gauss-Newton method.

Figure 10. The geometrical model 3D with $1 \times 2 \times 16$ electrodes – the image reconstruction: (a) model, (b) Total Variation, (c) Gauss-Newton method.
3. Conclusion

The non-destructive method of the brick wall dampness was tested by the electrical impedance tomography. The setup was used to determine the moisture of the test wall on specially built models. Numerical methods of the shape and the topology optimization were based on the Gauss-Newton method, Total Variation and the level set representation. The referred algorithms have been applied successfully in the reconstruction of measured data of the model wall. 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 modelling of the problem in the electrical impedance tomography, it is required to identify unknown conductivities from near-boundary measurements of the potential. The presented algorithms are effective for spatial determination of moisture in the walls. The Total Variation method gives a better result in 3D. In 2D, however, the hybrid method with topological components is the most effective.

References

