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Implementation of the LARS method to solve the inverse problem in electrical tomography

***Abstract**. The presented research presents a method of using the smallest angles regression algorithm to solve the inverse problem in electrical impedance tomography in relation to a damp wall. Highly correlated predictors in linear models make it difficult to precisely determine the influence of these predictors on the output variable. The standard application of the least-squares method to estimate unknown parameters may lead to a poor forecast. Adding a penalty parameter depending on quantities of parameters to the least square criterion allows us to determine the biased estimators but also to reduce the variance of estimators.*

***Streszczenie.** Przedstawione badania dotyczą sposobu wykorzystania algorytmu regresji najmniejszego kąta (LARS) do rozwiązania problemu odwrotnego w elektrycznej tomografii impedancyjnej w odniesieniu do wilgotnej ściany. Wysoce skorelowane predyktory w modelach liniowych utrudniają precyzyjne określenie wpływu tych predyktorów na zmienną wyjściową. Standardowe zastosowanie metody najmniejszych kwadratów do oszacowania nieznanych parametrów może prowadzić do złej prognozy. Dodanie elementu kary w zależności od ilości parametrów do kryterium najmniejszego kwadratu pozwala nam określić estymatory obciążenia, a także zmniejszyć wariancję estymatorów. (**Implementacja metody LARS do rozwiązywania problemu odwrotnego w tomografii elektrycznej**).*

Keywords: statistical methods; inverse problem; electrical impedance tomography.
Słowa kluczowe: metody statystyczne; problem odwrotny; elektryczna tomografia impedancyjna

Introduction

The tomographic method makes it possible to obtain moisture distribution inside the wall in a digital form. This is extremely useful when you need to obtain a high quality image in a non-invasive way. Visualization of the moisture inside the wall enables the implementation of effective protection of walls against moisture and in the case of old buildings - effective and fast drainage of walls. This is of particular importance for thick walls. The most important advantages of the proposed measurement system include non-invasive and non-destructive measurement of the tested object thanks to specially designed surface electrodes and the ability to display the moisture distribution inside the wall both on the plane (2D) and spatially (3D). Due to the fact that wall conductivity depends mainly on the degree of humidity, it is possible to determine the distribution of moisture inside the wall using the indirect method - based on the conductivity map. In the case of brick walls, this is the only cheap and non-invasive method, unlike the weight method, in which the wall must be drilled, and the heat generated evaporates a certain amount of moisture. This is, therefore, an invasive method of quality, not a quantitative method, thus subject to an additional error. We are interested only in differential (relative) images, on which we can distinguish specific colors from a dry background. Thanks to this, moisture content can be assessed in the tested cross-sections of walls or bricks. There are many different methods to optimize the solution mentioned above. problem [8-14,22,23]. This article presents the method of using the smallest angle algorithm [4] to solve the inverse problem in electrical tomography for damp wall [1-3,5-7,15-21].

Statistical method

Reduction of adverse effects of multi-polarization between predictors can be achieved by applying the lowest angle regression algorithm for this solution. The algorithm in question includes only independent variables in the linear model. From the set of predictors, you should select those input variables that directly affect dependent variables (outputs). The algorithm implemented in simulation experiments employed a linear model, built by step forward regression, where the best variable was added to the model at each iterative step.

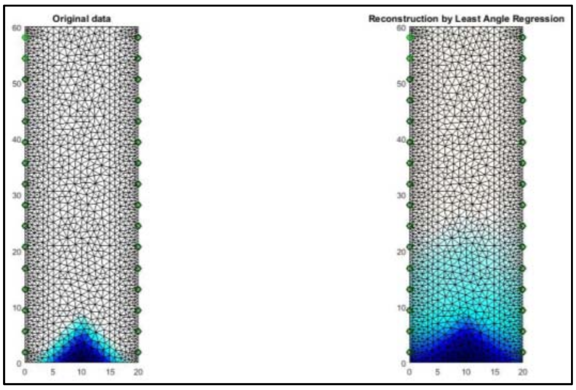
Algorithm of Least Angle Regression includes the following items and activities:

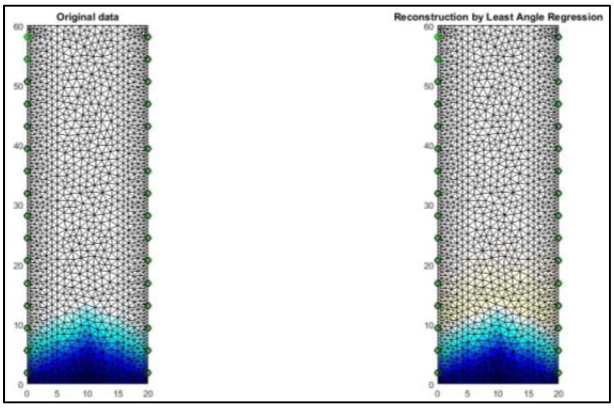
1. The predictors should be standardized. The intercept β_0 in expression (1) is equal a mean of response variable and we put $\beta_1 = \beta_2 = ... = \beta_k = 0$. Active set A (set of predictors) is empty.
2. Calculate the residuals $r = Y - \beta_0 - X_{(\mathrm{A})}\beta_{(\mathrm{A})}$ for the linear model with all predictors from active set A. Determine the predictor X_j (which is not in active set) most correlated with residuals r and attach to the active set A.
3. Move coefficient β_j from 0 towards its least-squares coefficient $\langle X_j, r\rangle$ until some other competitor X_k has a much correlation with the current residuals as does X_j.
4. Move β_j and β_s in the direction defined by their joint least square coefficient of the current residual on $\langle X_j, X_s\rangle$ until some other competitor X_l has a much correlation with the current residual.
5. Go to step 2 and continue in this way until all k predictors have been entered.

Measurement system

In the EIT system, the data acquisition module transfers the measured voltage values from the electrodes to the control panel and then processes the data to generate the tomographic images. Conventional data acquisition systems require a separate electronic circuit to digitize voltage, demodulation, filtering and data conversion, and a dedicated signal processor to transfer data to a computer. To enable the tomographic examination of wall humidity, a hybrid tomograph was made according to our own concept. This device provides non-invasive testing of spatial distribution of moisture inside the walls (see Fig. 1). The tomograph includes the simultaneous or separate use of two measuring methods: electrical capacitance tomography and electrical impedance tomography. The device allows you to perform measurements including a system of 32 electrodes. Due to the fact that in one measurement sequence the measurements concern the combination of many different electrode pairs, one measurement vector can count up to several hundred values (predictors).

Fig. 1. Measurement systems - the laboratory airbirck model.





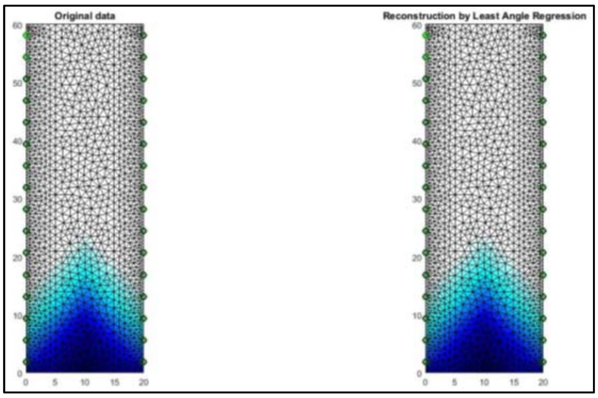


Fig. 2. The damp cellular concrete block and reconstruction based on the Least Angle Regression with 2 side measurements (2x16 electrodes) – models of moisture 2D.

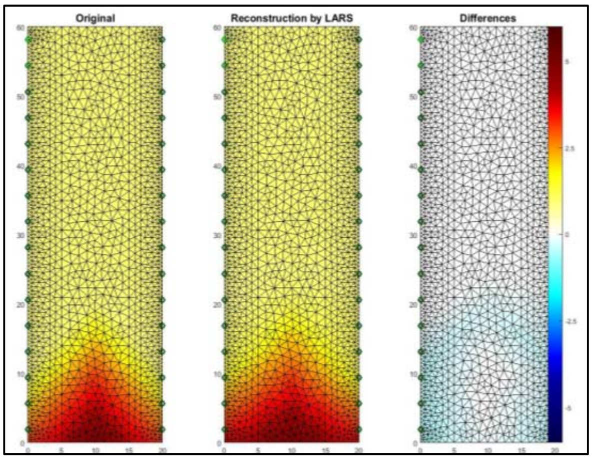


Fig. 3. The damp cellular concrete block and reconstruction based on the Least Angle Regression with 2 side measurements – model, reconstruction and differences.

Results

The influence of the measurement method and the reconstruction algorithm on the airbrick moisture analysis is presented below. Figure 2 shows the 2D damp cellular concrete block and reconstruction based on the Least Angle Regression with 2 side measurements (2x16 electrodes). The model, reconstruction and differences was presented in Fig. 3. Two measurement models have been proposed: model I with 2x8 electrodes on two side, model II with 2x8 electrodes on one side and model III with 2x16 electrodes on two sides.

An object whose internal electrical properties are unknown is tested at its edge and electrically excited in various combinations. Measurements are made for all possible ways of connecting the power source to the next electrode pairs. On the other sensors we measure voltage drops. In this way a series of measurements is created. In terms of calibration, we are only interested in measuring the degree of humidity. Conventional data collection systems require equipment to measure voltage, filter, demodulation and conversion to a digital form and signal processing unit to transfer data to a computer. Algorithms will provide results in leadership. The methods try to estimate the change in conductivity. The exact results depend on the algorithms (and the sensitivity pattern). Figure 4, 5 and 6 present of the Least Angle Regression with 1 and 2 side measurements. The pictures show a reconstruction with approximate values of conductivity. The tomograph equipped with 16 electrodes (2x8) and 32 electrodes (2x16). Intense colors indicate areas with higher humidity. It can be seen that the obtained reconstructive image is very close to the reference image. The difference image (Fig. 5 and 6 - bottom pictures) indicates small deviations of the grid points in the reconstructed image from the reference image. The colors in the images reflect the health of the individual pixels that each image consists of. The lack of the color of the original and the reconstructive images indicate a lack of moisture.

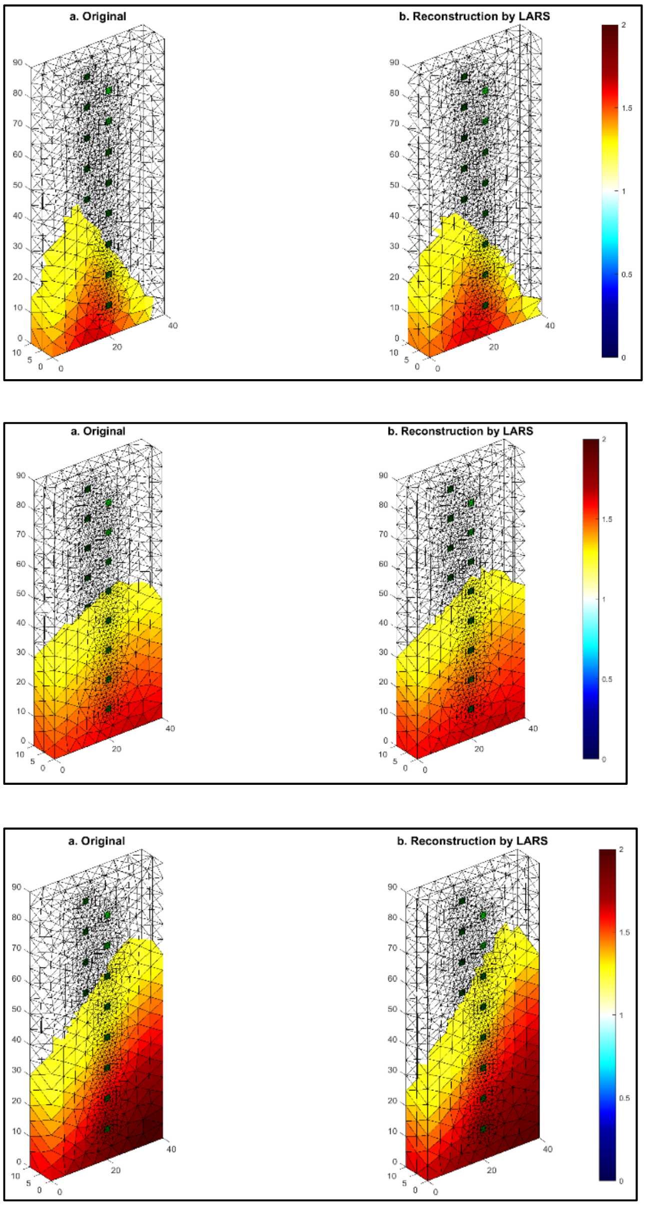
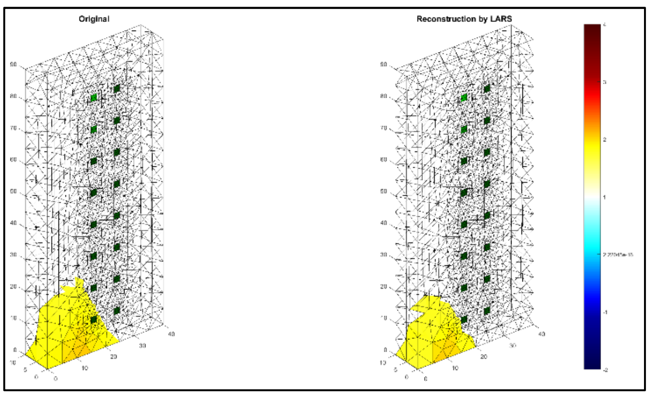
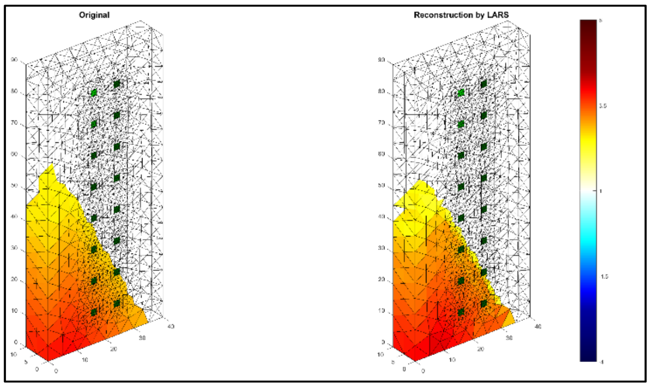
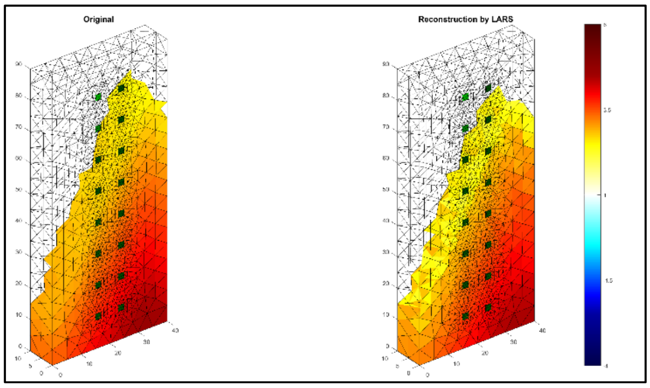


Fig. 4. The damp cellular concrete block and reconstruction based on the Least Angle Regression with 2 side measurements (2x8 electrodes) – models of moisture I.







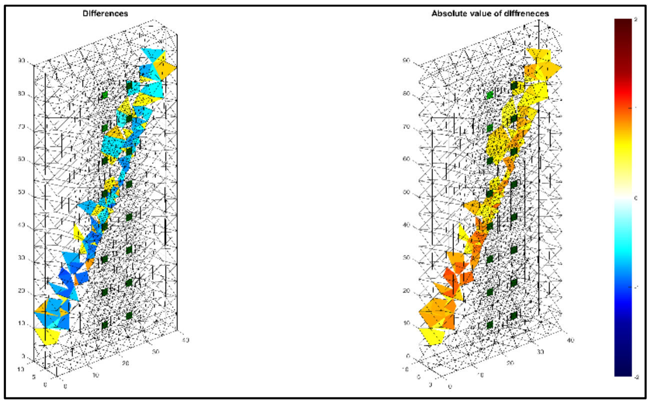
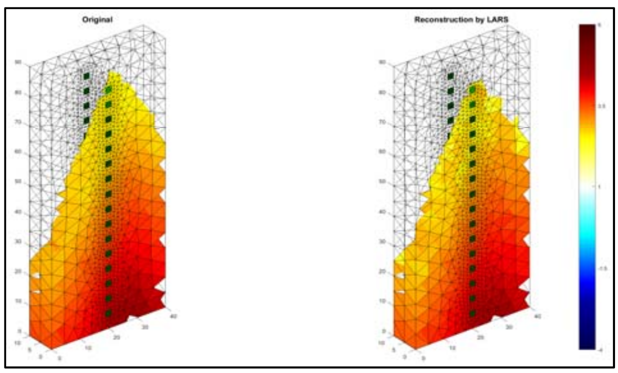


Fig. 5. The damp cellular concrete block and reconstruction based on the Least Angle Regression with 1 side measurements (2x8 electrodes)– model II.



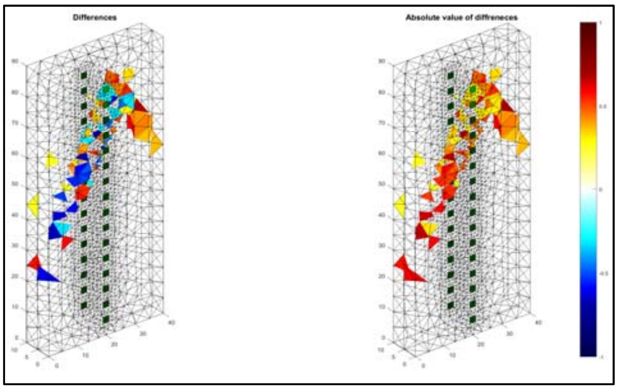


Fig. 6. The damp cellular concrete block and reconstruction based on the Least Angle Regression with 2 side measurements (2x16 electrodes) – model III.

Conclusion

There are many methods known to assess the moisture level in the walls. However, no single non-invasive method suitable for thick historical walls has been developed so far. None of the known and widely used methods makes it possible to estimate the moisture content in the entire volume of the tested wall part. Invasive standard methods allow only probing selected points of the wall body and at selected depths. In order to solve the inverse problem in the electrical impedance tomography for a damp masonry wall, the discussed algorithms used the smallest angular regression algorithm. To obtain more accurate and stable reconstruction results, the tested algorithms were based on statistical methods. The research used a physical phenomenon based on the dependence that moisture is closely correlated with the conductivity of porous building materials.

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