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Detection of seepages in flood embankments using the ElasticNET method

***Abstract**. The presented article discusses the proposition of using an algorithm based on the ElasticNET method to obtain accurate and reproducible results of reconstruction of tomographic images. In particular, the research concerned solving of the inverse problem in electrical tomography with reference to levees and dams. To enable the reconstruction of high resolution images using the impedance tomography, the ElasticNET algorithm was used, which is a combination of two methods: dorsal regression and LASSO. The results of the research have shown that thanks to the ElasticNET method you can obtain high resolution images that are faithful representation of the cross-section of the dam.*

***Streszczenie.** W zaprezentowanym artykule omówiono propozycję użycia algorytmu opartego na metodzie Elastic net w celu uzyskania dokładych i powtarzalnych wyników rekonstrukcji obrazów tomograficznych. W szczególności badania dotyczyły rozwiązywania problemu odwrotnego w tomografii elektrycznej w odniesieniu do wałów przeciwpowodziowych i zapór. Aby umożliwić rekonstrukcje obrazów o wysokiej rozdzielczości stosując tomografię impedancyjną zastosowano algorytm ElasticNET, który jest połączeniem dwóch metod: regresji grzbietowej i LASSO. Rezultaty badań wykazały, że dzięki metodzie ElasticNET można uzyskać obrazy o wysokiej rozdzielnoczści, będące wiernym odwzorowaniem przekroju zapory wodnej. (**Wykrywanie przecieków w wałach przeciwpowodziowych przy użyciu metody ElasticNET**).*

Keywords: electrical impedance tomography, elastic net, inverse problem.
Słowa kluczowe: elektryczna tomografia impedancyjna, elastic net, problem odwrotny..

Introduction

Electric tomography is based on the transformation of data taken from the surface of the tested object into the image of its cross-section. There are many methods to optimize the obtained image by solving the appropriate objective function [1-5,13,15,16,20-25,32]. The algorithm based on the ElasticNET presented in this article is a new proposal in tomography.

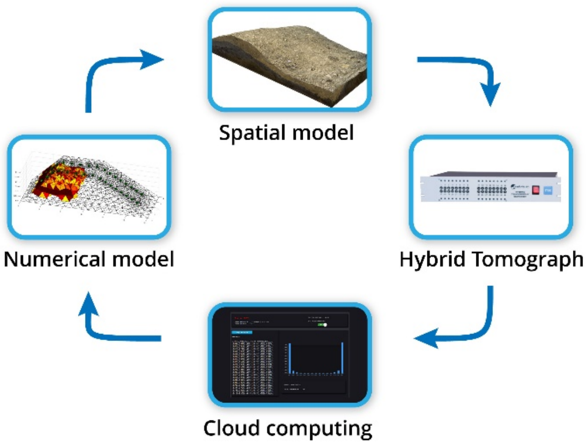


Fig. 1. Model of measuremnt system.

The way of working of electrical impedance tomography (EIT) consists in introducing electrical voltage to the tested object by means of a set of electrodes located on the surface of the object. Next, the measured values of electrical potentials between individual electrode pairs are collected. Conductance of individual sections of the cross-section of the tested object is reconstructed on the basis of known values of voltages and measured values of potentials. Reconstruction of the image obtained by electrical tomography requires sophisticated modeling. This method of imaging consists in the fact that the conductivity distribution of the tested object is estimated on the basis of measurements of electrical voltages and electrode potentials on the surface of their contact with the tested object. In order to obtain quantitative data on changes in the conductivity inside an object, it is more effective to apply a non-linear model in differential imaging [1,6-12,14,17-199,26-31]. In Fig. 1 shows the model of the measurement system.

ElasticNET

Let's consider the problem of recognizing linear dependencies

(1) $$Y = X\beta + \varepsilon$$

where $Y \in R^n$, $X \in R^{n\times(k+1)}$ are the observation matrices of a output variable and predictive variables respectively, $\beta \in R^{k+1}$ means a matrix of structural parameters, while $\varepsilon \in R^n$ vector of independent random variables. The well-known method of least squares consists in estimating unknown parameters $\beta = (\beta_0, \beta_1, ..., \beta_k)$ listed in the equation (1) by solving the task (2).

(2) $$\min_{\beta \in R^{k+1}} \|Y - X\beta\|^2$$

If $\det(X^T X) \neq 0$, then the best estimator of unknown parameters β equals $\hat{\beta} = (X^T X)^{-1} XY$.

In case the independent (input) variables are strongly correlated (collinear) to each other, the matrix $X^T X$ approaching a singular matrix. Using KMNK, the large absolute values of estimates (estimators) for unknown parameters are obtained. The predictions generated by such models are quite unstable. In tomography, the main goal is reconstruction of the image on the basis of the obtained from the electrodes measurements. During making measurements, we can see that the obtained values are highly correlated. Hence, we face the problem of input variables collinearity in the model (1). The possible solution is the introduction of an additional penalty. The penalty factor depending on the size of the parameter estimations in the task (2) consents the estimators to shrink. Finally, let's consider the task (3).

(3) $$\min_{(\beta_0,\beta')\in R^{k+1}} \frac{1}{2n}\sum_{i=1}^{n}\left(y_i-\beta_0-x_i\beta'\right)^2+\lambda P_\alpha(\beta'),$$

where $x_i=(x_{i1},...,x_{ik})$, $\beta'=(\beta_1,...,\beta_k)$ for $1\le i\le n$,
P_α is the penalty given by the model (4).

(4) $$P_\alpha(\beta')=(1-\alpha)\frac{1}{2}\|\beta'\|_{L_2}+\alpha\|\beta'\|_{L_1}=\sum_{j=1}^{k}\left(\frac{1-\alpha}{2}\beta_j^2+\alpha|\beta_j|\right)$$

As can be seen in equation (4), the penalty factor is a linear combination of norms L_1, L_2 and unknown parameters *β'*. Because of the introduction of a penalty subfunction to the function, which depends on the value of the model parameters (1), the absolute values of these parameters have been reduced. Parameter *λ* in the task (3) defines the penalty factor, and the parameter $0\le\alpha\le1$ creates a compromise between the LASSO (Least Absolute Shrinkage and Selection Operator) regression when $\alpha=1$ and pure ridge regression when $\alpha=0$. Ridge regression (called Tikhonov regularization) is one of the first methods of models regularization. LASSO regression was proposed by Robert Tibshirani. It consists in estimating unknown parameters and choosing models.

Solving the task (3) for established λ and α parameters we calculate estimators of unknown parameters for the model (1) with correlated variables. The expected values of the dependent variables are determined using the equation (5).

(5) $$\hat{Y}=X\hat{\beta}$$

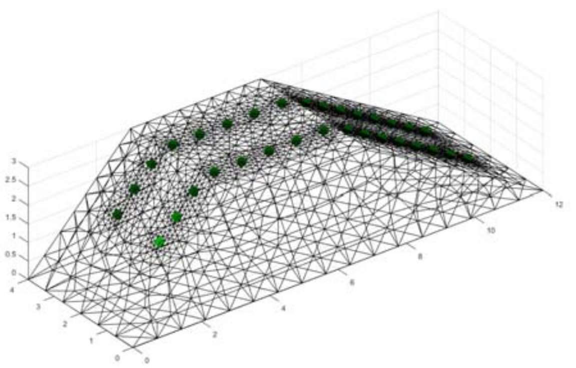
where $\hat{\beta}=(\hat{\beta}_0,\hat{\beta}_1,...,\hat{\beta}_k)$ is an estimator of unknown parameters.

Results

Fig. 2 shows a spatial model of a part of a flood embankment. All electrodes placed on the surface of the object are on one lane, which is perpendicular to the river bed or the center of the water reservoir. This means that in this case the electrodes were placed across the flood embankment. The tested model had the following parameters:

- type of electrodes: point,
- number of tetrahedrons: 12153,
- number of nodes: 2991,
- number of electrodes: 32.

The carried out experiments included 2 types of current stimulations. The first stimulation contained 192 measurements. The second stimulation contained 96 measurements. Parameters of linear models were generated using the algorithm based on ElasticNET. Fig. 3 shows the results of the obtained reconstructions.



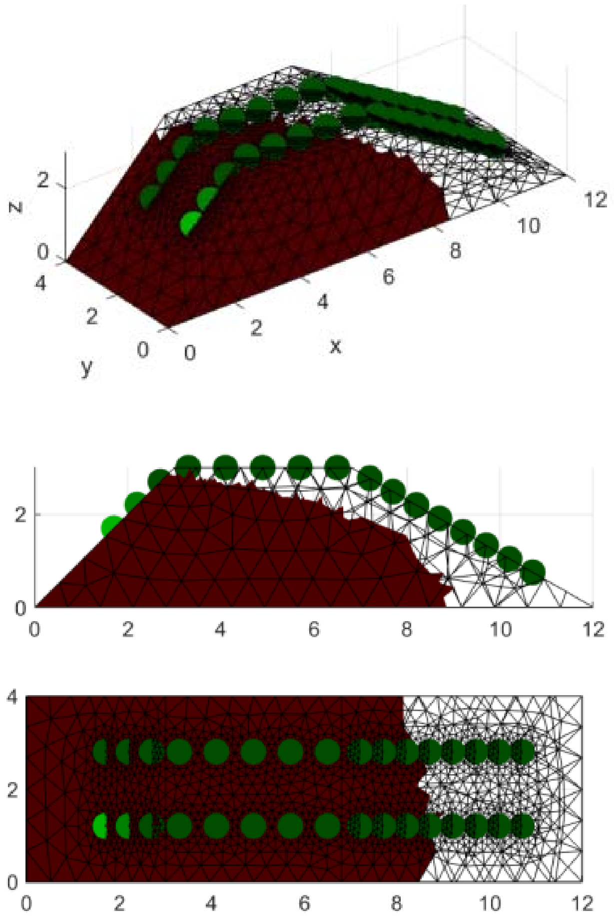


Fig. 2. Model of a flood embankment I with am injection of water.

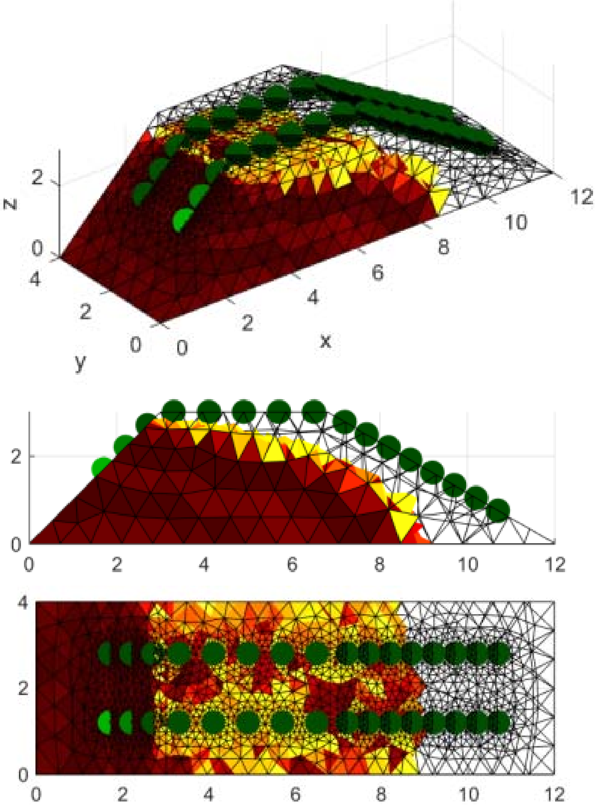


Fig. 3. Image reconstruction by the ElasticNET method.

Fig. 4 shows the three-dimensional model that represents a part of the flood embankment. All electrodes are arranged in two lines, which are parallel to the riverbed or the shoreline. This means that in this case the electrodes are arranged along the flood embankment or dam.

The tested model had the following parameters:

- type of electrodes: point,
- number of tetrahedrons: 17191,
- number of nodes: 4002,
- number of electrodes: 32.

The carried out experiments included 2 types of current stimulations. The first stimulus contained 192 measurements. The second stimulus contained 96 measurements. Parameters of linear models were estimated using the ElasticNET. Fig. 5 shows the results of the obtained reconstructions.

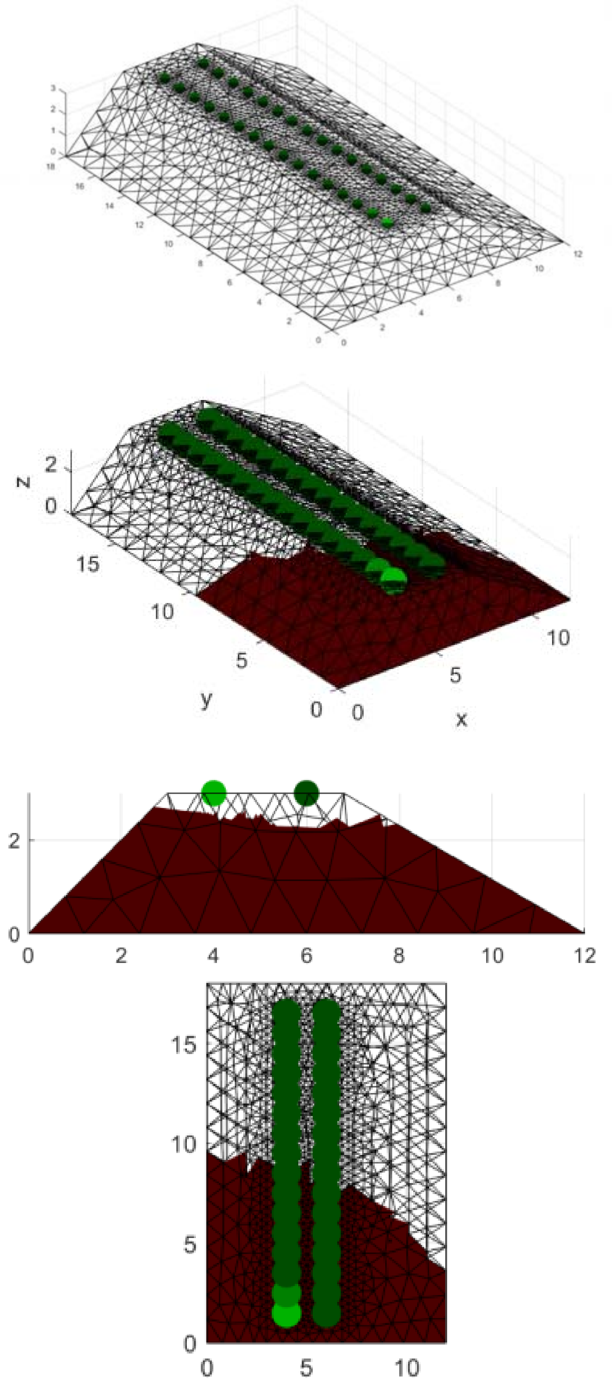


Fig. 4. Model of a flood embankment II with an injection of water.

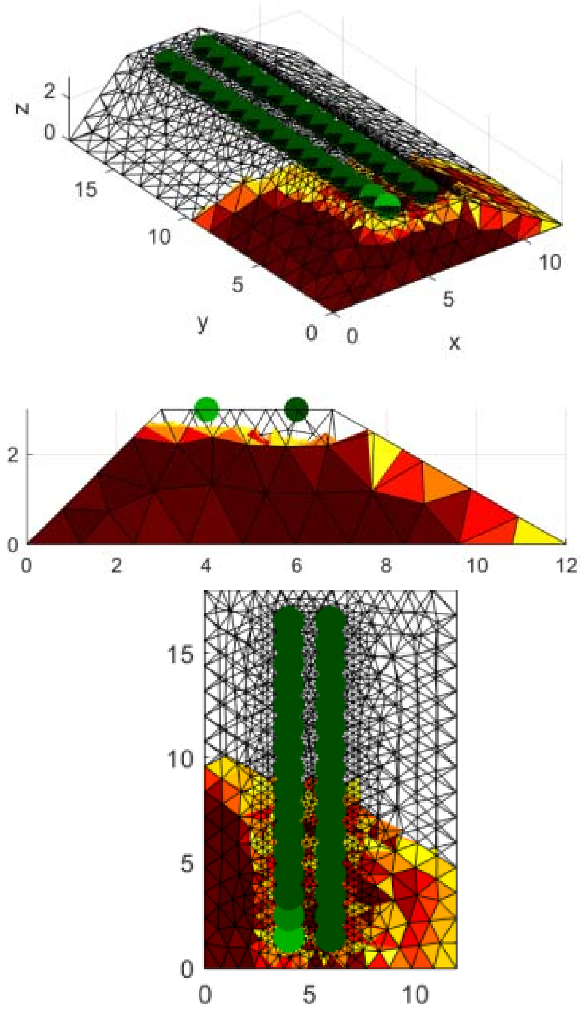


Fig. 5. Analysis of water injection from left side.

Conclusion

The article proposes an original methodology for solving problems related to risk assessment resulting from damages of flood embankments. The tested algorithm was based on the ElasticNET method. Thanks to the use of ElasticNET it was possible to solve the inverse problem in an efficient and effective manner, which resulted in obtaining more accurate and stable spatial reconstructions of flood embankment cross-sections. The solution developed thanks to the research described above has been successfully used in the embankments and dams simulation models. The results of simulation experiments as well as validations carried out on physical models provided promising results. Future work will be conducted towards the development and implementation of additional statistical algorithms in order to provide the best solution to the inverse problem.

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