Tomasz RYMARCZYK[1,2], Grzegorz KŁOSOWSKI [3], Paweł TCHÓRZEWSKI [1], Tomasz CIEPLAK[3], Edward KOZŁOWSKI[3]

Research & Development Centre Netrix S.A.(1), University of Economics and Innovation (2)
Lublin University of Technology (3)

doi:10.15199/48.2019.01.39

Area monitoring using the ERT method with multisensor electrodes

***Abstract**. The article presents a non-destructive method using multisensor electrodes to study cross-sections of interior objects such as landfills and flood embankments. Special sensors have been developed for deep measurements using electrical resistive tomography (ERT). It is an innovative approach to testing water and waste reservoirs, both due to the reconstruction model and the measurement method. The combination of tomographic techniques and original reconstruction algorithms allowed non-invasive and more accurate, spatial assessment of seepages and other damages of flood embankments.*

***Streszczenie.** W artykule przedstawiono metodę nieniszczącą z wykorzystaniem elektrod wielosensorowych do badania przekrojów wnętrza obiektów takich jak wysypiska i wały przeciwpowodziowe. Opracowano specjalne czujniki przeznaczone do pomiarów głębinowych za pomocą elektrycznej tomografii rezystancyjnej (ERT). Jest to innowacyjne podejście do testowania zbiorników wodnych i odpadowych, zarówno z uwagi na model rekonstrukcji, jak i metodę pomiaru. Połączenie technik tomograficznych i oryginalnych algorytmów rekonstrukcyjnych pozwoliło na nieinwazyjną i bardziej dokładną, przestrzenną ocenę infiltracji i innych uszkodzeń wałów przeciwpowodziowych. (**Monitorowanie obszaru metodą ERT za pomocą elektrod wielosensorowych**).*

Keywords: inverse problem; electrical impedance tomography; finite element method
Słowa kluczowe: problem odwrotny; elektryczna tomografia rezystancyjna; metoda elementów skończonych

Introduction

Tomography is a technique that allows obtaining a cross-sectional image of the examined object on the basis of data from the measurement of a given physical value (radiation, capacity, resistance, etc.) at selected points usually lying on the edge of the tested area. The resulting measurement vector is used to reconstruct the cross-section image using appropriate algorithms. The obtained image represents the distribution of a certain feature of the examined object depending on the type of tomography used. It can be material density, concentration, electrical permittivity, conductivity, etc.

Electrical tomography covers many tomographic imaging methods based on the processing of various electrical parameters [1,3,4,7,9,10,12-14]. Despite the fact that many methods have already been developed for assessing damage to flood embankments, there is no single universal tool for their diagnosis and monitoring. In this paper, a new method for testing flood embankments and landfills by means of electrical resistive tomography (ERT) was presented. For the needs of the research, a special measuring system was developed with special multisensor electrodes for depth measurements using ERT. The algorithms used for image reconstruction were based on gradient and topological methods. After minor modifications, it is possible to apply the discussed technique to solving reverse problems in electrical tomography [6, 18-23]. The combination of tomographic techniques with reconstruction algorithms allowed non-invasive and more accurate spatial assessment of seepages and damages to flood protections.

Model

Electric tomography including ERT enables non-invasive measurements of various types of technical objects. The internal structure of objects based on their electrical properties can be analyzed using electrodes located on the periphery or near the surface of the tested element. Fig. 1 shows the elements of the ERT model with multisensor electrodes.

The concept of the developed tomographic system assumes that the ERT system collects measured voltage values from multisensor electrodes, and then registers these data in a formalized way that allows their further processing. In order to carry out research and measurements, a tomographic system of data collection, demodulation, filtering and their transformation into a digital form enabling reconstruction was used.

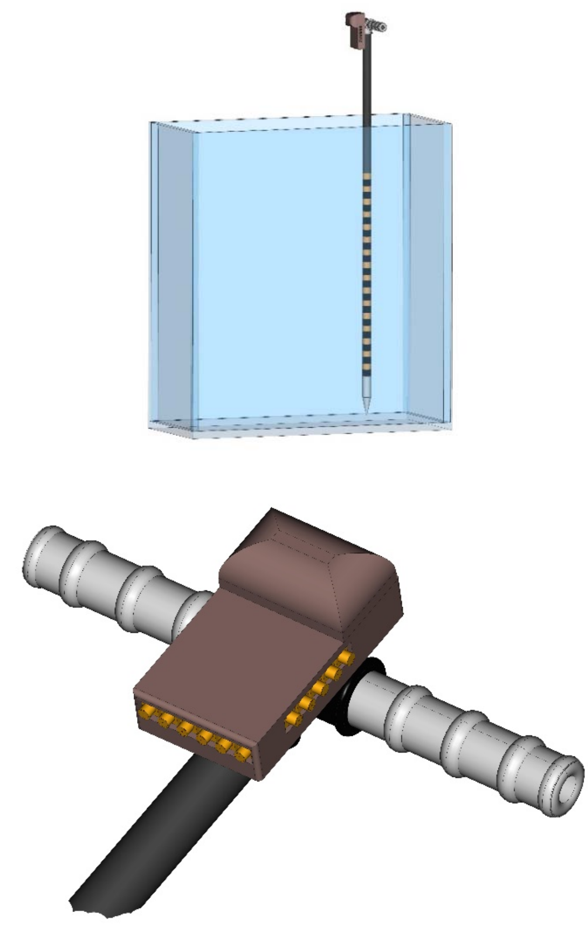


Fig. 1. Models of multisensor electrodes

Measurements

In order to obtain a better quality of ERT reconstruction, modern multisensor electrodes have been designed. ERT tomograph equipped with the above the electrode was verified on the laboratory real model presented in Fig. 2. The laboratory model was configured in two variants - in the measurement system using one and two electrodes. The above two variants give respectively 16 and 32 sensor systems.

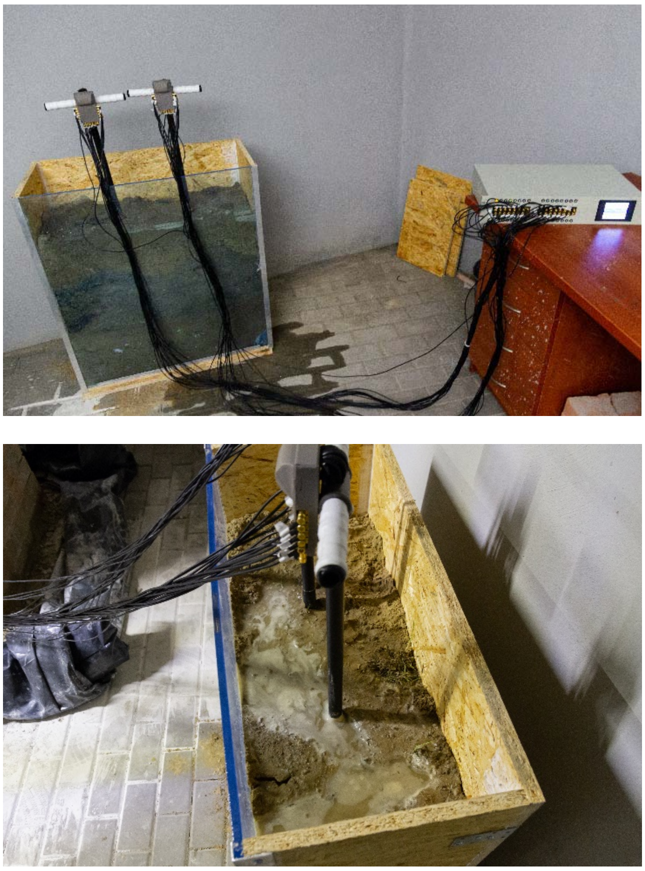


Fig. 2. Laboratory model - measuring electrodes

Image reconstructions

Numerous optimization methods have been described in the literature that can be applied in ERT [2,5,8,11,15-15,24]. The illustration below presents several cases of numerical measurements. Figure 3 shows the investigated object hidden inside of the ground is the sphere with the center at the point with coordinates x = 40 cm and y = 40 cm. The radius of the circle was R = 6 cm. Reconstructions were carried out with Gauss-Newton and Tikhonov regularization, Gauss-Newton and Laplace regularization methods and Total Variation method. Figure 4 presents the image reconstruction with the examined object shifted closer to the multi-sensor electrode.

One multi-sensor electrodes with real measurements was shown in Fig. 5. The Gauss-Newton with Tikhonov regularization and the Gauss-Newton method with Laplace regularization were used to the image reconstruction. Figure 6 presents results for two multi-sensor electrodes.

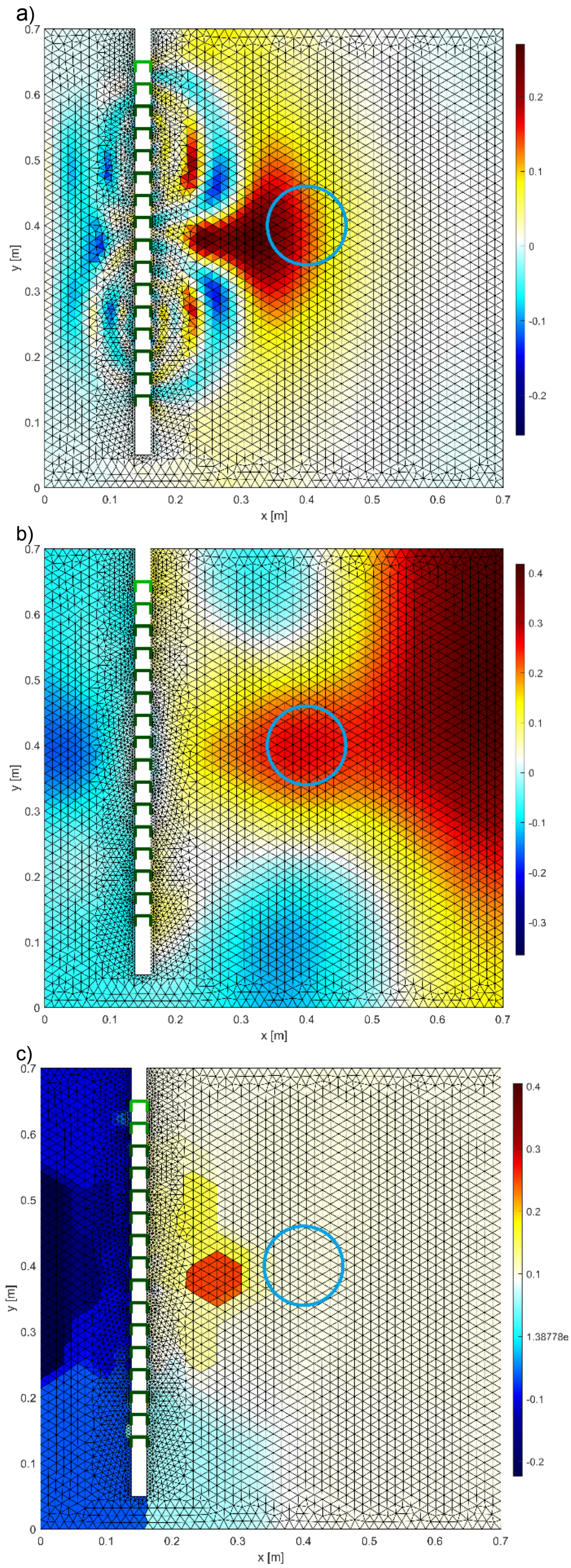


Fig. 3. One multisensor electrode – example I: a) image reconstruction by Gauss-Newton method with Tikhonov regularization, b) image reconstruction by Gauss-Newton method with Laplace regularization, c) image reconstruction by Total Variation method

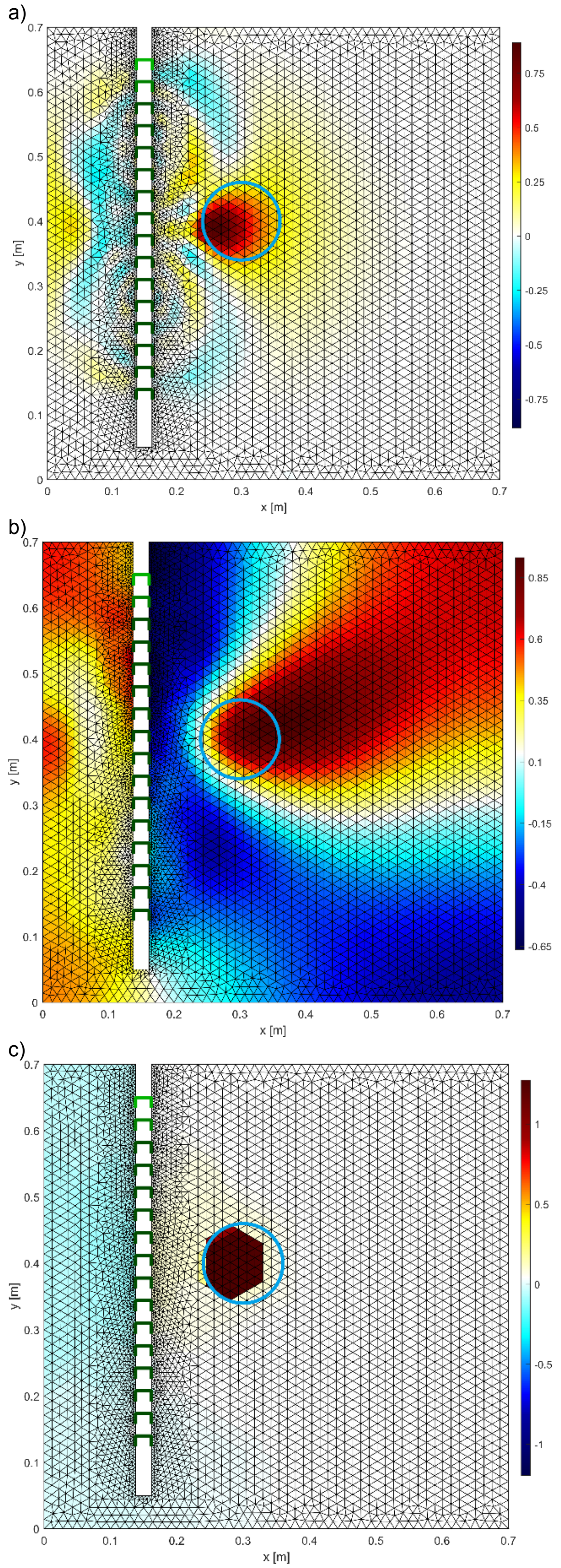


Fig. 4. Image reconstruction – example II: a) image reconstruction by Gauss-Newton method with Tikhonov regularization, b) image reconstruction by Gauss-Newton method with Laplace regularization, c) image reconstruction by Total Variation method

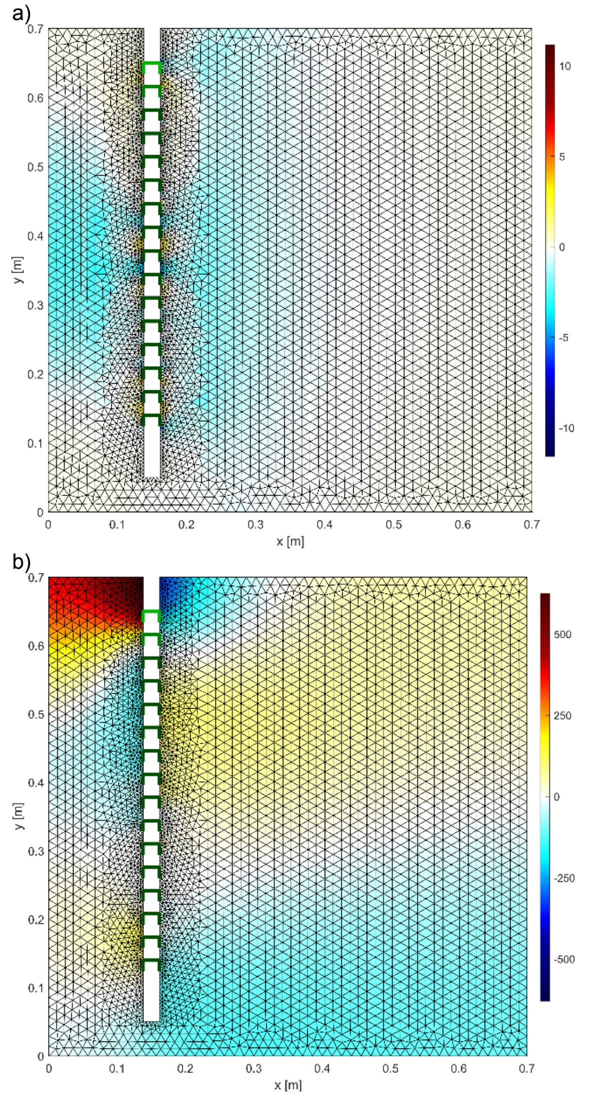
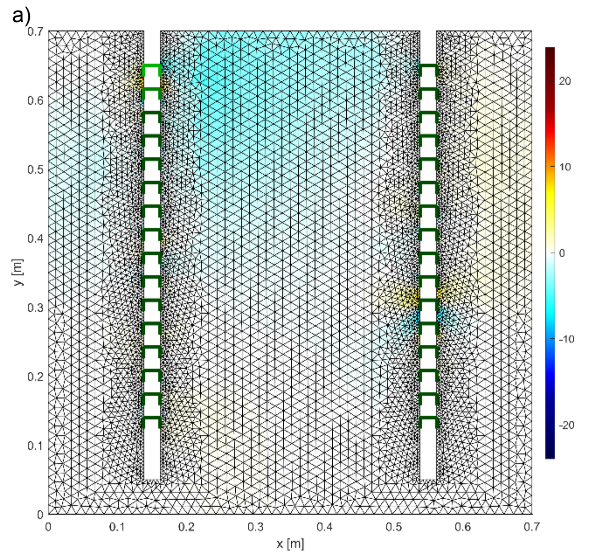


Fig. 5. One multi-sensor electrodes – real measurements: a) image reconstruction by Gauss-Newton method with Tikhonov regularization, b) image reconstruction by Gauss-Newton method with Laplace regularization



b)

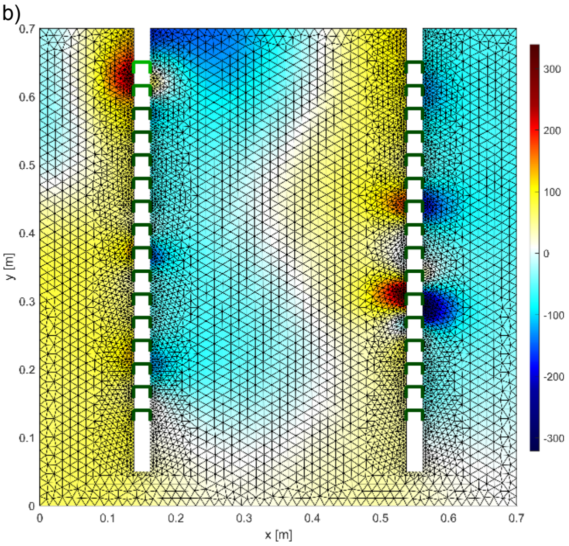


Fig. 6. Two multi-sensor electrodes – real measurements: a a) image reconstruction by Gauss-Newton method with Tikhonov regularization, b) image reconstruction by Gauss-Newton method with Laplace regularization

Conclusion

The article presents the system for investigation of damages inside objects such as flood embankment or dams based on innovative multisensor electrodes. Special kind of sensors for electrical resistance tomography (ERT) were implemented. This is an innovative solution for banks of water reservoirs testing, both in terms of the measurement way and the reconstruction method. The measurements were carried out with especially settled laboratory model. All reconstructions were based on the Gauss-Newton method with addition of appropriate regularization and the Total Variation method. The combination of tomographic techniques with reconstruction algorithms enabled spatial assessment of seepages and other damages hidden deep inside flood embankments. Further research will focus on the quest to develop improved algorithms for image reconstruction with higher resolution.

***Authors**: Tomasz Rymarczyk, Ph.D. Eng., University of Economics and Innovation, Projektowa 4, Lublin, Poland/ Research & Development Centre Netrix S.A. E-mail: tomasz@rymarczyk.com;; Grzegorz Kłosowski, Ph.D. Eng., Lublin University of Technology, Nadbystrzycka 38A, Lublin, Poland, E-mail: g.klosowski@pollub.pl; Paweł Tchórzewski, Research & Development Centre Netrix S.A., E-mail: pawel.tchorzewski@netrix.com.pl; Tomasz Cieplak, Ph.D., Lublin University of Technology, Nadbystrzycka 38A, Lublin, Poland, E-mail: t.cieplak@pollub.pl; Edward Kozłowski, Ph.D., Lublin University of Technology, Nadbystrzycka 38A, Lublin, Poland, E-mail: e.kozlovski@pollub.pl;*

REFERENCES

[1] Rymarczyk T., Tchórzewski P., Adamkiewicz P., Konrad Niderla and Cieplak T., The use of multisensor electrodes in ERT for area monitoring, PTZE — 2018 Applications of Electromagnetic in Modern Techniques and Medicine, 09-12 September 2018, Racławice, Poland.
[2] Babout L., Grudzień K., Wiącek J., Niedostatkiewicz M., Karpiński B., Szkodo M., *Selection of material for X-ray tomography analysis and DEM simulations: comparison between granular materials of biological and non-biological origins*, Granular Matter, 20 (2018), no. 3, 20-38
[3] Banasiak R., Wajman R., Jaworski T., Fiderek P., Fidos H., Nowakowski J., *Study on two-phase flow regime visualization and identification using 3D electrical capacitance tomography and fuzzy-logic classification*, International Journal of Multiphase Flow, 58 (2014), 1-14
[4] Duda K., Adamkiewicz A., Rymarczyk T., *Nondestructive Method to Examine Brick Wall Dampness*, International Interdisciplinary Phd Workshop 2016, (2016), 68-71
[5] Fiala P., Drexler P., Nešpor D., Szabó Z., Mikulka J., Polívka J., *The Evaluation of Noise Spectroscopy Tests*, ENTROPY, 18 (2016) , no. 12, 1-16
[6] Filipowicz S.F., Rymarczyk T., *The Shape Reconstruction of Unknown Objects for Inverse Problems*, Przegląd Elektrotechniczny, 88/3A (2012), 55-57
[7] Garbaa H., Jackowska-Strumiłło L., Grudzień K., Romanowski A., *Application of electrical capacitance tomography and artificial neural networks to rapid estimation of cylindrical shape parameters of industrial flow structure*, Archives of Electrical Engineering, 65 (2016), no. 4, 657-669
[8] Gola A., Nieoczym A., *Application of OEE Coefficient for Manufacturing Lines Reliability Improvement*, in Proceedings of the 2017 International Conference on Management Science and Management Innovation (MSMI 2017), (2017)
[9] Grudzien K., Romanowski A., Chaniecki Z., Niedostatkiewicz M., Sankowski D., *Description of the silo flow and bulk solid pulsation detection using ECT*, Flow Measurement and Instrumentation, 21 (2010), no. 3, 198-206
[10] Holder D., *Introduction to biomedical electrical impedance tomography Electrical Impedance Tomography Methods*, History and Applications, Bristol, Institute of Physics, (2005)
[11] Kosicka E., Kozłowski E., Mazurkiewicz D., *Intelligent Systems of Forecasting the Failure of Machinery Park and Supporting Fulfilment of Orders of Spare Parts*, (2018), pp. 54–63
[12] Kryszyn J., Wanta D., Smolik W., *Gain Adjustment for Signal-to-Noise Ratio Improvement in Electrical Capacitance Tomography System EVT4*, IEEE Sensors Journal, 17 (2017), no. 24, 8107-8116
[13] Krawczyk A., Korzeniewska E., Łada-Tondyra E., Magnetophosphenes – History and contemporary implications", Przeglad Elektrotechniczny, 94 (2018), No. 1, 61-64.
[14] Korzeniewska E., Walczak M., Rymaszewski J., Elements of Elastic Electronics Created on Textile Substrate, Proceedings of the 24th International Conference Mixed Design of Integrated Circuits and Systems - MIXDES 2017, 2017, 447-45.
[15] Lopato P., Chady T., Sikora R., Ziolkowski S., M., *Full wave numerical modelling of terahertz systems for nondestructive evaluation of dielectric structures*, COMPEL-The international journal for computation and mathematics in electrical and electronic engineering, 32 (2013) , no. 3, 736 – 749
[16] Polakowski K., Filipowicz S.F., Sikora J., Rymarczyk T., *Quality of imaging in multipath tomography*, Przeglad Elektrotechniczny, 85/12 (2009), 134-136
[17] Psuj G., *Multisensor Data Integration Using Deep Learning for Characterization of Defects in Steel Elements*, Sensors, 18 (2018), no. 1, 292
[18] Romanowski A., Big Data-Driven Contextual Processing Methods for Electrical Capacitance Tomography, IEEE Transactions on Industrial Informatics, (2018), 1551-3203
[19] Rymarczyk T., Sikora J., Applying industrial tomography to control and optimization flow systems, Open Physics, 16 (2018), 332–345
[20] Rymarczyk T., Kłosowski G., Application of neural reconstruction of tomographic images in the problem of reliability of flood protection facilities, Eksploatacja i Niezawodnosc – Maintenance and Reliability, 20 (2018), no. 3, 425–434
[21] Rymarczyk T., Kłosowski G., Kozłowski E., Non-Destructive System Based on Electrical Tomography and Machine Learning to Analyze Moisture of Buildings, Sensors, 18 (2018), no. 7, 2285
[22] Soleimani M., Mitchell C.N., Banasiak R., Wajman R., Adler A., Four-dimensional electrical capacitance tomography imaging using experimental data, Progress In Electromagnetics Research, 90 (2009), 171-186
[23] Ye Z., Banasiak R., M. Soleimani, Planar array 3D electrical capacitance tomography, Insight: Non-Destructive Testing and Condition Monitoring, 55 (2013), no. 12, 675-680
[24] Ziolkowski M., Gratkowski S., Genetic algorithm coupled with Bézier curves applied to the magnetic field on a solenoid axis synthesis, Archives of electrical engineering, 65 (2016), no. 2, 361-370