

## Using Electrical Resistance Tomography to Detect Leaks in Landfills

**Abstract.** This article presents the design of the device with active electrodes to examine the landfill and flood embankments. The presented solution was based on electrical resistance tomography (ERT). The basic information about the built model system is given. There was described the concept of active electrodes and measuring equipment for data acquisition. Electrical resistance tomography, which is based on measuring potential difference, can be used to calculate conductivity. The problem depends on the fact that every material has unique conductance. Its aim was to verify the repeatability of test results by eliminating laboratory equipment, and to validate the use of simple and cheap electronics to the structure of the ERT.

**Streszczenie.** W artykule przedstawiono projekt urządzenia z aktywnymi elektrodami w celu zbadania składowisk odpadów i wałów przeciwpowodziowych. Przedstawione rozwiązanie oparte jest na elektrycznej tomografii rezystancyjnej (ERT). Podano podstawowe informacje o zbudowanym modelu systemu. Opisano koncepcję aktywnych elektrod i przyrządów pomiarowych do gromadzenia danych. Do obliczenia konduktywności została zastosowana elektryczna tomografia rezystancyjna, która oparta jest na pomiarze różnicy potencjałów. W zagadnieniu tym, problem polega na tym, że każdy materiał ma unikalną przewodność. Celem zbudowanego systemu z urządzeniem ERT jest zweryfikowanie powtarzalności wyników testów poprzez wyeliminowanie sprzętu laboratoryjnego w bezpośrednich pomiarach środowiskowych. (Zastosowanie elektrycznej tomografii rezystancyjnej do wykrywania wycieków ze składowisk odpadów).

**Keywords:** Electrical Resistance Tomography, Finite Element Method, Sensors

**Słowa kluczowe:** elektryczna tomografia rezystancyjna, metoda elementów skończonych, sensory

### Introduction

Electrical tomography (ERT) is known that the inverse problem is nonlinear and highly ill-posed [13,18-24]. The problem is the low level of measured values which should be measured quite accurately and in a very short time. ERT involves placing electrodes on the examined object. The two electrodes are connected to AC power and the voltage drop is measured on others. Then, power supply is connected to the next two electrodes, and measuring steps are repeated until each electrode is connected to power supply. The measurement in electrical resistance tomography involves placing electrodes on the examined object. This solution allows to obtain a conductivity distribution within the test object, and this consequently allows a distinction between materials of different conductivity. Effective algorithms in the optimization process are topological methods [10-12, 14-17]. In carrying out further measurements over time and comparing them with previous we can observe the changes occurring in the study area.

pair [14]. Electrical signals are then transmitted through selected electrode locations while electrical potential measurements are recorded at numerous other locations. This process is repeated systematically for many different source-receiver combinations and the resulting data-set enables the reconstruction of a cross-section through the survey area [1-5,8,9]. The cross-sectional image, or tomographic slice, depicts a spatial distribution of electrical resistivity, which is closely related to the internal structure of the object. Contrasts in the electrical properties of different geological materials enable earth scientists to non-invasively map structures in the subsurface.

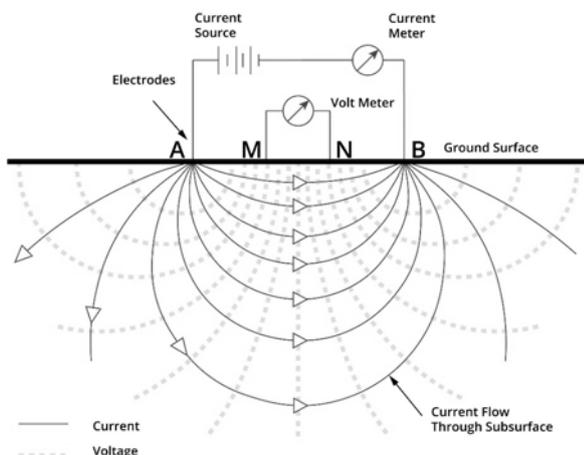


Fig. 1. Geophysical measurement model

ERT is a geophysical technique in which DC electrical current is injected into the ground between one pair of electrodes and the voltage is measured between another

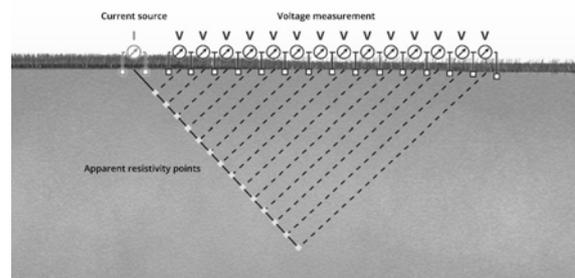


Fig. 2. ERT measurements in the geophysical environment

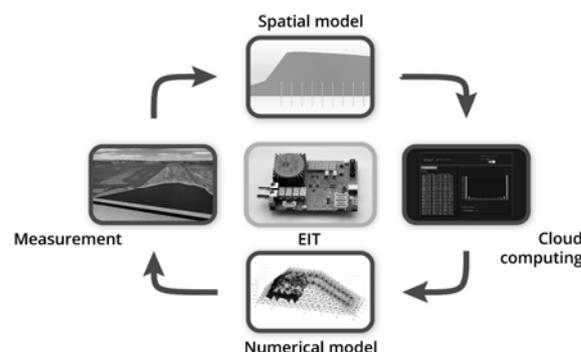


Fig.3. The measurement system

Figure 1 shows the geophysical measurement model and Figure 2 presents model of ERT measurements. The

model of measurement system with the EIT device, transfer data to the cloud computing and image reconstruction was presented in Fig. 3.

### Models

The model of the flood embankment is given in Fig. 4. Figure 5 shows the model of a landfill. The models of different inserted electrodes into the embankments were presented in Fig. 6. Figures 7, 8 and 9 show special multiply electrodes to measure inside the objects.

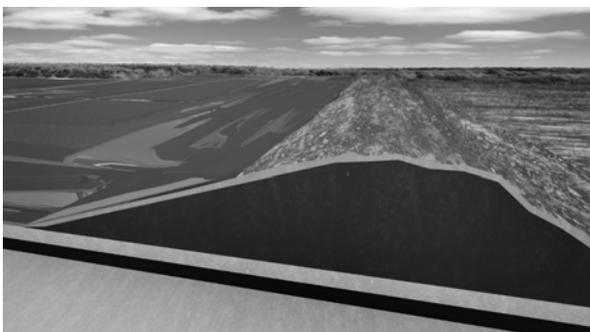


Fig.4. The model of the flood embankment

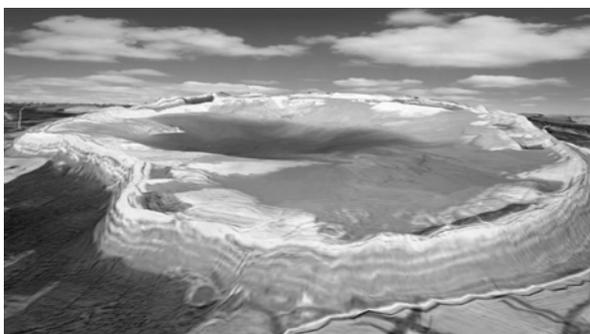


Fig. 5. The model of the landfill.

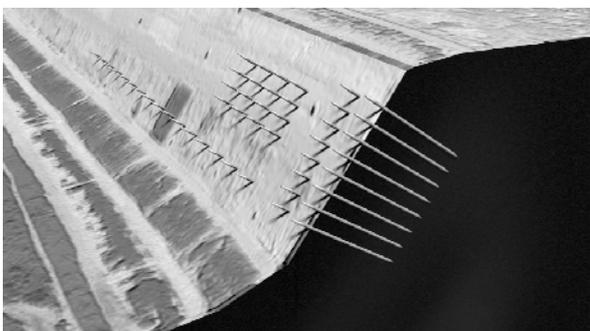


Fig. 6. The models of electrodes

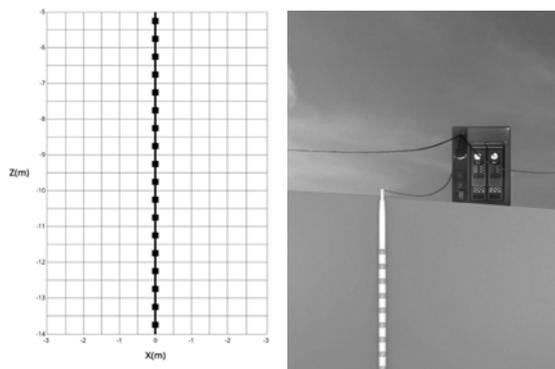


Fig. 7. The model of multiply electrode

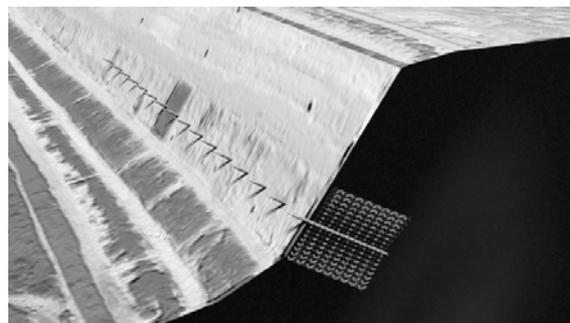


Fig. 8. The model of multiply electrodes in the landfill

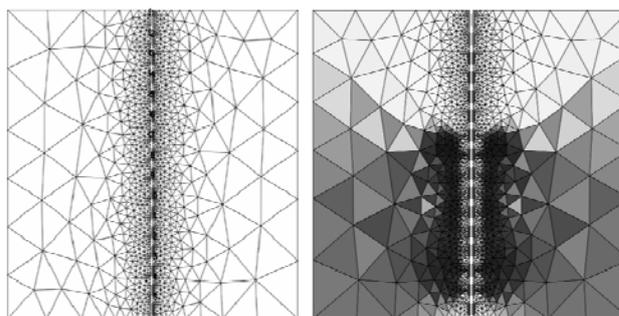


Fig. 9. Multiply electrodes – the discretization and the example of image reconstruction

### Measurement Device

There was created a new device after achieving good research results of measurements of the ERT. Its aim was to verify the repeatability of test results by eliminating laboratory equipment, and to validate the use of simple and cheap electronics to the structure of the ERT.

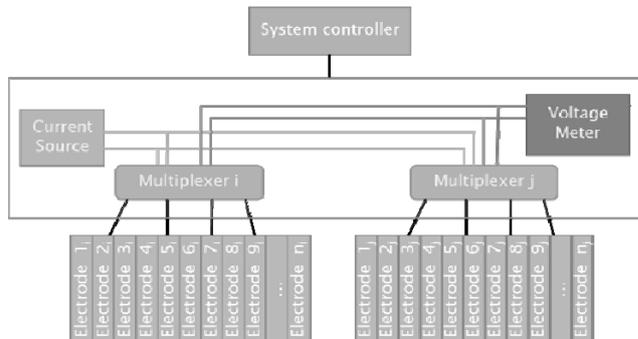


Fig. 10. The ERT measurement system schematic diagram

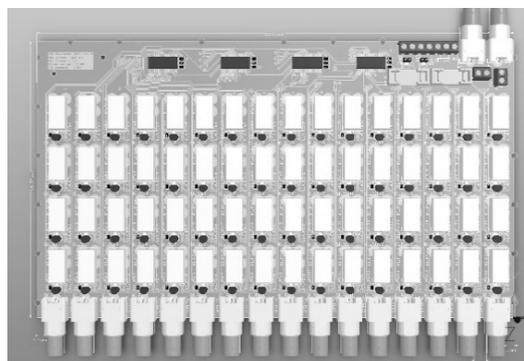


Fig. 11. The model of ERT multiplexer with mounted relays and BNC connectors

The ERT solution should make ERT measurements for reconstruction of resistive distribution at big areas (tens of meters) with resistance nature [6,7]. There are building of

few separated modules: current generator, measure block, multiplexer and controller. These modules should adapt to high voltages (about 250 V) and high currents (about 3 A). There should be possibility to connect more than one multiplexers to this system. Blocs should be design in way that one controller would control whole system. A schematic diagram of the system is presented in Fig. 10.

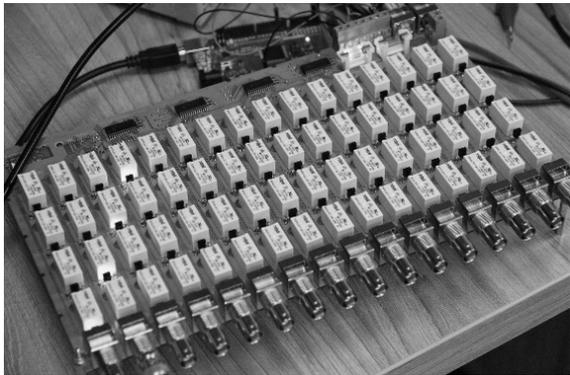


Fig. 12. The ERT multiplexer under diagnostic testing

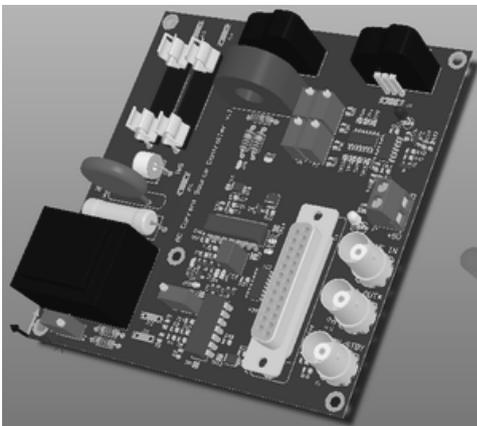


Fig. 13. PCB model of the circuit controlled by current source voltage

The way of switching electrodes is the same as EIT device – multiplexer 4 to 16. To switching so high voltages and currents it is necessary to use electro-magnetic or solid-state relays. Because of parameters and price electro-magnetic relays were chosen. To make multiplexer control easier, there are I2C bus expanders used. Thanks to this, it needs to use only two I2C wire – in place of eighteen. It makes possibility of expanding number of electrodes by connecting a few the same multiplexers. The multiplexer line design has proper width of nets to deal with high currents, and clearances that deal with high voltages to avoid interferences or current arc. Electrodes will be connected to multiplexer by BCN connectors and coaxial cables. A PCB Layout model is presented in Fig. 11. Figure 12 shows working, real multiplexer. Measure block will be measure drop voltages between each electrode that multiplexer sets. To making measures, 18-bit successive approximation ADC – AD7989 is used. A range of measured voltage this converter is  $\pm 5$  V, and it is compatible with SPI interface. To improve the conditions of the input signal, before ADC two instrumental amplifiers AD623 are included and it is possible to set three gains: 2, 10, 20 V/V on them. To match potentials between measuring signal and instrumental amplifier there is a toroidal transformer installed. It matches potentials and compensate signals to lower voltage. Changing ranges

measured voltages are worked out by switching pairs of voltage divider resistors by relay. In order to generate a sufficiently large inducement signal, a direct digital synthesis (DDS) generator is constructed. DDS allows to generate a signal of any waveform and a wide frequency range. The generator will be digitally controlled. The current source will be based on a transformer and power transistors.



Fig. 14. Multiplexer, VCCS and power amp in 2U

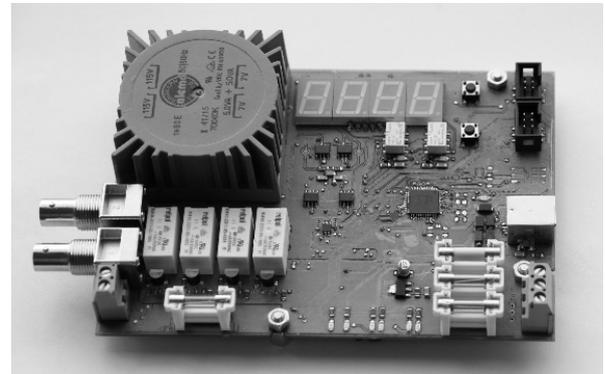


Fig. 15. PCB of voltage drop meter with a range of 1mV-250V (RMS)



Fig. 16. The measuring ERT field of laboratory meters

The purpose of the circuit in Fig. 13 is to compensate for an error on the output of the entire device, and to respond quickly to shorts of outputs, output openings, too high output currents, disconnection of the function generator by cutting off the current output. The output of the error amplifier circuit is fed to a power amplifier that amplifies the generated signal. The power amplifier output is connected to a transformer to reduce the output voltage and raise the amplitude of the current. The output of the current generator can have parameters up to 230V and 3A at frequencies from 1 to 1kHz. All components, excluding the power amplifier, are housed in a 2U enclosure. The signal power amplifier as a finished device is also located in the 2U housing (Fig. 14). The purpose of the measuring module is to measure the potential difference on the measuring

electrodes. Due to the varied parameters of the soil, which can vary according to atmospheric conditions, the range of measured voltages is from 1mV to 250V. The first step of the measuring module is a transformer that insulates galvanic signals from the entire circuit, lowers the voltage, and locates the signal with respect to the ground of the meter circuit. The next step is the pair of resistors that are switched by the relays. The purpose of this stage is to change the range of measured voltages. Behind the pair of resistors are operational amplifiers in the voltage repeater circuits, they serve to reduce the increase of the input impedance to the measurement path. The measuring path consists of two parallel measuring amplifiers. This solution eliminates the convergence of the measured signal, as well as the conversion of a simple to differential signal, which is necessary for the rapid measurement of many modern analogue-to-digital converters. That is precisely the Analog Devices AD7989, which was used in this module. This transmitter has an 18-bit resolution capability and can measure at a rate of 100k samples per second. The output of this transmitter is compatible with the SPI protocol. Measurement and range selection is monitored by the AtXmega processor, which can be sent to the monitoring unit for measurements or via USB (Fig. 15). Figure 16 shows the ERT field test bench with laboratory meters.

### Summary

The nondestructive method based on the electrical resistance tomography was presented to examine condition of flood embankments and landfills. The presented solution has been applied very successfully in such models. Even though this study reveals novel and promising results. Different type and number of electrodes were evenly distributed along and across the border of the grid estimation and numerical phantom. 16 and 32 sets of electrodes were evenly assigned to the experimental phantoms and their models. The designed ERT device to measure in the real environment is effective. The presented solution was based on electrical resistance tomography. The basic information about the built model system is given. There was described the concept of the measuring equipment for data acquisition. Electrical resistance tomography, which is based on measuring potential difference, can be used to calculate conductivity. Its aim was to verify the repeatability of test results by eliminating laboratory equipment, and to validate the use of simple and cheap electronics to the structure of the measurement system.

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### REFERENCES

[1] Adler A., Lionheart W.R.B., Uses and abuses of EIDORS: an extensible software base for EIT, *Physiological Measurement* (2006), Vol. 27, pp. 25-42

- [2] Borcea L., *Electrical impedance tomography*, *Inverse Problems* (2002), vol. 18, pp. 99–136
- [3] Duda K., Adamkiewicz P., Rymarczyk T., *Nondestructive Method to Examine Brick Wall Dampness*, *International Interdisciplinary Phd Workshop 2016* (2016), pp. 68-71
- [4] Filipowicz S.F., Rymarczyk T., *Measurement Methods and Image Reconstruction in Electrical Impedance Tomography*, *Przegląd Elektrotechniczny* (2012), vol. 88, Issue 6, pp.247-250
- [5] Filipowicz S.F., Rymarczyk T., *The Shape Reconstruction of Unknown Objects for Inverse Problems*, *Przegląd Elektrotechniczny* (2012), vol. 88, Issue 3A, pp. 55-57
- [6] Gunna D.A., Chambers J.E., Uhlemanna S., Wilkinson P.B., Meldrum P.I., Dijkstra T.A., *Moisture monitoring in clay embankments using electrical resistivity tomography*, *Construction and Building Materials* (2014)
- [7] Jones G., Sentenac P., Zielinski M., *Desiccation cracking detection using 2-D and 3-D Electrical Resistivity Tomography: Validation on a flood embankment*, *Journal of Applied Geophysics* (2014), Vol. 106
- [8] Holder D.S., *Electrical Impedance Tomography: Methods, History and Applications*, *Series in Medical Physics and Biomedical Engineering*, London (2005)
- [9] Lechleiter A., Rieder A.: *Newton regularizations for impedance tomography: convergence by local injectivity*. *Inverse Problems* (2008), 24(6)
- [10] Osher S., Sethian J.A.: *Fronts Propagating with Curvature Dependent Speed: Algorithms Based on Hamilton-Jacobi Formulations*, *Journal of Computational Physics* (1988), 79, 12-49
- [11] Osher S., Fedkiw R.: *Level Set Methods and Dynamic Implicit Surfaces*. Springer, New York (2003)
- [12] Osher S., Santosa F.: *Level set methods for optimization problems involving geometry and constraints. Frequencies of a two-density inhomogeneous drum*. *Journal of Computational Physics* (2001), 171, pp. 272-288
- [13] Rybak G., Chaniecki Z., Grudzień K., Romanowski A., Sankowski D., *Non-invasive methods of industrial process control*, *Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska* (2014), vol. 4, no. 3 pp. 41–45
- [14] Rymarczyk T., *Using electrical impedance tomography to monitoring flood banks*, *International Journal of Applied Electromagnetics and Mechanics* (2014), vol. 45, pp. 489–494
- [15] Rymarczyk T., *New Methods to Determine Moisture Areas by Electrical Impedance Tomography*, *International Journal of Applied Electromagnetics and Mechanics* (2016), vol. 37, Issue 1-2, pp.79–87
- [16] Rymarczyk T., Tchórzewski P., Sikora J., *Monitoring of Flood Embankment System by Nondestructive Method with Infinite Boundary Element*. *Studies in Applied Electromagnetics and Mechanics* (2015), 40, pp. 176-183
- [17] Rymarczyk T., Tchórzewski P., *Topological methods to determine damages of flood embankments*, *Przegląd Elektrotechniczny* (2016), 92(12), pp. 153-156
- [18] Sankowski D., Sikora J., *Electrical capacitance tomography: Theoretical basis and applications*, Warsaw, IEL (2010)
- [19] Sethian J.A.: *Level Set Methods and Fast Marching Methods*. Cambridge University Press, (1999)
- [20] Sikora J., Wójtowicz S., *Industrial and Biological Tomography: Theoretical Basis and Applications* (2010), Warsaw, IEL
- [21] Smolik W., *Forward Problem Solver for Image Reconstruction by Nonlinear Optimization in Electrical Capacitance Tomography*, *Flow Measurement and Instrumentation* (2010), vol. 21, pp. 70–77
- [22] Tai C., Chung E., Chan T.: *Electrical impedance tomography using level set representation and total variational regularization*. *Journal of Computational Physics* (2005), vol. 205, no. 1, 357–372
- [23] Wajman R., Fiderek P., Fidos H., Jaworski T., Nowakowski J., Sankowski D., Banasiak R., *Metrological evaluation of a 3D electrical capacitance tomography measurement system for two-phase flow fraction determination*; *Meas. Sci. Technol.* (2013), Vol. 24 No. 065302
- [24] Wang M., *Industrial Tomography: Systems and Applications*, Elsevier (2015)