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Monitoring of flood embankments with the use of tomographic systems with distributed architecture

***Abstract**. The subject of the presented article are studies on the automatic and reliable method of observing flood embankments using a multi-sensor integrated monitoring system. Designing and developing this type of system is a serious challenge, mainly due to the need to involve experienced specialists and scientists from various fields of science and technology. An element of such a system is the electrical tomograph presented in the article for non-destructive testing. With the help of the presented tomographic system, it is possible to carry out tests of technical objects such as flood barriers and industrial tanks. The described monitoring system, in addition to the software, consists of many subsystems and components, of which sensors play a special role. With their help, the system measures various types of physical parameters, including: wind speed, ambient temperature, voltage, etc. In this text, the authors focused on one of the subsystems of the described solution, namely on the electrical tomography. The principle of operation of the discussed system is based on the observation of the environment using many differentiated, intelligent measurement methods. In addition, an analytical module based on computational intelligence algorithms is an important element of the monitoring system. This module is used to analyze and visualize input data.*

***Streszczenie.** Przedmiotem prezentowanego artykułu są badania nad automatyczną i niezawodną metodą obserwacji obwałowań przeciwpowodziowych za pomocą wieloczujnikowego zintegrowanego systemu monitorowania. Projektowanie i opracowywanie tego typu systemu stanowi poważne wyzwanie, głównie ze względu na konieczność zaangażowania doświadczonych specjalistów i naukowców z różnych dziedzin nauki i techniki. Elementem takiego systemu jest tomograf elektryczny umożliwiający badania nieniszczące. Za pomocą systemu tomograficznego można przeprowadzać skanowanie obiektów technicznych, takich jak zapory przeciwpowodziowe i zbiorniki przemysłowe. Opisywany system monitorowania, oprócz oprogramowania, składa się z wielu podsystemów i komponentów, z których czujniki odgrywają szczególną rolę. Za ich pomocą system mierzy różne rodzaje parametrów, w tym: prędkość wiatru, temperaturę otoczenia, napięcie itp. W artykule skoncentrowano się na jednym z podsystemów przedmiotowego systemu, a mianowicie na tomografii elektrycznej. Zasada działania systemu monitorowania oparta jest na obserwacji środowiska przy użyciu wielu zróżnicowanych, inteligentnych metod pomiarowych. Ponadto ważnym elementem systemu jest moduł analityczny oparty na algorytmach inteligencji obliczeniowej. Moduł ten służy do analizy i wizualizacji danych wejściowych. (**Monitorowanie wałów przeciwpowodziowych za pomocą systemów tomograficznych o architekturze rozproszonej)**.*

Keywords: electrical tomography; microservices architecture; multi-agent systems, internet of things.
Słowa kluczowe: tomografia elektryczna; architektura mikroserwisowa; systemy wieloagentowe, internet rzeczy.

Introduction

The disaster of the flood embankment often results in large economic and social losses, as was the case in Poland during the flood in 2010. One of the main threats to the safety of the embankment is the development of filtration and erosion processes both in its body and the ground. The existing practice of monitoring and assessing the condition of flood embankments is insufficient to ensure the safety of these facilities. They are based primarily on local inspection and the implementation of geotechnical research in cross-sections spaced from each other. The basic disadvantage of traditional methods is their point (local) character. Identification of filtration and erosion processes, especially in their initial phase of development and assessment of their kinetics with these methods is usually impossible. Designing shafts due to their location, shape and material is quite complicated [19,20]. Monitoring of flood protections requires methods and systems which will have the following features: monitoring of destructive processes in real time during floods, continuous monitoring of space in the space, monitoring of early and precise detection of the destructive process, the possibility of evaluating the kinetics of the destructive process, the possibility of developing an automatic alarm system informing about the occurrence of a destructive process, a damage-resistant installation operating without a maintenance service.

Data acquisition

In systems based on the electrical tomography (ET) method, the data acquisition system collects measurements of the voltages generated by the electrodes [1-5,7-9, 17, 17-25]. These types of data can be processed locally or can reach the central analytical system. It mainly depends on such factors as: the geospatial dimensions of the monitored object, the computational power of the ET device, as well as the required resolution of the reconstructed image. Traditional data collection and processing systems require specialized equipment to measure voltage, demodulation, filtering and data conversion to a digital form. In addition, the system must have a module dedicated to signal processing, which allows data to be sent to a computer. The ET device should perform the measurements necessary to carry out the reconstruction of the resistive distribution on relatively large cross-sections, which often cover tens of meters. The flood dam monitoring system has several separate hardware modules: a current generator, a multiplexer, a controller and a measuring block. The above modules are adapted to high voltages (approximately 250V) and high currents (approximately 3A). More than one multiplexer can be connected to this system. The individual subsystems (blocks) have been designed in a way that allows the entire system to be controlled with a single controller. Standard methods of creating analytical systems include monolithic applications. Depending on the characteristics of the technical facility being monitored, the ET system hardware can be deployed in many places over a large area or, in extreme cases, can be placed in one small enclosure. In both cases, the entire system infrastructure is centrally managed. Its main purpose is to collect and process data and carry out all necessary measurements. The described system design was used to create a prototype device for ET analysis. During the tests, it was noticed that the management of a comprehensive ET-AQ application, whose task is to acquire data, manage measurements and monitor devices, is difficult. It turned out that further difficulties arise when the application needs to be expanded. From the beginning of the design work, the basic idea was to build a system that will enable the collection of data from devices, their storage and analysis, as well as the performance of basic visualizations of internal cross-sections of the tested object. In addition, the application enables continuous monitoring of the status of the tomographic device itself. An example of a flood embankment model with an ET device and a distributed system is shown in Figures 1 and 2.

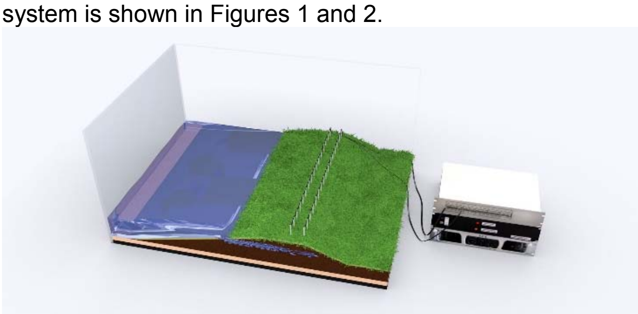

Fig. 1. The geometrical model of the flood embankment with ET device.

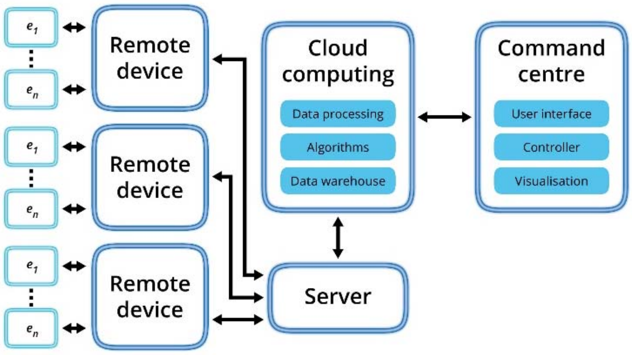

Fig. 2. Model of the distributed system.

Architecture of multi-agent system

Taking into account technical and operational conditions and the requirements of technical facilities, one can distinguish a certain group of features that are common to various applications of analytical systems. They are: simple and fast procedure of implementation and monitoring, not very complicated exchange of system components (if they are faulty or in case of an upgrade), flexibility in adapting to changing work conditions, resistance to damage, reliability. The analytical system should allow the use of various data sources. In addition, it should easily adapt variable analytical methods, as well as cooperate with many different applications previously used by users. The experience gained so far during the observation of similar processes indicates the existence of rapid changes in the applied, distributed system architecture, from building monolithic applications to the adaptation of microservice architecture. While the basic concepts of microservice systems are not new, they can sometimes be confused with SOA architecture. There is no doubt that micro-services are actually something else. The purpose of the microservices concept was to eliminate excessive complexity and instead to implement one simple functionality in an independent service. Micro servers can communicate with each other using protocols and mechanisms such as: HTTP, RESTful or API. The use of microservices in place of existing services is caused by growing challenges in terms of scalability, lack of efficiency, too slow development and difficulties in implementing new technologies, which always arise in the case of complex software systems designed as a single, large monolithic application. The advantages of microservices are not only the ease and elimination of standard problems caused by monolithic architecture. Highly dispersed systems require programmers to strictly follow the design guidelines. It is also necessary to maintain the standardization of the system architecture. There are many ready templates on the basis of which you can build a system. Nevertheless, the decision to choose the best way to design such a system is always difficult. The scheme of the analytical system is shown in Figure 3.

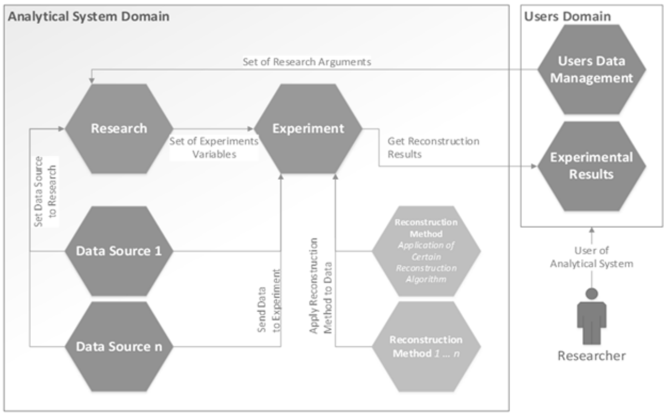

Fig. 3. Container diagram of analytical system.

Methods

Many different optimization methods can be used to solve the given fitness function [6,10,15,16]. The level set method is a numerical technique that allows tracking the hypersurfaces (curves in two-dimensional space, surfaces in three-dimensional space) evolving under the influence of a certain velocity field defined in its points, without the need to parameterize this hyper surface. This is possible due to the resignation of explicit representation of the hyper surface (explicit) at the exponent implicit cost (which means that we define the hypersurfing as the level of the scalar function defined in all points of the space), where this function is represented by a set of its values at the nodes of the Cartesian grid defined in the interesting us the area of space [12-14].

The movement is denoted as the convection of values from the function ϕ with the velocity field $\vec{v}$ and it is defined by the Hamilton-Jacobi formula:

$$\frac{\partial \phi}{\partial t} + \vec{v} \cdot \nabla \phi = 0. \quad (1)$$

We can describe p be the adjoint function as an equation:

$$\nabla \cdot (\gamma \nabla p) = -(u - u_m), \quad (2)$$

where $u - u_m$ is the variance between calculated and measured voltage values. The velocity $\vec{v}$ is assumed as:

$$\vec{v} = -(\nabla u \cdot \nabla p)\,\vec{n} \quad (3)$$

where $\vec{n}$ is a normal vector. The velocity can be defined as follows:

$$\mathrm{v}_n^k = \nabla u^k \cdot \nabla p^k \quad (4)$$

After the update, the formula takes the following form:

$$\phi^{k+1} = \phi^k - \left(\nabla u^k \cdot \nabla p^k\right) |\nabla \phi^k| \, \Delta t \quad (5)$$

Results

The model of the flood embankment with the system of 16 electrodes was presented in Fig. 4. However, another model with 32 electors has been shown in Fig. 5.

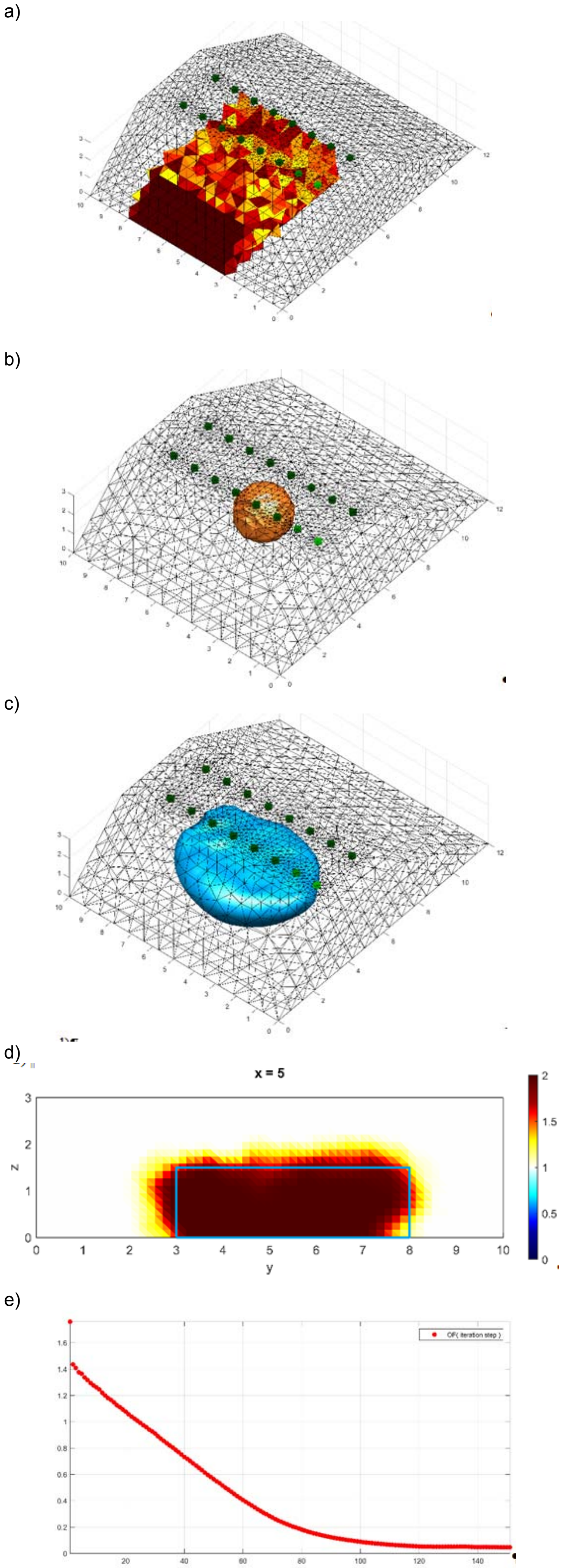

Fig. 4. Image reconstruction by the level set method: a) model, b) zero-level set, c) final level set, d) conductivity on the cross-section - plane { x - 5.0 = 0 }, e) objective function in the next iterative steps.

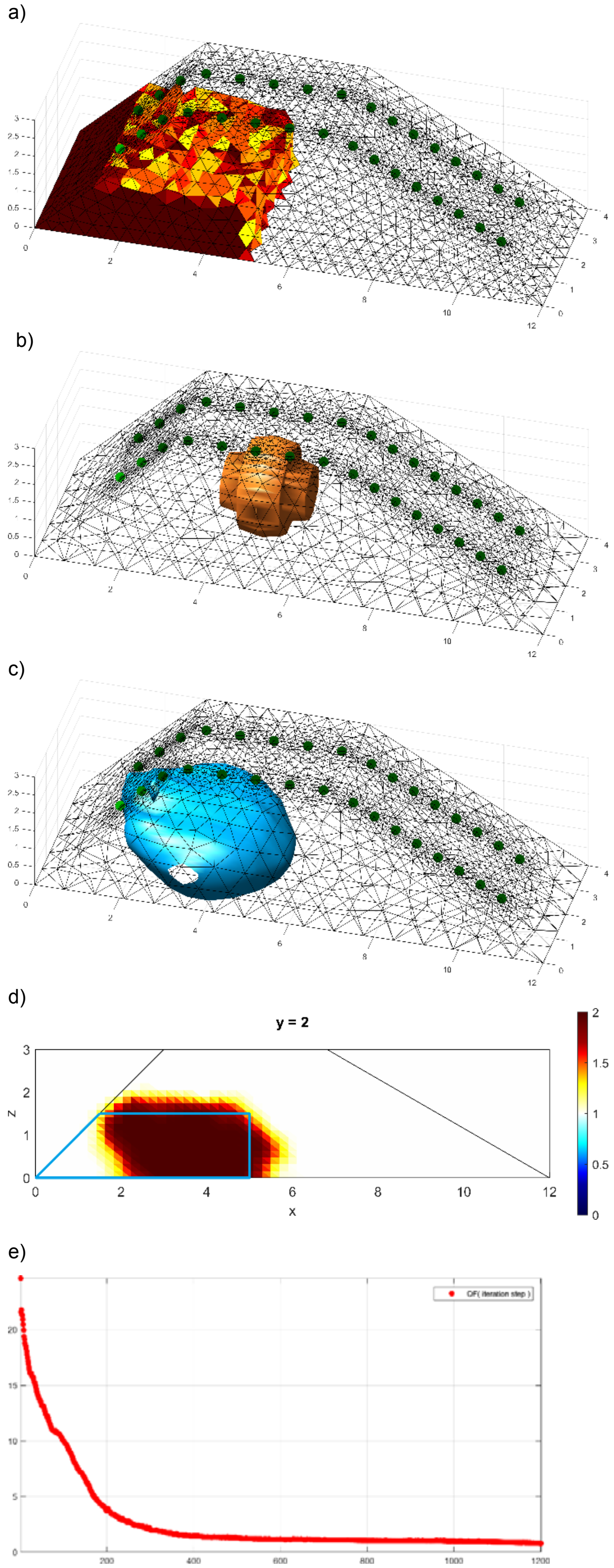

Fig. 5. Image reconstruction by the level set method: a) model, b) zero-level set, c) final level set, d) conductivity on the cross-section - plane {y – 2.0 = 0}, e) objective function in the next iterative steps.

Figures show the image reconstruction process with the use of the level set method. The individual parts of the drawing are as follows: (a) model (b) zero-level set, (c) final level set, (d) conductivity on the cross-section - plane, (e) fitness function in the next iterative steps.

Conclusion

This paper presents refers to research related to the design of a distributed multi-sensor system for monitoring flood embankments and dams. The atomized system was based on electrical tomography to test the hidden condition of technical objects. The described solution has been efficaciously applied in the investigated numerical model. The study gave promising results in the real monitoring of flood embankments. The newly developed system collects data from measuring devices and using them it reconstructs 3D cross-section images. The algorithms based on the Gauss-Newton and the level set method were used to identify leakages and anomalies posing a threat to the stability of the object. In the presented system, a special electronic device was designed and developed to perform relevant measurements. Research will be continued. Future activities will focus on the development of computational intelligence, soft computing methods and machine learning algorithms.

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