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Electrical Capacitance Tomography and Optical Detection in Quality Control System

***Abstract**. Modern production processes are increasingly complicated while customers require higher quality products at the lowest prices. This situation increases the importance of process optimization. Article contains description of the measurement system based on electrical capacitance tomography and optical detection techniques for optimization and production quality control. The most characteristic features of presented project are compact size of data acquisition module and its low energy demand. Complexity and cost of electrical capacitance tomography systems implementation into manufacturing processes as well as substantial size of equipment are the main reasons of their absence in the industry.*

***Streszczenie.** Nowoczesne procesy produkcyjne są coraz bardziej skomplikowane, a klienci wymagają wysokiej jakości produktów po najniższych cenach. Ta sytuacja zwiększa znaczenie optymalizacji procesu. Artykuł zawiera opis systemu pomiarowego oparty na elektrycznej tomografii pojemnościowej oraz optycznych technikach wykrywania w celu optymalizacji i kontroli jakości produkcji. Najbardziej charakterystycznymi cechami prezentowanego rozwiązania są niewielkie wymiary modułu gromadzenia danych i niski zapotrzebowanie na energię. Złożoność i koszt wdrożenia systemów elektroenergetycznych tomografii pojemnościowej do procesów produkcyjnych oraz znaczny rozmiar sprzętu stanowią główne przyczyny ich nieobecności w branży. (**Elektryczna tomografia pojemnościowa i detekcja optyczna w systemie kontroli jakości**).*

Keywords: Electrical Capacitance Tomography, Inverse Problem, Sensors
Słowa kluczowe: elektryczna tomografia pojemnościowa, zagadnienie odwrotne, sensory

Introduction

Modern production processes are increasingly complex, while customers are demanding higher quality products at the lowest price. This situation increases the importance of process optimization. Products and requirements are changing faster and faster, technologists have less and less time to learn the process and to optimize it solely on the basis of their own experience. On the other hand, very often the processes are automated and metered in detail, so we have plenty of data describing it. Analysis of the data may be used for process optimization in different ways and it can affect many aspects of process management. We can detect disturbances in the process, find the causes affecting the problems with quality, and choose the optimal settings for the process, comparing different preparation procedures and many others. It is worth noting that in the processes, there are many people involved in with different tasks and permissions. Therefore, data analysis tool should provide access control. The research project assumes creation of two measurement platforms: a set of multiphase flow system and a mini production line. In the first case we will be analysing two-phase flows of liquid (water) and air. That type of flow is commonly used in chemical reactors where air is mixing substances [4,9,10].

Electrical Capacitance Tomography

Electrical capacitance tomographs are devices capable of performing analysis of pipeline fragment or a vessel filled with examined medium [15]. Obtained cross-section's image reconstruction can be analysed further for an automated quality control system's autonomous and correct decision. However, existing industrial solutions are still of significant size and structurally complex [2,4,5]. This fact greatly limits the number of actual deployments. Decision makers are afraid of electrical capacitance tomography (ECT) implementation due to high costs of possible equipment failures and because of limited ability to support multiple elements in vast area of production lines. In response to the market demand and maintaining trend of complete automatic control, herein described system's project was created. It features some advantages of classic approach and meets the standards of modern industrial equipment at the same time. In this paper hardware issues, sample measurements and the image reconstruction are described.

Knowledge of the exact form of the technological processes is often crucial for achieving anticipated production quality or its proper efficiency. Control equipment providing man an essential information is, due to its role, mostly quite expensive and tightly integrated into production system. In order to monitor multiple elements there is a need for implementation of row of measuring devices. Furthermore, some complex phenomena have to be supervised by man due to technical problems with measurement. Such cases include research of multiphase flows, granular materials transport or inspecting processes of mixing substances using gases. In food, chemical or renewable energy industries those issues are significant and they are subjects of technological evaluation. The control and steering system for testing flow is presented in this publication. Multi-phase flow measurement technologies are still built and improved. [15-18,20]. There was proposed the prototype solution equally efficient as most of the currently existing ones.

Figure 1 presents the idea of ECT model sensors (measuring electrodes, steel grounding steel, screening electrode, pipe model of dielectric material). Complex system to the data acquisition, the image reconstruction with cloud computing model was shown in Fig. 2.

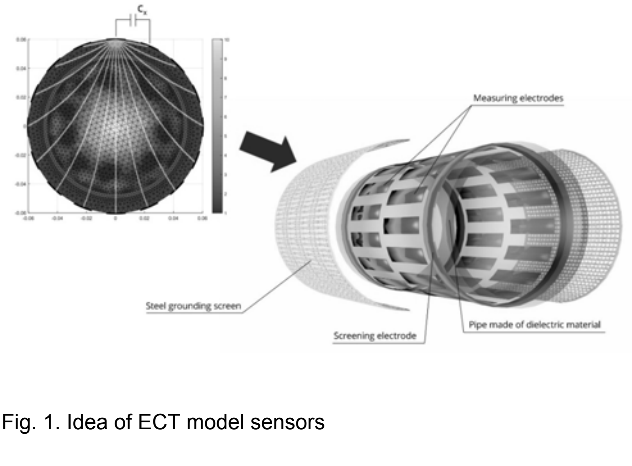


Fig. 1. Idea of ECT model sensors

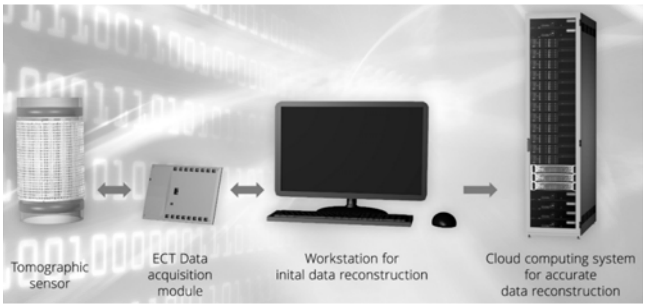


Fig. 2. Complex system to the data acquisition, the image reconstruction with cloud computing model

System for testing flow

Simple and low cost intrusive probes have been used in many operation systems to obtain flow information. Process tomography becomes even more appealing when nonintrusive sensors are used to obtain the cross-sectional images. Designed control system allows for correlative studies using sets of measuring electrodes. The present arrangement is not only measurements for testing various types of multiphase flow, but especially the development of the algorithms used in the electrical tomography [11-14,21]. One of the main goals of this research is to create a uniform system that will provide optimization and control of the production process. Virtual panels, the same as their physical counterparts, can be equipped with active elements (LEDs and audio controls, displays text and graphics), control and maintenance. Algorithms manual control and automatic cover issues related to the processing of data obtained from various sensors located at key nodes of the system. Supervision and control is in the range of acquired and processed data and device parameters implementing automation such as servo valves, pumps supply and rotary flow. The main feature of the use of methods of wireless is to obtain important information about the process and the state of the installation in real time by persons having strategic importance in the management and technical supervision [1,5-8]. The solution of designed system is presented in Fig. 3.

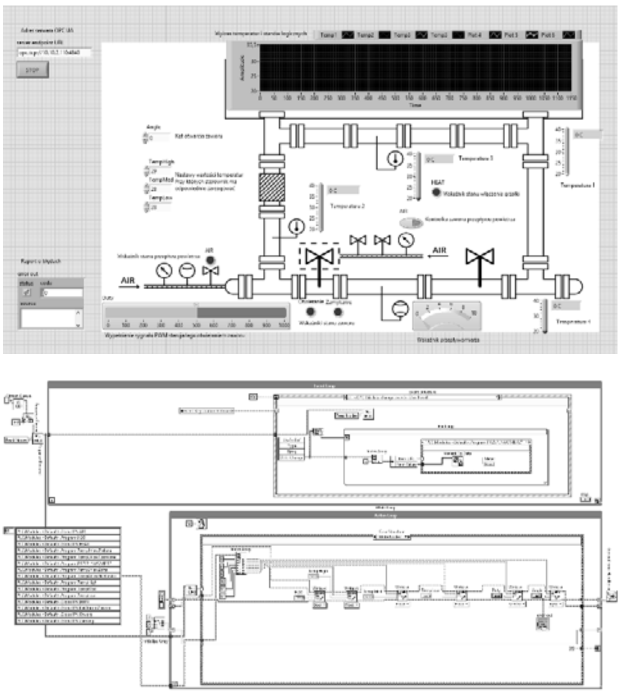


Fig. 3. Diagram of a multiphase flows and the synoptic board - block diagram

Scheme kit for multiphase flows comprising:
- Two-phase flow in horizontal and vertical
- Adjustable water flow
- Adjustable air flow
- Water flow measurement
- Water temperature measurement
- Registration flow method
- Registration flow method image segmentation

Smart ECT

Electrical capacitance tomography scanners are devices capable of imaging interior of pipelines or vessels made of dielectric material. Obtained cross-section's reconstruction may be further analysed. However, existing solutions feature significant size and structural complexity. Project of herein presented low cost ECT system's prototype consists of 4 main elements: ECT sensor, data acquisition device, optional network infrastructure and a computer. Figure 4 shows the schematic model of Smart ECT measurement system. The data acquisition module is connected to ECT sensor and at the same time to a computer via network infrastructure. Direct low latency USB 2.0 connection is available as well. Computer processes measurements obtained from the device hence real-time image reconstruction may be achieved with proper software. Compact size of data acquisition module is a result of two significant factors. Firstly, the device's design consists of integrated circuits performing multiple functions simultaneously, e.g., Atmel ATmega32U4 merging classic microcontroller with USB controller or Texas Instruments CD4067BM integrated multiplexers instead of separate CMOS decoders and switches. Secondly, the number of electrodes has been limited to 16. These solutions greatly limit the number of tracks needed and thus overall PCB size. In electromagnetically stable environments optional Wi-Fi module with ESP-8266 chipset may be applied. Single PC workstation is able to receive and process transmissions from several devices at the same time, provided they are all connected to the same network. The main part of the data acquisition module is Analog Devices AD7746 capacitance-to-digital converter. It is capable of measuring in range of ±4.096 pF with resolution up to 4 aF. Its high accuracy and precision is achieved at the expense of speed. Maximal output conversion rate is 90.1 Hz [2,3,19].

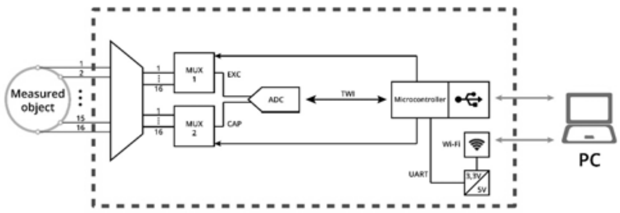


Fig. 4. Schematic model of Smart ECT measurement system

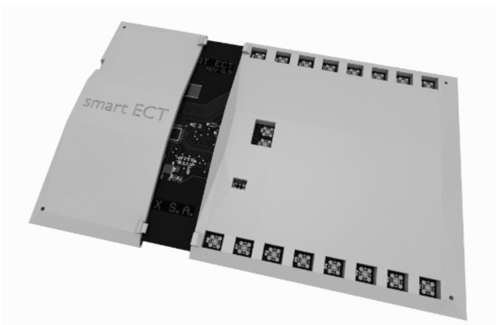


Fig. 5. The data acquisition module

Smart ECT's efficiency has been tested with classic cylindrical ECT sensor built from a tube made of plexiglass with copper foil electrodes mounted externally. Internal diameter of the tube is 94 mm, while the external one is 100 mm. Data acquisition module was combined with ECT sensor via 16 coaxial cables RG174 type and 40 cm long. Due to its compact size data acquisition module may be mounted in close proximity to the ECT sensor. Figure 5 shows device's PCB mosaic and external overview respectively.

The common approach to tomographic measurements data analysis is their processing in order to obtain a reconstructed image of the distribution of a required property in the examined cross section area. In the case of ECT, this property is the electric permittivity. The visualization of the inside of the investigated body is obtained on the basis of the recorded capacitance measurements. These permittivity distributions could be directly related to the material concentration present in the sensor (probe) space. In a typical measurement ECT sensor use between 8 and 16 electrodes symmetrically spaced around cylindrical container (tube, pipe, etc.), as shown in the following Fig. 6. The tube measurements with rods are presented in Fig. 7.

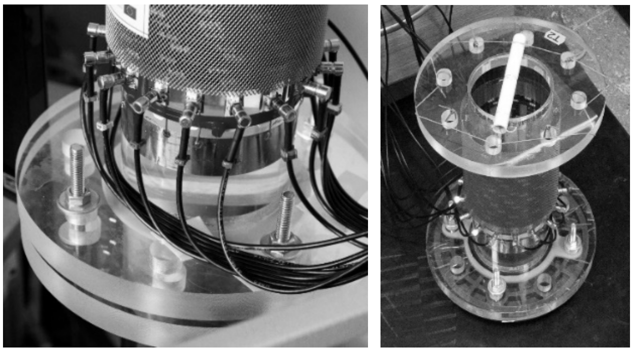


Fig. 6. The pipeline tomography model and the tube measurements

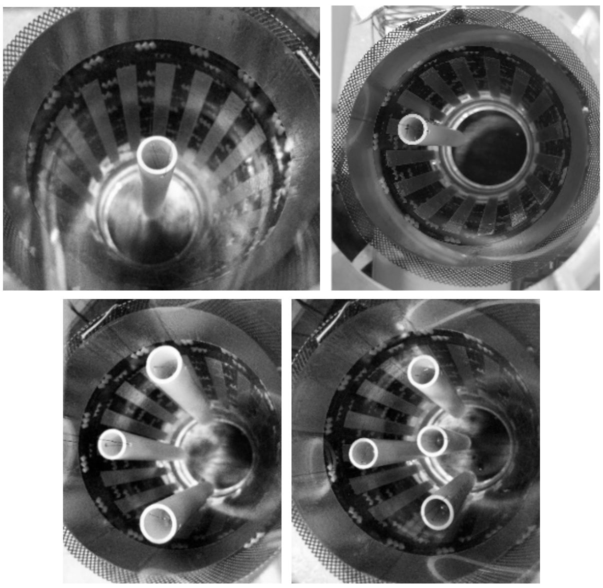


Fig. 7. The tube measurements with rods

Results

The purpose of the study was to obtain measurement results for various phantom configurations measured using alternative methods. The consequence of this action is both a practical verification of the quality of the individual solutions (also observing differences between them) and the same numerical package itself.

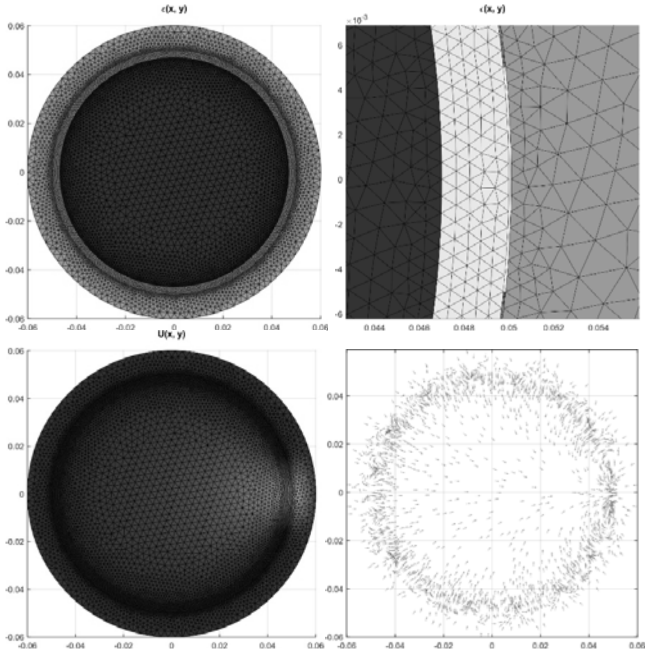
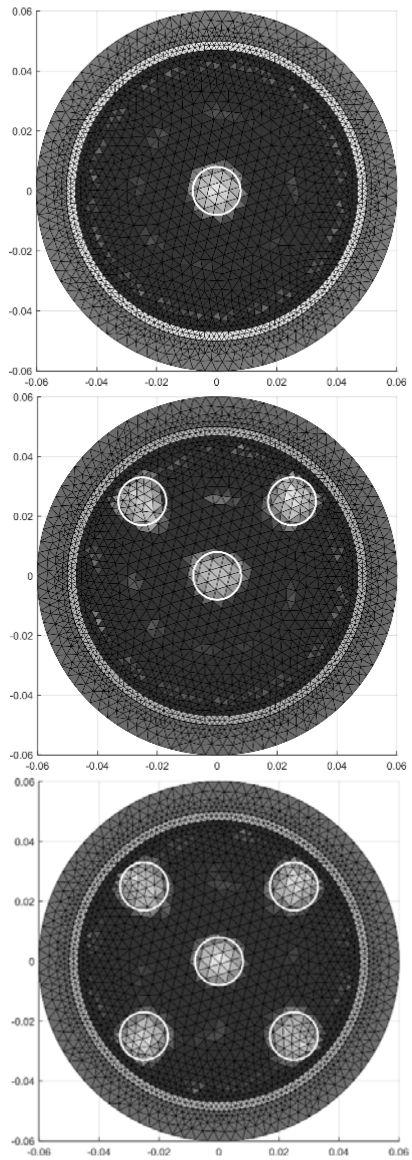


Fig. 8. Model of mesh and solution of the forward problem



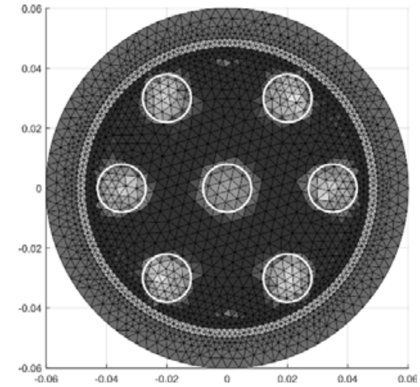


Fig. 9. The example of the image reconstruction

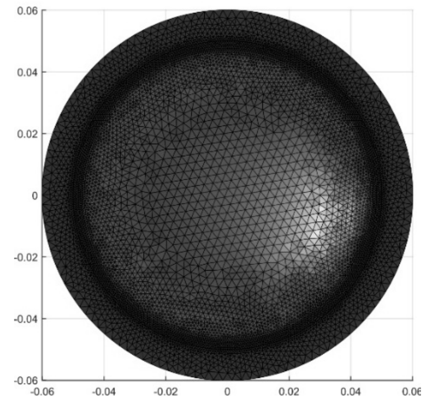


Fig. 10. The example of the image reconstruction by ECT - real data

The simple problem was solved using the finite element method. Grids used in calculations: rare 2 218 knots and 4 146 finite elements, dense 7 861 nodes and 15 146 finite elements (Fig. 8). The example of the image reconstruction was shown in Fig. 9 and 10 for the simulation and the real image reconstruction by the ECT device measurement. The Levenberg-Marquardt method was used to solve the inverse problem.

Summary

In this work, there was presented the solution using electrical capacitance tomography. There was designed Smart ECT device to control the flow process. The development of new systems based on capacitive tomography technology can significantly improve the production process at various stages. The challenge is to create a single optimal and efficient measurement. It is also important to develop optimal algorithms for solving the inverse problem for accurate reconstruction. Nowadays, optimization plays an increasingly important in the production process.

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