Beyond Imaging - Interactive Tabletop System for Tomographic Data Visualization and Analysis

Mikołaj Woźniak[1], Aleksandra Polak-Sopińska[2](✉), Andrzej Romanowski[1], Krzysztof Grudzień[1], Zbigniew Chaniecki[1], Aleksandra Kowalska[1], and Magdalena Wróbel-Lachowska[2]

[1] Institute of Applied Computer Science, Lodz University of Technology, Stefanowskiego St. 18/22, 90-924 Lodz, Poland
mikolaj@pawelwozniak.eu, {androm, kgrudzi, z.chaniecki, akowalska}@iis.p.lodz.pl

[2] Faculty of Management and Production Engineering, Lodz University of Technology, Wolczanska 215, 90-924 Lodz, Poland
{aleksandra.polak-sopinska, magdalena.wrobel-lachowska}@p.lodz.pl

Abstract. This paper presents an innovative endeavour towards more efficient and convenient analysis of large, complicated numerical datasets, such as the results gathered through electric capacitance process tomography. The proposed solution employs the approach of utilising interactive tangible displays for more efficient and appealing data visualisation. The ultimate goal was to deliver a tool which could not only enhance the analyst's performance, but also enable deriving supplementary observations and conclusions. The objective was obtained through implementing the system onto the tabletop display, which may be operated as an interactive table or a desktop touchscreen. The solution was tested in action through the series of industrial task experiments, to be completed using various setups of the system. The results of the post-exercise surveys show that the best performance is obtained using the inclined tabletop display. The classic table approach was rated as relatively inconvenient, while providing fair effectiveness. The seated-user desktop display was rated to be neither comfortable nor satisfactorily functional.

Keywords: Electric capacity tomography · ECT · Data analysis
Data visualization · Tangible devices · Interactive displays
Ergonomic work setups · Human-Machine interaction

1 Introduction

Process tomography is one of the most compelling techniques of analysis for multiple industrial trials. It enables investigation of the processes taking place in examined objects in non-invasive and non-destructive way [1, 2]. Moreover, reconstruction of images is possible even if there is no access to the interior of the system [3, 4], as well as being an ultimate solution for offline examination and simulation of processes. It is

W. Karwowski et al. (Eds.): AHFE 2018, AISC 793, pp. 90–100, 2019.
https://doi.org/10.1007/978-3-319-94196-7_9

commonly used in chemistry, pharmacy, geology and environment protection. The most well-known approach to tomography are hard-field techniques (e.g. X-ray tomography), ordinarily used in medicine. However, in numerous cases such approach is unsuitable due to physical features of monitored substance, high cost of implementations and low acquisition speed of the measurement units. In order to fulfil the needs of industrial implementations, where accurate measurement of dynamic processes is very important for their proper control, tomography modalities based on analysis of electrical field properties inside investigated objects are developed [5, 6]. An example of such tomographic system is electrical capacitance tomography (ECT), which is useful for monitoring state of granular flows [7, 8].

Nowadays, development of ECT systems can be discussed in several aspects such as development of data acquisition, algorithms for better reconstruction of images, tomography data processing for deep analysis of monitored processes or adaptation of ECT approach in control systems. Nonetheless, it is a vital issue to properly view, visualise, analyse and interpret both the raw measurements and the reconstructed data. It is essential to provide informative and appealing visual forms of data presentation, as it highly simplifies analysis and contribute to better understanding of the problem itself [9–11].

Presented system is an approach to face the challenge of providing clear and intuitive tool for tomographic data analysis. The main goal is to enable the user to easily and efficiently navigate through raw measurement records as well as create visual presentation and interpretations of collected data. This goal is realized via desktop application using multi-touch surfaces. This paper focuses on applying ECT tomographic approach for purposes of investigating the pneumatic flow processes [12, 13].

2 ECT Tomography Data

The examination of the presented system was made through applying the solution to deal with the challenges of dynamic flow control. The experimental scenarios were prepared based on investigating the pneumatic conveying of granular material in the pipeline system.

The ECT system consists of 3 components - the measurement unit, the sensors and the operational computer. The electrical capacitances are measured simultaneously between pars of matching electrodes located all-around the investigated setup. All the paired electrodes form the ECT sensor. The sensor collects a set of numerical measurements, from which the reconstructed 2D or 3D image of the process may be retrieved. Each set contains information about process state in quasi-time instance. The images are reconstructed with the assumptions of all measurements being gathered at the same instance of time.

Figure 1 presents the 3 features of process imaging – the investigated material (in presented case – the granular material), measurement setup and the reconstructed image.

Obtained measurements are reconstructed to the form of image (typically 32×32 pixels of size), representing information on material distribution inside the sensor. In case of pneumatic conveying of solid or gravitational silo discharging, the images

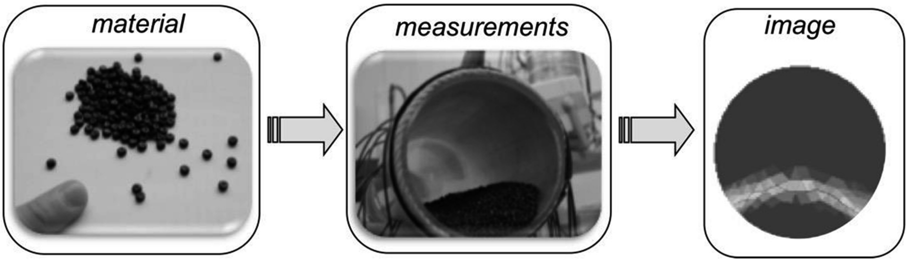

Fig. 1. Three features of granular flow - granular material, measurement setup, reconstructed image

provide knowledge about the level of granular material concentration in the sensor space. Figure 2 presents an example of ECT - image data gathered during pneumatic conveying of solid. The data is usually normalized and presented as the ratio of the material-occupied space to the total ECT sensor scope. Determining of the concentration profile enables further analysis of the flow parameters through calculating the velocity profile and the mass flow rate. All those parameters provide extensive knowledge on the monitored process.

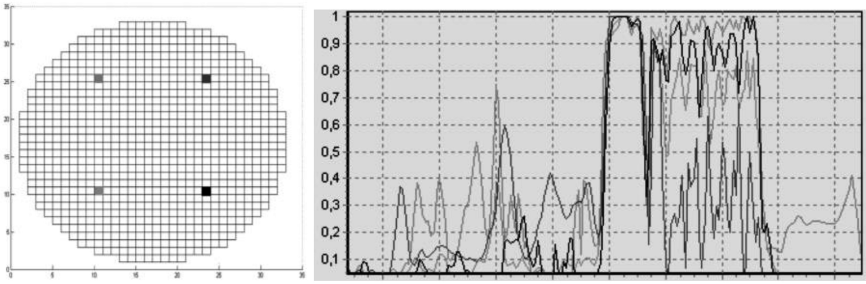

Fig. 2. ECT image representation of pneumatic conveying flow, (a) discretization of cross-section of ECT sensor with marked pixels, (b) granular material concentration changes in pixels marked in Fig. (a).

The typical way of ECT data processing for both measurement data and reconstructed images, is based on investigating the temporal and spatial changes in the pixel values (when images are concerned) or material distribution profile in ECT sensor space. Current state of the process can be assessed through single reconstructed image, sequences of images or set of bare measurements. Analysis of the material concentration distribution for the granular flow is based on image is supported with its temporal changes profile, which may be represented through analysis of measurements or the sequence values of image pixels.

Over the course of dynamic flow analysis, large sets of different data are gathered – the raw measurement data, the reconstructed images and flow conditions are generated by the system. Common ECT setup provides between 100 and 200 frames per second, each image with 812 significant pixels representing the shape of pipe cross-section. It requires loads of time and labour to successfully analyse such a great set of data and conduct proper comparisons for different conditions. Therefore, developing an efficient tool of off-line analysis and data processing is necessary.

3 Visual Support for Data Analysis

In order to enable deep understanding of the investigated process, as well as provide handy tool for industrial control – different forms of representing those large sets of numerical data are required. While the reconstructed images fulfil the task of process representation at particular instance of time, they do not support the time and space related comparisons to satisfactory extent. Therefore, it is necessary to provide additional tools which could assist such scope of investigation. In accordance with the rules regarding the information perception [14, 15], the graphs and topograms seem to be the most advantageous solution to those issues. The graphs are found to be useful in time-related analysis of material concentration, while the topograms enable extensive investigation in space and time simultaneously. The ease of rapid switching between the time and space related results is one of the key advantages of the introduced solution.

3.1 Images

The input data is reproduced to the form of images in order to generate more descriptive graphical representation. The solution provides support for enhanced navigation along the images and creating interpretations for the information from the image. The program displays scrollable image sequence, which represent measurement data. User taps an image from the downscaled range bar and can easily magnify the particular scope of the image through zooming and pinching. The display can be controlled through scrolling and panning. The key feature for image analysis is the ability to choose the range of the image to be interpreted further and instantly generate corresponding graph or topogram, as desired.

3.2 Graphs

Graphs can be generated for arbitrary sets of data. Plots generated for the desired range may be further analysed through magnifying, scaling and choosing more precise scope or a certain point. Moreover, choosing a single spot enables finding the corresponding image. This feature highly increases the ease of inspecting only the most interesting part of collected information and its farther examination. This mechanism is supported by interactive operations such as scaling and distortion. Using commonly applied gesture pattern, employing tapping, pinching, zooming and scrolling, the user is able to increase precision of examination through scaling the graph, while being dynamically supplied with corresponding images, being straight representation of raw data. [16, 17]. Figure 3 presents the graph with few images corresponding to particular instances assigned.

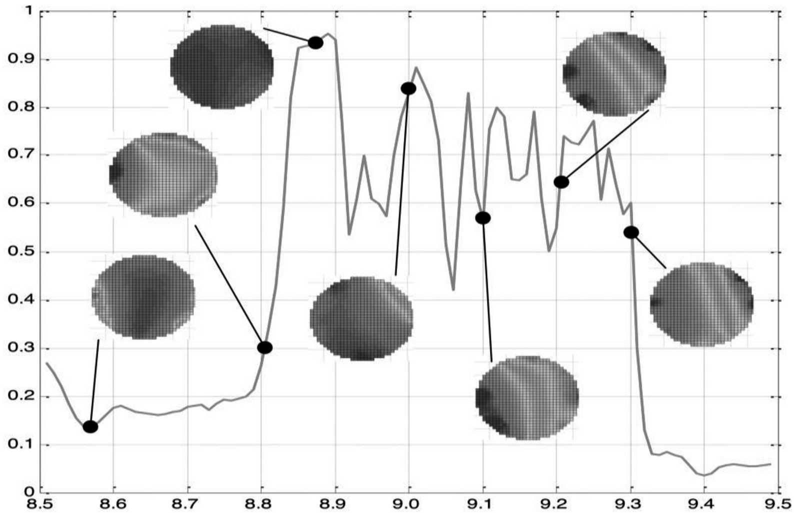

Fig. 3. Graph representation of material concentration in time, with the images assigned.

3.3 Topograms

Topograms are an interesting form of representation of tomographic data. They consist of a set of records, acquired from the same row or column, extracted from all images in the sequence. Such representation provides clear and understandable depiction of changes occurring in a certain area of examined object. The solution supports generating topograms for any specific row or column chosen from the image. In order to generate such, user pans through the desired piece of data and taps proper option on a menu bar.

3.4 Setup Arrangements

The ultimate goal of the design was to provide a tool which could boost up the workflow of process control, through enabling the rapid analysis in different scopes, as well as delivering a convenient experience of the analysis itself. Therefore, the multitouch interface was implemented onto the tabletop, enabling operation in various arrangements. Three different approaches were concerned during the study – using the horizontal tabletop, the inclined tabletop and the desktop arrangement, similar to use of common desk touchscreen (Fig. 4).

Various arrangements are advantageous in terms of applying the system as embedded feature of ECT measuring systems. Moreover, the tabletop approach is highly favourable for collaborative tasks, providing enough workspace for multiple users to interact with the system simultaneously [18]. Throughout this study, the different setups were compared, in order to establish which turns out to be the most efficient and convenient for the operator to use during completing the everyday tasks.

Fig. 4. Different arrangements of the display setup. From the left: (a) inclined tabletop (b) horizontal tabletop (c) desktop-like arrangement

4 System Evaluation

4.1 Evaluation Procedure

The system was evaluated with the aid of N = 13 participants, for whom an exemplary industrial task was prepared. At the very beginning, the users were introduced to the task through watching a short 5-min video on the process tomography and data analysis, with special emphasis put onto the pneumatic conveying of pellets. Then, the issuers were briefly introduced to system operation. Each participant was provided with three tasks, all connected with recognizing the stable slug flow within the sequence and its detailed analysis. Participants were asked to establish the percentage of cross-section occupancy of stationary layer. Each task was to be completed with different arrangement of the display. After accomplishing of every task, the user experience, as well as the efficiency were rated through the surveys. For each task, the time elapsed was measured as additional factor of efficiency evaluation. The experimental scenarios were prepared in a way that a particular exercise did not last longer than 20 min.

4.2 Results and Discussion

Right after completing the task, users were asked to give feedback on their experience with the system. The opinions were gathered through surveys, examining satisfaction with system interface and studying how challenging the task was. In order to investigate how demanding the exercise revealed to be, the Task Load Index [19, 20] was established. Results of this survey present that users felt successful with their performance, although the task was considered as difficult. However, their frustration on realisation is relatively low (Fig. 5).

Further, participants were asked to assess their experience with different display arrangements. Users clearly suggest that the tabletop approach was considerably more convenient than the desktop display. Moreover, the users mentioned that they found the system easier to operate with the tabletop approach, with special emphasis on the inclined variant. The time-related assessment results conform well with those observations, as the tasks realised with the use of desktop display took significantly longer to complete.

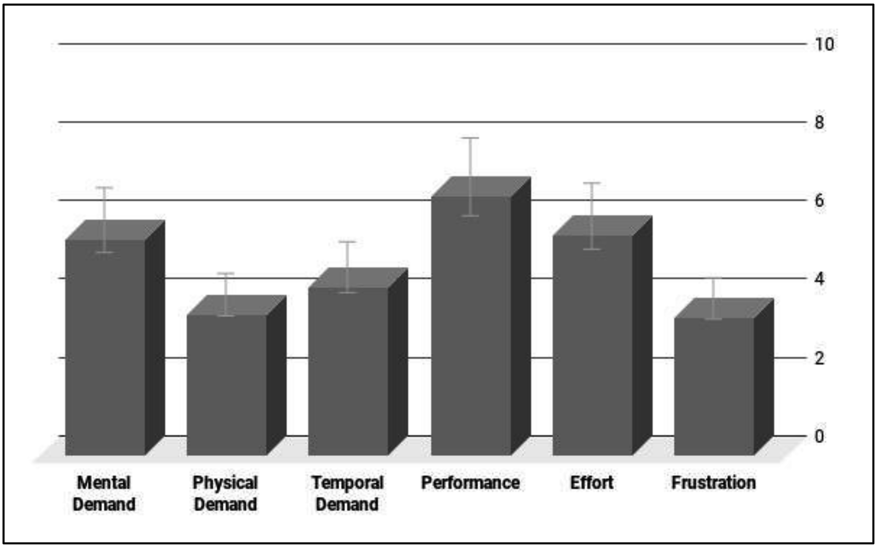

Fig. 5. Task Load Index survey results

The tasks in general are perceived as time-consuming and requiring precise operation, therefore the seated position is favourable. The horizontal table approach was commented: *"It's difficult to operate while seated", "I would rather not stand for so long"*. However, vertical arrangement, similar to the one of commonly used desktop screens was also referred as inconvenient: *"I'd rather use the mouse or some touchpad", "It's hard to navigate"*. The inclined table top was rated as the most comfortable position, maintaining the advantages of easy operation and possibility to seat while working. This arrangement was commented as follows: *"It's nice I can easily operate it without standing, as the screen is not too big", "If I needed to cooperate, I'd probably stand up, but I like that I can seat when working alone"*.

The system was tested using 27' inch touchscreen. The users made comments, that applying the system to full-size tabletop (e.g. Microsoft Surface) would be less comfortable to use, as it would require standing position from the operator. Some users also suggested, that developing a tablet version of the solution might be useful for reporting and collaborative discussion purposes (Fig. 6).

The desktop-like arrangement utilizing a 27' inch touchscreen is likely to cause the arm to be lifted of an angle greater than 60° in the sagittal plane, which is undesirable for static positions or the operational manners requiring more than two moves per minute. Such occurrence might be permissible only if less than two movements per minute are concerned, and only for short periods of time, according to the EN 1005-4 standard [21]. Furthermore, according to the standard ISO 14738:2002, it is advisable to arrange the display in the inclined manner, within the angle of 30–60° (with respect to the horizon line), when both observations and manipulations are concerned [22]. The advice provided by standard ISO 9241-5:1998, stating that the inclination of the main line of sight with respect to the horizon line shall be approximately 35°, while the optimal angular range of sight is approx. 15° are applicable to non-interactive displays only [23].

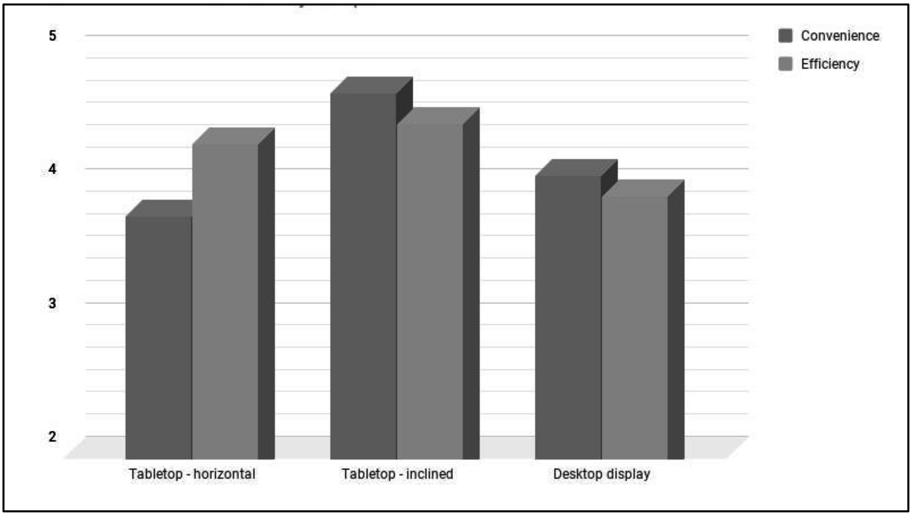

Fig. 6. Results of the convenience and efficiency survey, for different display setups

On the other hand, the horizontal arrangement of the display, where the observation and manipulation area is within the angular range of 60 to 90°, requires the user to significantly lean the head and/or torso towards the display and frequently move the head sideways, which is highly inadvisable, when recurrent observations are concerned, according to the ISO 14738:2002 standard [22].

The Rapid Upper Limb Assessment (RULA) approach also concurs with the assumption of the inclined tabletop setup being the most favorable. The lowest results were obtained for this arrangement, both in terms of observational and operational scope of interaction. The results of RULA analysis are presented in detail in Table 1.

Performed evaluation indicated a certain need for developing more accessible tools which can significantly improve the workflow of tomographic data analysis. Nowadays, it is not only accuracy that is required, but also proper usability, so the act of analysis is no more complex and frustrating. Proposed solution faces the challenges of improving the experience of ECT data analysis, although there is still room for further improvements. The multi-touch approach appears as reasonable due to being cognitively intuitive and sufficiently efficient. Tabletop implementation increases the usability even more, introducing the intuitive and productive interface, enabling full commitment to the challenge being solved. It would be advisable to pay efforts on developing design of each functionality, as the choice of visualisation forms revealed to be accurate as well.

Table 1. The results of the RULA analysis: 1 – observation and operation in the central part of the tabletop; 2 – observation and operation in the border right and left parts of the display.

RULA		Inclined tabletop		Horizontal tabletop		Desktop-like screen	
		1	2	1	2	1	2
Upper arm	Score	2	3	1	2	3	4
	Position	$+20^0 \div 45^0$	$+20^0 \div 45^0$, abducted	$+20^0 \div 20^0$	$+20^0 \div 20^0$, abducted	$+45^0 \div 90^0$	$+45^0 \div 90^0$, abducted
Lower arm	Score	1	2	1	2	2	3
	Position	$+60^0 \div 100^0$	$+60^0 \div 100^0$, arm is working across midline or out to side of the body	$+60^0 \div 100^0$	$+60^0 \div 100^0$, arm is working across midline or out to side of the body	$0^0 \div 60^0$	$0^0 \div 60^0$, arm is working across midline or out to side of the body
Wrist	Score	2	3	2	3	3	4
	Position	$0^0 \div \pm 15^0$	$0^0 \div \pm 15^0$, bent from the midline	$0^0 \div \pm 15^0$	$0^0 \div \pm 15^0$, bent from the midline	$> \pm 15^0$	$> \pm 15^0$, bent from the midline
Wrist twist	Score	1	1	1	1	1	1
	Position	mid-range					
Table A		3	4	2	3	4	6
Muscle use	Score	1	1	1	1	1	1
		action repeatedly occurs 4 times per minute or more					
Force/load	Score	0	0	0	0	0	0
		load < 4,4 lbs. (intermittent)					
Score A		4	5	3	4	5	7
Neck	Score	2	2	3	4	1	1
	Position	$10^0 \div 20^0$	$10^0 \div 20^0$	20^0+	20^0 + , twisted	$0^0 \div 10^0$	$0^0 \div 10^0$
Trunk	Score	1	1	2	2	1	1
	Position	$0^0 \div 10^0$	$0^0 \div 10^0$	20^0	20^0	$0^0 \div 10^0$	$0^0 \div 10^0$
Legs	Score	1	1	1	1	1	1
	Position	legs & feet supported and balanced					
Table B		2	2	3	5	1	1
Muscle use	Score	1	1	1	1	1	1
		posture mainly static					
Force/load	Score	0	0	0	0	0	0
		load < 4,4 lbs. (intermittent)					
Score B		3	3	4	6	2	2
Final score		3	4	4	6	4	5
Level of risk		Medium	Medium	Medium	High	Medium	High

5 Summary and Future Work

We demonstrated the principles of operation, as well as the technical potential in terms of efficiency and usability of the system for analysis and interpretation of process tomography data. Initial results reveal that proposed multi-touch interface, coupled with carefully designed visual forms of data presentation and manipulation proved qualitatively to over-perform the classical approaches to data exploration and interpretation. Moreover, the tabletop implementation proved to be desired for the users, as it enables more effective and comfortable workflow. The proposed application is a successful endeavour to answer the demand for efficient and user-friendly tool for improving the experience of tomographic data examination. Furthermore, future research on both the interface as well as the back-end side seems to be promising in terms of data analysis further advancement. Big data analysis of experimental datasets, if properly implemented, will offer yet unseen opportunities for data mining, pattern recognition and data understanding. Especially, the web-based implementation of the system will enable to employ it for crowdsourcing tasks as proposed in [25, 11].

References

1. Sankowski, D., Sikora, J.: Electrical Capacitance Tomography: Theoretical Basis and Applications. Instytut Elektrotechniki, Warsaw (2010)
2. Wang, M.: Industrial Tomography: Systems and Applications. Woodhead Publishing, Elsevier (2015)
3. Filipowicz, S.F., Rymarczyk, T.: Measurement methods and image reconstruction in electrical impedance tomography. Przeglad Elektrotechniczny **88**(6), 247–250 (2012)
4. Fidos, H., Jaworski, T., Nowakowski, J., Sankowski, D., Wajman, R., Fiderek, P., Banasiak, R.: Metrological evaluation of a 3D electrical capacitance tomography measurement system for two-phase flow fraction determination. Measur. Sci. Technol. **24**(6), 065302 (2013)
5. Rymarczyk, T.: Using electrical impedance tomography to monitoring flood banks. Int. J. Appl. Electromagn. Mech. **45**, 489–494 (2014)
6. Fiderek, P., Kucharski, J., Wajman, R.: Fuzzy inference for two-phase gas-liquid flow type evaluation based on raw 3D ECT measurement data. Flow Meas. and Instrum. **54**, 88–96 (2017)
7. Romanowski, A., Skuza, M., Wozniak, P., Grudzien, K., Chaniecki, Z.: Big data computational environment for tomography measurement data. In: Process Tomography WCIPT7, Poland (2013)
8. Watzenig, D., Fox, C.: A review of statistical modelling and inference for electrical capacitance tomography. Meas. Sci. Technol. **20**(5), 052002 (2009)
9. Mazza, R.: Introduction to information visualisation. In: Resources of Faculty of Communication Sciences, University of Lugano (2004)
10. Grudzień, K.: Visualization system for large scale silo flow monitoring based on ECT technique. IEEE Sens. J. **17**(24), 8242–8250 (2017)
11. Jelliti, I., Romanowski, A., Grudzień, K.: Design of crowdsourcing system for analysis of gravitational flow using x-ray visualization. In: Ganzha, M., Maciaszek, L., Paprzycki, M. (eds.) Proceedings of the 2016 Federated Conference on Computer Science and Information Systems. Annals of Computer Science and Information Systems, vol. 8, pp. 1613–1619. IEEE (2016)

12. Mosorov, V.: Flow pattern tracing for mass flow rate measurement in pneumatic conveying using twin plane electrical capacitance tomography. Part. Part. Syst. Charact. **25**(3), 259–265 (2008)
13. Jaworski, A.J., Dyakowski, T.: Application of electrical capacitance tomography for measurement of gas-solids flow characteristics in a pneumatic conveying system. Meas. Sci. Technol. **12**(8), 1109 (2001)
14. McCormick, J.: Antropotechnika: przystosowanie konstrukcji maszyn i urządzeń do człowieka, pp. 493–496. Wydawnictwo Naukowo-Techniczne, Warszawa (1964)
15. Ward, M.O., Grinstein, G., Keim, D.: Interactive Data Visualization: Foundations, Techniques, and Applications. CRC Press, Natick (2010)
16. Schmidt, S., Nacenta, M.A., Dachselt, R., Carpendale, S.: A set of multi-touch graph interaction techniques. In: ACM International Conference on Interactive Tabletops and Surfaces (ITS 2010). ACM, New York (2010)
17. Szafarz, J., Woźniak, M., Romanowski, A., Grudzien, K., Chaniecki, Z.: The design and implementation of interactive visualisation system for ECT data analysis, In: IIPhDW2017, Łódź (2017)
18. Müller-Tomfelde, C., Fjeld, M.: Tabletops: interactive horizontal displays for ubiquitous computing. Computer **45**(2), 78–81 (2012)
19. Hart, S.G.:. NASA-task load index (NASA-TLX); 20 years later. In: Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting, pp. 904–908. HFES, Santa Monica (2006)
20. Hart, S.G., Staveland, L.E.: Development of NASA-TLX (Task load index): results of empirical and theoretical research. In: Hancock, P.A., Meshkati, N. (eds.) Human Mental Workload. North Holland Press, Amsterdam (1988)
21. EN 1005-4 Safety of machinery - human physical performance - part 4: evaluation of working postures and movements in relation to machinery
22. ISO 14738:2002 Safety of machinery – Anthropometric requirements for the design of workstations at machinery
23. ISO 9241-5:1998 Ergonomic requirements for office work with visual display terminals (VDTs) – Part 5: Workstation layout and postural requirements
24. Chen, C., Wozniak, P.W., Romanowski, A., Obaid, M., Jaworski, T., Kucharski, J., Grudzien, K., Zhao, S., Fjeld, M.: Using crowdsourcing for scientific analysis of industrial tomographic images. ACM Trans. Intell. Syst. Technol. **7**(4), 1–25 (2016)