

Wojciech MALEIKA

WEST POMERANIAN UNIVERSITY OF TECHNOLOGY, FACULTY OF COMPUTER SCIENCE AND INFORMATION TECHNOLOGY
ul. Żołnierska 49, 71-210 Szczecin

Algorithm for creating three-dimensional models of internal organs based on computer tomography

Dr inż. Wojciech MALEIKA

Graduated from the Faculty of Computer Science and Information Technology, Szczecin University of Technology in 1998. In 2004 obtained PhD degree in the field of computer science. Main research interests: medical data processing, hydrographic data processing, web applications. Employed as Associate Professor at the Faculty of Computer Science and Information Technology, West Pomeranian University of Technology, Szczecin.



e-mail: wmaleika@wi.zut.edu.pl

Abstract

The paper describes a method for creating 3D objects of selected organs based on images of successive sections obtained from a computer tomograph. In the presented algorithm there were taken into account: image binarisation, seeking out contours, labelling, transformation into polar system, generation of objects (triangulation). The test investigations were carried out with the use of real images of patients from Kołobrzeg hospital.

Keywords: computer tomography, 3D modeling, Canny method, conformity between vertices, FTA.

Opracowanie metody tworzenia modeli trójwymiarowych organów na podstawie zdjęć z tomografii komputerowej

Streszczenie

W artykule na wstępie opisano badania jakie prowadzono w różnych ośrodkach naukowych związane z tworzeniem obrazu trójwymiarowego wybranego organu na podstawie zdjęć przekrojowych uzyskanych z tomografii komputerowej, a także przykłady takich wizualizacji z programów komercyjnych. W dalszej kolejności zaprezentowano autorską metodę rekonstrukcji obiektów 3D (organów człowieka) na podstawie kolejnych przekrojów CT. W prezentowanym algorytmie uwzględniono wiele etapów takiego procesu: binaryzację obrazów (z dolnym i górnym progami), wyszukiwanie konturów i krawędzi (metoda Canny'ego), etykietowanie, przetwarzanie obiektów do układu biegunowego, generowanie obiektów 3D (szybka triangulacja - FTA). W każdym z zaprezentowanych etapów wskazano mocne i słabe właściwości zastosowanych rozwiązań. Opisane poszczególne metody połączono ze sobą i przedstawiono kompletny schemat opracowanego algorytmu. Wyniki jego działania zaprezentowano na trzech przykładowych wizualizacjach (płuca, czaszka, miednica) zrekonstruowanych na podstawie zdjęć z CT. Wszystkie badania testowe były przeprowadzone z wykorzystaniem rzeczywistych zdjęć pochodzących z badań pacjentów szpitala w Kołobrzegu.

Słowa kluczowe: tomograf komputerowy, modelowanie 3D, metoda Canny'ego, dopasowanie wierzchołków, FTA.

1. Introduction

The application of IT to medicine commenced in the United States in the sixties of the previous century. In the 70s there appeared the first image systems in medical diagnostics. Among these techniques an important position is held by computer tomography which uses monochromatic digital images when collecting diagnostic data and binary ones when analysing and processing these data. Monochromatic images, i.e. with gray gradation, are widely applied to medical diagnostics, as they permit penetrating location and exposing focal spots in the organ examined. The images obtained in result of medical examinations are two-dimensional and are mostly monochromatic (Radiography

- RTG, Magnetic Resonance Imaging – MRI, Ultrasonography – USG, Computed Tomography – CT)

The paper describes research pertaining to the preparation of a method for creating a three-dimensional image of a selected organ based on section images obtained from computer tomography. The following problems were considered when working out this method:

- examination and selection of an edge-detection method, designating an outline of objects on particular images,
- examination and selection of 3D model creation methods based on series of successive contours of a particular object,
- preparing a method for 3D model generation based on images from computer tomography,
- verification of method using real CT images.

2. Basics of medical imaging

Many modern depiction methods, computer tomography included, cannot be applied without computer technology and digital image processing. Digital recording permits the obtaining of even more information about the patient, which in turn permits the specialists to observe various types of structures and physiological processes taking place inside the human body. Their processing and analysis, combined with the doctors' knowledge, enhances the efficiency of diagnosing diseases.

2.1. Medical monochromatic images

Medical images mostly record information on brightness in 8 bits. Images of this kind are applied *inter alia* to computer tomography and magnetic resonance, as the data obtained from diagnostic apparatus are frequently beyond the range of visible waves [1]. In order to depict them in the correct way, grades of gray are applied.

In medical imaging many sources of image multidimensionality can be encountered. Most frequently they are two-dimensional (2D) and present radiological images or, in the case of computer tomography, sections. 3D imaging may be a sequence of 2D images presenting a static object. If, in addition, the presented object moves, then we have to deal with 4D images. Spectrographic heart images can be examples of such imaging.

The main applications of imaging methods:

- visualisation – imaging of possible changes in the organism,
- quantitative analysis: measuring the size of object examined, and also detection of all kinds of pathological changes,
- determining the location of a given change.

2.2. Computer tomography

Computer tomography (CT) serves the purpose of obtaining cross-section images of the human body in a non-invasive way. It is applied in the following [2]:

- examination of the central nervous system aimed at assessing the brain and other intracranial structures,
- chest diagnostics (e.g. tumour processes, traumas),
- examination of parenchymal organs of the abdominal cavity (liver, pancreas),
- assessment of the alimentary tract, examination of the osseous-articular system,
- assessment of vascular changes,
- diagnostics of neoplastic tumours,
- diagnosing perfusion disturbances like stroke and bleedings.

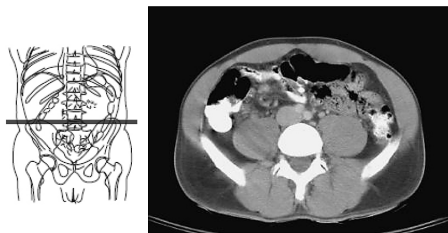


Fig. 1. Example of section image obtained from computer tomography [3]

Rys. 1. Przykład zdjęcia przekroju uzyskane w tomografii komputerowej [3]

2.3. DICOM Standard

The DICOM standard (Digital Imaging and Communication in Medicine) has been worked out for the needs of recording and archiving of all kinds of medical images. Its aim is to permit information exchange in medical diagnostics between apparatus of different manufacturers (with the preservation of certain cohesion) and IT systems obtained by means of various diagnostic apparatus. DICOM has been adapted to on-line information exchange by means of TCP/IP protocol [4]. It is also based on Open System Interconnection model worked out by ISO, permitting cooperation with off-line carriers like CD disks. Photographs used in the research were delivered in a format in accordance with DICOM standard.

2.4. Representation of 2D and 3D medical images: existing solutions

There are a lot of algorithms and IT tools permitting the representation of images both in 2D and 3D space. One of the simplest and most popular representation forms of 3D image is graphics based on polygon net, where the lateral surface of the solid is described by means of a set of polygons. In practice, a net made up of triangles is most frequently used. Another frequently used method for representing and analysing medical and scientific data is volume (voxel) modelling.

In the case of computer tomography, multi-row CT in particular (i.e. tomographs containing a large number of detectors), spatial visualisation can be performed in the case when we have to deal with section images. In such images the distances between successive measurements are rather small. They can be generated after the application of various available reconstruction techniques. Among the most important the following are counted:

- Maximum Intensity Projection,
- Shaded Surface Display,
- Multiplanar Reconstructions,
- Volume Rendering.

Another means of reconstructing medical images into 3D space is subjecting a given image to analysis according to the following algorithm:

- assigning a set of points belonging to an edge (using special filters for edge detection),
- transforming assigned points into three-dimensional space,
- applying morphing transformations aimed at a full mapping of the spatial object.

The three-dimensional model obtained by this method has many positive features. It can be manipulated in a variety of ways, like turning, calibrating, removing elements blocking the view of the structure assessed, changing colour and intensity of the texture. It is very useful in the process of planning surgeries and training specialists.

There are many algorithms and methods of 3D reconstruction of internal organs [16, 17, 18, 19, 20]. One of the exemplary approaches presented in [14] employs volumetric visualisation. There were also attempts to visualise specific elements (teeth, foot bones etc.) in the real-time [15].

On the market there is also a number of programmes realising the subject described, yet these are usually programmes attached to the medical apparatus prepared by their manufacturers. The solutions accepted in them, the kind of algorithms used and the accuracy of created 3D models constitute a commercial secret. It is also difficult to compare the results obtained (of 3D models) when using various programmes. Figure 2 presents an example of model image obtained by 3D-Doctor application.

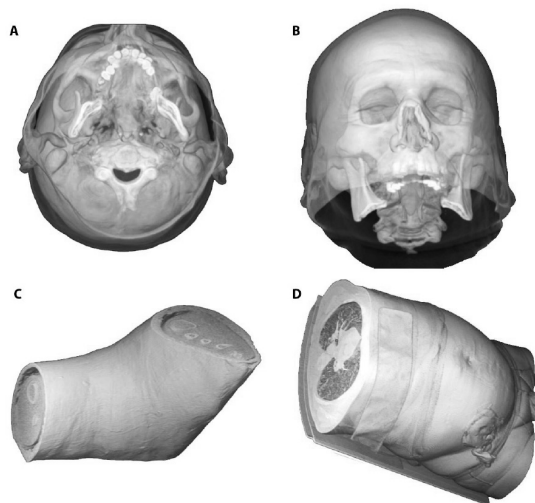


Fig. 2. Examples of images generated in 3D-Doctor programme, after selecting VR technique. A, B – head model, C – knee, D – abdominal cavity [own study]

Rys. 2. Przykładowe obrazy wygenerowane w programie 3D-Doctor, po wybraniu techniki VR. A, B – model głowy, C – kolano, D - jama brzuszna [opracowanie własne]

3. Method of 3D reconstruction based on CT sections

The methods describe below form a complete algorithm developed by the author which makes it possible to create a 3D model of a specific, chosen organ, based on subsequent CT slices. The results of the algorithm can be compared with other approaches and evaluated in the subjective manner only, using visual inspection.

In the research there were used the images from medical diagnostics conducted by computer tomography, made available by Kołobrzeg Regional Hospital. These include inter alia images of chest, abdominal cavity, knee and head.

The method consists of two basic steps. In the first stage, embracing algorithms of designating points belonging to the edge of object outlined, an analysis of digital images is performed, aiming at designating sets of those points. The second stage is the triangulation algorithm, that is building a surface model of the scanned object in the form of set of triangles. As a final result, the data describing the 3D model of the organ examined are obtained. On their basis visualisation and medical analysis can be made.

3.1. Designating sets of points belonging to an edge

The first basic task to be solved is the automatic pull-out of object edges located on CT images. There is no typical definition of "object edge". It is usually assumed to be a certain part of the image, where a sudden change of brightness (luminance) takes place. Analysis of gray levels of the objects scanned and the background in the image are frequently in accordance with reality, that is the characteristic features of the object are faithfully reproduced. The working out of a universal algorithm for edge detection is rather difficult, as it has to be universal and correctly detect objects with differentiated features.

3.1.1. Binarisation

The initial stage is the binarisation of tomographic images. Binarisation is a method of segmentation and consists in transforming images with different levels of gray into two-colour images. This change is performed with a view to simplify further calculations. In the algorithm worked out two binarisation algorithms are made use of:

- lower-threshold binarisation, in order to determine the dark areas of e.g. lungs
- upper-threshold binarisation, in order to determine the brighter area of e.g. bones.

The binary images obtained provide the basis for further morphological transformations.

3.1.2. Singling out objects from an image

For isolating desired shapes from an image, the following morphological transformations were used:

- flooding holes in an object,
- labelling.

Flooding holes in an object aims at filling them in singled out areas. This method is used for designating object parameters without consideration of its holes inside the object. The algorithm realising the function of flooding the holes functions with the following specified stages [5, 6]:

- the negative of the output image is determined,
- on the basis of the negative obtained, the edge cleaning takes place,
- the logic sum of the input image and the edge obtained in result of cleaning is determined (OR operation).

An example of binarisation and the algorithm of hole flooding is shown in Fig. 3.

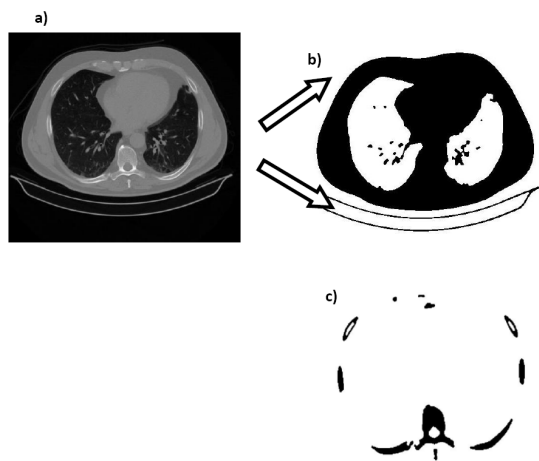


Fig. 3. Effect of applying hole flooding: a) source image of chest, b) lower-threshold filter, c) upper-threshold filter [own study]

Rys. 3. Efekt zastosowania zalewania otworów: a) obraz źródłowy klatki piersiowej, b) filtr z dolnym progiem, c) filtr z górnym progiem [opracowanie własne]

3.1.3. Labelling

The next stage of the method is object labelling (indexing). The application of this function aims at singling out and describing all independent objects in the image. Fig. 4 presents examples of images after labelling.

Labelling objects is necessary for detecting the edge for each object separately, and for successive images (successive object sections) it will be possible to create a 3D object (a triangle net).

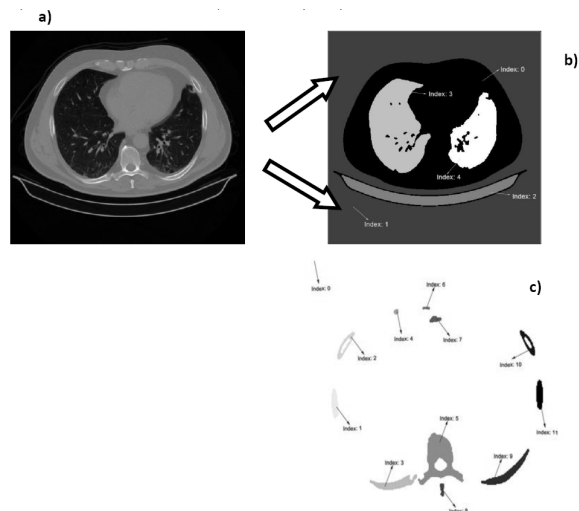


Fig. 4. Effect of applying labelling: a) source image of chest, b) filter with lower threshold, c) filter with upper threshold [own study]

Rys. 4. Efekt zastosowania etykietowania: a) obraz źródłowy klatki piersiowej, b) filtr z dolnym progiem, c) filtr z górnym progiem [opracowanie własne]

3.1.4. Edge detection by Canny method

For edge detection in CT images the Canny method is applied most frequently (it gives the best results) [2, 7]. For designating sets of points belonging to the edge the gradient operator is used, by means of which the values for pixels neighbouring in the image are compared. This method aims at:

- minimising errors appearing during edging,
- detecting the edge in its proper location,
- creating a contour by generating particular single points.

In Canny edge detection the effects of detecting non-existent edge are undesirable, that is false-positive detection errors, as well as non-detection of existing edges, that is false-negative errors. The Canny algorithm owes its effectiveness to the ability of detecting curved edges and corners. In addition, this method also determines the step-edge detector.

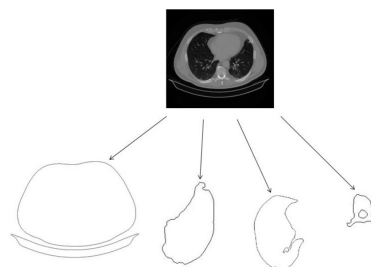


Fig. 5. Example of using the Canny method for edge-detection [own study]

Rys. 5. Przykład wykorzystania metody Canny'ego do wykrywania krawędzi [opracowanie własne]

3.1.5. Designation of edge points

From among points making up the edges, those are to be selected that will form polygons mapping the object shape. The designated points will fulfil the role of polygon vertices when creating the triangle net. This process consists of the following stages:

- selection of the uppermost and leftmost point for a given object,
- designating the next point situated clockwise closest to the previous one (designated points are ordered),
- designating the gravity centre of the element whose points were determined in previous steps,

- recording pixels in polar coordinates (r, ϕ) , where r denotes distance from the system designated centre, and ϕ – angle of inclination,

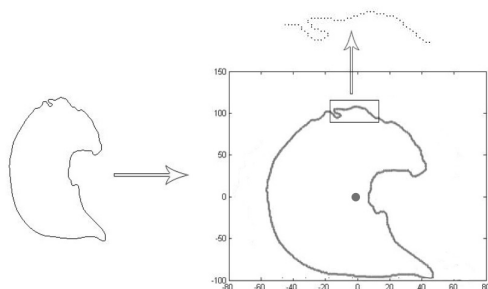


Fig. 6. Example of designating edge points and gravity centre [own study]
 Rys. 6. Przykład wyznaczenie punktów krawędzi i środka ciężkości [opracowanie własne]

3.2. Finding conformity between vertices

An essential problem demanding solution during 3D reconstruction is to find the conformity between the vertices of two polygons [8]. It is aimed at matching the vertices of two polygons so that they should be close to each other. This is particularly essential in cases when the object in successive sections has a various number of vertices.

The determination of vertices consists in the proper reading of a rectangular table of $m \times n$ dimensions, where m and n determine the number of vertices in two polygons. In order to calculate and compare the pairs of vertices, in a further part there will be used a similarity function resulting from the geometric properties of these vertices.

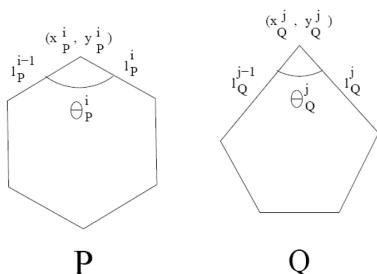


Fig. 7. Geometric properties of vertices for similarity functions [8,9]
 Rys. 7. Własności geometryczne wierzchołków dla funkcji podobieństwa [8,9]

In the first phase two polygons P and Q were defined:

$$P = [v_0, v_1, \dots, v_{n-1}] \quad Q = [w_0, w_1, \dots, w_{m-1}] \quad (2)$$

where m and n determine the number of vertices with the assumption that $m \leq n$.

The table of $m \times n$ conformity is marked as T , where the columns represent the vertices of P polygon, whereas the lines represent polygon Q. Each vertex in table T is assigned a certain function value, called vertex similarity function. For vertex (i, j) this value shall be calculated by comparing vertices from polygon P and Q. This signifies conformity between vertices v_i and w_j . This value is calculated using the following features of the vertices:

1. For interior angles θ_p^i and θ_q^j with both vertices the value f_1 will be designated from the formula:

$$f_1 = 1 - \frac{|\theta_p^i - \theta_q^j|}{360} \quad (3)$$

2. $l_p^{i-1}, l_p^i, l_q^{j-1}, l_q^j$ are the length of respective edges coming out of both vertices. They are characterised by the following formula:

$$f_2 = 1 - \frac{|l_p^{i-1} \times l_q^j - l_q^{j-1} \times l_p^i|}{l_p^{i-1} \times l_q^j + l_q^{j-1} \times l_p^i} \quad (4)$$

3. x_p, y_p, x_q, y_q are Cartesian coordinates of both vertices. Their conformity is characterised by the number calculated on the basis of the formula:

$$f_3 = 1 - \frac{(x_p^i - x_q^j)^2 + (y_p^i - y_q^j)^2}{(x_p^i)^2 + (x_q^j)^2 + (y_p^i)^2 + (y_q^j)^2} \quad (5)$$

Analysing the above properties, the similarity function can be determined by assigning proper weights to the functions determined above f_1, f_2, f_3 :

$$f = w_1 f_1 + w_2 f_2 + w_3 f_3 \quad (6)$$

where: w_1 - weight for the function determining the angle, w_2 - weight for the function determining the distance between points, w_3 - weight for the function determining the location of point x and y .

The values of the above weights should be so selected that their sum should amount to 1. In result of experimental research the following values were accepted: $w_1=0.3, w_2=0.3, w_3=0.4$. Thus, the similarity function value is mostly affected by the weight determining the location of two vertices. The higher the value, the smaller the obtained value of similarity function. The calculated similarity function values are assigned to particular elements of similarity table.

The similarity table T with respectively assigned values of similarity functions is aimed at designating similar points on two successive cross images, which is creating what is called a path. This occurs after assigning the value of function covering similarities of vertices of table T elements. After assigning these values, a search of table T follows aimed at finding the path defined as finite continuum of table elements.

$$p = \{t_{i,l}^p\}_{i=0}^{d-1} \quad (7)$$

where:

- table element shall be marked as t_{kl} (k -th column and l -th line) such that $t_i^p = t_{kl}$ for $k \in \{0, 1, \dots, n-1\}, l \in \{0, 1, \dots, m-1\}$, and $\forall_{i=0, 1, \dots, d-1}$,
- p – defined path,
- d – length of path.

The defined path is created according to the following procedure [8, 9]:

1. Successive path elements are located one step eastwards, south-eastwards or southwards from the previous element t_{kl} .
2. Maximum gain is chosen (value of similarity function vertices) out of 3 possible movements (east, south-east, south).
3. Each time the eastward movement is chosen, when the table element is reached a new vertex is inserted in the polygon Q on the edge $w_k w_{k+1}$ when $k < m-1$ and on the edge $w_{m-1} w_0$ for $l = n-1$.
4. Each time the southward movement is chosen, when the table element is reached a new vertex is inserted in the polygon P on the edge $v_l v_{l+1}$ when $l < n-1$ and on the edge $v_{n-1} w_0$ for $l = n-1$.
5. South-eastern movement reaching table element $t_{(k+1)(l+1)}$, is understood as established conformity between two vertices w_{k+1} and v_{l+1} .

In operations presented in this procedure vertices are made use of which can coincide with existing ones. This principle was used when implementing the algorithm in the method prepared.

3.3. Fast Triangulation Algorithm

Fast Triangulation Algorithm (FTA) [10] is frequently used for building biomedical models. Triangulation is considered one of the most important means of presentation in practice, being a relatively simple method with satisfactory visual effects.

Having a given layer model arranged parallel, it can be observed that the contours of two neighbouring elements are located in a short distance from each other. The dominating points of these similar contours can be joined into groups and triangulation can be implemented in the parts created by binding those points. Such solution permits the generation of correct visual effect, after using a simplified algorithm. The FTA method is in accordance with the following principles:

- dominating points of neighbouring contours are matched to each other,
- points not matching each other are ignored,
- while matching a threshold value is determined expressed by a value called Ratio of Matching,
- if the result of this matching is smaller than this value, it means that the two contours are different, and in such situation the processing of global optimisation is applied. In other words, the general optimisation method may be applied for the triangulation of each small segment.

Figure 8 presents an example of links between particular vertices. Possible link solutions are shown here.

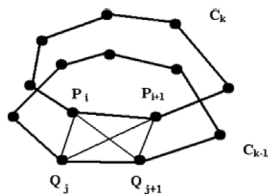


Fig. 8. Example of links between points in FTA method [10]
 Rys. 8. Przykład połączenia punktów w metodzie FTA [10]

3.4. Joining points into triangles

The last stage of 3D images reconstruction is the linking of corresponding similar points. Having a set of points recorded in three-dimensional space, such points are joined into triangles for two sections in the following way:

- each polygon vertex located on the first section is joined clockwise to the vertex of the same polygon, this point having been joined with a "similar" polygon vertex from the second section examined, designated in previous stages,
- each polygon vertex located on the second layer is joined with successive vertex of this section (clockwise), and also with the "similar" vertex from the first section.

An effect of the functioning of stages described above is the obtaining of three-dimensional image of a given object. Figure 9 presents a way of joining points into triangles (for two successive CT layer images).

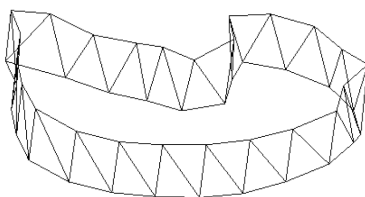


Fig. 9. Result of joining two successive CT sections into triangles – a lung [own study]
 Rys. 9. Wynik łączenia w trójkąty dwóch kolejnych przekrojów CT – płuco [opracowanie własne]

3.5. Algorithm of 3D objects generation based on CT sections

The whole procedure of obtaining a 3D model from tomographic images is depicted by the following flow chart (Figure 11).

4. Results

Figs. 10, 12, 13 show the models of skull, left lung and pelvis, generated with use of the method presented in the paper.

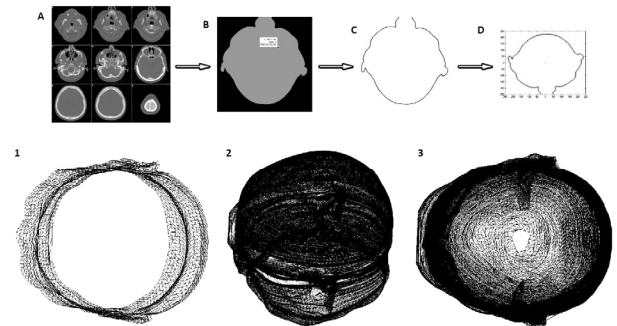


Fig. 10. Results images of skull [own study]
 Rys. 10. Obrazy wynikowe czaszki [opracowanie własne]

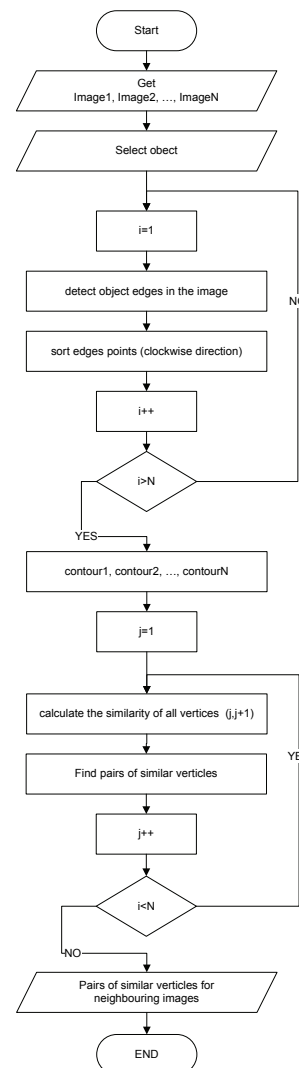


Fig. 11. General flow chart of the method worked out
 Rys. 11. Ogólny schemat blokowy opracowanej metody

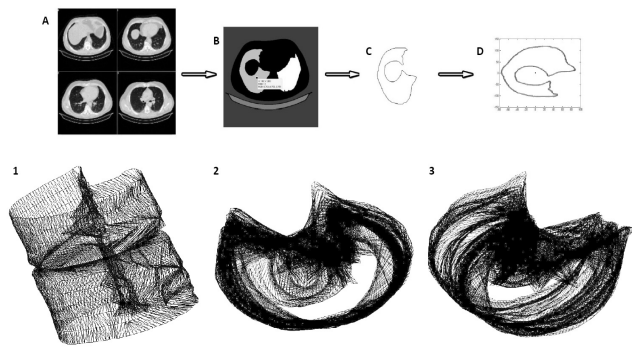


Fig. 12. Result images of the left lung [own study]

Rys. 12. Obrazy wynikowe lewego płuca [opracowanie własne]

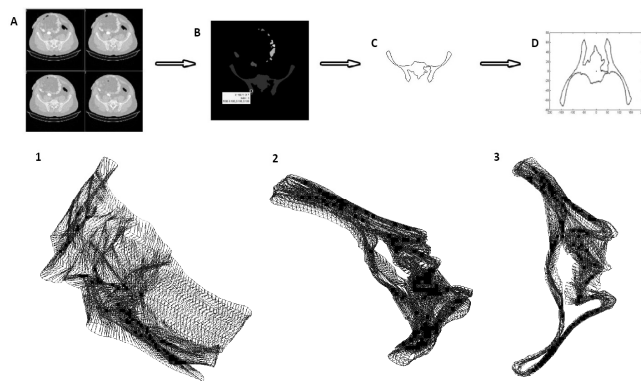


Fig. 13. Result images of the pelvis [own study]

Rys. 13. Obrazy wynikowe miednicy [opracowanie własne]

The source data were constituted by CT images from a computer installed at Kołobrzeg hospital. Particular elements in the figure denote: A – examples of cross-section images at the input, B – labelling, C – edge-detection, D – transformation of Cartesian coordinates into polar coordinates in relation to designated gravity centre, 1 - 3D image of selected fragment of the examined object composed of 5-15 layers, 2 – example of the object side view with consideration of all layers, 3 - example of the upper view with consideration of all layers.

The method presented generates 3D models of high accuracy, yet it is strongly dependent on distances between successive cross sections in the input image. Mapping fidelity can further be increased by applying suitable morphing algorithms between two polygons. In result of its functioning a few polygons will be obtained constituting a transition series between two objects examined, with the possibility of preserving the most important features of these objects like convexity and concavity of the polygon respective components. An additional method to be used is the designation of minimum convex decomposition (MCD algorithm). Such decomposition into convex parts can take place with the introduction of additional points inside the polygon, as also with the use of already existing vertices. A detailed description of this algorithm functioning is to be found in works [9, 11].

5. Conclusion

The paper presents the author's method for generating 3D models based on computer tomography series of images. In order to verify the algorithms a package of programmes was created realising particular stages of the method. Based on real data from examination of patients, a series of 3D models of various organs were generated. The quality of results obtained was examined merely subjectively, by visual estimation. In order to increase the reliability of research, the results should be consulted with medical

specialists. The method presented combines many methods pertaining to image processing as also methods pertaining to three-dimensional computer graphics.

6. References

- [1] Techniki w medycynie, [21.01.2009], <http://medtech.eti.pg.gda.pl/dodatki/metpo.html>
- [2] Cytowski J., Gielecki J., Gola A.: Cyfrowe przetwarzanie obrazów medycznych. Algorytmy. Technologie. Zastosowania. Akademicka Oficyna Wydawnicza EXIT, Warszawa, 2008.
- [3] Moeller T. B., Reif E.: Pocket Atlas of Sectional Anatomy Computed Tomography and Magnetic Resonance Imaging. Volume 2: Thorax, Abdomen and Pelvis, Thieme, Germany, 2001.
- [4] Socha M.: DICOM Digital Imaging and Communications in Medicine, M/DICOM, [15.08.2009], <http://home.agh.edu.pl/~socha/pmwiki/DICOM>
- [5] Tadeusiewicz R., Korohoda P.: Komputerowa analiza i przetwarzanie obrazów. Wydawnictwo Fundacji Postępu Telekomunikacji, Kraków, 1997.
- [6] Wróbel Z., Koprowski R.: Praktyka przetwarzania obrazów w programie MATLAB. Akademicka Oficyna Wydawnicza EXIT, Warszawa, 2004.
- [7] Ludwiczuk R.: Algorytm Canny'ego detekcji krawędzi w procesie segmentacji obrazów medycznych, [22.04.2009], <http://kis.pwzschelm.pl/publikacje/II/Ludwiczuk.pdf>
- [8] Dharmarante A., Harada K.: Vertex correspondence between polygons In different applications. MG & V, 12(3), 2003, s. 311-333.
- [9] Cytowski M.: Zastosowanie morfingu obrazów w odtwarzaniu obiektów trójwymiarowych. Praca magisterska na kierunku matematyka. Uniwersytet Warszawski, Wrzesień, 2004.
- [10] Huang Y., Duan Z.C., Zhu G.L., Gong S.H.: A Fast triangulation algorithm for 3D reconstruction from planar contours. Int. J. Adv. Manuf. Technol., 2004, 24 s.98-101.
- [11] Keil J.M.: Decomposing a polygon into simpler components. SIAM J. Computing, 14(4), 1985, s.799-817.
- [12] Herman G. T.: Fundamentals of computerized tomography: Image reconstruction from projection, 2nd edition, Springer, 2009.
- [13] Udupa J.K. and Herman G. T.: 3D Imaging in Medicine, 2nd Edition, CRC Press, 2000.
- [14] Choplin R.H., Buckwalter K.A., Rydberg J., Farber J.M.: CT with 3D Rendering of the Tendons of the Foot and Ankle: Technique, Normal Anatomy, and Disease. RadioGraphics, March 2004, p. 343-356.
- [15] Hongjian Wang, Xiaoming Pu: 3D Medical CT Images Reconstruction Based on VTK and Visual C++, Bioinformatics and Biomedical Engineering, 2009.
- [16] Cifune N.G.: The Third Dimension: 3D MRI, CT and Ultrasound are Catching On, Medical Imaging - July 2000.
- [17] Reuben A.D., Watt-Smith S.R., Dobson D., Golding S.J.: A comparative study of evaluation of radiographs, CT and 3D reformatted CT in facial trauma: what is the role of 3D? British Journal of Radiology (2005) 78, 198-201.
- [18] Kelley D.J., Farhoud M., Meyerand M.E., Nelson D.L., Ramirez L.F., Dempsey R.J., Wolf A.J., Alexander A.L., Davidson R.J.: Creating Physical 3D Stereolithograph Models of Brain and Skull. PLoS ONE 2(10): e1119. doi:10.1371/journal.pone.0001119.
- [19] Cox RW (1996) AFNI: software for analysis and visualization of functional magnetic resonance neuroimages. Comput Biomed Res 29: 162-173.
- [20] Gering D.T., Nabavi A., Kikinis R., Hata N., O'Donnell L.J., et al.: (2001) An integrated visualization system for surgical planning and guidance using image fusion and an open MR. J Magn Reson Imaging 13: 967-975.