Reconstruction of 3D Shape of Medical Object by 2D Cross-Sections

A. Nedzved[1)], P. Lukashevich[1)], S. Ablameyko[1)], T. M. Deserno, nee Lehmann [2]
1) UIIP NAS, Surganov str. 6, Minsk, 220012, Belarus
NedzvedA@newman.bas-net.by
2) Aachen University of Technology, Department of Medical Informatics,
Pauwelsstraße 30 52074 Aachen, Germany
deserno@ieee.org

Abstract: *A new techniques is presented in order to reconstruct 3D object surface from several closed, in general, non-planar curves, including contours that were outlined manually. 2D distance map used to reconstruct object of a different shapes. Branching problem also discussed.*

Keywords**:** 3D surface, 3D shape, reconstruction, 2D distance map.

1. INTRODUCTION

The task of three-dimensional object surface reconstruction is well known in different applications, especially in medicine. It is used in many applications such as MRI, CT, 3D USI, etc.

The reconstruction tasks can be divided by interaction level into automatic, semi-automatic and manual. In common case the task can be formulated as object shape reconstruction by arbitrary points cloud.

But usually we are working with 2D contours, representing the object of interest cross-sections on medical image slices. Achievement of these cross-sections can be the challenging problem, and can be performed either manually or automatically. For example organ outlining on 3D USI is a very complex problem and this task usually performed by medical expert.

There are also some features associated with the relative placement of contours in space. For example at the MRI and CT they are located in strictly parallel planes, but for some types of 3D USI – for example freehand USI – slices located at arbitrary planes, depending on the scanning protocol.

In some cases there are strongly recommended to reconstruct object only by several contours from the set, especially in case of manual contour outlining. This can help medicine workers by saving him from routine of all slices hand-held outlining.

There are many medical reconstruction methods proposed in lasts years. First of all we must mention about raster object reconstruction in the voxel cube. Such methods discussed in G.M.Treece works [1,2]. Articles describes different methods of reconstruction for parallel plane and freehand scanning, object complex form cases discussed.

The main idea for this methods group is special approach for interlayer voxels interpolation, depending on relative slice location and cross-section form.

We should notice, that voxel-based methods usually slow and inconvenient for usage and object visualization.

By this reason there are a lot of methods developed for object surface approximation by splines and curves of various types. For example we can reconstruct object vector surface by NURBS curves [3], which is the best approximation for outlined object contours. But the quality of this approach is highly dependent on the number of contours. And this is not always possible to restore the object contours on all layers of medical scanning, especially in case of manual outlining.

In the case of object reconstruction by few outlines we can use one of model based methods, which works better for the definite object type. One of such approaches use one-parameter splines for thyroid gland reconstruction on 3D USI [4].

In other work [5], discussed more common problem of shape reconstruction from unorganized cross-sections. Proposed approach consists of two main steps: cutting planes arrangement computation, and reconstruction and approximation of the object from its intersection with the boundary of the cell. The possible branching problem solved by the use of the Delaunay triangulation. The reconstruction step provided by linear interpolation. This method is quite complex, but it can be applied in different reconstruction application. Sometimes for good reconstruction results we can use highly tailored and more simple method for achieving better results.

For example to reconstruct simple medical 3D object from non-parallel object cross-sections Bogush et al. [6] use two-dimensional morphological morphing, affine transform and cubic spline interpolation. This method was successfully tested on 3D freehand ultrasound data.

There is also large class of methods for object shape reconstruction by arbitrary cloud of points. This class of methods used in different tasks, such as lased caner data processing, multiview stereo applications, remote sensing applications and so on. But these approaches can be used in medical application too, especially on the high resolution input data.

Large subclass of shape by points cloud reconstruction is known as active meshes or simplex meshes algorithms. In [7] the simplex mesh algorithms for 3D ultrasound images reconstruction presented. The algorithms are used non-parallel cross sections for simplex meshes adaptation to manually traced object boundaries on several representative. Also, there may be issues in the reconstruction of complex shapes, for example branching objects. The similar method also presented in [8].

Also, an interesting ways of restoration of cloud pixels – ball-pivoting algorithm [9], and Bayesian surface reconstruction [10]. First of them is some kind of morphological restoration on the vector space. The second use statistical technique for the reconstruction and subsequent decimation of 3D surface models from noisy sensor data.

Our method is used for the same tasks and based on intermediate object cross-section generation on the basis of distance transform. It is quite simple to implement and understand, and worked out especially for rendering of complex objects and tumors in medical application.

The main advantages of the method – the opportunity to generate an arbitrary number of intermediate layers. Also the original approach for solve the branching problem proposed. In general, the algorithm can operate on parallel and nonparallel slices with defined order.

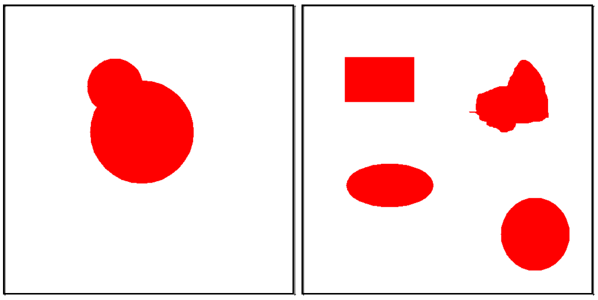


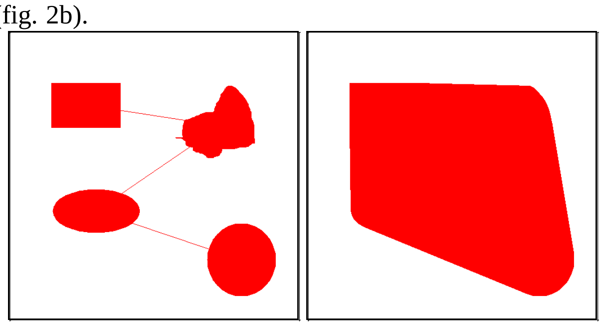
Fig.1 – Started layer with one object and finished layer with four objects.

2. DEFINITION OF OBJECTS CONTOURS FOR INTERMEDIATE SLICE

The construction of intermediate layers can be realized by analysis of distance map properties [11,12,13 – or somthing]. Rides of distance map correspond to contours of optimal intermediate layer. Also they correspond to watershed lines. If number of objects for started layer is same as for next layer, this construction of intermediate layer is very quality. But for point of branches this methods has a few problems.

However, such properties of distance map can be used for intermediate layer reconstruction in branching point. But in this case two intermediate layers will be constructed. Let's initial started layer include one contour-root, initial finished layer include many contours-branches.

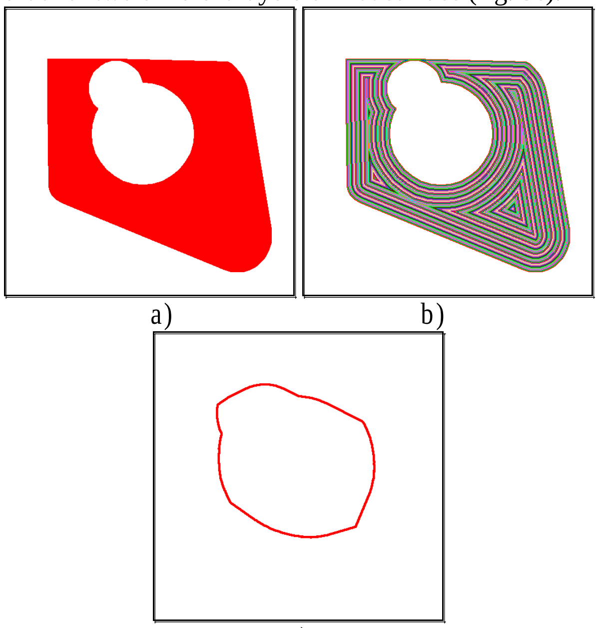
It is necessary to use the same number of contour for begin and finish layers. For solving of this problem definition of convex is used. There are some algorithms of convex calculation, but all of them work only for connected objects. Therefore it is necessary connect all objects on layer. The objects connection is realized thought measurement coordinate of center of mass and drawing line thought these points (fig. 2a). Then convex shapes are constructed for all objects on the layer (fig. 2b).



a) b)

Fig.2 – Consolidation of all objects thought centers of mass (a) and convex shape for finished layer (b).

An object contour on middle layer constructed between a started layer and a finished layer. The region of definition object contour for middle layer enclose between border of started layer object and convex contour of finished layer (fig. 3a). This region is constructed by layers subtraction. This contour lay on ride of distance map (fig. 3b) that correspond to identical 2D distance between objects border of two different layers on flat surface (fig. 3c).

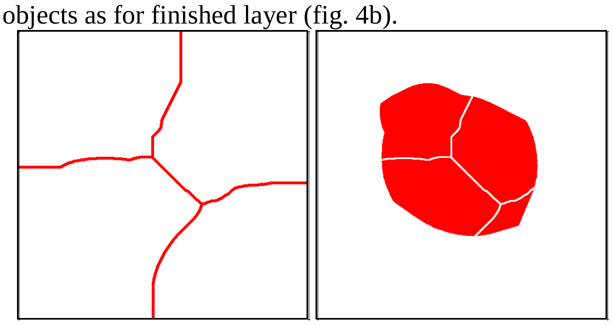


a) b)

c)

Fig.3 – Region for detection of object contour on middle layer its distance map and watershed line- contour of object .

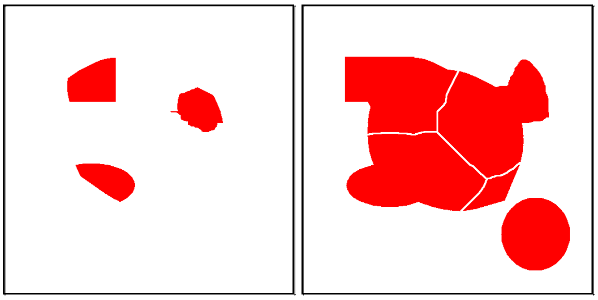
Next task is dividing of object on middle layer to many objects. This number of objects corresponds to number of objects from finished layer. Lines of dividing should be reflecting to position objects on finished layer. The best solution of it is using watershed lines between objects for finished layer (fig. 4a). The subtraction of this watershed lines from middle layer construct second middle layer. This layer includes the same number of objects as for finished layer (fig. 4b).



a) b)

Fig.4 – Watershed lines for finished layer (a) and objects on middle layer (b).

First and second middle layers have neighborhoods positions.

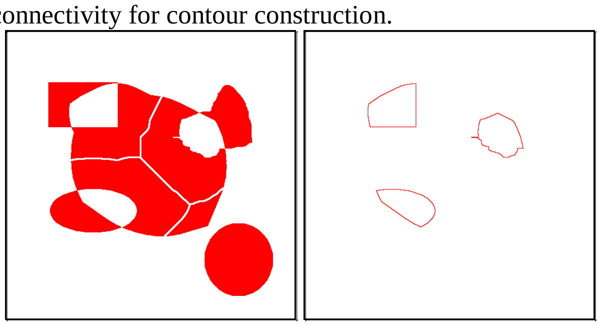


a) b)

Fig.5 – Results of conjunction (a) and disjunction (b) of second middle layer and finished layer

Next steps are definitions of intermediate layers from started to fist middle layers and from second middle to finished layers. A processing of layers is identical but the second case is more complex. Therefore for next description we will use only construction between second middle layer and finished layer. For this construction every layer includes equal number of contours. But objects have different size, position and shape. The task is defining optimal contour of objects for intermediate layer. These contours correspond to optimal distance between first and second layers. It easy to define by using conjunction and disjunction images of layers (fig. 5).

The difference of these results allows to take region of contour definition (fig. 6a). A conjunction this result with contour of second middle layer (fig.6b) allows to preserve connectivity for contour construction.



a) b)

Fig.6 – Region of contour definition (a) of second middle layer and finished layer, contour of second middle layer for preservation of connectivity

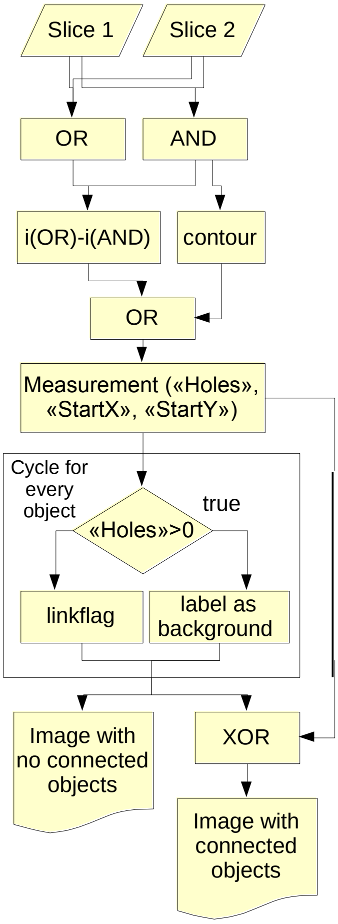


Fig.7 – Algorithm of objects classification for contour detection

This way (fig. 7) allow to define objects with contour finding region and no connected objects

The trouble is definition regions for distance map construction in 2D space. On united layers image it possible to have as crossed as no crossed image. A measurement of image objects for hole existing allow to remove all objects with hole (crossing objects) (fig. 8a).

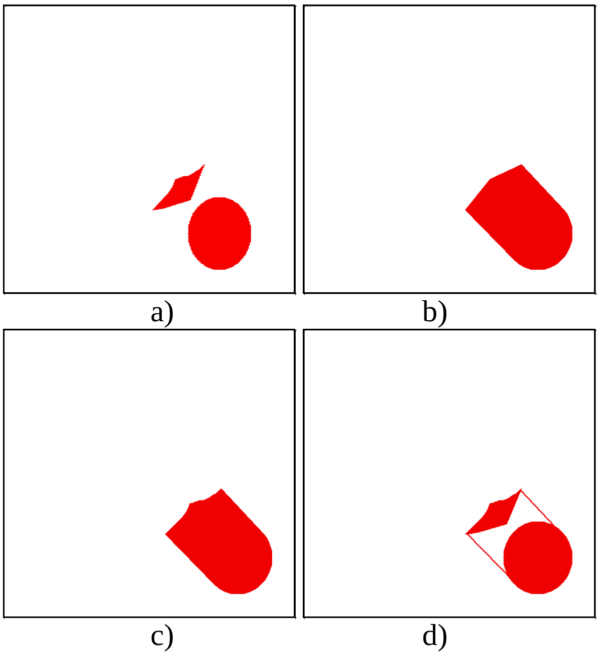


Fig.8 –Processing of no crossed objects: no crossed objects (a), convex shape of objects (b), after border correction (c), new connected object (d).

Regions of contour defining are constructed by connection neighbouring object by convex shape (fig. 9).

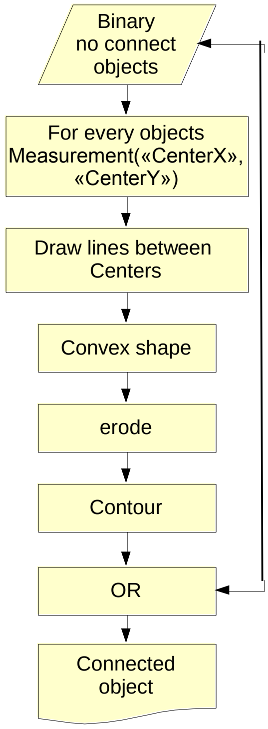


Fig.9 – Algorithm of construction of regions for definition.

Then for all no crossed objects distances between center of mass analyzed. On base this information formed pair of objects. For every pair convex shape is calculated (fig8b). A border this convex shape is corrected by watershed line of previous level (fig.8c). Consolidation of corrected convex contour and objects allow to define regions for contour detection (fig. 8d).

Disjunction of results of processing connected and no connected objects (fig.9 a) allow to detect intermediate objects contour by watershed (fig.9 b). Similarly detected objects contour for other intermediate levels. After creating of intermediate levels collection it is possible spend 3D reconstruction with more high resolution (fig. 10).

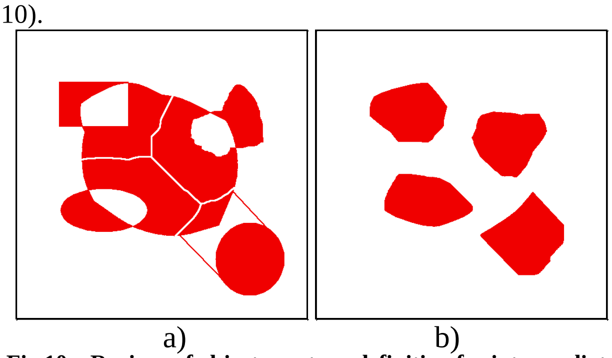


Fig.10 – Regions of objects contour definition for intermediate layer (a) and objects of intermediate layer(b).

The algorithm processing results for input data on fig. 1, shown on fig. 11.

3. RESULTS (DISCUSSION ?)

The results obtained will contribute to the development of diagnostic software ray techniques to correctly calculate the data on the dynamics of the regression of tumor masses and the amount of residual tumor, optimizing the decision on the tactics and the level of therapy, including organic and safe surgical treatment. Determining the correct path of treatment will significantly reduce the cost of medicines and therapeutic procedures.

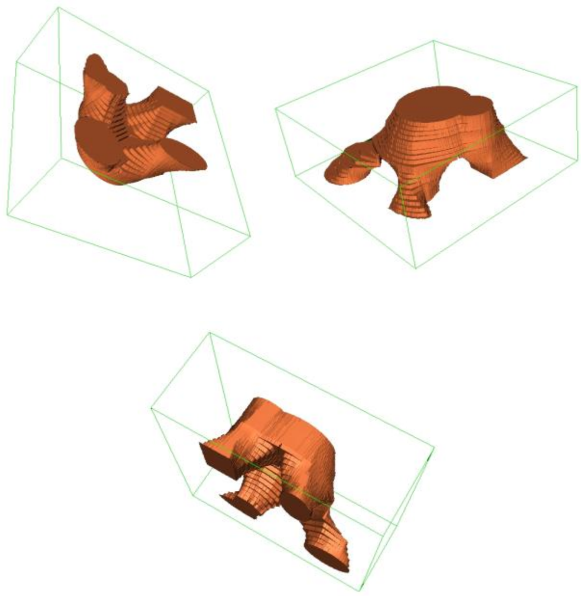


Fig.11 – Results of 3D reconstruction between two parallel layers by construction of 20 intermediate layers .

4. CONCLUSION

This work is dedicated to the restoration of complex medical images and sent to the task of reconstruction and spatial visualization of the complex structure of the source data, derived from CT studies. The work is aimed to improve the information content of data of primary diagnosis, to provide comfort for medical professionals in the analysis of survey results.

6. ACKNOWLEDGEMENT

This work was supported by grant B-1489 of the International Science and Technology Center.

5. REFERENCES

[1] G. Treece. *Volume Measurement and Surface Visualization in Sequential Freehand 3D Ultrasound.* PhD thesis Univer. of Cambridge, Department of Engineering, 2000. 183 p.

[2] G. Treece, et al. Fast surface and volume estimation from non-parallel cross-sections, for freehand 3-D ultrasound. *Medical Image Analysis*, 3(2) (1999). pp. 141-173.

[3] C. Anderson, S. Crawford-Hines. *Fast Generation of NURBS Surfaces from Polygonal Mesh Models of Human Anatomy*. Technical Report, Department of Computer Science, Colorado State University, Fort Collins. February 9, 2000.

[4] P. Lukashevich, B. Zalesky. Reconstruction of 3D Surfaces by Spline Technique. *Proceedings of the 8-th International Conference "Pattern Recognition and Information Processing"*, Minsk, May 18-20, 2005. pp. 351-354.

[5] J. Boissonnat, P. Memari. Shape reconstruction from unorganized cross-sections. *Proceedings of the Fifth Eurographics Symposium on Geometry Processing.* Barcelona, Spain, July 04-06, 2007. pp. 89-98.

[6] A.L. Bogush, A.V. Tuzikov, S.A. Sheynin. 3D object reconstruction from non-parallel cross-sections. *Proceedings of the 17th International Conference on Pattern Recognition.* Cambridge, UK, 23-26 Aug, 2004. Vol. 3, pp. 542-545.

[7] E.V. Snezhko, A.V. Tuzikov. External Force Generation for Object Segmentation on 3D Ultrasound Images Using Simplex Meshes. *Proceedings of the Pattern Recognition and Image Analysis International Conference*. 2006, Vol. 16, pp. 89-92.

[8] H. Delingette. General Object Reconstruction Based on Simplex Meshes. *Int. J. Comput. Vision*. 32 (2) (Aug.1999). p. 111-146.

[9] F. Bernardini, et al. The Ball-Pivoting Algorithm for Surface Reconstruction. *IEEE Transactions on Visualization and Computer Graphics*. 5(4) (Oct. 1999). p. 349-359.

[10] Q. Huang, B. Adams, M. Wand. Bayesian surface reconstruction via iterative scan alignment to an optimized prototype. *Proceedings of the Fifth Eurographics Symposium on Geometry Processing.* Barcelona, Spain, July 04-06, 2007. pp. 213-223.

[11] G. Borgefors, Distance Transformations in Arbitrary Dimensions , Computer Vision , Graphics, and Image Processing, Vol. 27, 1984, pp. 321-345.

[12] S. Svensson, G. Sanniti di Baja. Image and Vision Computing, Vol. 20 (8), pp.529-540, June 2002.

[13] Carlo Arcelli and Gabriella Sanniti di Baja. Finding Local Maxima in a Pseudo-Euclidean Distance Transform. CVGIP, vol. 43, pp. 361-367, 1988. (http://bibnetwiki.org/wiki/Category:G._Sanniti_di_Baja_Paper)