

MEDICAL IMAGE 3D VISUALIZATION BY VECTOR BASED METHODS

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ABSTRACT

This paper describes approaches and methods that are aimed to solve various medical image processing tasks, including extraction of region of interest, the extracted regions contour processing and the following 3D visualization of the extracted region. Two different approaches for control point acquisition and 3D model reconstruction using the points acquired from the region of interest are proposed. The proposed methods of 3D visualization use a vector-based surface model creation rather than raster-based systems to significantly improve computational efficiency and the quality of generated 3D models. The proposed methods were tested on the medical images of a brain acquired by computer tomography and proven to be applicable to different types of region of interest. The results can be used to provide practical improvements to the reliability of medical diagnostics.

KEYWORDS

Medical images, image analysis, image processing, visualization, modeling.

1. INTRODUCTION

The 3D visualization is an important aspect of image analysis and research. Analysis and visualization of different medical images, obtained by computer tomography (CT) or magnetic resonance imaging (MRI), is important to medical research and clinical practice. In this case, some the most important initial phases of medical image processing are tasks of extraction and analysis of different image regions (a medical object or a pathology zone) [7]. In relation to this, a necessity to solve the task of 3D visualization of the region of interest emerges in computer diagnostics. The ability to visualize the orientation, position, size of structures in medical images can be vital to researchers and physicians. In order to obtain a 3D model of the region, the medical image must first be segmented, following the region extraction from the medical image. Afterwards, the extracted region contour control points, which are further used for 3D visualization of the object must be selected.

There are many manual, semi-automatic and automatic image segmentation methods for different image types [2, 3]. However, the properties of medical images require a specific approach for segmentation, based not on the visual intensity or color of image pixels, but rather on the information about the density of every image element. Manual segmentation is a slow process, subject to operator error and bias. Automatic segmentation methods require little user interaction; however, in practice automatic methods sometimes fail and require manual correction (adjustment of the boundary that identifies the region). In this work, a semi-automatic segmentation algorithm described in [5] was implemented for region of interest extraction.

Although there are methods that allow segmentation and visualization of the medical image [8], the existing approaches of 3D visualization are not always able to provide a high-quality smooth surface of the 3D model. The resulting 3D models have a distinct aliasing (staircase) effect (Fig 1). The well-known marching cubes algorithm also has flaws, like aliasing effect and other negative aspects described in [6]

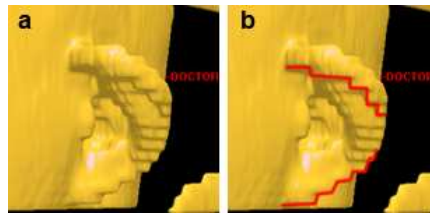


Figure 1. Aliasing effect. a) original 3D model, b) the red line shows the aliasing effect.

In this paper, two approaches of contour analysis and selection of control points are proposed, as well as three methods of 3D visualization. The first approach is based on the even control point selection, while the second approach is based on an uneven point selection. Two control point selection approaches were used in order to test whether the even or uneven control point selection has any effect on the resulting surface quality. The proposed methods of 3D visualization use a vector-based surface model creation rather than raster-based systems to significantly improve computational efficiency and the quality of generated 3D models. The proposed methods result in a better quality of surfaces of the 3D model.

2. MATERIALS AND METHODS

2.1. Contour Analysis and Visualization based on Even Point Selection

The proposed method selects control points on the contour evenly, which ensures a more precise 3D model reconstruction.

The initial image is limited by two border lines that are parallel to y axis and an initial point is selected, which is positioned on the first intersection of the contour and a line, parallel to the border lines and crossing the middle of line segment that connects the border lines. The control point selection algorithm can be described as follows:

1. A radius R is defined and from the last found control point a circle line is drawn. Afterwards, intersection points between the circle line and the contour are found.
2. If there are more than two intersections between the circle line and the contour (Fig 2.2), then, radius R is gradually decreased until there are only two intersection points (Fig. 2. 3).
3. When there are two intersections between the circle line and the contour (Fig 2.1), from these two points, the one that is the furthest from the previously found point is selected. In the beginning, when the previous point is concurrent to the initial point, any of these two points can be selected as the next point.
4. A new circle line is drawn from the last found control point (Fig. 2.4). If the radius was decreased previously and it does not equal R , then if there are only two intersection points, the radius increases until it reaches R or until it reaches a value just before the point, where there are more than two intersections. Steps 1-4 repeat, until the initial point is reached again.

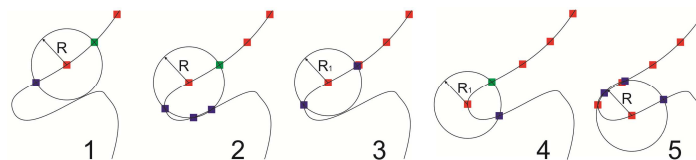


Figure 2. Even selection of control points

The algorithm described in pseudo code is shown on Figure 3.

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VAR  $P_i$ : current control point in search,  $i = 0, 1, 2, \dots$ ;  $R$ : defined radius of search circle;  $C$ : center coordinates of search circle;
 $N$ : number of intersections between circle line and contour;

REPEAT
IF  $i > 0$  THEN  $C = P_{i-1}$  ELSE  $C = P_0$ ;
draw circle with defined radius  $R$ ;
IF  $N > 2$  THEN REPEAT decrease radius and redraw circle UNTIL  $N = 2$ ;
IF  $N = 2$  THEN
BEGIN
IF  $i > 0$  THEN  $P_i$  = intersection point that is farthest from  $P_{i-1}$ ;
IF  $i = 0$  THEN  $P_i$  = any intersection point;
END
 $C = P_i$ ;
increase  $i$ 
UNTIL  $P_i = P_0$ 

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Figure 3. Pseudo code for even control point selection

When the algorithm finds the control points on all tomograms, excess points, which are obtained when the radius was decreased, are deleted. In order to delete the excess points, the following algorithm is used: firstly, the first point on the tomogram is taken, and the distance between this point and its neighboring points are checked. The first point, for which this distance will be equal or greater than the given radius R will be saved, all the others with lesser distance are deleted. Then the algorithm moves to the last saved point and repeats the process, and thus the algorithm checks all the points on the tomogram and saves only points with the distance between them not less than radius R .

After the acquiring of control points a 3D model can be constructed. This task is solved by triangulating the acquired point dataset, forming a mesh for the 3D model. The triangle vertices are formed from the three adjacent control points. The first two adjacent points are iteratively taken from the contour on the first tomogram and the third one is the next slice contour control point, which is the closest to the first vertex of the triangle (Fig. 4.1 and Fig. 4.3). When searching for the third control point, only points closest to the last selected third vertex are taken into consideration, in order to avoid shifts in the mesh. Initially, only 10 points are taken into consideration, but the number may increase, if the distance between these points and the last selected one is lesser than the minimal threshold, which is equal to five radiuses R . Furthermore, if there is a hole between the constructed triangle and a previous triangle, it is closed up with a triangle, where the first vertex is the lower control point of the hole and the other two are iteratively taken from the top slice (Fig. 4.2 and Fig. 4.4).

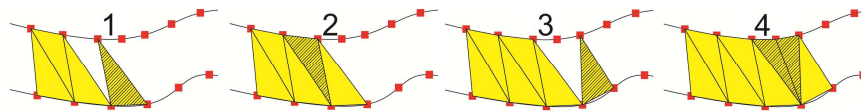


Figure 4. Triangulation of the acquired control points

2.2. Contour Analysis and Visualization based on Uneven Point Selection

For the uneven selection of the control points a method described in [4] is used. The proposed method consists of two stages, illustrated by Fig. 5: the selection of initial control points for the adaptive contour using the clockwise algorithm (Fig. 5.1) and adjustment of the adaptive contour to match the objects contour (Fig. 5.2-5.5).

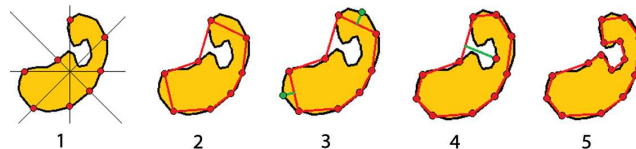


Figure 5. Uneven selection of control points

The advantage of this method is that it provides a minimum number of points, required to precisely interpolate the contour. However, due to the uneven form of the control points, there may be shifts in the 3D model during the reconstruction. To solve this problem a special parameter $t_{i,j}$ is used to mark every control

point. In this case, each j^{th} point $p_{i,j}$ of the contour on slice i is assigned a special parameter $t_{i,j}$ that is further used to create a 3D mesh from the control points. The parameter $t_{i,j}$ is calculated according to the following equation:

$$t_{i,j} = \frac{l_{i,j}}{P_i}, \tag{1}$$

where P_i – is the perimeter of the contour on slice i ;

$l_{i,j}$ – is the contour length from the point $p_{i,0}$ to point $p_{i,j}$.

As the result of this algorithm each point on the slice has its own parameter $t_{i,j}$, which is taken in consideration when triangulating points. The triangulation algorithm processes the slices in pairs. In each pair of slices, the slice with the lesser amount of points is considered to be the first slice and the algorithm processes slices in two stages:

1. The first slice is considered as the base for triangulation, meaning that two points on this slice are taken as base vertexes for the triangle and the third vertex is taken on the second slice (Fig 6.1). The base vertexes of the triangle are formed by neighboring contour points on the first slice. Then for each pair a third vertex is found on second slice. Only points where the difference between its parameter and the base vertices parameter does not exceed some given threshold Δt are taken in consideration. Among these points, the one with the minimal distance between it and the previous two vertices is chosen to be the third vertex.

2. The remaining connections between the two slices are found. The base vertexes of the triangle are formed by neighboring contour points on second slice. For each pair a third vertex is found on first slice. For the current pair of points on bottom slice, two adjacent existing triangles A and B are found. Then, the vertex p_{AB} that is shared by both triangles is added as the third vertex (Fig. 6.2).

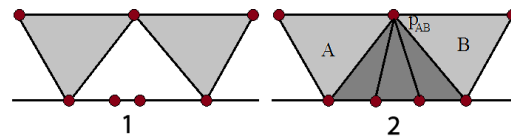


Figure 6. Triangulation of the acquired control points

3. EXPERIMENTS

The proposed approaches were tested on the medical images of a brain, acquired with computer tomography. The results of the proposed methods were compared with a 3D imaging software 3D-Doctor [1]. Fig. 5 illustrates the comparison of various methods.

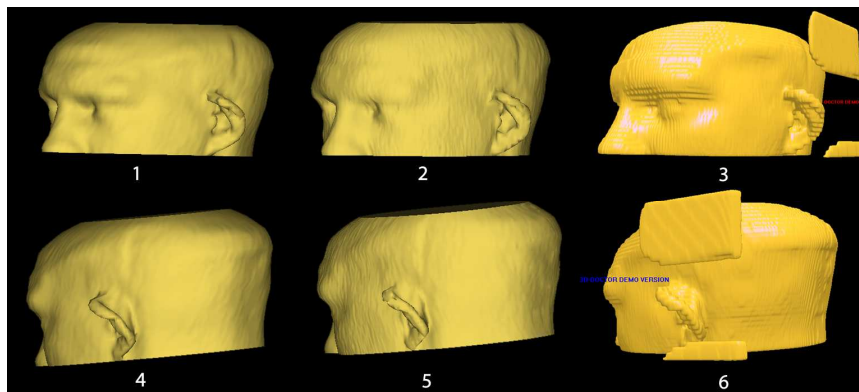


Figure 7. Comparison of different methods. 1,4) Visualization method based on even point selection, 2,5) Visualization method based on uneven point selection, 3,6) 3D-Doctor visualization.

As seen from the results of comparison, the proposed methods (Fig. 7.1, Fig. 7.4) and (Fig. 7.2, Fig. 7.5) provide a better result on image quality. The 3D-Doctor approach (Fig. 7.3, Fig. 7.6) has an aliasing effect on the surface.

The experimental results also show that the control point selection method (even or uneven) has no effect on 3D model quality. Both approaches gave similar result without the aliasing effect on the surface of the object. An additional advantage of the uneven control point selection is that it provides a minimal amount of control points necessary to interpolate the surface of the object, resulting in quicker surface generation as less calculations are necessary for surface reconstruction.

4. CONCLUSION

In this paper, methods of control point selection on the contour of region of interest and methods of 3D visualization are proposed. The methods have been tested on medical images of the brain acquired by computer tomography.

The methods have been compared with existing solutions and the experiments show that the proposed methods give a better visual result than existing method of 3D-Doctor. The surface of the model is smoother, without an aliasing effect. The experimental results also show that the control point selection method (even or uneven) has no effect on 3D model quality. Overall, vector-based methods show stable results in visualization and may be implemented in medical software to provide better 3D visual quality of the reconstructed medical object.

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