A modified method of surface construction for medical image 3D visualization

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Introduction. Medical image three-dimensional visualization is one of the most important tasks in medicine, because such information allows physicians to plan surgical interventions. In turn, the precise and correct representation of a three-dimensional surface proves to be the most interesting challenges in medical visualization. The three-dimensional surface is obtained by processing medical image scalar data, which is defined in three-dimensional space. The given data is the region of interest's contour control points that can be selected either evenly or unevenly. In order to obtain the three-dimensional surface, the given data points must be connected to form a three-dimensional surface mesh. Such process is often called triangulation, because the points are usually connected by triangular polygons.

In this paper, an uneven set of data points is used to represent the medical image data. The reason for selecting an uneven set of data points over an even set is the lesser amount of points necessary to construct a precise surface and that is a great advantage in terms of calculations and use of computer resources.

There are various solutions for obtaining an accurate three-dimensional surface representation, for example, the Marching Cubes algorithm [3]. The Marching Cubes algorithm generates the surface by inspecting given data using a cube as a scanning form. The set of intersection points can be triangulated to yield an approximation to the surface within the cube. The triangulation must choose which pairs of intersections to connect. An inconsistent strategy can lead to holes when surfaces in adjacent cells use different connections on the common face [2].

Thus, an approach was proposed in [1] that had no such disadvantage: the surface had no holes. Although the problem of surface inconsistency was solved, it has been noted, that the given approach can create distortions in the more complex parts of three-dimensional surface. This is due to the limited analysis of the data set: only one parameter is examined during the triangulation process, which is not enough to reconstruct a precise representation of the medical image data. Distortions can be clearly seen in the more complex areas of the surface, like ears, for example (Fig. 1).

In this paper, a modification of the method described in [1] is proposed, that allows accurate triangulation of an uneven set of data points and has no disadvantages like surface distortions and holes in the surface mesh.

Proposed method. The given input data is set of unevenly selected data points, obtained by using the method of control point selection, described in

[1]. Each j^{th} point $p_{i,j}$ of the contour on slice i contains information about its three-dimensional coordinates (x, y, z), the matter's density in Hounsfield Units (h) and a special parameter that defines the point's place on the contour of a medical image slice ($t_{i,j}$).

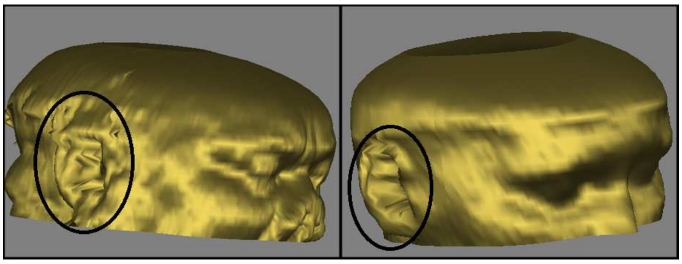

Fig. 1. Distortions in constructed surface

Triangulation algorithm's decription:

I. The triangulation algorithm consecutively processes the slices in pairs. *The number of control points on each slice is also taken into consideration. The slice with the greater number of control points is considered to be slice s_i. The second slice in pair is considered to be slice s_{i+1}.* The pair of slices is processed in two steps:

1. Slice s_i is considered to be the base slice for the triangle polygon, i.e. there are two neighboring vertices taken from slice s_i and the third vertex is found on slice s_{i+1}.
   - 1.1. Slice s_i neighboring points are taken as base for triangle polygon, creating following pairs: ($p_{i,0}$, $p_{i,1}$), ..., ($p_{i,j}$, $p_{i,j+1}$),..., ($p_{i,N-1}$, $p_{i,N}$).
   - 1.2. For each pair of base vertices a third one is found on slice s_{i+1}. *Several conditions must be met:*
     - 1.2.1. the point's $p_{i+1,k}$ parameter $t_{i+1,k}$ must be different from the vertices pair normal value by no more that the given threshold T_t:

$$\left| \frac{t_{i,j} + t_{i,j+1}}{2} - t_{i+1,k} \right| < T_t , \tag{1}$$

where

$$T_t = 2 \cdot \left| t_{i,j} - t_{i,j+1} \right| \tag{2}$$

     - *1.2.2. control point's parameter k must be different from the previously selected control point consecutive number k_{last} by no more that the given threshold T_k, that is dependent on the number of points N in contour:*

$$\left| k - k_{last} \right| < T_k , \tag{3}$$

where

$$T_k = 0.01 \cdot N\ , \qquad (4)$$

1.2.3. control point's distance from the vertices pair normal point (x_{vid},y_{vid}) must be minimal:

$$\sqrt{(x_{i+1,k} - x_{np})^2 + (y_{i+1,k} - y_{np})^2} \to \min\ , \qquad (5)$$

After the first step some triangle polygons, connecting the control points will be found

2. Slice s_{i+1} neighboring points are taken as base for triangle polygon, creating following pairs: ($p_{i+1,0}$, $p_{i+1,1}$), ..., ($p_{i+1,j}$, $p_{i+1,j+1}$),..., ($p_{i+1,N-1}$, $p_{i+1,N}$).
   2.1. For each pair of base vertices a third one is found on slice s_i. Several conditions must be met:
      2.1.1. If in the current pair both points during the first step of the algorithm were selected as third vertices for neighboring triangle polygons *A* and *B*, then the shared point p_{AB} is chosen as the third vertex.
      2.1.2. If in the current pair during the first algorithm's step only one or no points were chosen to be the third vertex that the third vertex is found as follows: two closest existing triangle polygons *A* and *B* are found and all the pairs between these polygons are given the point p_{AB} as the third vertex.

The modifications to the method are shown in *italic*. The first modification is selecting the slice with the greater number of control points as the first base slice for triangulation. This is done to obtain as many consistent triangle polygons as possible so there would be minimal number of errors during the second step of the algorithm. This allows minimizing the risks of possible holes in the surface.

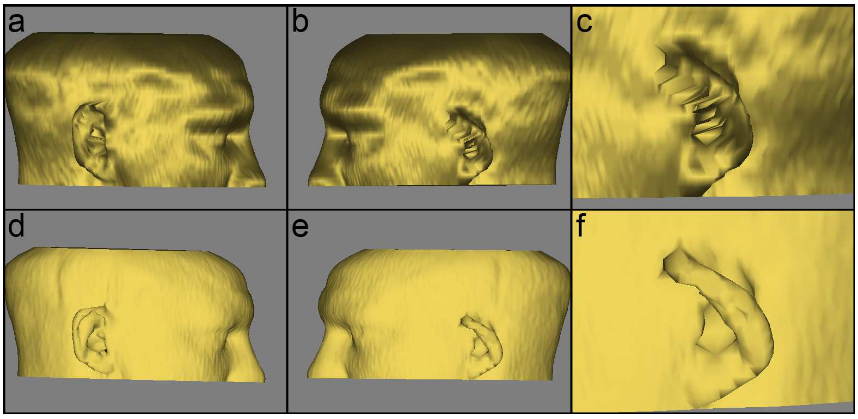

Fig. 2. a, b, c) Results of the unmodified method [1], d, e, f) Results of the proposed modified method

The next modification consists of adding several more conditions to the process of finding the third vertex during the first step. These conditions are: monitoring the Euclidian distance between the three points and making sure that the selected vetex's consecutive number is as close to the previously selected created triangle's vertex. These two conditions minimize the distortions in the created mesh, thus the surface is smooth and accurate.

The results of the proposed modified method and the unmodified method can be seen on Fig. 2.

Conclusions. The results show that the proposed modified method of three-dimensional model construction is more accurate than the unmodified method. Due to several modifications that include a more thorough analysis of the input data, the resulting surface of the proposed algorithm is smoother and contains no distortions that are visible in the unmodified version of the method.

The proposed method of uneven data triangulation is consistent and accurate and can be used to achieve better results in medical visualization, which will aid the physicians when planning various surgical interventions.

References

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A modified method of surface construction for medical image 3D visualization

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This work describes a method of constructing a three-dimensional surface from medical image data. The proposed method is a modification of the existing data point triangulation for unevenly selected data points. The results of comparison between the existing method and the modified method show that show that the surface generated by the proposed method is of higher quality it is smoother and contains no distortions even in complex areas of the surface. Therefore, the proposed method can be successfully used to achieve more precise results in medical visualization, therefore aiding the physicians in the planning of surgical intervention.