Fast and Interactive 3D–Segmentation of Medical Volume Data

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Abstract

The segmentation of tomographic image data is an important prerequisite for a meaningful visualization in medicine. To circumvent difficulties related to automatic approaches, we suggest interactive segmentation which includes the knowledge of a user more efficiently. Using intelligent scissors, as presented in [1] for the 2D case, we suggest 3D filters for the calculation of the cost matrix, an automatic procedure which propagates contours to adjacent slices and three communicating 2D displays for convenient delineation of contours in volume data. Additionally, we provide volume growing based on a statistical approach, as presented in [2, 3], allowing to select coherent subvolumes interactively. For the immediate evaluation we introduce additional 3D displays for the visualization of polygonal and volumetric representations of the segmentation results.

1 Introduction

For the spatial orientation within complex medical volume data various techniques for 3D visualization have been developed. In order to obtain more meaningful images for diagnosis, interior structures contained in MR– and CT–data must be detected and separated. However, segmentation turned out to be very problematic, and as a major drawback of the automatic methods, the complete knowledge required for a successful segmentation is often not included. Consequently, extensive post–processing is required to remove segmentation errors manually. In order to circumvent this problem we suggest to follow a class of methods which allows to supervise and assist the process of segmentation interactively with related work found in [4, 5].

Based on a local cost function and optimal path finding “Intelligent Scissors”, as presented in [1] for the 2D case, are applied. They allow to guide the segmentation process by using on–the–fly calculation and visualization. Considering the inter–slice relation of tomographic image data, we suggest 3D filters for the calculation of the local costs. In order to reduce the manual work, we present a technique to propagate segmented contours to adjacent slices automatically. Ensuring convenient interaction, we further suggest to use three communicating 2D displays showing orthogonal slice images which encourage to choose the most appropriate direction of view depending on the topology of the object. Additionally, volume growing based on a statistical approach is provided , as presented in [2, 3]. After transforming the original image data to a new distribution a coherent subvolume is selected interactively. For the immediate visual evaluation of the results, we finally introduce additional 3D displays showing a polygonal or volumetric representation of the current stage of segmentation.

2 Intelligent Scissors

Boundary definition based on a graph is the main part of the approach based on Intelligent Scissors. Using two voxels representing a starting and a destination node, it consists of searching for an optimal path of minimum cumulative costs. Therefore, the costs associated with every voxel according to significant features are of major importance. According to [1] a weighted sum of the gradient magnitude, the gradient direction and the Laplacian zero–crossing is suggested. Applied to data used for hyperthemia treatment planning, as presented in [6], the gradient magnitude was

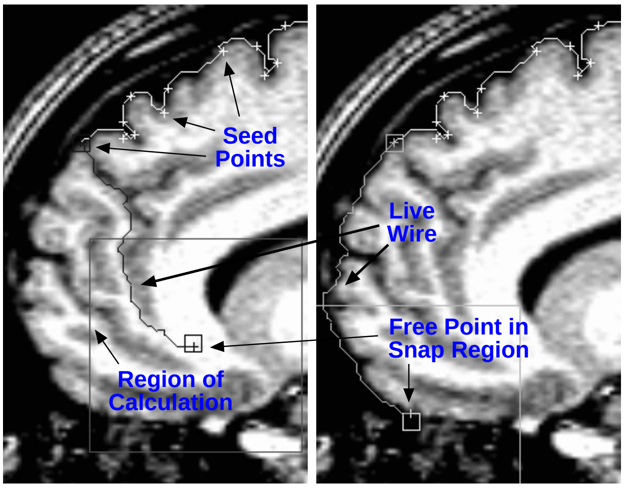


Figure 1: Live–wire as it snaps to the boundary of the brain in MR after moving the free point.

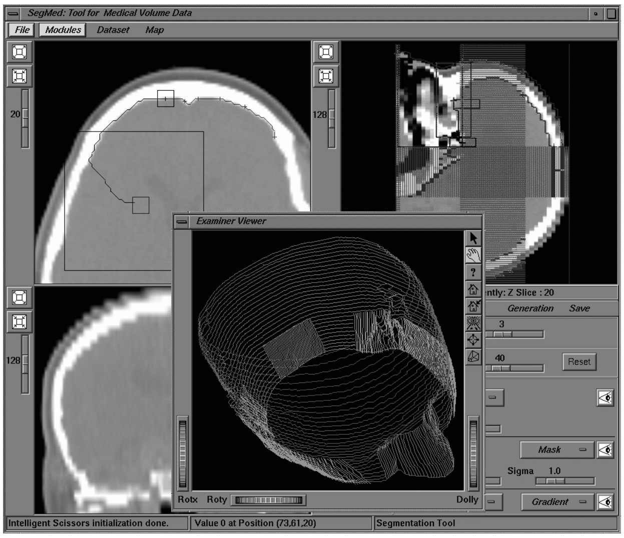
used exclusively, and graph pruning was introduced to obtain smooth contours. In our implementation we provide all features allowing the user to choose the weights interactively.

After performing the graph search based on *dynamic programming*, as presented in [7], the user selects a seed point and interactively guides a free point (see Figure 1) in order to find the optimal boundary. Every movement of the free point causes a contour between both points to move like a wave as it adapts to the new path of minimal costs. Therefore, in comparison to other approaches based on active contours or snakes [8, 9], this method has the advantage of immediate visual feedback allowing the user to select the most suitable result interactively. Several features are provided in our implementation which lead to convenient manipulation and robust segmentation:

- A *snap region* of adjustable size assists the user placing the seed point by snapping to the voxel of minimal costs.
- A *region of calculation* following the mouse position restricts the area used for the graph search. This ensures the interactive behavior of the wave front.
- A *dynamic training* procedure avoids snapping to neighboring boundaries of lower costs by considering the most recently accepted parts of a contour.

A correct segmentation of volume data requires to consider in–slice and inter–slice information. Therefore, the calculation of the cost function is performed in a 3D neighborhood of a voxel using respective filters. In order to reduce the number of multiplications, a separation to 1D filters was applied. Taking into account the anisotropic size of voxels, distortions related to filtering are avoided. Instead of interpolating the whole dataset, the respective filter is adjusted accordingly leading to further acceleration.

The segmentation process gets difficult if the cut plane used for delineating an object lies tangential to its boundary. Meanwhile it is easy if the orientation is perpendicular. Therefore, three communicating 2D displays are provided showing orthogonal planes of different direction of view (see Figure 2). Passing through a common point of intersection, the user chooses the most appropriate direction depending on the topology of the object. In order to ensure a consistent surface two types of contours are used (see Figure 3). *Segment contours* belong to the currently selected direction of view. As a constraint they must share their start and end points if they intersect with *closed contours* which were already defined in any other direction. If the boundary of an object varies slightly for a specific direction, an already delineated contour provides an array of seed points which perform segmentation automatically in adjacent slices.



Intelligent Scissors initialization done.
Value 0 at Position (73,61,20)
Segmentation Tool

Figure 2: Using three communicating 2D displays for convenient segmentation and on–the–fly 3D visualization of segmented contours within CT.

3 Volume Growing

Another technique provided for the interactive segmentation of tomographic image data is based on volume growing, as presented in in [2, 3]. Contrary to the intelligent scissors it requires some automatic pre–processing which consumes little time in order to classify the image data. Starting with a user–defined seed point within an adjusted volume of interest, the gray–value information of the tomographic image data is transformed to a new distribution. Along a path of minimum connectivity a statistical process assigns a value to every voxel. Depending on the image content it describes the similarity of the voxel to the seed point. Finally, the user interactively chooses a level of similarity which corresponds best with the target structure by immediate visual inspection of the resulting segmentation (see Figure 4).

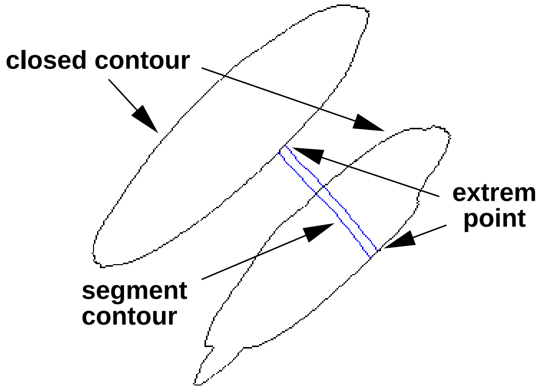
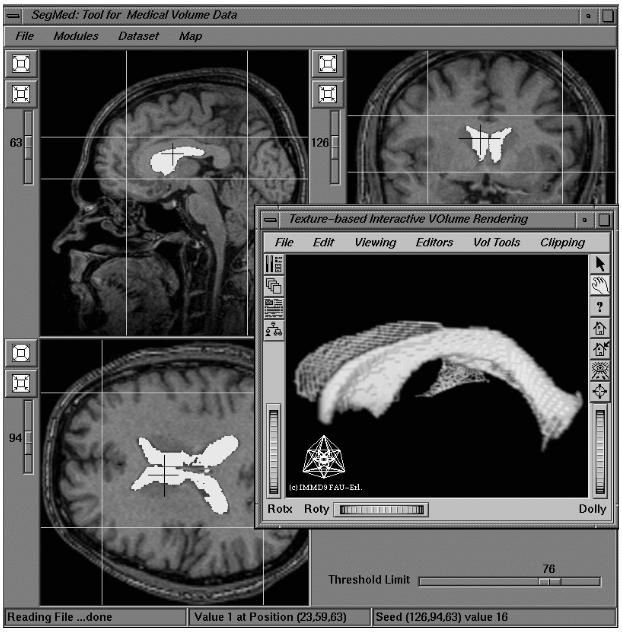


Figure 3: Example showing *segment contours* with their *extreme points* connected to already defined *closed contours* of a different direction.

4 Interactive 3D–Display

At any stage of the segmentation the results are transferred to different volume rendering procedures allowing for intuitive and interactive evaluation within a 3D display. In case of intelligent scissors the delineated contours are immediately visualized within an OpenInventor based viewer. Thereby, the selected direction of view of every contour, and inconsistencies between neighboring boundaries are clearly conveyed (see Figure 2). Optionally, a stack of adjacent contours is triangulated in order to convey the resulting surface representation (see Figure 5 (left)). Applying the volume grower procedure the segmented volume data is interactively visualized with an approach of direct volume rendering based on 3D–texture mapping which was integrated into OpenInventor [10]. Marking the respective voxels within the original dataset, a single "tagged" volume is created which allows to assign separate transfer functions for color and opacity to every tag (see Figure 5 (right)).



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Value 1 at Position (23,59,63)

Seed (126,94,63) value 16

Figure 4: Interactive segmentation based on volume growing and immediate hardware accelerated direct volume rendering of ventricles within MR.

5 Results and Discussion

Providing intelligent scissors and volume growing based on a statistical approach, we presented two interactive procedures which include the knowledge of the user efficiently to the process of segmentation. Applied to MR– and CT–data, volume growing achieved very good results as can be seen in Figures 4 and 5 (right). As an advantage no input parameters are required which make it simple to operate. Using the same data for the evaluation of intelligent scissors (see Figures 2 and 5 (left)) we found out that robust segmentation strongly depends on the appropriate weighting of the features constituting the cost function. As presented in [6], the gradient magnitude turned out to be the most dominant feature while the directional information and the zero–crossing of the Laplacian were quite useful if noise was reduced in the beginning. However, in case of MR–data the Laplacian was neglected completely. Contrary to that dynamic training was quite helpful to improve the robustness in general. Applying 3D filters for the calculation of the local costs provided better segmentation since the delineation of a contour was more consistent to the results obtained in neighboring slices. Using the automatic procedure allowing to propagate a contour to neighboring slices showed good performance if there was little variation of the target boundary between slices. Thereby, the manual work was reduced considerably and the attention of the user was better focused on the interactive evaluation of the segmentation. Using three communicating 2D displays made the delineation of volumetric objects very clear and convenient. Integrating additional 3D displays based on interactive indirect and direct volume rendering presented the results at any stage of the segmentation process. Allowing for immediate evaluation within the 3D neighborhood they proved to be a very helpful feature for the segmentation of volumetric objects.

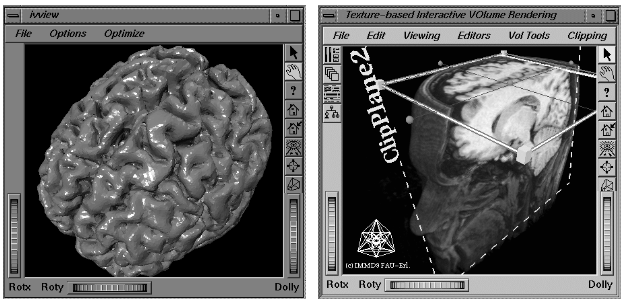

Figure 5: Segmented brain in MR: (left) polygonal rendering — (right) interactive direct volume rendering using a "tags".

6 Conclusion

Using intelligent scissors and volume growing which were applied to medical volume data, we have presented two fast and interactive 3D–segmentation approaches. Integrating a combination of 2D and 3D displays into the segmentation process allows for convenient delineation and intuitive evaluation of the results at any stage of the segmentation. Future work will mainly focus on improving the local cost function and further integration of interactive segmentation and volume visualization.

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