Interactive Direct Volume Rendering of the Inner Ear for the Planning of Neurosurgery

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Abstract A high quality polygonal model of the temporal bone and the structures related to the middle and inner ear is presented. The segmentation of the spiral CT–data and the reconstruction was performed in an iterative process taking several hours to complete. In comparison to this, the power of direct volume rendering is presented which produces meaningful images of the same data in a very short time by interactively adjusting pre–defined color look–up tables. Additionally, using hardware assisted registration, the fusion of CT– and MR–data gives an even more comprehensive representation of the whole situation. Examples demonstrate the direct clinical application and show the value for the planning of neurosurgery.

Keywords: Polygonal Reconstruction, Volume Rendering, Registration

1 Introduction

For the analysis of the temporal bone high–resolution spiral CT–data is an important source of information since it provides detailed imaging of the anatomy. However, the full spatial understanding of the situation proves considerably difficult with the small and complex structures of the middle and the inner ear which requires appropriate three–dimensional visualization. Polygonal representations are usually obtained after a time consuming process of explicit segmentation and reconstruction. Thereby, the data is reduced to a specific surface representation which is considerably difficult to obtain in a normal situation and impossible in cases such as effusion in the temporal bone. Contrary to that, direct volume rendering takes into account all the information inherent in a data set. Applying transfer functions for color and opacity, semi–transparent views give insight to interior structures by enhancing or suppressing groups of specific data entries. This makes separate segmentation dispensable.

In section 2 the generation of a high quality polygonal model of the small and complex structures of the inner ear is presented which gives an impression of the necessary segmentation and reconstruction process. However, in order to obtain a meaningful visualization of the volume data in a much shorter time an approach of direct volume rendering based on 3D texture mapping is suggested in section 3 which was introduced previously [1]. In addition, fusion of MR and CT leads to a comprehensive overview during the planning of surgery since the spatial relation of the inner ear and a lesion area is clearly shown. This is provided by a registration procedure, briefly demonstrated in section 4. It uses mutual information for accurate alignment and hardware acceleration for fast performance. Finally, clinically relevant examples are presented in section 5.

2 Polygonal Model

The generation of polygonal models from medical image data always requires an explicit segmentation. Since the robustness of fully automatic procedures is often insufficient, a semi–automatic approach [2] was chosen in order to obtain a detailed delineation of the middle and inner ear from spiral CT data. It is mainly based on sophisticated volume–growing, hysteresis–thresholding, intelligent scissors and pixel painting. Having extracted the boundary of the segmented region with a simple algorithm for contour detection on every slice, an initial polygonal model is triangulated with an approach presented by Geiger [3]. Since the resulting surface is generated from voxel data on a uniform grid, it contains many misleading edges which require further post–processing. For this purpose discrete fairing, as presented by Kobbelt [4], is used which leads to a smooth representation. In a second step the total number of triangles is reduced using a polygon reduction algorithm according to Campagna [5]. In order to obtain an optimal model both algorithms use specific tolerance values and have to be applied alternately during several iterations.

3 Direct Volume Rendering

As an alternative approach, direct volume rendering allows the efficient visualization of tomographic 3D image data, using implicit segmentation based on transfer functions for color and opacity values. However, it requires a huge amount of interpolation operations which are the most limiting factor for interactive manipulation of any visualization parameter. Modern high–end graphics computers allow the application of 3D texture mapping with hardware accelerated trilinear interpolation. As presented by Cabral [6], this feature is efficiently exploited to guarantee direct volume rendering at high image quality and interactive frame rates. Having loaded the volume data to 3D texture memory the visualization process requires clipping of planes parallel to the viewport against the bounding box of the data set. During rasterization the resulting polygons are textured with their corresponding image information directly obtained from the 3D texture by trilinear interpolation. The final image is produced by blending the textured polygons back–to–front onto the image plane. Since the trilinear interpolation operations are completely performed within the graphics hardware, the time consumed for rendering is negligible compared to software solutions. In order to produce a semi–transparent representation hardware is also exploited for the interactive adjustment of pre–defined look–up tables for color and opacity. Thereby, fast implicit segmentation leads to meaningful and sufficient visualization in many cases. Additionally, several independent clipping planes and a functionality for clipping [7] with arbitrary geometry allow to suppress insignificant regions of the volume.

4 Registration

The preparation of surgery close to the structures of the inner ear requires comprehensive anatomical information about the location of the target lesion. Therefore, registration and consecutive fusion of CT and MR is performed. In order to provide an initial alignment a least squares optimization of a set of corresponding anatomical landmarks is applied. Subsequently, the accurate solution is achieved with an approach based on mutual information which makes extensive use of graphics hardware, as suggested in [8]. Similar to the approach used for direct volume rendering the method uses the imaging and texture mapping subsystem. Thereby, all trilinear interpolation operations are completely performed with hardware assisted 3D texture mapping. In addition to that, the marginal and the point probability distributions required for mutual information are obtained with the blending functionality and the histogram extension within OpenGL.

5 Results

The presented approach was so far applied to 7 patients. The basis of all examinations was spiral CT data with an image matrix of 512^2, 60–120 slices and a resolution of $0.11 \times 0.11 \times 0.5$ mm. In addition, MR_{T1} scans were performed in 4 cases due to a lesion in the close vicinity of the inner ear. Since 3D texture mapping hardware is required, all visualization and registration was performed on a SGI Onyx (R10000, 195MHz) with RE-II graphics hardware providing 64MB of texture memory.

As presented in Figure 1 *(top)* the segmentation and consecutive reconstruction of a high quality model of the middle and inner ear was performed in one case. Showing the temporal bone, the cochlea and the semi–lunar canals, it mainly serves for reference and demonstration purpose making impressive endoscopic fly–throughs possible. However, the model has to be adjusted in a time consuming process in order to correct errors related to the segmentation and triangulation process. Therefore, its practical application is limited. Contrary to that, Figure 1 *(middle)* shows the same data using direct volume rendering for visualization. In order to ensure a convenient inspection pre–defined look–up tables for color and opacity values are used. They are adjusted interactively with only a few manipulation operations, similar to changing the center and width parameter during the process of windowing used for slice images.

In Figure 1 *(bottom)* the fusion of CT and MR gives a comprehensive overview of a tumor which lies very close to the structures of the inner ear. Taking into account the whole analysis, the registration procedure including both pre–alignment and fine tuning requires about 5–10 minutes, whereas optimizing the transfer functions during visualization takes another 5 minutes.

6 Conclusion

Based on 3D textures interactive direct volume rendering of spiral CT–data provides meaningful images of the structures related to the inner ear without explicit segmentation. Using hardware accelerated registration to MR, a fast and comprehensive overview of related structures is provided. Consequently, the method is a useful tool for the diagnosis and planning of surgery in case of patients with anatomic anomalies and tumors of the temporal bone.

References

1. P. Hastreiter, H.K. Çakmak, and Th. Ertl. Intuitive and Interactive Manipulation of 3D Data Sets by Integrating Texture Mapping Based Volume Rendering into the OpenInventor Class Hierarchy. In *Bildverarbeitung für die Medizin: Alg., Sys., Anw.*, pages 149–154. Inst. f. Med. Inf. u. Biom. d. RWTH, Aachen, 1996.
2. P. Hastreiter and T. Ertl. Fast and Interactive 3D–Segmentation of Medical Volume Data. In H. Niemann, H.-P. Seidel, and B. Girod, editors, *Proc. of Img. and Multidim. Dig. Sig. Process. (IMDSP)*, pages 41–44. IEEE Sig. Proc. Soc., 1998.
3. B. Geiger. Three-dimensional modeling of human organs and its application to diagnosis and surgical planning. Technical Report 2105, INRIA, 1993.
4. L. Kobbelt. Discrete Fairing. In *Proc. 7th IMA Conf. on the Math. of Surf.*, pages 101–131, 1997.
5. Swen Campagna, Leif Kobbelt, and Hans-Peter Seidel. Enhancing Digital Documents by Including 3D-Models, 1998. To appear in Comp.s & Graphics.
6. B. Cabral, N. Cam, and J. Foran. Accelerated Volume Rendering and Tomographic Reconstruction Using Texture Mapping Hardware. *ACM Symp. on Vol. Vis.*, pages 91–98, 1994.
7. R. Westermann and T. Ertl. Efficiently Using Graphics Hardware in Volume Rendering Applications. In *Proc. of SIGGRAPH*, Comp. Graph. Conf. Series, pages 169–177, 1998.
8. P. Hastreiter and T. Ertl. Integrated Registration and Visualization of Medical Image Data. In *Proc. CGI*, pages 78–85, Hannover, Germany, 1998.

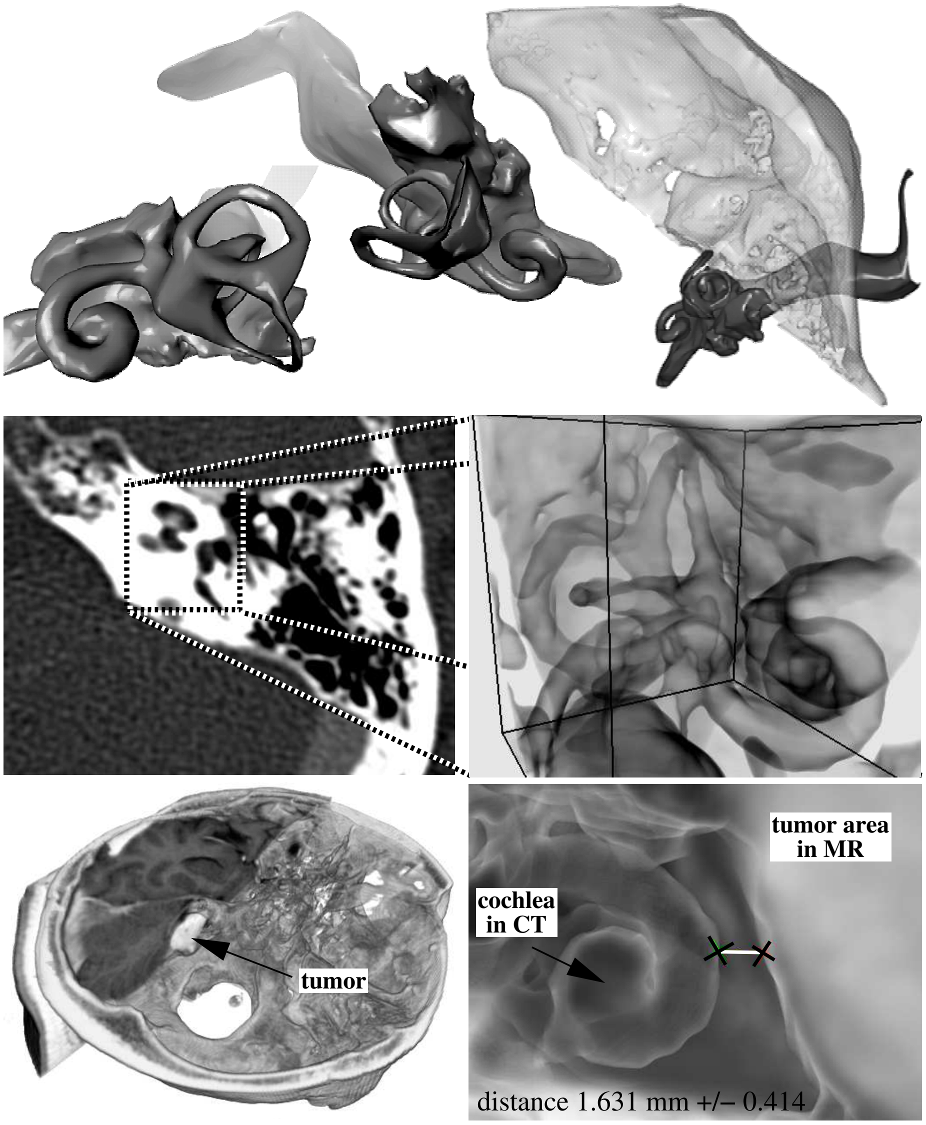

Figure1. Polygonal model of temporal bone and inner ear extracted from CT after time–consuming segmentation and reconstruction *(top)* — Fast delineation of inner ear with direct volume rendering *(middle)* — Fusion and distance measurement of tumor (MR) relative to inner ear (CT) *(bottom)*