Enhanced Visualization of Diffusion Tensor Data for Neurosurgery

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Abstract. Diffusion tensor imaging is a recent magnetic resonance technique that provides comprehensive information about water diffusivity. Since diffusivity correlates with tissue structure at the microscopic level diffusion tensor imaging reveals fibrous structures such as white matter pathways in the field of neurosurgery. White matter tracts are thereby of major interest and the ability to distinguish between different white matter patterns is subject of growing research in neurosurgery. Different approaches for the examination of the data such as streamline tracking or direct volume rendering have been developed. In this work an integrated method for visualizing this kind of data is presented utilizing glyph- and streamline-based visualization in combination with magnetic resonance data showing anatomy to obtain a maximum of information.

1 Introduction

With the introduction of Diffusion tensor imaging (DTI) [1, 2] a new imaging method providing tensor data is available for medical diagnosis and for inspection during surgery. Particularly neurosurgery benefits from this magnetic resonance (MR) sequence since DTI provides a deeper insight into the structure of the brain in vivo [3]. This is achieved by exploiting the fact that diffusion of water is affected by surrounding tissue. Notably, white matter (WM) tracts force water to linear diffusion which results in a distinctive anisotropic diffusion characteristic. In neurosurgery, it is of high value to have information about the location of major WM tracts available for surgical planning which requires a comprehensive visualization strategy [4, 5]. Due to the huge amount of information contained in the tensor data the software tools must provide utilities for the extraction of the required information with respect to the medical problem.

2 Material

For all data acquisition a Siemens MR Magnetom Sonata Maestro Class 1.5 Tesla scanner equipped with a gradient system with a field strength of up to 40

mT/m (effective 69 mT/m) and a slew rate of up to 200 T/m/s (effective 346 T/m/s) was used. With regard to the integrated visualization of DTI data and MR_{T1} data the two sequences were gathered back-to-back.

Parameters for DTI were TR = 9200, TE = 86 ms, b_{high} = 1000 s/mm^2, b_{low} = 0 s/mm^2, field of view 240 mm, voxel size 1.875 × 1.875 × 1.9 mm^3, 1502 Hz/Px bandwidth, acquisition matrix 128 × 128, 60 slices with no intersection gap. The diffusion-encoding gradients for the six diffusion weighted images were directed along the following axes: (±1,1,0), (±1,0,1) and (1,±1,0).

The conventional MR_{T1} was acquired with the following parameters:
TR = 2020 ms, TE = 4.38 ms, field of view 250 mm, voxel size 0.488281 × 0.488281 × 1.0 mm^3, acquisition matrix 256 × 256, 160 slices.

3 Methods

The approach is based on the incorporation of three different visualization techniques: Beside direct volume rendering of MR_{T1} data providing anatomical information, fiber and glyph representations of the DTI data are incorporated into the rendering as shown in figure 1. While direct volume rendering of a MR_{T1} dataset as intensity volume is directly possible, DTI datasets require some precomputation to transform them into a representation applicable for visualization and simulation.

Therefore, in a first step, a diffusion tensor was computed for each grrid point by solving the Stejskal-Tanner equations system [6]. Filter operations were then applied to the tensor field performing 3D gauss filtering for each tensor component. These operations result in a 3D second order tensor field that serves as a basis for further processing.

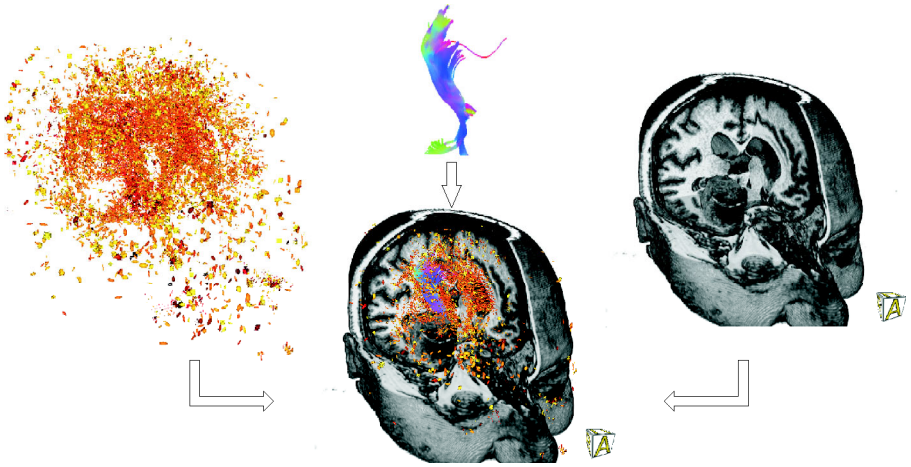
In general, fiber tracking algorithms are based on streamline methods [7] which work on vector fields. The tensor information thus had to be reduced to a vector which was achieved by deriving the eigensystem of a tensor and focusing on the major eigenvector. However, for reasons of accuracy, the tracking algorithm did not evaluate the original tensors directly but used trilinear tensor interpolation before using fourth order Runge-Kutta integration. Fractional anisotropy (FA) was used as tracking threshold to ensure that fibers are only propagated in areas with anisotropic diffusion characteristics.

Applying user-defined regions of interest (ROIs) only fibers traversing those ROIs were displayed. Otherwise, fibers were visualized within the whole brain comprising all WM. Since the resulting structures are rather complex, display of specific tract systems using ROIs was preferred.

Afterwards, rendering of the fibers was achieved using the OpenGL API. Each tract was thereby stored in a vertex array and was drawn as a set of lines. Color encoding followed the standard strategy using the major eigenvector components as RGB values.

Similar to fiber tracking, glyph-based visualizations require eigensystems instead of direct tensor information. Though, in case of glyphs an eigensystem evaluation per voxel was enough. Interpolation would only be necessary for

Fig. 1. Fusion of the three different visualization methods glyphs *(left)*, fibers *(middle)* and direct volume rendering *(right)* into an integrated rendering *(bottom)*.

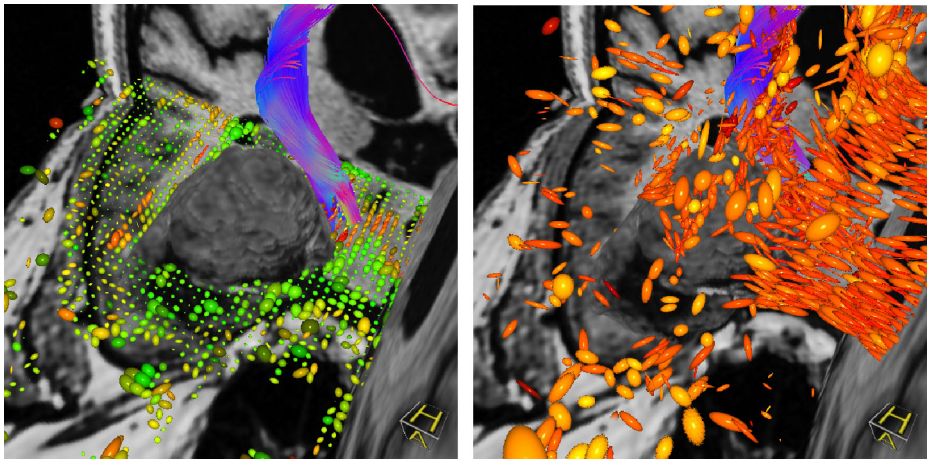


super-sampling which was not applied. Considering the nature of tensors the glyphs are superior to fiber representations since they incorporate the whole tensor information and are not restricted to the major eigenvector problematic with respect to anatomical representation. To improve this advantage the shape of the glyph is crucial. An appropriate shape for representing second order tensors using glyphs is an ellipsoid. Since the polygon model of an ellipsoid would be very cost-intensive for rendering the presented approach uses hardware accelerated ellipsoids as glyphs [8, 9]. They were entirely calculated on the graphics processing unit (GPU) using vertex and fragment shaders to obtain interactive rendering. To avoid overloading of the resulting images with glyphs, a threshold based on FA was applied. In some cases it was also advantageous to display glyphs only in a single slice (see figure 2). This was of particular interest for the investigation of border areas of tumors.

Finally, volume rendering of anatomical data was included. Since fibers and glyphs are opaque objects they were rendered in advance with enabled depth buffer. Applying direct volume rendering subsequently leads to a correct result.

For enhanced volume rendering, 2D transfer functions were applied leading to an emphasized representation. In addition to that, culling within the volume allowed uncovering hidden structures such as the pyramidal tract or the corpus callosum. To achieve interactive manipulation of an arbitrary clipping geometry an additional 3D texture was generated that was used within a fragment program defining the influence on each voxel.

Fig. 2. Comparison of a single slice glyph representation *(left)* and a 3D representation *(right)*. FA threshold is set to 0 for single slice display since occlusion is marginal. For 3D alignment the threshold was set to 185. FA was mapped to values between 0 and 255.



4 Results

The approach has been applied to 15 brain tumor cases. In each patient the spatial relation of tumor and pyramidal tract was examined by investigating fibers and glyphs. The ROIs for fiber tracking were manually defined by an expert identifying the internal capsule and the motor cortex. The fusion of tracking results and anatomical data already provided a good spatial impression about white matter tracts and tumor.

Furthermore, the visualization was enhanced by a glyph based rendering of the tensor data showing more comprehensive information at the tumor border for selected slices. Integrating fibers and glyphs into standard MR_{T1} data thus provided an improved representation of the information contained within the data and allowed evaluating the reliability of the visualization.

However, it must be mentioned that DTI data shows distortion artifacts in certain areas such as the frontal lobe and the brain stem which are caused by the echo planar imaging (EPI) sequence used for DTI acquisition. Results in those areas must be treated with caution. First steps towards non-linear distortion correction were applied [10].

In the context of practical use, interactivity of the rendering procedure was of major concern since clinical the acceptance is directly related to usability and interactive manipulation. To provide the physician interactively with the maximum of information available, hardware accelerated tensor visualization utilizing glyphs was applied.

5 Conclusion

We presented a method for interactive and comprehensive display of DTI data. Fiber tracts which are easy to interpret and glyphs which provide better representation of tensor data were combined in an integrated approach. To further support the investigation of the data, anatomical information was integrated by additionally visualizing T1 and T2 weighted MR data using direct volume rendering. Combining the presented visualization techniques leads to a more comprehensive display providing enhanced visualization of major WM tracts related to brain tumors applicable for preoperative planning and intra-operative inspection.

6 Acknowledgments

This work was supported by the Deutsche Forschungsgemeinschaft in the context of SFB 603, Project C9 and the Graduate Research Center "3D Image Analysis and Synthesis".

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