Interactive visualization of DTI for intraoperative use

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Introduction:

Visualization of diffusion tensor imaging (DTI) data has recently gained increasing importance. This is of particular interest for neurosurgeons since it allows analyzing the location and topology of white matter (WM) structures such as the pyramidal, sensory and optical tracts. Up to now, miscellaneous visualization approaches have been developed such as fiber tracking and glyph representation showing different features of DTI data.

Material:

All diffusion tensor images were acquired using 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). The imaging parameters 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 x 1.875 x 1.9 mm^3, 1502 Hz/Px bandwidth, acquisition matrix 128 x 128. Sixty slices with no intersection gap were measured, 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). A standard PC (Intel 3.0 GHz) with NVidia GeForceFX 5950 graphics card equipped with 256 MB graphics memory was used for the fiber tracking and the visualization utilizing the glyphs.

Methods:

The presented approach for the visualization of DTI utilizing glyphs and fibers requires several preprocessing steps. Beside the calculation and filtering of the tensor field we perform fiber tracking [1] using second order Runge-Kutta integration. Afterwards, the visualization is performed incorporating the traced fibers and the voxel based representation of the tensor. While fibers were visualized using straight forward line rendering, the glyph representation of tensors was achieved utilizing ellipsoids [2]. We limited the visualization to the display of ellipsoids. For intraoperative use of the presented visualization method a crucial requirement is the immediate availability and the interactive presentation of the achieved results. While the preprocessing is already achievable in acceptable time, about 15 to 20 seconds for a whole brain tracking, the interactive visualization is challenging. Generally, objects are discretized and represented as a mesh of triangles. Accordingly, each glyph must be described as mesh which can be very time consuming since curved surfaces have to be split in a huge amount of very small triangles to achieve a smooth surface. In case of ellipsoids, we provide an efficient method to avoid this bottleneck. The entire object discretization is done by the graphics hardware. Vertex- and fragment programs provided by current consumer graphics cards are used to accelerate the rendering. Therefore, only one point per glyph has to be sent through the visualization pipeline. The vertex program then calculates the maximal covered screen space exploiting the current view situation and the orientation and elongation of the ellipsoid given as attributes. Finally, the fragment program calculates the proper shape of the ellipsoid and applies lighting.

Results:

Fig. 1 shows the visualization of the fiber tracking results and direct glyph representation of several slices of the DT data. Coloring of the fibers takes place by mapping the direction of the fiber into RGB color space. The glyphs can be colored the same way. Nevertheless, practical use has shown that it is advantageous to apply different color schemes. Therefore, other values like anisotropy are utilized for color mapping. In case of Fig. 1 cl, cp, cs introduced by Westin et. al [3] are used, mapping cl to red, cp to yellow and cs to green. Fig. 2 shows the frames per second (fps) achieved. In axial view mode only certain slices from the dataset were rendered as glyphs. In 3D mode glyphs for all voxels in the dataset were generated as long as their fractional anisotropy (FA) value was above a certain threshold. For the axial view the threshold was set to 0 and all glyphs were rendered. The screen area for rendering had a size of 655 x 961 pixel. The number of glyphs was 4862 for 1 slice in axial view, 14664 for 3 slices, 7147 for 3D with FA threshold 175 and 2362 for FA threshold 200. The number of lines tracked for the pyramidal tract, optical tract and the whole brain was 242, 327, and 3984 respectively. The clinical application of this visualization tool in a series of 16 patients undergoing glioma surgery allowed an immediate intraoperative visualization within less than one minute after data acquisition.

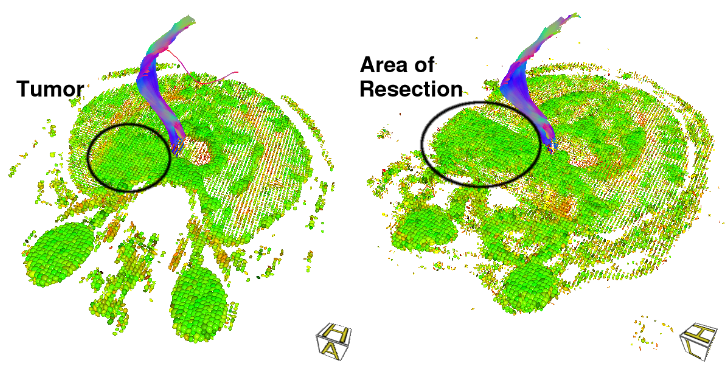

Fig. 1 Result of a tracking for the pyramidal tract and a set of 3 axial slices colored using cl, cp, cs as described in a patient with a right temporal lobe glioma (left: preoperative, right: intraoperative). Irregularities in slice orientation and offset are due to tilted position of the patient during intraoperative data acquisition. The area of resection in the right image appears with similar density of the glyphs due to filling the resection cavity with saline.

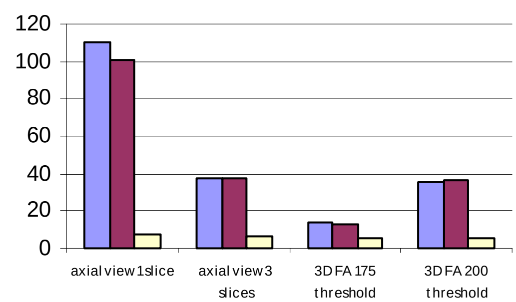

Fig. 2 Frame rates for different viewing modes, measured in frames per second. Blue bars show the combined display of glyphs and a pyramidal tract. Red is associated to an optical tract and yellow applies to a whole brain tacking.

Conclusion:

The presented work introduces a considerably improved approach for the interactive visualization of DTI data applying consumer graphics hardware for the rendering of ellipsoids. Overall, high image quality and interactive frame rates are achieved, which are essential for clinical application especially in the OR.

References:

[1] L Zhukov, A Barr. Oriented tensor reconstruction: tracing neural pathways from diffusion tensor MRI, Proc. on Visualization '02

[2] G Kindlmann. Superquadric Tensor Glyphs, Proc. of Symposium on Visualization 2004

[3] CF Westin, SE Maier, B Khidhir, P Everett, FA Jolesz, R Kikinis. Image Processing for Diffusion Tensor Magnetic Resonance Imaging, MICCAI 1999 441-452