RBF-based reconstruction of fiber orientation vector field for the white matter fiber tract modeling

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INTRODUCTION AND PURPOSE

The fiber tracking technique based on MR diffusion tensor image (DTI) is a powerful tool for visualizing structures of the fiber tracts in the brain white matter [1]. One of the most important problems in the fiber tracking is error in determining tracking direction at a fiber-crossing part where diffusion tensor is observed as a mixture of several tensors in different orientations. Several techniques for dealing with the problem were reported, which are categorized in two. One is a group of data-driven approaches such as controlling tracking direction based on diffusion anisotropy, separating mixture of tensor, tracking based on diffusion spectrum images (DSI), and so on. The other is model-based approach mainly by fitting curves based on energy minimization. As known well in image segmentation problems, the former approach has certain limitation due to signal loss and noise. Major problems of the latter are determination of initial shape before fitting, convergence to local minima and time-consuming process of iterative energy minimization. As a practical solution for the problem, we propose a hybrid approach for modeling only target fiber tract to be extracted, based on the *reconstructed vector field of fiber orientation* (RVFFO). Quantitative studies were performed for proving feasibility of our approach by analyzing errors in computing RVFFO with clinical data.

METHODS

Our technique of fiber tracking (modeling, indeed) consists of two procedures; (1) reconstruction of vector field of fiber orientation with limited numbers of principle vector ($\mathbf{e}_1$) of diffusion tensor, and (2) line propagation in fiber orientation interpolated by using RVFFO. The vector field is reconstructed based on an interpolation technique by using radial basis functions (RBF), which is a family of the spline interpolator/extrapolator for reconstructing scalar or vector field as implicit function [2]. The RVFFO must be updated for every fiber modeling with updated set of ROI. Each step is described in detail below.

(1) ***RBF-based reconstruction of fiber orientation vector field with limited voxels***: First of all, several ROI are set interactively in the same manner as conventional fiber tracking , along target fiber tract avoiding fiber-crossing parts. In our prototype software, a ROI, a group of connected voxels, can be grown based on 3D region growing technique by using thresholds of $\mathbf{e}_1$ orientation and FA value and controllable growing distance. Next, an array of pairs of $\mathbf{e}_1$ and location of voxel in ROI is prepared. Then, several $\mathbf{e}_1$ vectors in the array are flipped based on maximization of the summed vector length so that reconstructed vector field is smooth without any singular points such as attracting focus, saddle point and so on [3]. Three components (x, y, and z) of the vector filed are reconstructed independently by solving linear equations under constraint of orthogonality to represent RVFFO as three implicit functions. Number of those voxels used for control points in the interpolation often reaches several thousands, which leads to time- and memory-consuming process. We skipped several voxels at a regular interval to reduce the total number of voxels.

(2) ***Fiber tracking in RVFFO***: Tracking seeds are placed interactively on the target tracts or ROI used in RVFFO interpolation is utilized. Line propagation is iteratively performed by determining fiber orientation by interpolation of vector components by RVFFO and normalization of the vector. As termination criterion for tracking, FA value of original tensor field is employed in our study.

RESULT AND SUMMARY

Fig.1 shows a result based on RVFFO with clinical DTI data. As shown in Fig.1a, parts of fibers through the corpus callosum (CC) run across vertical tracts such as corticospinal fibers. A conventional $\mathbf{e}_1$ tracking started from the CC often merges the vertical tract group, or the superior longitudinal fasciculus at crossing part and mostly fails to go beyond the crossing part (Fig.1b). In our approach, by selecting ROI consisting of about 1500 voxels avoiding the crossing part as shown in Fig.1c, fibers through CC and beyond the crossing can be also depicted as shown in Fig.1d. Note that selected ROI voxels exist not only on the shown slice but also spread on several adjacent slices. Fig.2 shows a result of analyzing angle between original $\mathbf{e}_1$ and estimated fiber orientation vector by RVFFO computed at each voxel in the crossing part and in the other part within ROI for RVFFO interpolation. It is natural that the error angle is high at crossing part because estimated orientation is computed for smooth connection around fiber-crossing without $\mathbf{e}_1$ at crossing. On the other hand, the angle at the other voxels is low and is about 2.3 deg. in average, which must be ideally zero. We confirmed that the error is caused by skipping voxels in collecting control voxels for faster computation, through experiments by changing skip interval. Thus, our preliminary results show that the approach based on RVFFO is feasible and effective in fiber modeling beyond fiber-crossing.

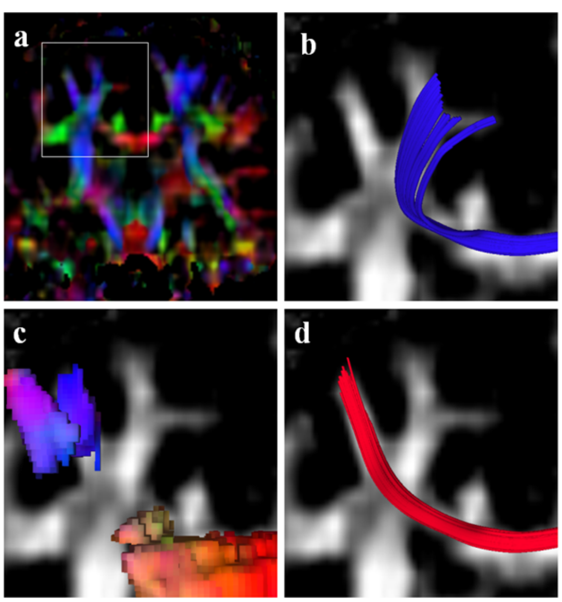

Fig.1 Fiber Modeling based on RVFFO
a: coronal section of color-coded $\mathbf{e}_1$ image, **b**: fiber tracking from CC by conventional $\mathbf{e}_1$ tracking, **c**: control ROI (FA>0.3) used for RVFFO, and **d**: a modeling result by proposed method. The background in **b**-**d** is FA image.

REFERENCES

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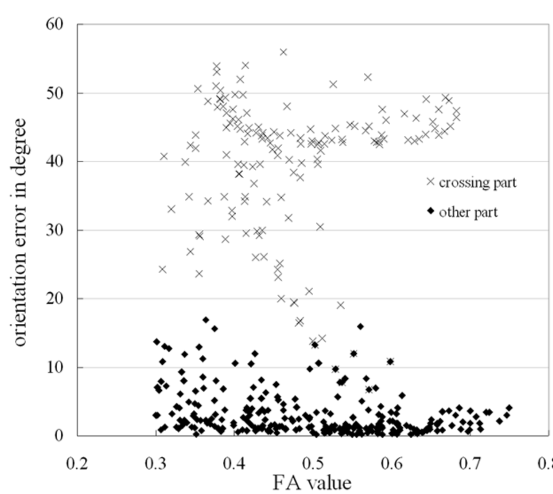

Fig.2 Error Angle Analysis of Estimated Fiber Orientation