HYFF-HYbrid tractography with Fiber assignment by continuous tracking and Fast marching

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Introduction

Tractography based on diffusion imaging provides an efficient and noninvasive means to reveal the morphology of white matter tracts. Diffusion imaging methods include simple diffusion tensor imaging (DTI) and the more sophisticated high-angular and sampling and data processing strategies [e.g. 1-3]. There are numerous limitations of DTI. However, it is still so far more widely used in clinical scanners because DTI data can be acquired with enough signal-noise-ratio (SNR) in relatively short time. Before high-angular imaging becomes routine clinical protocol, exploring the methods to resolve crossing and diverging fiber problem based on DTI data and with low computation cost is still necessary. Conventional streamline method such as fiber assignment by continuous tracking (FACT) [4] is known to have limitation of tracing only single lines. Fast marching tractography (FMT) [5] allows fiber crossing and branching based on DTI information, but is bound to discretization errors. In this study, we tested possibility of combining FACT and FMT. The proposed HYFF (HYbrid tractography with Fiber assignment by continuous tracking and Fast marching) is a streamline method which ensures correct directions of tracing by forcing the traced lines to go downstream of the time field generated from FMT. The motivation of developing this method is that we want to fuse the properties of continuous and smooth tracing from FACT and propagation of the front through crossing and branching fiber area from FMT. In this abstract, we demonstrated this hybrid method and compared it with FACT and FMT.

Methods

Data acquisition: A 3T Philips Achieva MR system was used. DTI data was acquired using a single-shot echo-planar imaging (EPI) sequence with SENSE parallel imaging scheme (SENSitivity Encoding, reduction factor =2.3). DWI parameters were: FOV=224/224/132mm, in plane imaging matrix = 112× 112, axial slices thickness = 2.2 mm, parallel to the anterior–posterior commissure line, 30 independent diffusion-weighted directions with b-value = 1000 sec/mm^2, TE=97ms, TR=7.6s. To increase signal noise ratio (SNR), two repetitions was performed, resulting total imaging time 13 minutes. ***HYFF:*** Seed points were set up initially and time field was calculated with the front evolution [5]. The streamline path $\gamma(\vec{x})$ satisfies the following two equations: $\gamma(\vec{x}) = f(\vec{v}_1, \vec{x}, T)$ and $\gamma(\vec{x}) = \arg\min \int_{\gamma(\vec{x})} |\nabla T(\gamma(\vec{x}))| d\vec{x}$, where $\vec{v}_1$, $\vec{x}$ and ***T*** are primary eigenvector of the tensor, the coordinates of the front of the line and time field, respectively. The first equation shows that different from FACT, HYFF tracing was also determined by time field. HYFF tracking followed the direction of the primary eigenvector of the tensor unless the time field information indicated the tracing was not going downstream of the time field, namely, the time field value of the next voxel was no less than the one of the current voxel. Under this circumstance, the voxel with the minimum time field value around the current voxel would be the next voxel. For three-dimensional (3D) tractography with the human brain DTI data, the seed points were part of midsagittal CC body. The regions-of-interest (ROI) were manually delineated in 20 coronal slides, covering end points of CC projecting to the medial part of frontal lobe. The one-time computation time for time field calculation was around 30 minutes with a workstation with 2.99GHz CPU and 2G RAM. And the HYFF tracing from the ROI was almost instant, similar to FACT.

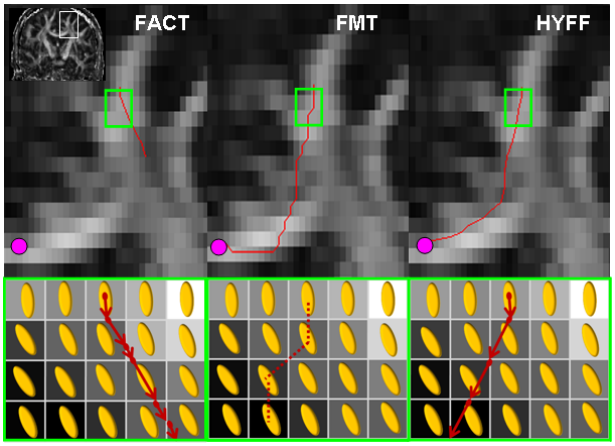
Results

The upper row of Fig. 1 demonstrates the tracking with a single-voxel seed point which is the purple dot at the midsagittal corpus callosum (CC). The time field was generated with the seed point. Tracking was within the 2D plane which is magnified from a 2D coronal fractional anisotropy (FA) map where the three fibers, CC, anterior corona radiata (ACR) and superior longitudinal fasciculus (SLF) cross. Tracings with three methods all start from the same voxel in corpus callosum above the green box. FACT follows the direction of primary eigenvectors but fails to go back to the seed point. It deviates from the CC, enters the area of low FA values due to tract crossing and stops. FMT can trace back to the seed point, but discretization errors make the lines turn with only 0°, 45° and 90°. HYFF keeps the smoothness of the traced fiber which also follows the correct anatomy. From the lower row of Fig. 1, FACT tracing goes into the voxel with higher time field value and leads to big deviation from the correct tract. FMT is characterized with zigzag traced line and HYFF line follows downstream direction of time field in each step. Fig. 2 shows the 3D reconstructed callosal fibers with FACT, FMT and HYFF methods. A lot of fibers from FACT tracing wrongly join cortical spinal tract (CST) or can not trace back to the seeds. Fibers from FMT also deviate from the CC and merge into other tracts before they finally go back to the seeds. Around midsagittal plane, the traced CC from FMT is horizontal, while the traced lines from FACT and FMT follow the natural curve of CC. FMT fuses the advantages of both FACT and FMT. The traced lines from FMT are more smooth and natural and agree to the real anatomy of the tract.

Discussion

Streamline method which follows the primary eigenvector of the tensor has been proved to successfully trace the major white matter tracts and the morphology of those tracts match the histology. Failing to resolve crossing and branching fibers is a great limitation for streamline method such as FACT. HYFF can be regarded as a modified version of FACT as it mainly follows FACT rules and changes path only when the tracing is not going downstream of the time field. Implementing HYFF algorithm is relatively efficient in computational cost and this computation efficiency makes HYFF ready to be used in clinical studies practically.

References: [1] Frank, L.R. (2002) MRM 47, 1083. [2] Tournier, J.D. et al. (2004) NeuroImage 23, 1176. [3] Tuch, D.S. et al., (2003) Neuron 40, 885. [4] Mori, S. (1999) Ann. Neurol. 45, 265. [5] Parker, G.J.M. (2002) IEEE TMI 21, 505. **Acknowledgment:** This study is sponsored by NIH RR02584.



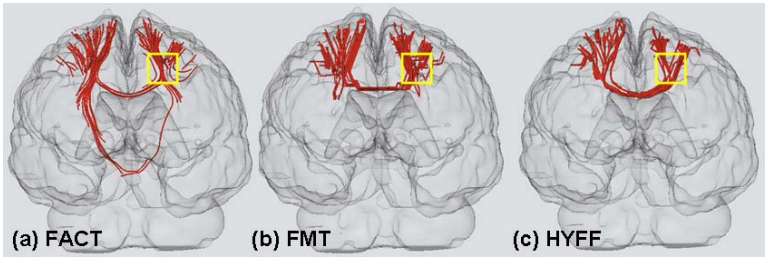


Fig. 1: (Left) Upper row is the FACT, FMT and HYFF tracing from a single voxel ROI in enlarged 2D coronal FA maps including the region where three tracts cross. The original 2D coronal image is shown at the upper left corner. The lower row shows the directions of primary eigenvector of the tensor and background gray scale denotes the time field values. Fig. 2: (Right) The 3D reconstructed fibers with FACT (a), FMT (b) and HYFF (c) methods. The yellow box indicates the area of fiber crossing. It is clear that the fibers traced with HYFF can smoothly go through the area and get back to the seed points.