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Fiber tracking of human brain using rank-4 tensor and high angular diffusion imaging

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Diffusion tensor magnetic resonance imaging is an extension of conventional MRI with the added capability of tracking and measuring the random motion of water molecules in all three dimensions. Typical fiber tracking schemes reconstruct the pathways of white matter tracts by starting from a seed voxel and tracing them down in a voxel-by-voxel manner, using an estimate of the local fiber orientation determined by the principal eigenvector in each voxel. These streamline techniques appear to give excellent results in many instances if the principal eigenvector field is smooth. However, it suffers from a couple of significant limitations, particularly those related to noise and partial volume effects. The vector field is error prone in voxels effected by noise in DT-MRI data and will influence the direction of the principal eigenvector, yielding an accumulation of orientational errors and, thus, an erroneous fork of the trajectory reconstruction process. The partial volume effects, on the other hand, will cause it to run into trouble in tracking fibers correctly and reliably through the primary eigenvector field in regions of fiber crossing, branching, or merging, which renders a complicated averaging of multiple fiber populations within a single voxel. Since the current resolution of DT-MRI is millimeter scale while the diameter of nerve fibers is in the magnitude of micrometers, it is difficult for the measured diffusion tensor to describe such entangled structures in these areas.

We proposed a new design for high rank tensors (FLAHRT), which is capable of decoding the information provided by ADC profiles in different diffusion directions. We have used rank-4 tensors in our study; the generalized design of this approach, however, allows to expand the tensors to rank-n, if data is acquired in atleast F directions, where, F is the number of distinct tensor components needed to describe the tensor which is given by formula $(n+1)(n+2)/2$.

The matrix representation of these high rank tensors allows to use the diffusivity information for further postprocessing beyond identification of complex voxels

We have implemented and studied the capabilities of FLAHRM for rank-4. We could show that fiber tracking on the basis of this data is highly noise resistant; this resulted in less erroneous fibers resulting from the fiber tracking procedure. Furthermore the algorithm allows to sense different fiber bundle directions within a voxel. This algorithm shows better results when compared to the Standard rank-2 tensor. From our point of view, FLAHRM is the superior technique because it not only gives consistent and more accurate fiber tracking results but also shows high potential of resolving fibers in voxels with heterogeneous fiber directions. It is a promising approach to further study the application of FLAHRM with more diffusion directions, parameter maps and iterations of fiber tracking. The generalized design of FLAHRM also allows us to extend the same approach to tensors of rank-6 or higher.