A recursive algorithm to decompose orientation distribution function and resolve intra-voxel fiber directions

F-C. Yeh[1], V. J. Wedeen[2], and W-Y. I. Tseng[1,3]

[1]Center for Optoelectronic Biomedicine, National Taiwan University College of Medicine, Taipei, Taiwan, [2]MGH Martinos Center for Biomedical Imaging, Harvard Medical School, Charlestown, MA, United States, [3]Department of Medical Imaging, National Taiwan University Hospital, Taipei, Taiwan

Abstract We present a recursive decomposition algorithm for resolving intra-voxel fiber directions in diffusion spectrum imaging (DSI) and q-ball imaging (QBI). The proposed algorithm recursively decomposes orientation distribution function (ODF) and obtains fiber directions. This approach is compared with local maximum approach, which has long been used to determine fiber directions from ODF. Simulation showed that the proposed recursive decomposition method outperformed the local maximum method in determining the minor fiber directions of the crossing fibers. By applying the proposed method to *in-vivo* DSI dataset, a clear fanning pattern of the corticospinal tract above the internal capsule was demonstrated.

Introduction Diffusion spectrum imaging (DSI) and q-ball imaging (QBI) are model-free methods for obtaining ODFs of intra-voxel fibers[1-2]. For resolving intra-voxel fiber directions based on these ODFs, local maximum method, which detects local peaks of ODF has been applied. However, local maximum approach may hardly resolve multiple fibers in certain situations [3], and may undermine the accuracy of tractography results. In this study, we present a recursive decomposition algorithm for analyzing ODFs obtained from DSI or QBI. Instead of searching for local maxima, discarding abundant information in ODFs, our approach recursively estimate a maximized single fiber ODF and then subtracted it from the entire ODF. These steps are repeated until termination criteria are met.

Materials and Methods In single fiber ODF, the distribution presented symmetric and decreasing pattern around fiber direction, which is the direction with maximum distribution value of ODF. These properties can be formulated as follows:

$$\text{If } |\hat{u}\cdot\hat{a}| = |\hat{v}\cdot\hat{a}| \text{ then } ODF(\hat{u}) = ODF(\hat{v}) \qquad \text{(Axial symmetry)}$$
$$\text{If } |\hat{u}\cdot\hat{a}| > |\hat{v}\cdot\hat{a}| \text{ then } ODF(\hat{u}) > ODF(\hat{v}) \qquad \text{(Angular decay)}$$

where $\hat{a}$ is the fiber direction and $\hat{u},\hat{v}$ are any unit vectors. In our algorithm, the first step is to search for a maximum single fiber ODF Ψ_1, which has the maximum total probability and obey the following constraints: 1)Ψ_1 is a single fiber ODF, and 2) In any direction, the distribution value in Ψ_1 is not greater than overall ODF Ψ_0. Fiber direction and the principle single fiber ODF Ψ_1 can be obtained from the maximization process. Then, the second step is to subtracted the maximized single fiber ODF Ψ_1 from overall ODF Ψ_0.

$$\Psi_0 \leftarrow \Psi_0 - \Psi_1$$

The above two steps (maximization and subtraction) are repeated until remained probability is below certain threshold.

Results To demonstrate the performance of the proposed method in comparison with local maximum approach, we simulated ODFs of multiple fibers and analyze them with the proposed recursive decomposition algorithm and with local maximum approach. ODF is discretized to 162 sampling direction with angular resolution of about 15 degrees. The simulation is based on mixed Gaussian models and three cases groups are generated by different FA values (0.4, 0.6, 0.7). Each group contains two fiber populations with various combinational ratios ranged from 1:1 to 100:1 and crossing angles ranged from 15 to 90 degrees. The analyzed results are focused on the direction of the minor fiber. If the estimation of the direction of minor fiber is correct, we regarded it as a successful estimation (printed as blue areas). Comparison results are illustrated in figure 1a and 1b.

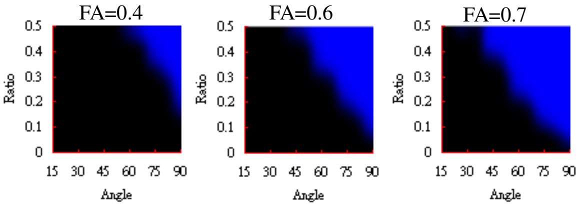

Figure 1a. The performance of local maximum method on resolving the direction of minor fiber. Blue areas are correct estimation whilst black areas are incorrect.

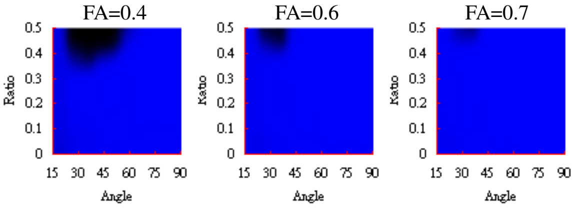

Figure 1b. The performance of recursive decomposition method on resolving the direction of minor fiber.

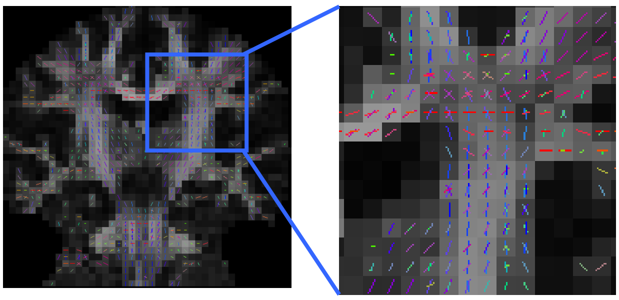

Figure 2. Three-way crossing of the corticospinal tract, corpus callosum and superior longitudinal fasciculus (left). The recursive decomposition method shows crossing fibers with distinct minor components (right).

Performance analysis shows that local maximum method can hardly resolve minor fibers in cases of sharp inner angle or low minor fiber fraction. In these cases, major fibers override local maximum of minor fibers and make it hard to be detected. On the contrary, recursive decomposition method is good at resolving minor fiber of small fraction. This is because minor fibers can easily induce axial asymmetry in overall ODF, and are thereafter enhanced. However, in cases of high fraction with sharp angle, the overall ODF is similar to single fiber ODF and forms a difficult situation to deal. In addition, noise may also cause false detection of minor fibers, and thus smoothing should be performance beforehand to prevent this drawback. We applied the proposed method on DSI data and resolve fiber directions of each voxel. Results in coronal view are illustrated in figure 2. Branching fibers of corticospinal tract (CST) are focused. Tractography were reconstructed by utilizing stream-line tracking algorithm on resolved information (figure 3). Tracking results showed a clear fanning pattern of CST above the internal capsule, terminating at a wide range of motor stripe.

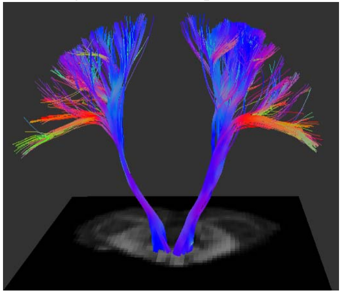

Figure 3. Tractography of corticospinal tract (CST) based on recursive decomposition method shows a clear fanning pattern of CST above the internal capsule.

Discussion and Conclusion Recursive decomposition algorithm outperforms local maximum method in resolving minor fibers. Further, we showed that the proposed method can resolve branching fibers in CST and facilitate the visualization. This makes it possible to investigate minor fibers, which may play significant role in several clinical researches.

Reference [1] Wedeen et al. MRM 54:1377,2005 [2] Tuch MRM 52:1358, 2004 [3] Zhan et al. JMR 183 (2006) 193–202