Enhancing the performance of local maximum method for extracting fiber directions from the orientation distribution function using maximum variation and clustering methods

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Introduction:
High Angular Resolution Diffusion Imaging (HARDI) is introduced to overcome the limitations of conventional diffusion tensor imaging (DTI) in resolving crossing and kissing fibers. In conventional DTI the data is analyzed using a single second order tensor. Several methods have been proposed to solve the limitation of second order tensor methods [1-2]. The average diffusion propagator of HARDI data is obtained using either Q-ball imaging (QBI) or diffusion spectral imaging (DSI) based on how the data is acquired. An alternate method for multi fiber reconstruction is to describe the apparent diffusion coefficients (ADC) using higher order diffusion tensors [3]. Several methods have been proposed for estimating the higher order tensors with positive definite constraints, [4-6]. Using HARDI data, Cartesian tensor field fiber orientation distribution function (ODF) is calculated, from which the principal diffusion directions (PDD) are, extracted [7]. For resolving intra-voxel fiber directions based on these ODFs, local maximum method is applied. However, local maximum approach may not resolve multiple fibers in certain situations [8] and may undermine the accuracy of tractography results. In this study, we developed a method to obtain the principal diffusion directions from the ODF where the local maximum method fails. This method is applied to analyze the human brain diffusion data. In this study we focused on the analysis using the fourth order tensor

Theory: The local maximum method has two limitations: 1) inability to identify all the local maxima if the second or third expected local maxima are dominated by the neighbors with large ODF values and 2) if the two crossing or branching fiber orientations are close to each other. These problems can be overcome by our proposed method. Suppose **u** is a unit vector and **N** is the set of closet neighborhoods of **u** on the unit sphere. ODF (u) is said to be a local maximum if $\mathrm{ODF(u)} - \mathrm{ODF(v)} \geq 0$ for all $v \in N$. Similarly, ODF (u) is a pseudo-local maximum if $\mathrm{ODF(u)} - \mathrm{ODF(v)} < 0$ for at most 2 members $v \in N$. The variation at **u** is defined as: $\mathrm{var}iation(u) = \max_{v \in N} |ODF(u) - ODF(v)|$. Our proposed method has three main parts: (1) identify the local maximum values whenever they exist, (2) identify the pseudo- local maximum values excluding points around the PDDs in step 1 whose variation values with the closest neighborhoods is less than 0.09, and (3) cluster the points obtained from step 2 around a unit vector with maximum number of neighborhoods. The unit sphere is sampled in 642 points with angular resolution of about 11° to reconstruct the ODF. Fiber tracking was performed using the procedure described in [9].

Materials and Methods:
The proposed method was verified using the HARD data acquired on a Philips 3T scanner on three normal controls**.** A 32-chanel coil with SENSE factor 2 was used for data acquisition. Multi-slice, diffusion-weighted images were acquired using a single shot spin echo EPI sequence with 81 diffusion encodings. The sequence parameters were: FOV= 256x256 mm^2, slice thickness=3mm, TR/TE = 8235/72 ms, b-value=1600 s/mm^2.

Results:
The proposed method was tested using three different sets of brain data sets. Fig.1 shows an example of a voxel from the centrum semiovale, where the local maximum method produced the first and the third PDDs but not the second. Red, green and blue colors refer to left- right, anterior - posterior and inferior-superior directions, respectively. Yellow, magenta and cyan refer to the first, second and third PDDs, respectively. As an example fiber tracking on *two subjects* from the seed regions indicated in Fig.2 was performed using two sets of PDDs obtained using local maximum (Figs 2 A and C) and the proposed method (Figs 2B and D). The improvement in the volume of reconstructed fibers and continuity of the pathways with the proposed method can be appreciated from Fig. 2. In Fig.2 (A) parts of the superior longitudinal fasciculus (SLF) which projects to the temporal lobe are missing, whereas they are recovered using the proposed method. In Figure 2 (C) the parts of SLF to the left of the seed region is missing whereas they can be seen in Fig.2 (D), obtained with the proposed method.

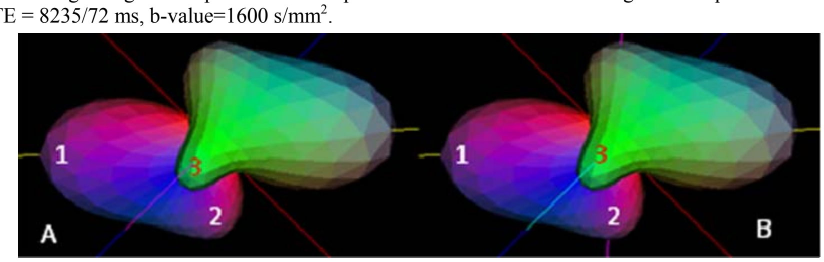

Fig.1: PDDs using local maximum (A) enhanced local maximum method (B)

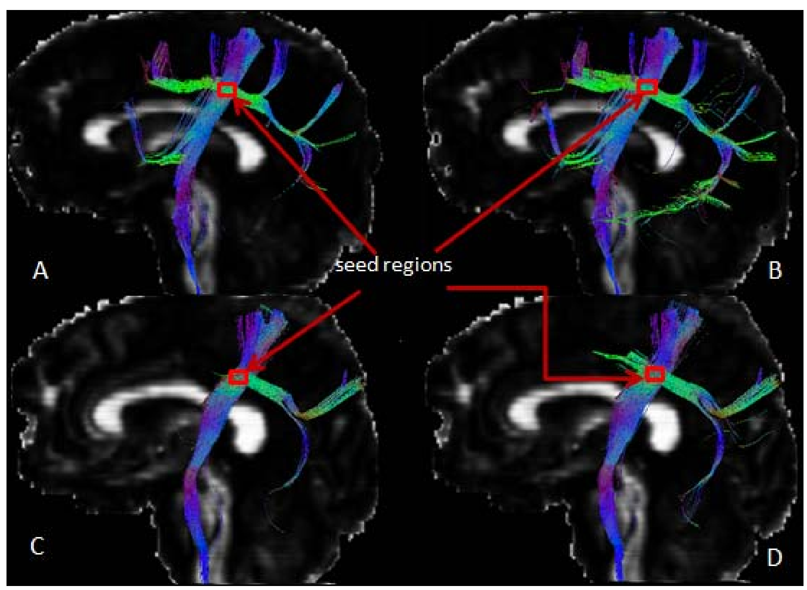

Fig.2: Parts of CST and SLF. (A and C) reproduced using local maximum method and (B and D) using enhanced local maximum method.

Discussion and Conclusion:
The local maximum method is an efficient way for determining the fiber orientation provided it has clearly defined peaks. But sometimes the ODF values of points between the major and minor fiber orientations override the peaks of minor peaks that make it hard detect the peaks. These limitations are greatly overcome by our proposed procedures as demonstrated by the results. Using the proposed method we have obtained three PDDs and improved the fiber reconstruction. Accurate estimation of PDDs improves fiber pathways reconstruction that deals with crossing and touching fibers.

References:
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