A principal eigenvector based segmental approach for reproducible white matter quantitative tractography

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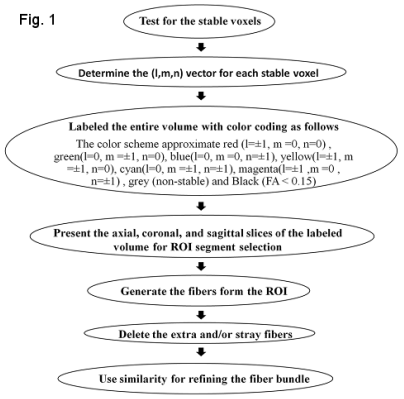
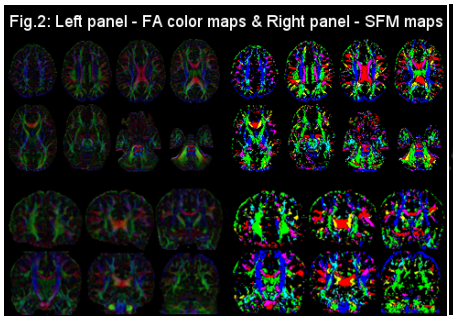
Introduction: The objective of this study is to develop a reliable, reproducible and a "pleasure to work with" computational methodology facilitating quantitations for a better understanding of brain connectivity and integrity through quantitative analysis of diffusion images. Whereas the entire fiber mass is easily available using FACT or similar procedures [1], the basic problem in Diffusion Tensor Tractography (DTT) is sorting out the fibers of a bundle of interest from it. The methods in literature do it by generating the fibers passing through expertly chosen Region of Interest (ROI) and suffer from the subjectivity of the user as well as extensive deletion of stray fibers. Principle Eigen Vector Field Segmentation (PEVFS) tries to tackle the problem on both fronts simultaneously, by reducing the time for ROI specification and also improving its accuracy. This technique exploits the direction of maximum diffusion at each available voxel via the DT-MRI to automatically delineate the white matter structures and track the nerve fibers.

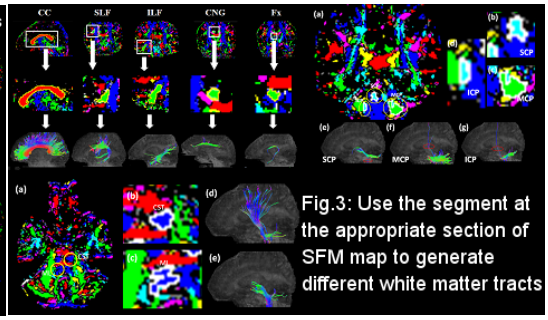
Fig. 1



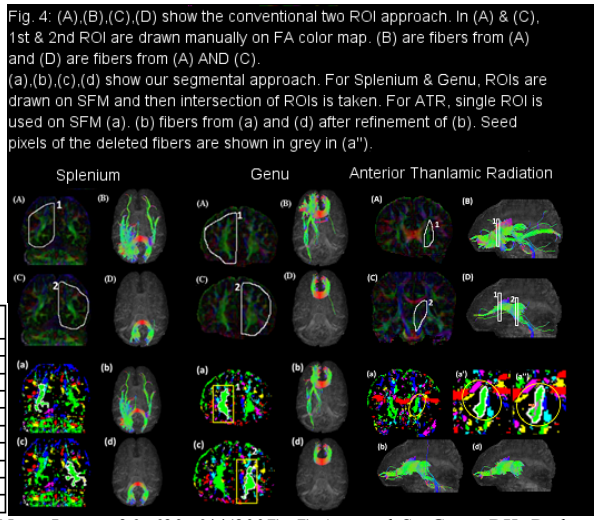
Methods: A pre-segmented map called Stable Fiber Mass (SFM) map is prepared initially to aid in the identification of white matter structures. The key idea of our method (Fig. 1) is to do a segmentation of the principal eigenvector field into stable voxels having a minimal e_1 variation (curvature). Thus a voxel P is a member of the stable fiber mass, if there is a neighboring voxel Q such that e_1's at P and Q point out to each other. Mathematically it translates to the relation G(F(P)) = P, where with u = (1,1,1); $F(P) = ROUND(P + e^1(P) + 0.5u)$ and $G(Q) = ROUND(Q - e^1(Q) + 0.5u)$. The method, thus, firstly generates the stable fiber mass and then segments it by coloring its voxels according to the following scheme: The vector joining P and Q has the form (l,m,n), where l, m, n can take the values -1, 0, +1, utilizing which the voxel P is colored according to step3 in Fig. 1. Typical segmented axial and coronal color maps along with the conventional FA color maps are shown in Fig. 2. Using SFM color maps our method narrows down the ROIs selection to pointing out to a color segment inside a broader ROI of interest through a single click of mouse.

Results: Fig. 3 shows the applicability of our method of delineating regions of interest, the tracking of fibers and their pruning to successfully lead to a reproducible, reliable and accurate tractography of major fiber bundles. We also make a comparison of our methods with the conventional ROI methods, whenever available, as suggested in the literature [3, 4, 5, 6] (Fig. 4). In particular, we have observed that the reproducibility of fiber tractography in whatever successful methods in the literature turns out to be essentially due to the choice of a second ROI. This involves extra work, whereas using our approach the same comes effortlessly in all cases through a single ROI click. (The interface using the above idea finds out the ROI just by one click at any pixel in the segment [7]). Unwanted fibers appeared because of noise effects, partial volume averaging, are removed by using fiber cleaning technique developed in this study. A refinement procedure using similarity measure is developed to allow branching. All the data were obtained from a GE 1.5T scanner.





Discussion/Conclusion: For the first time the concept of a stable voxel is introduced and the stability property of diffusion ellipsoid is explored and reported. Stability of a voxel is determined not only by its own principal eigenvector (PEV) but also by the PEV of the closest voxels connected to it. Stable Fiber Mass (SFM) maps are compared with FA color maps. Both B0 as well as FA reference images generated from DTI are of a very low resolution, which makes manual placement of ROIs a serious challenge. To this end, SFM provides a map consisting of only true colors which are much less in number than those of the FA color map set ($256^3 >> 2^3$) and hence makes very small structures clearly visible. Keeping the coloring scheme of SFM as that of the FA color map puts it in an obvious extra advantage over the FA color map. PEVFS scheme uses fiber tractography for segmentation but the threshold values (such as FA threshold and the inner product threshold) are not being used during segmentation: because it might lead to a loss of data and flawed tracking afterwards; and because FA is a quantity for analysis too; using it for segmentation could, in principle, lead to systematic error. Technique is demonstrated on 1.5-T whole brain DTI, but it can operate on other field strength MR scanners. Methodology and Results of the proposed method have been validated for a number of control and patient data by experienced radiologists and in publications [7, 8, 9, 10] (Table).



Regions	FA (Mean ± SD)	Regression Coefficients		Model Diagnostics		
		a_0	a_1	R^2	F	Significance
CC	0.34 ± 0.04	0.32	0.02	0.61	78.05	< 0.001
Right SLF	0.27±0.03	0.24	0.02	0.61	62.46	< 0.001
Left SLF	0.27±0.04	0.24	0.02	0.68	83.13	< 0.001
Right ILF	0.30±0.04	0.27	0.02	0.50	39.31	< 0.001
Left ILF	0.31±0.04	0.28	0.02	0.49	38.83	< 0.001
Right CG	0.26±0.03	0.25	0.02	0.62	66.35	< 0.001
Left CG	0.27±0.04	0.26	0.02	0.48	38.23	< 0.001
Right FX	0.27±0.03	0.26	0.01	0.44	26.12	< 0.001
Left FX	0.27±0.03	0.26	0.01	0.37	44.21	< 0.001

References: 1) Mori S. et al. Annals Neurology 45:265(1999). 2) Mori S. et al. MRM 47:215-223(2002). 3) Catani M. et al. Brain; 126: 2093-2107(2003). 4) Concha L. et al. AJNR Am J Neuroradiol; 26: 2267–2274(2005). 5) Mori S. et al. Elsevier (2005). 6) Wakana S. et al. NeuroImage; 36: 630–644(2007). 7) Agarwal S., Gupta RK, Rathore RKS et al. ISMRM 2009(3540). 8) Trivedi R., Agarwal S. et al. ISMRM 2009(3422). 9) Trivedi R., Agarwal S. et al. ISMRM 2009(492). 10) Trivedi R., Agarwal S. et al. ISMRM 2009(493).