Estimation of Multiple Fibre Orientations using Convex Optimization

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Introduction

Recent technical advances allow the acquisition of diffusion weighted imaging (DWI) with higher b-values and high angular resolution, suggesting the possibility of considering models that go beyond the diffusion tensor (DTI) [1] and capture complex microstructure such as the crossing of white matter fibre tracts. Some of these alternative models are: Multiple Tensors [2], PAS [3], Higher Order Tensors [4], Q-ball [5], etc. However, some of these methods are complex and have large numbers of degrees of freedom, that may lead to the detection of spurious components. To overcome this limitation, we develop a multiple-tensor model that uses concepts from Convex Optimization [6] to avoid overfitting and find only a few fibre orientations per voxel. In order to evaluate the robustness of the method across b-values we used datasets from post mortem brain tissue.

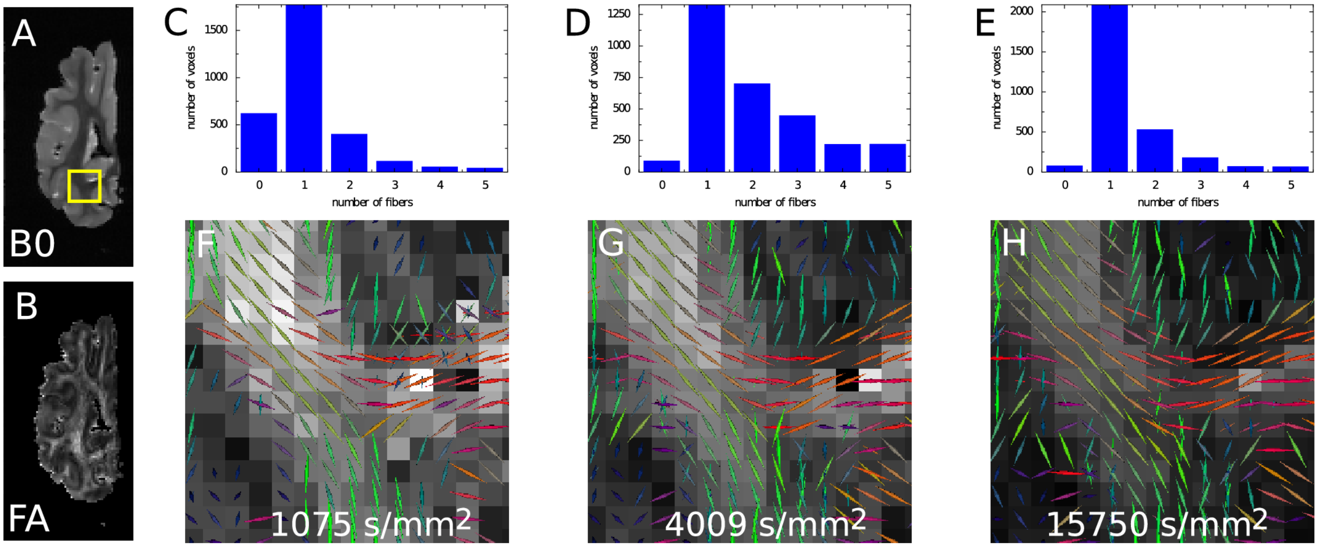
Methods

We model DWI datasets as a superposition of tensors oriented in different angular directions on the unit sphere and a single isotropic compartment: $\frac{S(b,g_i)}{S_0} = \sum_{j=1}^{N-1} f_j \exp(-b g_i^T D_j g_i) + f_0 \exp(-bd)$, where all the *N-1* diffusion tensors *D* are axially symmetric, have the same shape, but their principal directions are distributed over the surface of the sphere (a similar approach was explored in [7]). The degrees of freedom are the weights of the compartments *f*. Now, if *K* is the number of non-collinear DW directions used, and *N*>*K*, there are more unknowns than equations and we must include a penalization for the number of compartments being used. Penalizing with the sum of the weights *f*, the estimation is posed as a regularized least-squares problem with nonnegativity constraint [6]. This regularization favors sparsity (only a few coefficients *f* are going to be nonzero). The minimization functional is convex and doesn't have local minima. It can be solved using a standard interior-point algorithm that finds the unique solution in less that 0.15 sec per voxel in a Pentium IV 1.8 Ghz computer.

Diffusion weighted imaging was obtained in a perfusion fixated pig brain on an experimental 4.7T Varian Inova scanner (see [8] for a complete description). Seven DWI datasets with increasing b-values were obtained: 1075, 2475, 3069, 4009, 5911, 8181 and 15750 s/mm2. Parameters: TE: 67.8 ms; TR: 2500 ms; FOV: 65x32 mm; matrix: 128x64; 5 slices; voxel size: 0.51x0.51x0.5 mm3 . Diffusion parameters were: DELTA: 33.5 ms; delta: 27 ms. Each DWI dataset consisted of 3 non-dw and 61 (non-collinear directions) DW image volumes. A NEX=4 resulted in a SNR of 21.

Results

Figure 1 shows results for datasets acquired with three extremely different b-values: 1075, 4009 and 15750 s/mm2. Figs. 1 FGH show fibre orientations reconstructed by the proposed method (*N*=252) for the small region indicated with a yellow square in Fig. 1A (non-dw image). Principal as well as some secondary fibre orientations are robustly detected and spatial coherence is observed across b-values. The histograms (Figs. 1 CDE) indicate that for intermediate b-values (4000-8000 s/mm2), comparatively more voxels (in GM and CSF regions) with more than one orientation are found. These orientations are associated to extremely low weights *f*.



Reconstruction using regularized multi-tensor model was able to detect crossing fibres with b-values as small as 1000 s/mm2 (Fig. 1F).

Discussion

We demonstrate a fast multi-tensor extension of DTI that can be posed as a convex optimization problem, and is able to extract consistent fibre directions from DWI. The method was able to extract multiple fibre orientations, and show consistency as the b-value was varied. Results suggest that the reconstruction can be further improved by using a denoising algorithm before the estimation. The multiple fibre orientation found by this method could be used by tractography algorithms for better connectivity maps and tract delineation. Additionally, this method provides an importance estimate of each anisotropic component within a voxel by their weights which might be beneficial in tractography when streamlining through complex regions.

References

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