A REGULARISED TWO-TENSOR MODEL FIT TO LOW ANGULAR RESOLUTION DIFFUSION IMAGES

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Introduction

Partial volume causes artefacts in Diffusion Tensor Imaging (DTI) that limit our ability to resolve crossing fibres. Given that routine clinical use of high angular resolution diffusion imaging is still tentative, a simplified two-tensor model to resolve fibre crossings from conventional DTI datasets (32 diffusion sensitizing directions, b=1000 s/mm^2) is presented. To overcome the problems of fitting multiple tensors, a model that exploits the planar diffusion profile in regions with fibre crossings [1] was utilised. A spatial regularisation scheme was applied to reduce noise artefacts, which can be significant due to the relatively low number of acquired images, as well as artefacts arising from model inaccuracies.

Methods

Geometrically Constrained Two-tensor Model: Intravoxel crossing of two fibres is characterized by a planar diffusion profile [1]. Such profiles can be decomposed to two prolate tensors, whose principal eigenvectors provide the orientations of the crossing fibres. Furthermore, these orientations lie on the plane defined by the primary and secondary eigenvectors of the single tensor model [1]. Assuming tensor cylindrical symmetry, common principal eigenvalues and secondary eigenvalues that are equal to the third DTI eigenvalue, Peled et al introduced a 4-parameter two-tensor model [1]. This model has been found through simulations appropriate for voxels that have a relatively high planar index Cp [1].

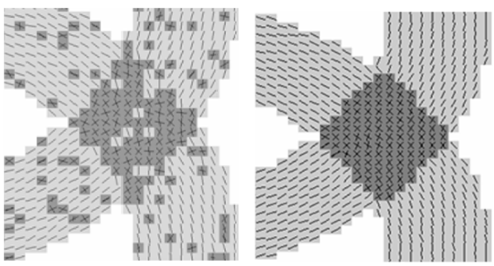

Figure 1

Spatial Regularisation of Orientations: Our simulations (Figure 1) showed that the above model is quite sensitive to noise, especially when few DW directions are used. Therefore, we applied a regularisation scheme, which was based on relaxation labeling (RL). RL is an iterative method that assigns to a voxel *i* one of *L* predefined labels. Assignment is based on the support dP_{ij} that a label *j* gets from the neighbors of voxel *i*. In our case, we used a set of basis directions to convert the two-tensor model of [1] to many one-parameter models, by making the orientation parameters equal to the set elements. That gave us N models, N being the basis set cardinality. These models acted as N labels for regularization. Utilising RL, we could then select from amongst these N models those that preserve continuity of orientations across neighbors, by defining a support function that fulfilled this condition.

Model selection: Instead of using a threshold on the Cp to identify regions of fibre crossings, as suggested in [1], we regularised the model selection mask. RL was used to preserve continuity of planar regions in a neighborhood. That way, voxels were planar only when their neighbors were also planar. Voxels with a high mean diffusivity or high fractional anisotropy (FA) were considered CSF or WM respectively, and were excluded from the model selection procedure.

Data Acquisition and Processing: Scans were performed on a healthy subject that gave informed consent using a single-shot, spin-echo, echo-planar, DW sequence (acquisition matrix 112x112 with in-plane resolution 2x2 mm, 2 mm slice thickness, TE=60 ms, TR=9500 ms) in a Philips 3T Achieva clinical imaging system. A parallel imaging factor of 2 was used. Three non-DW and 32 DW images were acquired at b=1000 s/mm^2, with the total scanning time being less than 6 minutes. The SNR of the non-DW image was 18.8 in the white matter. Images were corrected for eddy current distortion using FSL [3] and the single tensor model was fit as described in [4]. Two-tensor models were fit using a downhill simplex algorithm.

Tractography: Streamlines were generated using two-tensor or DTI orientation estimates, where applicable, as input to CAMINO [5].

Results

Figure 1 presents the result of applying the two-tensor model, with and without regularisation, to a simulated fibre crossing with an SNR=10. Dark gray indicates regions identified as planar, where the two-tensor model was fit, while fibre orientation estimates are plotted as lines. When regularisation was applied, both the region of fibre crossing and the crossing orientations were better resolved. Figures 2 and 3 show tractography results using from left to right the single tensor model, the non-regularised two-tensor model, and the regularised two-tensor model. The streamlines are superimposed on coronal views of FA maps. In Figure 2, the seed ROI is placed in the internal capsule of the left hemisphere. Even if the non-regularised two-tensor model resolves the crossing at the level of the pons and does not allow propagation to the right hemisphere, improvements are even more profound with the regularised approach, where fanning of the cortico-spinal tract to the cortex is shown. In Figure 3, the seed ROI is placed in the body of the corpus callosum close to the mid-sagittal plane, with the results from the regularised two-tensor model exhibiting the greatest fanning.

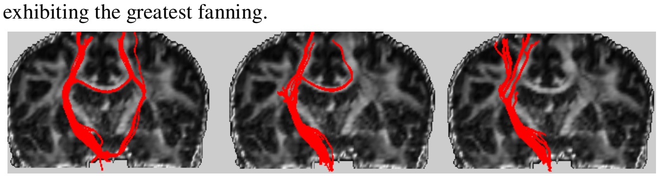

Figure 2

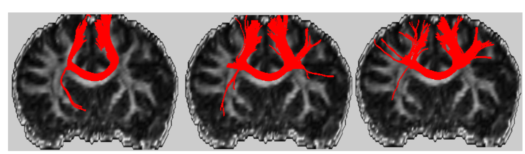

Figure 3

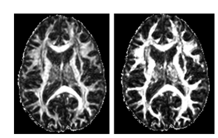

Figure 4

Figure 4 shows on the left an FA map calculated from the eigenvalues of the DTI model, while a revised anisotropy map is shown on the right. In the latter, the FA is equal to its DTI value in non-planar regions, while the new eigenvalue estimate of the regularised two-tensor model is used in planar regions, as these are identified by the regularised model selection mask. Higher FA values (mean 0.6618, st. deviation 0.1469) were observed in regions identified as containing crossing fibres, compared to the FA value (mean 0.4548, st. deviation 0.1478) from the single tensor fit in the same region.

Discussion

A regularised two-tensor model that resolves complex intravoxel structures using low angular resolution DW data was presented. The regularisation scheme was based on relaxation labeling and on a discrete set of basis directions. Simulations showed (results not presented) that the results in a noisy environment (SNR<20) are not very sensitive to the fineness of the set, as long as the step size is smaller than 10^o, given that the crossings that can be resolved have a larger angle separation (>50^o). Regularisation improved direction estimates in cases where the two-tensor model suffered from noise artefacts in simulated data. It also improved tractography results obtained from in vivo DTI images. Apart from directions, revised anisotropy and diffusivity information could be obtained using full brain coverage datasets acquired in less than 6 minutes.

References: [1] Peled S, Friman O, Jolesz F, Westin CF. Magn Reson Imaging 2006;24(9):1263-1270**,** [2] Rosenfeld A, Hummel RA, Zucker SW. IEEE Trans Systems, Man, and Cybernetics 1976; 6: 420-433. [3] Smith SM, Jenkinson M, Woolrich MW et al. NeuroImage 2004; 23(S1):208-219, [4] Basser PJ, Mattiello J, LeBihan D. J Magn Reson B 1994;103(3):247-254, [5] Cook PA, Bai Y, Nedjati-Gilani S et al. 2006 ISMRM Meeting; Seattle, WA, USA, p. 2759.

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