Exploiting peak anisotropy for tracking through fanning structures

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Introduction Probabilistic Index of Connectivity (PICo) [1] tractography generates a map of connectivity of each voxel to a specified seed voxel. The original PICo algorithm uses a Gaussian distribution to model the uncertainty of fibre-orientation estimates obtained from diffusion tensor (DT) estimates. Parker and Alexander [2] generalize PICo to use PASMRI reconstruction [3] by using the peaks of the PAS functions as fibre-orientation estimates and the peak sharpness to predict uncertainty in the estimate. Cook et al [6] show that the Watson distribution [7] is a better model of uncertainty than the Gaussian PDF used in [2] and that further improvements come from using the Bingham distribution, which models anisotropy in the uncertainty. Here, we propose a further generalization that uses information about the sharpness and anisotropy of the peaks of the functions generated using multiple-fibre reconstruction algorithms to improve tracking through complex white-matter architecture such as fanning structures. We provide preliminary results on human brain data and compare them with results from the original method and the generalization described in [2].

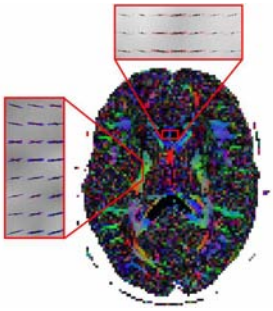

Figure 1 – Axial slice through a healthy human brain showing the fractional anisotropy of the PAS Hessian at the dominant peak. The colour encodes the principal direction of the cross-section (Hessian principal eigenvector) in the usual way, so red indicates a peak is broad in the left-right direction. The expanded regions show the PAS functions for the corpus callosum(top) and the cortico-spinal tract (left).

Methods Here, we combine the Bingham distribution with the PICo generalization in [2] to allow us to capture extra information about the uncertainty of the fibre-orientation estimates of multi-fibre reconstructions. We hypothesize that the shape of the peaks of the PAS or ODF function reflects the underlying spread of fibre orientations and thus the uncertainty in the single estimate the peak provides. The shape of the PAS or ODF function peaks can be characterized using the Hessian, or matrix of second partial-derivatives, at the peaks. Figure 1 shows the magnitude and direction of the anisotropy of the dominant peak from the PAS in each voxel. As expected, the anisotropy at the centre of the Corpus Callosum low, since the fibres spread equally in all directions. However, the PAS peaks in the Cortico-Spinal Tract (highlighted with the left box), which fans at this level, have highly anisotropic peaks.

As in previous PICo implementations, we construct the lookup table using simulations on functions with known peak directions. Specifically, for a large number of noisy trials we reconstruct fibre-orientation estimates and associated Hessian matrices from the multiple-fibre reconstruction of choice. In each trial, we compute the deflection between the reconstructed and true directions and collect deflections into bins with similar Hessian eigenvalues. We fit the parameters of the Bingham distribution in each bin containing 50 or more samples. Finally, we fit a quadratic surface to the log of each Bingham parameter as a function of the Hessian eigenvalues. This calibration is described in detail in [8].

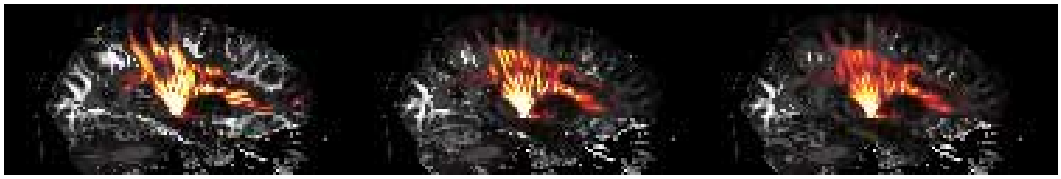

Figure 2 – probability maps from DT PICo (left), PAS PICo using the Watson distribution (centre) and PAS PICo using the Bingham distribution (right).

Experiments In this section, we illustrate the new framework using PASMRI reconstruction in a normal human brain data set and compare results with those using DTI. We emphasize however, that the general framework we outline above can exploit other multiple-fibre reconstructions using exactly the same procedure.

We acquired diffusion-weighted images with 61 gradients and a single b=0 image. The diffusion weighted imaging was performed on a Philips 3T Achieva scanner using a SE echo-planar imaging sequence with TE=54ms, TR=11884ms and b=1200 smm^{-2}. A 112×112 acquisition matrix was used, which was interpolated to 128×128. In total, we imaged 60 2.1mm axial slices at an in-plane reconstruction resolution of 1.875mm. We performed distortion-correction using the method described in [9]. The total imaging time was approximately 28 minutes. The averaged SNR in the white-matter regions of the b=0 image is 20. The calibration dataset contains one and two fibre populations, which are modelled using diffusion tensors.

We reconstruct using PASMRI and estimate the fibre-orientations and Hessians of the dominant peaks. We run 5000 PICo iterations from the base of the cortico-spinal tract using the calibration from the method described above. The experiment was repeated using the original diffusion tensor approach and Parker and Alexander's multi-fibre approach using PASMRI, both adapted to use the Watson distribution, for comparison.

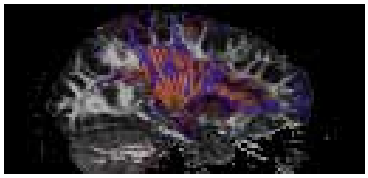

Figure 3 – difference map between the Watson and Bingham PICo maps. Red indicates that the Watson probabilities are higher whereas blue indicates that the Bingham probabilities are higher.

Results Figure 2 shows PICo maps from each experiment. Although DT PICo gives high probabilities of connection, there are large 'holes' in the structure which result from fibre crossings. In the original PAS PICo algorithm using the Watson distribution, the connection probability is more uniform across the fanning structure. Visually, the results from the Bingham PDF implementation appear similar, but smoother than the results from Watson PDF implementation. The difference map in figure 3 shows that the results from using the Bingham distribution have higher connection probabilities where the Watson results have gaps, which suggests a better overall representation of the fanning structure. Also, the Bingham PICo map shows less false positives in the Corpus Callosum (not shown here).

Discussion and Conclusions We have introduced a method that extends the PICo tractography algorithm to account for complex fibre configurations. When comparing the PICo map from the new technique to the PICo map from the method described by Parker and Alexander in [2], we see that there are structured differences between the maps. Although objective assessment is difficult in the absence of ground truth, theoretical properties of the Bingham suggest that the generalized technique presented here is a better approach. Our results indicate that PICo tractography performed using PASMRI gives better results then using diffusion tensor data. The approach extends naturally to other multiple-fibre reconstructions. These implementations of PICo are all available in Camino (www.cs.ucl.ac.uk/research/medic/camino), an open-source diffusion toolkit.

References and Acknowledgements [1] Parker, G.J.M. *et al*, JMRI, 18, pp.242–254, 2003. [2] Parker, G.J.M. and Alexander, D.C., Phil Trans of Roy Soc, 2005. [3] Jansons, K.M. and Alexander, D.C., Inverse Problems, 19, pp. 1031-1046, 2003. [4] Tuch, D.S., MRM, 52, pp. 1358-1372, 2004. [5] Tournier, J-D *et al*, NeuroImage, 23, pp. 1176-1185, 2004. [6] Cook, P.A. *et al*, Proc. IEEE ISBI, pp. 332-336, 2004. [7] Mardia, K.V. and Jupp, P.E., "Directional Statistics", Wiley, 2000. [8] Seunarine, K.K. *et al*, MIUA, 2006. [9] Embleton K.V. *et al*, Proc ISMRM, pp.1070, 2006.

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