Exploiting the fibre-orientation distribution for probabilistic tractography

K. K. Seunarine[1], S. Nedjati-Gilani[1], M. G. Hall[1], P. A. Cook[2], and D. C. Alexander[1]

[1]Department of Computer Science, University College London, London, United Kingdom, [2]Department of Radiology, University of Pennsylvania School of Medicine, Philadelphia, PA, United States

Introduction: Probabilistic tractography [1,2,3] generates a map of connectivity of each voxel to a specified seed voxel. Probabilistic tractography algorithms typically use models of the uncertainty in each fibre-orientation estimate to provide fibre-direction samples for multiple repeats of the streamline tractography process. The assumption is that these uncertainty models reflect the true underlying distribution of fibre-orientations in each voxel, but those distributions may differ significantly in practice. Here, we present an initial study into using the actual fibre-orientation distribution directly and show comparative results.

The Probabilistic Index of Connectivity (PICo) [1] algorithm uses synthetic data to learn a mapping between the fractional anisotropy (FA) of the diffusion tensor (DT) and the width of a Gaussian model of uncertainty on the fibre-orientation estimate obtained from the DT. Cook et al [4] show that the Watson distribution [5] is a better model of uncertainty than the Gaussian PDF used in [1] and further improvements come from using the Bingham distribution, which models anisotropy in the uncertainty. In this work, we use a similar calibration procedure to learn a mapping from the DT to the true distribution of fibre-orientations and use that for probabilistic tractography. Results show significant differences to the standard techniques.

Methods: The calibration constructs a mapping between features of the fitted DT and the parameters of a Bingham distribution, which describes the distribution of fibre orientations. We learn the mapping from synthetic data for which the true fibre-orientation distribution is known. The model for the synthetic data is a 20^3 grid of sub-voxels each containing an instance of Behrens' ball and stick model [2]. The volume fraction and diffusivity is constant over the grid. The orientation of each anisotropic component is along the radial line through the centre of the sub-voxel from a point at distance *d* from the centre of the grid (see figure 1). (We can model bending configurations using tangential, rather than radial, directions.) The parameter *d* controls the level of fibre divergence in the model. To obtain configurations that fan out more in one direction than the other we reduce the dimension of the grid in one dimension so only the central slices remain. We synthesize diffusion-weighted measurements in each sub-voxel of the grid and take the average over the whole grid to obtain measurements from a single voxel containing the whole structure.

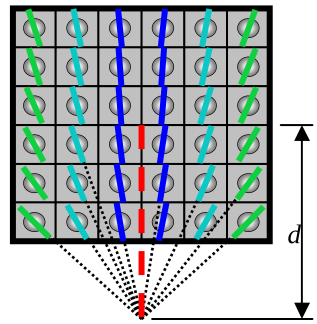

Figure 1. An illustration of the sub-voxel model. The orientations are aligned to the line that passes through the centre of the sub-voxel from point at distance *d* from the centre of the grid.

Rician noise is added to the synthetic measurements at a level comparable to the scanner data. We fit the DT to the measurements and compute two shape features: the FA and the secondary FA, which is the anisotropy perpendicular to the principal direction, i.e., of the two smallest eigenvalues. The full set of orientations in the sub-voxel grid provide the true fibre-orientation distribution, which we model using a Bingham distribution. For various combinations of fibre divergence and divergence anisotropy, we compute the FA and secondary FA of the fitted DT and the parameters κ_1 and κ_2 of the Bingham model of the fibre orientations. We fit a linear model relating the anisotropy features to the Bingham parameters, which we use during tractography to predict the true distribution of fibre orientations from the shape of the diffusion tensor.

Experiments: We compare PICo maps using the fibre-orientation uncertainty (traditional method [4]) to those using the fibre-orientation distribution (new method).

We acquired diffusion-weighted images with 61 gradients along with 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 s mm^{-2}. A 112×112 acquisition matrix was used, which was interpolated to 128×128. In total, we imaged 60 axial slices. 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 consists of data synthesized from sub-voxel grids with size $20 \times i \times 20$, $i=1,\ldots,20$ for various *d* in the range [0, 4000].

We fit the DT in each voxel of the brain data, compute FA and secondary FA and use the mapping to predict the Bingham parameters of the fibre-orientation distribution. Tracts seeded at the base of the cortico-spinal tract are generated for 5000 iterations. The experiment was repeated using Cook et al's extension to PICo [4], which uses the fibre-orientation uncertainty (traditional method).

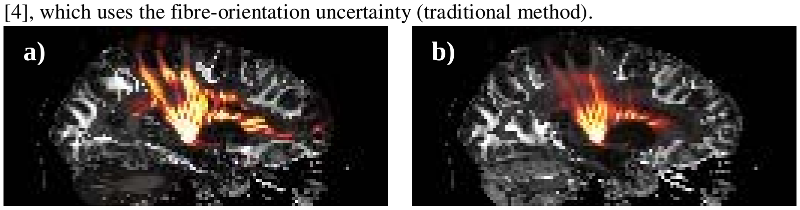

Figure 2. PICo connectivity maps from PICo using a) the fibre-orientation uncertainty and b) the fibre-orientation distribution.

Results: Although DT PICo gives high probabilities of connection, there are large 'holes' in the structure where there are fibre crossings, as demonstrated in figure 2. The connectivity maps from the new method that uses the fibre-orientation distribution show significant differences to the original algorithm that uses the fibre-orientation uncertainty. Even though the connection probabilities are lower with the new method, they are more evenly spread over the descending motor pathways.

Conclusions & Discussion: We have introduced a method that extends the PICo tractography algorithm to exploit the true fibre-orientation distribution in each voxel. When comparing the PICo map from our technique to the PICo map from the method described by Cook et al in [4], we see that there are structured differences between the maps. Our results show that PICo tractography performed using knowledge of the fibre-orientation distribution gives significantly different results to those from using uncertainty alone. Here we show only a simple application of the idea of using true fibre-orientation distributions in PICo instead of models of uncertainty on individual fibre directions. The diffusion tensor model is too simple to distinguish many kinds of bending and fanning configurations. However, more sophisticated reconstruction algorithms, such as PASMRI [7], Q-Ball [8], SD [9], etc, are more sensitive to differences in each configuration. The ideas we develop here extend naturally to exploit those techniques, which is the focus of further work.

References and Acknowledgements [1] Parker, G.J.M. *et al*, JMRM, 18, pp. 242–254, 2003. [2] Behrens, T.J.M. *et al*, JMRM, 50, pp. 1077-1088, 2003. [3] Jones, D.K. and Pierpaoli, C., MRM, 53, pp. 1143-1149, 2005. [4] Cook, P.A. *et al*, Proc. IEEE International Symposium on Biomedical Imaging, pp. 332-336, 2004. [5] Mardia, K.V. and Jupp, P.E., "Directional Statistics", Wiley, 2000. [6] Embleton, K.V. *et al*, Proc. ISMRM, pp. 1070, 2006. [7] Jansons, K.M. and Alexander, D.C., Inverse Problems, 19, pp. 1031-1046, 2003. [8] Tuch, D.S., MRM, 52, pp. 1358-1372, 2004. [9] Tournier, J-D *et al*, NeuroImage, 23, pp. 1176-1185, 2004.
We would like to acknowledge G. J. M. Parker and K. V. Embleton for providing the human brain data used in this work. This work is funded by the EPSRC grant GR/T22858/01