Application of Rotational Tensor Interpolation to Tractography

M. M. Correia[1,2], and G. B. Williams[2]

[1]MRC Cognition and Brain Sciences Unit, Cambridge, Cambridgeshire, United Kingdom, [2]Wolfson Brain Imaging Centre, Cambridge, Cambridgeshire, United Kingdom

Introduction: Diffusion MRI was the first imaging modality to allow the visualization of white matter fibre paths in vivo, and non-invasively. The process by which the white matter tracts are reconstructed from diffusion tensor data is called tractography. Tensor interpolation methods have often been used to improve the reproducibility and reliability of tractography results (e.g [1]). In this abstract we will introduce a new method for 3D tensor interpolation based on work by Batchelor [2], and use simulated data to compare its performance to well established methodologies.

Methods:

Rotational Interpolation: In [2] Batchelor *et al* describe a novel interpolation method between two positive definite tensors called rotational anisotropy. According to this method, the interpolated tensor, $\underline{D}(s)$, between tensors $\underline{D}_1$ and $\underline{D}_2$ will be given by:

$$\underline{D}(s) = \underline{R}(s)\underline{\Lambda}_1^{s}\underline{\Lambda}_2^{(1-s)}\underline{R}(s)^T$$

where $\underline{\Lambda}^s_i$ is a diagonal matrix with the eigenvalues of tensor $\underline{D}_i$ along the diagonal, and $\underline{R}(s)$ is given by:

$$\underline{R}(s) = \underline{R}_1(\underline{R}_1^T\underline{R}_2)^s$$

and R_i is the rotational matrix such that $\underline{D}_i = \underline{R}_i\underline{\Lambda}_i\underline{R}_i^T$. Figure 1 compares the diffusion ellipsoid profiles obtained with standard (linear) and rotational interpolation between the light blue (s=0) and the dark blue (s=1) tensors, which have the same eigenvalues but orthogonal principal axes. A simple approach to three-dimensional interpolation using rotational interpolation, is to consider only the eight voxels closest to the point of interest, and apply rotational interpolation along one coordinate in space at a time.

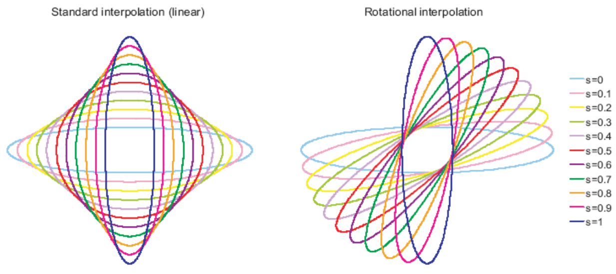

Figure 1 – Rotational interpolation *vs* standard interpolation.

Digital phantoms: For the purpose of this study, we developed a digital phantom tool that can simulate the diffusion-weighted signal from a fibre of circular cross-section and constant anisotropy aligned along a semicircular path. A semicircular model was chosen to allow a simple simulation of the more highly curved sections of a nerve fibre [3]. Different values for step-length, SNR, fibre radius, fibre cross-section, and fibre anisotropy were considered.

Tracking algorithm: The diffusion tensor for the seed voxel is calculated by fitting the image intensities for each gradient sampling direction to the single tensor model. The normalised principal eigenvector of the diffusion tensor is then computed by tensor diagnolisation. The tracking algorithm moves along this direction for a distance equal to the step length, defining the next point along the path. At this stage, the new direction along which the path will proceed is calculated. We will compare four methods: no interpolation, B-spline interpolation [1], B-spline approximation [1], and rotational interpolation. After the new direction has been identified, the tracking algorithm moves a distance equal to the step length along this direction. The algorithm will proceed iteratively as described, until one of the stopping criteria is met.

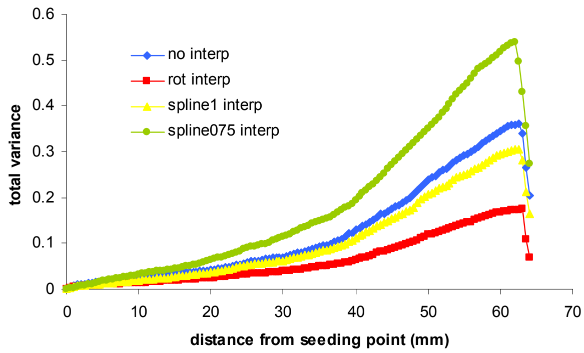

Figure 2 – Results obtained for σ_{total} for a fibre with radius =20 voxels, cross-section = 3 voxels, FA=0.5, SNR=25, and a step length of 0.5 voxels.

Data Analysis: In order to evaluate the quality of the results produced by a particular algorithm, for each combination of model parameters and each tracking algorithm, we calculated the following output parameters:

(1) the distance between the end point of the computed track and the true end point of the simulated fibre;

(2) the total standard deviation (sd) between the points obtained for each of 100 tracts, as a function of the distance from the seeding point. We first calculated the standard deviation for the x, y and z coordinates independently (σ_x, σ_y, σ_z) for each iteration of the tracking algorithm, and the total sd was then defined as $\sigma_{total} = \sqrt{\sigma_x + \sigma_y + \sigma_z}$. This metric is indicative of how reproducible a track is.

Experimental data: Brain scans were obtained for a healthy volunteer using a Siemens 3T Trio scanner. Diffusion weighted images were acquired along 63 gradient directions (b=1000 s/mm^2), as well as one b=0 image. Tracts were generated using rotational interpolation to define the tracking direction. The distance between seed points was 4mm, and the step length was 1mm.

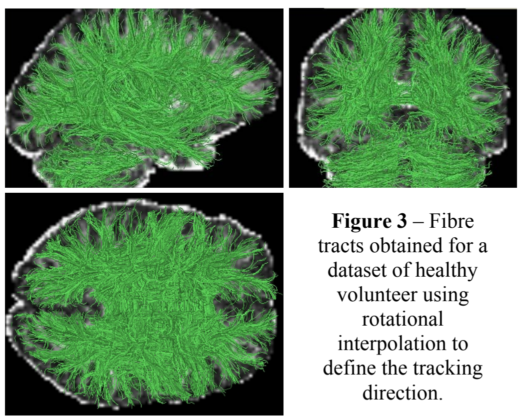

Figure 3 – Fibre tracts obtained for a dataset of healthy volunteer using rotational interpolation to define the tracking direction.

Results and Discussion: Our results showed that the accuracy of tractography can be increased by tensor interpolation, especially for high levels of noise. In addition, the best overall results were obtained with rotational interpolation (an example is shown in Figure 2). Figure 3 shows the tracts obtained for the experimental dataset, showing that rotational interpolation produces reasonable tracts when applied to brain data.

References: [1] MRM 44: 625-632, 2000. [2] MRM 53: 221-225, 2005. [3] MRM 47: 701-708, 2002.