ND-Track: Tractography utilising parametric models of white matter fibre orientation dispersion

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Target audience: Researchers in the field of diffusion weighted magnetic resonance imaging interested in new tractography methods.

Purpose: This work develops a tractography algorithm to leverage fibre dispersion estimates derived from fitting parametric models of orientation dispersion to diffusion data. Tractography techniques are powerful tools to probe white matter (WM) connectivity non-invasively. Most current techniques follow a small number of discrete directions per voxel to identify WM connections. This approach addresses the limitation of traditional DTI-based tractography for regions with crossing fibres. However, it remains an oversimplification for regions with fanning and bending configurations, where the underlying fibre orientation distributions are continuous rather than discrete [2]. Following only a discrete set of directions in this case misrepresents the underlying anatomy and is likely to result in false negative connectivity estimates. Recent parameterized models of fibre dispersion represent such sub-voxel fibre architecture more realistically and provide more accurate estimates of dispersion than non-parametric techniques such as spherical deconvolution, which are vulnerable to noise [3]. Here, we present a new tractography algorithm, hereby referred to as ND-Track (Neurite Dispersion Tracking), that leverages directional information gathered from parametric models of dispersion. We investigate the advantages of tracking with dispersion measures on a simple phantom and in *in-vivo* data, tracking through the coronal radiata, a region known to exhibit a significant degree of fibre dispersion. We further demonstrate that this approach does not compromise the tracking of the WM pathways for which the standard technique works well.

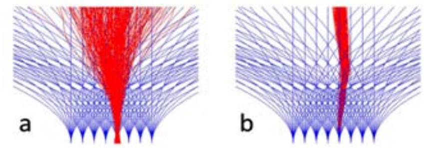
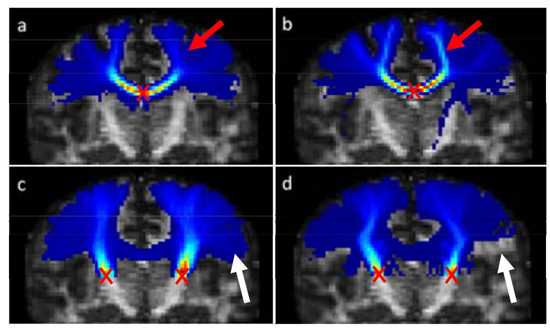


Figure 1: Synthetic phantom exhibiting dispersion (blue lines), tracking results (red lines)

Methods: We aim to sample directions from the dispersion patterns in each voxel while maintaining smoothness to produce biologically plausible tracks. Starting from a seed point, ND-Track propagates a streamline by sampling permissible directions in each voxel it passes through. Orientation distribution functions (ODF) modelling dispersion are derived via the NODDI technique [1]. NODDI yields a dispersion pattern in each voxel in the form of a Bingham distribution. For a streamline entering a voxel with direction $\boldsymbol{v}$, a set of 500 candidate directions are sampled from the local Bingham distribution via a rejection sampling algorithm. The candidate directions are then weighted by a Watson prior distribution, with mean direction $\boldsymbol{v}$. This favours candidate directions that deviate minimally from the previous step while adhering to the locally permissible set of fibre orientations. One of these candidate directions is then selected probabilistically as the next propagation direction and the track propagated in this direction by a step size of 1mm, or half a voxel. This ensures the propagation of smooth streamlines that follow directions sampled directly from dispersion-modelling distributions. Tracks are terminated upon entry into a grey matter mask, derived from a Freesurfer parcelation. All *in-vivo* tracking results are displayed as maximum intensity projections thresholded at 1% of maximum intensity.



ND-Track **CSD**

Figure 2: Tracking results from seed regions in the CC and the IC, cross-hairs show locations of seeds

Data: The diffusion data was acquired from a healthy male subject on a clinical 3T Philips system with isotropic voxels of 2mm. It consists of one 30 direction shell with *b*-value of 1000 s/mm^2, a 60 direction shell with *b*-value 2000 s/mm^2, and 9 b=0 images with SNR about 20.

Results and Discussion: Figure 1 a) shows how the algorithm performs on a numerical phantom exhibiting dispersion, Figure 1 b) shows the result of standard PICo tracking for comparison [4]. The blue lines outline the synthetic fibre structure of the phantom and the red lines show the tracking result from a single seed at the base of the image. The standard PICo tracking algorithm performs poorly on this dispersing phantom, only covering a very narrow range of connections. By utilising models of dispersion, ND-Track recovers much more of the potential connections of the phantom. Figure 2 shows a comparison of results of ND-Track with tracking results from constrained spherical deconvolution (CSD) using MRTrix from seed regions in the midbody of the corpus callosum (CC) and the internal capsule (IC). The techniques give comparable results, however two notable differences can be identified. CSD tracking more heavily favours the characteristic vertical connections from the CC, as indicated by the red arrows in Figures 2a and 2b. Furthermore, ND-Track gives a more even representation of connections spread throughout the cortex, this is most clear in Figures 2c and 2d, the white arrows indicate a region where lateral cortical connections are covered better by ND-Track. Figure 3 shows the major white matter pathways, for which the standard tracking techniques work well, successfully tracked by the algorithm. The images show successful recovery of the inferior longitudinal fasciculus (ILF), the superior longitudinal fasciculus (SLF), the cingulum (Ci) and the occipito-frontal fasciculus (OF).

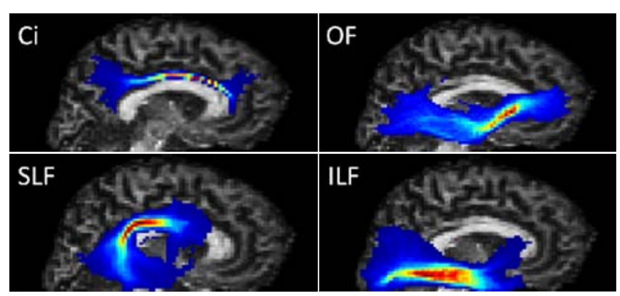


Figure 3: ND-Track results on major white matter structures

Conclusion: We present a tractography algorithm leveraging distributions modelling dispersion to propagate streamlines. ND-Track shows expected performance on major white matter structures and advantages in tracking through regions of fanning fibre structure, both in simple numerical phantoms and *in vivo* data. At this preliminary stage the algorithm does not consider crossing fibre configurations, however despite this limitation this preliminary investigation shows that results can be obtained comparable to state of the art multi-fibre techniques. In future work, a straightforward extension is planned to include multiple dispersing fibre populations per voxel.

References: [1] Zhang *et al*. NIMG12 [2] House & Panksy 1960 [3] Sotoripoulos *et al*. NIMG 12 [4] Parker *et al*. JMRI03