Improved Diffusion Tractography with the Funk-Radon and Cosine Transform

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Introduction:
Accurate white matter tractography depends on the accurate estimation of fiber orientations from the diffusion MRI signal. However, the accuracy of fiber orientation estimation has been limited by the confounding effects of multiple crossing fibers, as well as trade-offs in spatial resolution, signal-to-noise ratio, image contrast, and examination time. As a result, existing white matter fiber tractography results are often inaccurate and incomplete. These obstacles have limited existing diffusion MRI studies of the brain (Jones, 2010; Jbabdi 2011; Ciccarelli, 2008).

A common approach to tractography has been to acquire high-angular resolution diffusion imaging (HARDI) data, followed by processing via the Funk-Radon Transform (FRT) (Tuch, 2004; Descoteaux, 2007). While the FRT is widely-used, it has a number of theoretical limitations, and many alternative strategies have also been proposed (Aganj, 2010; Tournier, 2007). Unlike the FRT, which is purely linear, nonparametric, and can be characterized analytically, the alternative approaches are frequently nonlinear and/or require additional assumptions on the diffusion signal.

We have recently introduced a novel family of nonparametric linear transformations for data defined on the sphere, for which the FRT is a special case (Haldar, 2012). Another special case from this family, which we’ve named the Funk-Radon and Cosine Transform (FRACT), overcomes the theoretical limitations of the FRT while retaining all of its advantageous features (Haldar, 2012). The FRACT is fast to compute, can be completely characterized theoretically, and empirically has superior angular resolution to the FRT, though also has slightly more sensitivity to noise. This work describes our preliminary experience in comparing FRACT-based tractography with FRT-based tractography.

Methods:
Full-brain spin-echo EPI HARDI data was acquired with 2mm isotropic resolution at the USC Dana & David Dornsife Cognitive Neuroscience Imaging Center. 144 different diffusion encodings were acquired with a b-value of 2,000 s/mm^2. The measured data was modeled using a spherical harmonic representation, where the spherical harmonic coefficients were obtained using a regularized least-squares fitting procedure (Descoteaux, 2007). Orientation distribution functions were then computed for both the FRT and the FRACT. Computation was very efficient, due to the fact that the spherical harmonics are eigenfunctions of both the FRT and the FRACT (Descoteaux, 2007; Haldar, 2012). Subsequently, the orientation distribution functions were passed as inputs to the streamline tractography algorithm distributed with Diffusion Toolkit (Wang, 2007). Orientation distribution functions and tractography results are visualized in BrainSuite (Shattuck, 2002; http://www.loni.ucla.edu/Software/BrainSuite).

Results:
The first two figures show a comparison between orientation distribution functions estimated with the FRT and with FRACT. FRACT demonstrates significantly higher angular resolution and better-defined maxima, particularly in regions of significant white matter fiber crossings. The last two figures show a comparison of tractography results obtained with both methods, for an ROI sphere placed in the white matter core of the frontal lobe. The FRACT results are significantly more congruent with neuroanatomical expectations.
Conclusions:

Tractography based on the FRAC was compared with that of the conventional FRT. The higher resolution afforded by the FRAC enables better resolution of crossing fiber structures, and leads to more anatomically reasonable tractography results. We expect that the FRAC will prove useful in a wide range of HARDI studies. However, it should also be noted that the FRAC is one of the most basic transforms in the new family of transforms introduced in (Haldar, 2012), and it is anticipated that other members from this family will yield significant further improvements in the analysis of diffusion MRI data.

Modeling and Analysis Methods:
Diffusion MRI Modeling and Analysis

Abstract Information

References

Aganj, A. (2010), 'Reconstruction of the orientation distribution function in single- and multiple-shell q-ball imaging with constant solid angle', Magnetic Resonance in Medicine, vol. 64, 554-566.


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