ROBUSTIFYING PROBABILISTIC TRACTOGRAPHY BY USING TRACK ORIENTATION DISTRIBUTIONS

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Introduction: By extending the concept of track-density imaging (TDI) **[1] (**of a dense full-brain short-tracks tractogram **[2])** to also encode the *angular* distribution, a new kind of orientational information becomes available in each voxel (compared to the fiber orientation distribution (FOD)). In this work, we explore the idea of using this information anew for probabilistic tractography. We show results for data of challenging quality w.r.t. standard constrained spherical deconvolution (CSD) practice.

Methods: A single healthy subject was scanned in a Siemens 3T scanner, using a TRSE sequence, at 2.5x2.5x2.5mm³ isotropic voxel size. 10 non-DWI volumes (averaged) and 40 uniformly distributed DWI-directions at b=1000s/mm² were acquired. The data were processed by performing super-resolved constrained spherical deconvolution (super-CSD), using a spherical harmonic (SH) order of 8. A "***short-tracks***" tractogram consisting of 80 million tracks was generated by probabilistic tracking within a full-brain mask using the following parameters: stepsize = 0.2mm, min. radius of curvature = 1mm, min. track length = 15mm, ***max. track length = 30mm***, min. FOD amplitude to initiate tracks = 0.2, min. FOD amplitude to continue tracking = 0.1. The "***short-tracks***" strategy was chosen because it distributes track densities more evenly over the brain (rather than yielding artificially higher densities for longer tracts) **[2]**. In order to map complex track distributions, we extended the recently proposed track-density imaging (TDI) **[1]**: rather than simply adding a scalar "1", each track now contributes a full angular function to the voxels it intersects. To achieve this, each infinitesimal line element of a track is represented by an apodized point spread function (PSF) **[3]** (of maximum SH order 16), pointing along the local orientation of the track. A track's contribution to a voxel is calculated by averaging the PSFs of its line elements in the voxel (through integration along the track, divided by the length of the intersecting part of the track). The final track orientation distribution (TOD) is obtained by summing the contributions of each track in the voxel. The full process is illustrated in **Fig. 1**. While this technique is – just as TDI – amenable to super-resolution, we calculate the TOD in this work using the original voxel grid, so we can compare it more directly to the original FODs. Even though the TOD in each voxel has – by definition and construction – a completely *different meaning* as compared to the FOD, it is of a *similar qualitative nature* in the sense that both have sharp lobes in directions associated with white matter pathways. Per consequence we can also use the TOD to generate a new 80 million short-tracks tractogram and a new TOD (we refer to the former as TOD-1, the latter as TOD-2); the only difference in parameters is: min. TOD amp. to initiate tracks = 10000, min. TOD amp. to continue tracking = 5000 (both chosen to reflect the difference in magnitude between FOD and TOD). We then test the capability of FOD, TOD-1 and TOD-2 to guide a targeted tractography experiment: 10000 tracks are seeded in the genu of the corpus callosum (and this time, there is of course no max. track length). All implementation, processing and visualization was performed using MRtrix **[4]**.

Results: Some results are presented in **Fig. 2**. Because we deliberately chose to work with data of challenging quality relative to typical CSD recommendations (40 directions is not enough for regular CSD at SH order 8 and b=1000s/mm² provides only very limited angular contrast), the FODs display a good amount of spurious peaks and their main lobes' orientations show some random errors. The inherent continuity constraints of the (short tracks) tractogram, however, resulted in the elimination of most spurious peaks and a more coherent structure of TOD-1. A further, albeit more subtle, improvement along this trend can be seen in TOD-2. The quality of FOD, TOD-1 and TOD-2 is fully reflected in the targeted tractography outcome: less false positive/negative tracks and more coherent bundles are observed. We also experimented with datasets of different quality as well as several software phantoms, and saw consistent – often drastic – improvements (*results not shown*).

Discussion: There are many ways to *understand* the meaning and effectiveness of using the TOD for tractography, but we particularly like to highlight a conceptual similarity with the iFOD2 strategy **[5]**: both try to *"plan ahead"*. iFOD2 takes the joint probability along each candidate path into account. The TOD has inherent information on *the support of directions by the surroundings*: it can guide a track to where it is most likely to find more continuous structure over a longer distance.

Conclusion: The short-tracks TOD shows great angular structure, contrast and coherence in continuous structures, and serves as a robust basis for fiber tractography.

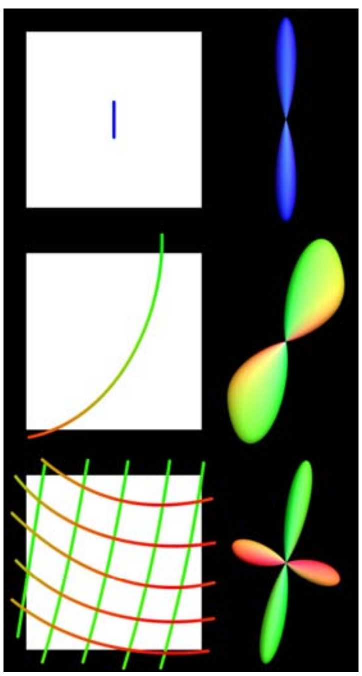

Fig.1:
Top: an infinitesimal line element, represented by an apodized PSF.
Middle: a part of a track, represented by the averaged PSFs of its line elements.
Bottom: a group of tracks, represented by the sum of its tracks' contributions.

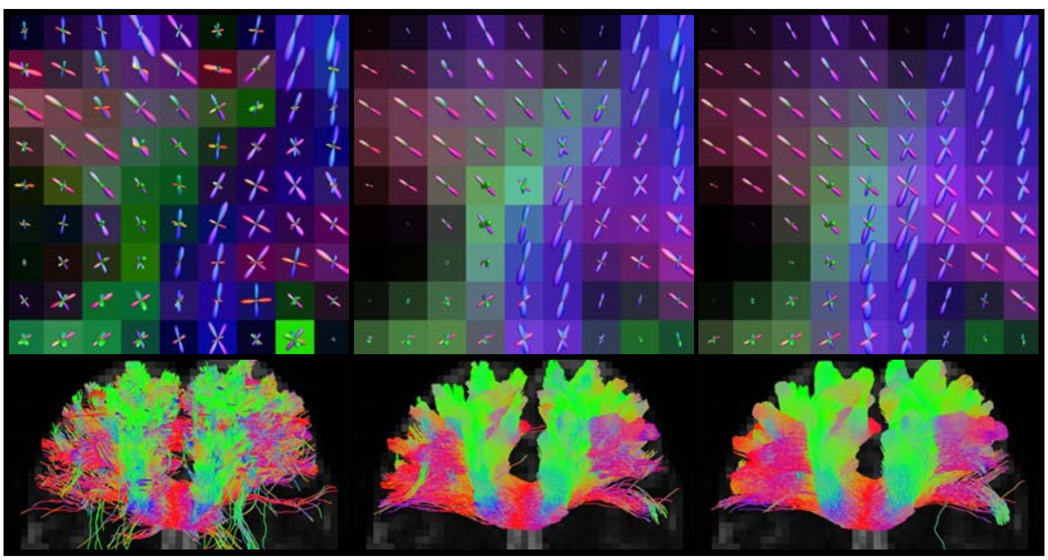

Fig.2: ***Top***: comparison of ***FOD***, ***TOD-1***, ***TOD-2*** in a region of crossing (corpus callosum, corticospinal tract, superior longitudinal fasciculus) on a coronal slice. ***Bottom***: probabilistic tracking (10000 tracks), seeded at the intersection of the midsagittal plane and the genu of the corpus callosum; guided by ***FOD***, ***TOD-1***, ***TOD-2***. (viewed from the bottom)

References:
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