A semi-local tractography approach using neighborhood information

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Target audience: This abstract is intended for researchers in the field of diffusion MRI working on methods for fiber tractography.

Purpose: Local fiber tracking methods reconstruct fibers by successively stepping in the direction of principle diffusion derived from the DT or ODF of the current spatial position. Hence, these algorithms are prone to errors but fast regarding computation time. On the other hand, global tractography methods optimizing a global objective are more reliable but computationally expensive. We present a semi-local approach that is based upon the fast streamline method but reduces accumulation of noise by including diffusion information of neighboring regions.

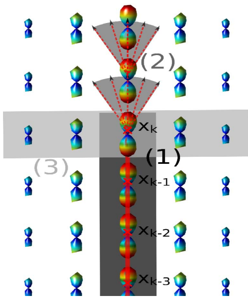

Figure 1: Strategies to obtain neighborhood information.

Methods: Our tractography algorithm uses orientation distribution functions (ODFs) as input. The ODFs were reconstructed from HARDI data using a constraint spherical deconvolution (CSD) approach similar to the one described by Reisert and Kiselev¹. Our tractography algorithm extends standard local tractography by the following three parts which are illustrated in Figure 1.
(1) neighbors behind: In each iteration step k a locally optimal tracking direction d_k is computed that is both close to the main diffusion direction $d_\varphi = \underset{d \in S_2}{\operatorname{argmax}}\, \varphi(x_k, d)$ indicated by the maximum of the ODF and a guiding direction d_{extr} derived from N previously tracked path points $x_{k-N},...,x_{k-1}$, where $d_i = (x_i - x_{i-1})/\lambda$, using extrapolation. Hence, the direction is chosen such that an objective $\left\| d - d_\varphi \right\|^2 + \alpha \arccos(d, d_{extr})$ consisting of data misfit and a regularization term weighted by a factor α is minimized.
(2) neighbors in front: (i) Out of a small region around the tracking direction d_k computed in (1) a set of candidate directions is determined. A weight specifying the related strength of diffusion is assigned to each candidate direction. Candidate points are computed by stepping in candidate directions with a certain step length, respectively. (ii) To explore the region ahead, (1) and (2.i) are repeated for the candidate points. The most promising direction is chosen to compute the new fiber path point.
(3) left and right neighbors: If the current fiber path point is located close to the margin of a fiber bundle where anisotropic diffusion is decreasing due to partial volume effects it is shifted towards the center.

Data and Results: Our method has been tested on the data of a diffusion phantom² that was also used by Fillard et al.³ We chose the data set with b = 1500 and resolution 3x3x3mm. We perform fiber tractography with constant step length $\lambda = 1$ starting at the center of seed voxels that were denoted by the numbers 1, 13, 14 and 15 in the paper by Fillard et al.³ For the computation of d_{extr} in (1) we consider in each step k the five previously tracked points $x_{k-5},...,x_{k-1}$ and choose $\alpha = 10$. With respect to (2), we regard the first set of candidate points which means that the region that lies one step ahead is explored by the algorithm. Figure 2 shows the result for the method using (1) ,(2) and (3), whereas in Figure 2. For comparison between these results and tracks generated without method (3), the symmetric Root Mean Squared Error[3] (sRMSE) with respect to the ground truth is stated in Table 1. Moreover, we computed tracks from 25 equidistantly spaced points within each of the four seed voxels. Figures 3 and 4 illustrate the results in the areas highlighted in Figure 2.

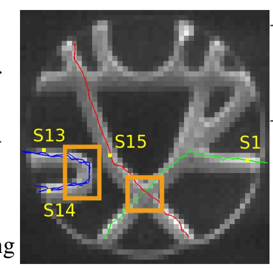

Figure 2: Single fiber tracks using (1), (2), (3)

		Fiber 1 (S1)	Fiber 2 (S15)
sRMSE	(1), (2), (3)	3.07379	4.04371
	(1), (2)	2.41689	23.2

		Fiber 3 (S13)	Fiber 4 (S14)
sRMSE	(1), (2), (3)	7.0063	3.80156
	(2)	28.4533	29.7618

Table 1: Comparison of results with the ground-truth provided by Fillard et al.[3]

Discussion: Starting from the provided seed points, our method can correctly reconstruct the four fibers using the same settings, whereas omitting of certain parts of the overall method leads to deviations at critical regions (Figure 2, Table 1). Improvements can also be seen in Figures 3 and 4 where the method is performed on a set of seed points: At the fiber crossing and at the bending, less fibers are deflected.

Conclusion: The presented method improves results of local tractography at critical regions such as fiber crossing or sharp bending by including information of neighboring voxels

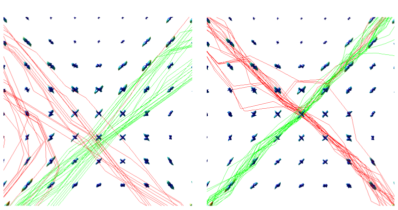
Figure 3: Tracks for S1and S15. *left*: using (1) and (2), *right:* (1), (2), (3)

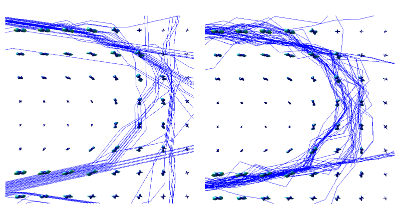
Figure 4: Tracks for S13 and S14. *left:* using (2), *right:* (1), (2), (3)

References: 1. Reisert and Kiselev, *IEEE Transactions on Medical Imaging* 30(6):1274-1283 (2011), 2. Poupon et al, *Magnetic Resonance in Medicine* 60(6):1276-1283 (2008), 3. Fillard et al, *Neuroimage* 56(1):220-234 (2011).