COMPARATIVE ASSESSMENT OF DT-MRI FIBER TRACTOGRAPHY ALGORITHMS

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Synopsis: DT-MRI based in-vivo fiber tractography (FiT) is based on following the principal eigenvectors of diffusion tensors. Despite its potential, FiT remains to be controversial due to the lack of a consensus on methodology. The degrees of freedom in FiT include *i)* data related parameters (structure, DWI parameters), *ii)* interpolation/regularization methods, *iii)* tracking methods per se. The FiT's performance was tested with different methodologies on 3D phantoms with virtually any geometry (rings, kissing and twisting fibers). Our results suggest that voxel size and SNR are the important parameters irrespective of the methodology, when the tracking step sizes are small.

Methods: We generated high resolution (0.1 units) phantom data (with FA_fiber=0.82, FA_nonfiber=0.13) using typical diffusion values. We chose all fiber diameters to be 1 unit. The DW-MR signals were computed for diffusion-encoding along 6 directions and one base signal. We added independent Gaussian noise (σ=1/SNR) to real and imaginary parts of each complex MR signal. Subsampling was done by truncation in k-space followed by Hamming window smoothing. Final MR signals were used to compute diffusion tensor fields.

The data was re-sampled at 0.1 units at the end of B-Spline interpolation and approximation schemes [1]. We did not apply any such re-sampling for the linear scheme. This is because linear interpolation is already used *during* tracking in all cases to facilitate continuous tracking. Thus, we could compare different methods when they were used to recover the high resolution data (0.1 unit resolution).

We performed fiber tracking using the Euler and the 4th order Runge-Kutta methods with constant stepsize of 0.1 units in all cases, to generate the computed track, P. The true track, T, is the central axis of each fiber sampled also at 0.1 units. Tracking stopping rule is: FA$\leq$0.15 or length(P)$\geq$length(T). Note that P and T are both sampled at the same resolution. The performance measure (ξ) is the mean of the pointwise Euclidian distances between P & T. When a computed track, P, falls short of the true track's length, it is penalized by increased ξ because the excessive points on T are all compared with respect to the end points of P. We selected 10 seed points on each fiber and performed bi-directional tracking. Mean and standard deviation of ξs are reported for each fiber.

Results: As an example of our results, Table 1 presents ξ values for a single fiber (kissing fibers with 10° separation). Each cell in Table 1 reports the mean and standard deviation over 10 different seed points, of the mean (over the points along the tracks) Euclidean distance between P and T. The units are arbitrary. Note that the fiber diameters are 1 unit. As can be seen: *i)* Euler and RK4 have similar performances at small step sizes. *ii)* The resolution (relative to the size of the structures of interest) should be higher than 80% of the size of that structure (eg. fiber/bundle diameter). *iii)* Single channel SNR=32 seems sufficient. *iv)* B-Spline regularization schemes do not improve FiT's performance unless there are similar structures nearby (as in Fig 1(right)).

Discussion: It should be noted that the performance measure is an average number over the complete fiber length. A more instructive measure would be rate of accumulation of error as one proceeds while tracking. This can easily be assessed using our data and is reserved for future analysis. We are also planing to increase the number of seed points to get more reliable statistical results. The Euler and the RK4 methods would differ at larger step sizes, which would save computation time and thus make RK4 preferable. In the presence of parallel structures (fibers), the effect of B-splines is blending information from nearby fibers. It should also be noted that any interpolation/approximation scheme (including B-splines) have to deal with spurious negative eigenvalues that appear due to smoothing. Such data points have to be corrected afterwards or the algorithms should be constrained to generate positive eigenvalues. For a more accurate estimation of of the tracking error, a Monte-Carlo like simulation would be beneficial. However, the extensive computation times require high computation power.

The presented results are not meant to be final conclusions as FiT has a large degree of freedom and further research is required to investigate them. We currently excluded total variation based regularization and stochastic tracking schemes.

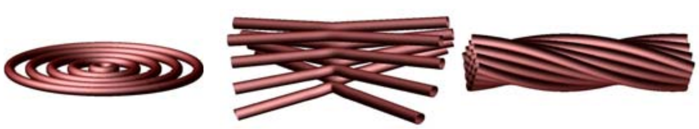

Figure 1 Geometry of the DTI phantoms used in this study: Rings, kissing fibers, twisting fibers

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References

[1] Pajevic S, Aldroubi A, Basser PJ. J Magn Reson 2002;154:85-100

		Euler			4th Order Runge-Kutta		
	VoxelSize	SNR=8	SNR=32	SNR=128	SNR=8	SNR=32	SNR=128
Linear	0.2	2.05±0.92	0.05±0.00	0.01±0.00	2.09±0.90	0.05±0.01	0.01±0.00
	0.8	1.43±0.97	2.04±1.00	2.23±1.03	1.43±1.01	2.08±1.02	2.26±1.05
B-Spline Interpolation	0.2	1.74±1.12	0.07±0.02	0.02±0.00	2.04±1.78	0.06±0.02	0.02±0.00
	0.8	2.25±1.34	2.09±1.07	2.12±1.07	2.21±1.38	2.13±1.09	2.17±1.09
B-Spline Approximation	0.2	1.21±0.78	0.04±0.01	0.02±0.00	1.33±0.81	0.04±0.01	0.02±0.00
	0.8	2.65±1.52	2.19±1.13	2.32±1.05	2.74±1.47	2.22±1.14	2.36±1.06

Table 1 Mean tracking errors (ξ) for the upper-most kissing fibers in Figure 1(center)