TENsor Deflection (TEND) Tractography with Sub-pixel Adaptive Step Size

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Purpose:

TENsor Deflection (TEND) tractography [1] has the potential of tracing the fiber in the crossing region that allows tracts passing through the planar- and spherical-shaped tensors. In step size consideration, constant small step size is strongly suggested for fiber tractography [2]. However, in TEND tractography, different stepping size results in variant degree of deflection on incoming vector toward the principal diffusion direction of tensor. Therefore, our purpose is to find the proper step size suitable for TEND tractography to trace fiber in both the linear and nonlinear anisotropic regions.

Theory and Method:

In TEND tractography, the outgoing vector, Vout, at different step size can be defined as Vout = D^n*Vin, which determines the tract direction by using the entire diffusion tensor, D, to power of n, where n denotes the number of steps in single pixel (n=1/StepSize). When applying 0.1 (pixel) small step size, Vin will be deflected by D for ten times (eg.Vout = D^{10}*Vin) toward principal direction of D, *e*1, so that Vout will be nearly parallel to *e*1 of D. Therefore, small step size is suitable for TEND to trace fiber in the linear anisotropoic region. When applying 1 (pixel) large step size, Vout = D*Vin, which determines Vout by once operation of tensor deflection on Vin. Therefore, large step size will be suitable for TEND to trace fiber in the crossing region where the D is highly planar or spherical shape.

To achieve success of tracing fiber in both linear and nonlinear anistoropic regions, we utilize linear-coefficient of tensor, $C_L = (\lambda_1-\lambda_2)/\lambda_1$ [3] as an index to properly adjust current step size by StepSize = 1-C_L. With this approach, as Vin encounters linear- shaped tensor, TEND intensively deflect the incoming vector toward the *e*1 of linear-shaped tensor, and as Vin encounters highly planar- or spherical-shaped tensor, it prevents Vin from following uncertain *e*1 of nonlinear tensor in the presence of noise. In this study, we tested this modified algorithm on simulated images (both hemispheric fiber and crossing fiber) as well as human brain data.

Results:

In phantom simulations, with the small step size, TEND succeeds in hemispheric phantom, in which tracts correctly follow its true fiber trajectory (Fig 1a); however, in crossing phantom tracts fail to traverse through the crossing region (Fig 1d). While using large step size, tracts depart from true fiber trajectory of hemispheric phantom pointed by gray arrowhead (Fig 1b), but it succeeds to traverse through the crossing region in crossing phantom (Fig 1e). With adaptive stepping, tracts not only correctly follow the true fiber trajectory of hemispheric phantom (Fig 1c) but also traverse through the crossing region in the crossing phantom (Fig 1f). In human brain, corpus callosum (CC) is known as the single-fiber region in curved shape and will intersect with corona radiata (CR), proved by David Tuch et. at. in [4], in the region pointed by a hollow yellow arrowhead in Fig 2d. Tractography with large step size in splenium corpus callosum (SCC) shows the departure of tracts from true trajectory (arrowhead in Fig 2b) compared with curvature of fiber traced by using small step size (white lines in Fig 2a). Tractography with large step size shows the success of fiber tracking in the crossing region where CC and CR intersects with each other (arrowhead in Fig 2e). When using small step size, tracts fail to traverse through that crossing region (arrowhead in Fig 2d). Tractography with adaptive step size shows good results both in SCC (Fig 2c) and in the crossing region where CC and CR intersects each other (Fig 2f).

Conclusion:

By utilizing linearity of diffusion tensor to adjust current step size, we can improve the TEND tractography not only in linear region but in nonlinear anisotropic regions. We conclude that adaptive stepping is a helpful adjunct to TEND tractography.

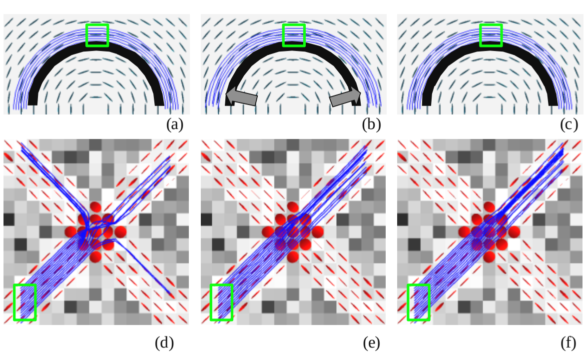

Figure 1. Tracking fibers in hemispheric and crossing phantoms with 0.1 (pixel) constant step size (a,d), with 0.5 (pixel) constant step size (b,e), and with adaptive step size (c,f).

References:

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[3] A. Sigfridsson, *et al, Proc. of th 9th International Workshop on Computer Aided Systems Theory*. (2003)

[4] David Tuch. *et al*. *Neuron*. 40: 885-895 (2003)

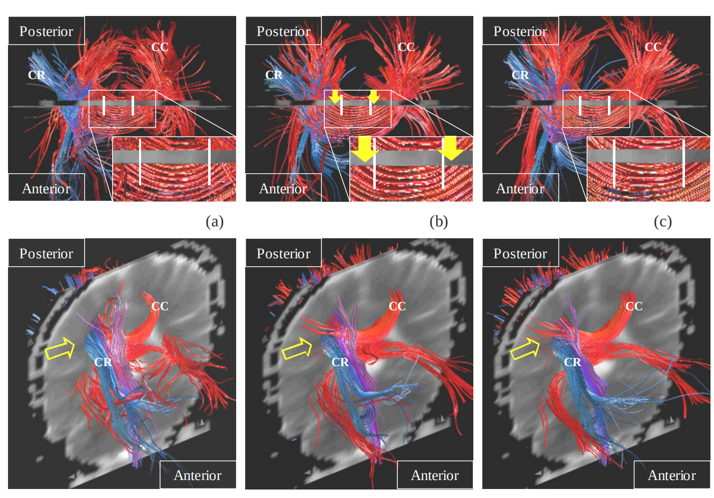

Figure 2. TEND tractography in human brain data with 0.1 (pixel) constant step size (a,d), with 0.5 (pixel) constant step size (b,e), and with adaptive step size (c,f). Top row shows the superior-inferior view. Bottom row shows the oblique view.