Advances in Fiber Tracking Quantification

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Introduction. As an addition to purely qualitative anatomical assessment of diffusion-based fiber tracks, a quantitative method based on curvatures and torsion was proposed in [1]. One drawback of that method is that curvatures and torsions are very sensitive to discretisation. Here we propose to: a) discuss an appropriate smoothing method, b) propose additional tools to quantify fiber tracts, c) compare them with previously proposed tools. The methods are demonstrated on both synthetic and *in vivo* datasets.

Methods. We investigated in a systematic way the influence of smoothing on the curvatures and torsions, using a Gaussian filter, (*Curvature and Torsion Scale Space* see [2]). The curvatures and torsions are *local* invariants. Because they may still be sensitive to discretisation, we introduce another set of potential *quantitative shape tools* for fiber tracts: namely Fourier descriptors (FD), and, to distinguish modes of variation, Principal Component Analysis (PCA) of the shape [5]. Fourier Descriptors are Fourier components of coordinates, manipulated to ensure rigid body invariance. In this way, the essential features of the curves can be kept without considering uninteresting higher frequencies. Shape analysis via PCA is obtained by registering all tracts to a mean shape, and matching points from arc-length parametrisation. These methods are *global*, in that they treat a fiber tract as a whole (see text box for details of their computation).

a) Fourier Descriptors*:* $c = [c_x, c_y, c_z]$ are tracts coordinates..
$C_u = FFT(c_u),\ u = x,y,z$
$FD(m) = (|C_x(m)|^2 + |C_y(m)|^2 + |C_z(m)|^2)^{1/2}\ m=0..30$
For two curves c_1 and c_2, compute $\sum_m (FD_1(m) - FD_2(m))^2$ to quantify the difference between c_1 and c_2. To get scale independence, divide by the value at m=0, for translation independence, subtract the centroid.
b) PCA of Shapes*:* Register all curves in the bundle to the mean shape until stabilization. Build the covariance matrix of the registered coordinates minus centroid, the shape modes are the eigenvectors of this matrix.

Two *in vivo* DT-MRI datasets were acquired on a 1.5T scanner, with 20 regularly distributed directions with b = 1000s/mm^2 [3] (multi-slice twice-refocused DW-EPI, TE=110ms, 60 slices, thickness 2mm, FOV 256x256). Fibre tracking was performed using a standard streamline algorithm [4,5]. For each tracking experiment, two planar (start and end) regions were placed in the region of interest, with seed points 0.25mm apart up to a radius of 3 to 6mm from the centre of the ROI. Tracts that did not reach the end region were discarded (tract-editing method). This produced 160 CST tracts and 91 MCP for the first dataset, 49 CST, and 270 MCP tracts for the second one.

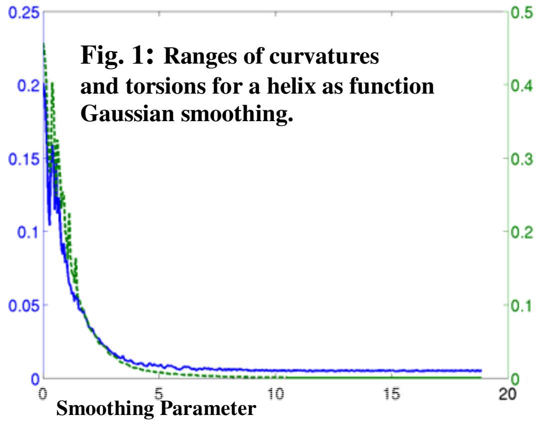
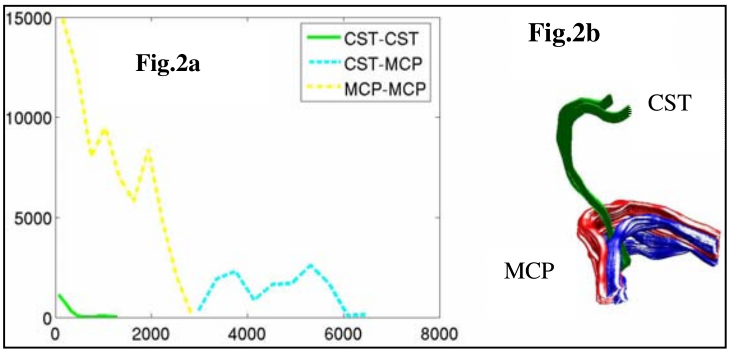
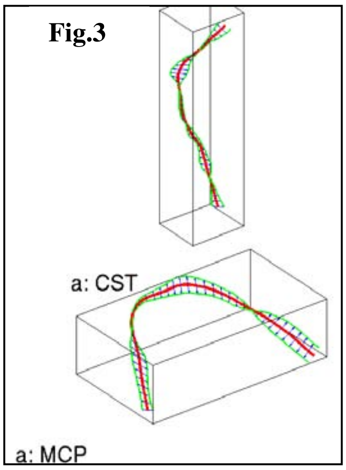


Fig. 1: Ranges of curvatures and torsions for a helix as function Gaussian smoothing.

Results. **Figure 1** shows the range of curvatures and torsions observed in a synthetic voxelised helicoidal dataset with dimensions comparable to the *in vivo* ones, as functions of smoothing parameter. Note that the curvatures and torsions of a helix are constant, thus their range should ideally be 0. From this a smoothing parameter of 6π was considered to ensure good reliability of curvature computation. **Figure 2** shows on the left (**Fig2a**) histograms of FD distances (cf. text box, **a)**) between all possible pairs of fibers from the Middle Cerebellar Peduncle (MCP and Cortico-Spinal Tract (CST) in an *in vivo* dataset. On the right, (**Fig2b**) the two clusters corresponding to the two peaks in the MCP-MCP distance, showing its relationship to the CST. **Figure 3** shows the first modes of variations as arrows from mean shape (cf. text box, **b)**) for each bundle in an *in vivo* dataset, using PCA on the spatially normalized coordinates.





Discussion.
We have introduced new, complementary methods to quantify fiber tracts. We have improved the robustness of the computations of local invariants (curvature and torsion) by embedding them in a scale space framework [2]. These invariants allow local aspects of the curve to be quantified, but remain sensitive to noise and discretisation errors. The Fourier descriptors complement these measures by being much more robust to noise, and allow clustering fibers with relative ease. Finally the shape analysis (PCA) shows what the trends of variations of shape are. Altogether, this method provides a powerful collection of tools to classify and quantify fiber tracts, potentially greatly enhancing their usefulness, beyond what can be achieved by visual inspection alone.

References: [1] Batchelor et al, *ISMRM2003*. **[2]** Mokhtarian*, Comp. Vis. And Image Understanding,* **68,** 1-17, (1997). **[3]** Jones et al, *MRM,* **42,** 515-525, (1999). [4] Conturo et al, *PNAS USA* **96,** 10422-10427 (1999). [5] Mori et al, *Ann Neurol*. **45**, 265-269 (1999). **[5]** Thodberg et al. *Proc. of the BMVC*, 2003.