Use of Independent Component Analysis to Estimate Multiple Fibers within a Voxel

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Introduction

Detecting multiple fibers within a voxel remains a challenge in DTI tractography. The problem is usually addressed by high angular resolution diffusion imaging (HARDI) [1], which requires a large number of gradient direction, usually >100, thereby limiting its role in practice. The objective of this work was to investigate whether Independent Component Analysis (ICA) would be applicable to the problem of resolving multiple fibers (as multiple components) from DTI signals per voxel and if so, to demonstrate its potential in routinely acquired human DTI data (~25 gradients). This work was restricted to detecting two fibers (two components) per voxel.

Method

ICA requires that individual sources (components) be nongaussian. Though our clinical data are acquired with 25 gradients, the central assumption of nongaussianity was tested with 55 gradient directions (to increase statistical power of the test) on a 1.5 T GE EXCITE scanner at TR=10.3s, field-of-view 26cm, 128×128 matrix, 28 contiguous 4mm thick slices with b=1000s/mm^2 and one b=0 acquisition. Representing the DTI signal x at each voxel as a 55-element vector whose components are equal to $\log(s_j/s_0)$ where s_j is the b=1000 signal at each gradient direction j (j=1, 2,…, 55) and s_0 is the b=0 signal, an example of the probability density function (PDF) of voxels most likely to contain a single fiber, identified by linear anisotropy > 0.22, (the top 5% values), FA> 0.45 (the top 5% values) is shown in Fig. 1, suggesting non-gaussian statistics for single-fiber signals. Thus ICA would be applicable to unmix multiple fiber signals from a voxel.

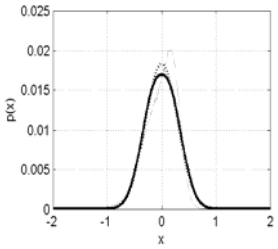
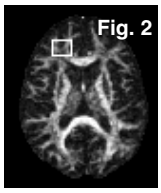


Fig. 1 (gray): PDF of measured signals; (dotted): Gaussian PDF with the same mean/std as the measured signals; (solid): Laplacian PDF fitted to the measured signal. Power value of fitted laplacian PDF model, β = 2.13 (2 for gaussian), kurtosis = 0.01 (0 for gaussian), negentropy = 0.05 (0 for Gaussian).



DTI data were acquired from 6 normal healthy subjects using the same sequence as before but with only 25 gradient directions to conform to our clinical protocols. Regions of Interest (ROIs) likely to contain fiber-crossing were identified by clusters of voxels with high planar (>0.3) and low linear (<0.1) anisotropy. It was found that a prefrontal region (see Fig. 2) was consistently identified in all six subjects as likely to contain crossing fibers and was used as the targeted ROI for this study. Assuming that fiber-crossing for any voxel would be manifested over a 3x3x3 neighborhood, with different mixing ratios among these voxels, the data matrix **X** for ICA decomposition was constructed with a 25-element row vector at 19 locations within the 3×3×3 window, representing diagonal, vertical or horizontal crossings. Two independent components were estimated from **X** using a deflationary orthogonalization method [2]. The ICA components were incorporated in a standard streamline tractography algorithm where seed voxels containing two components were visited twice, once for each component. The IC component indicating the smaller deflection angle was selected in neighboring voxels for interpolation [3].

Results and Discussion

An example of two IC components from a voxel and their respective tensors is shown in Fig. 3.

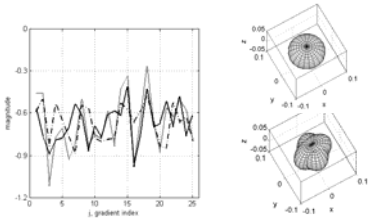


Fig. 3: Measured signal (gray), first IC component (black), second component (dotted). Respective tensors are shown at the right. Single tensor (top), two intersecting tensors (bottom).

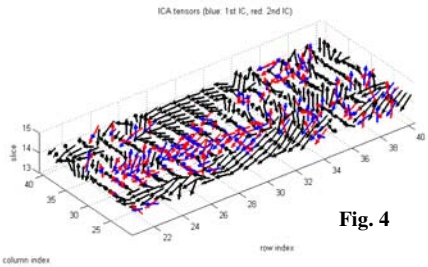


Fig. 4

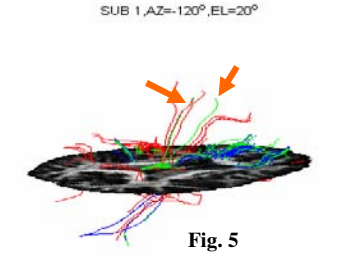


Fig. 5

Fig. 4 shows an example of detecting two components in all voxels within the targeted ROI likely to contain multiple fibers. The primary eigen vectors of the two crossing tensors per voxel are shown in blue and red respectively. Fig. 5 shows results of tractography incorporating these two components with their corresponding tracts shown in blue and red. For comparison, tracts assuming a single fiber per voxel from these seed voxels are shown in green. It is obvious that ICA is able to detect many tracts that were missing in conventional single fiber tractography. In addition, the two green tracts identified by the arrows could be detected by single fiber tractography only from seeds outside the ROI but showed high similarity to the red tracts (minimum distance between fibers) suggesting that ICA was able to detect tracts within the ROI that were undetectable by conventional single-fiber tractography, but similar to those outside the ROI. Thus ICA may improve continuity of tracking through regions likely to contain fiber crossing.

[1] DS Tuch, Magn. Res. Med., 52: 1358-1372, 2004. [2] A Hyvarinen et al. J Wiley & Sons, Inc., New York, 2001. [3] GJM Parker and DC Alexander, Phil. Trans. R. Soc. B 360: 893-902, 2005.