ICA based multi-fiber tractography

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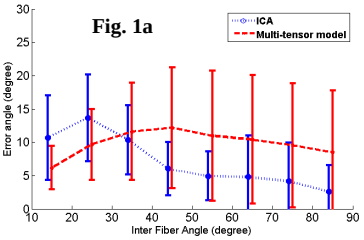
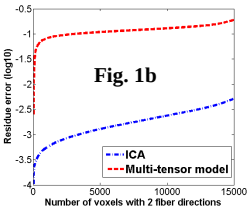
Introduction

Q-space and HARDI (high angular resolution diffusion imaging) are commonly used to detect multiple fibers within a voxel. These approaches generally require a relatively large number of gradient directions (>100) and may not be suitable for clinical applications. Alternatively, probabilistic and multi-tensor compartmental (MTC) models [1] have been used to process DTI data acquired from fewer gradients but these approaches are computationally intensive, may not converge (MTC) or require *a priori* hypotheses about tract connectivity (probabilistic approaches) that may be difficult to justify. ICA, which is computationally much faster than the probabilistic and MTC models, has been suggested as another alternative to estimate multiple fiber orientations with DTI data from ~25 gradient directions [2], making it attractive for clinical studies. However, ICA based multiple-fiber tractography is still not well-developed. The objectives of this work were to: a) to compare ICA to MTC as there are some similarities in these two approaches and b) conduct human DTI tractography studies to compare the performance of ICA to single fiber PCA for identifying tracts that are usually difficult to detect due to crossing fibers.

Method

ICA is traditionally used for "blind" separation of multiple sources mixed within a sensor. Here we assume each voxel is a sensor and the n-element diffusion profile of each fiber is one source, when n is the number of gradient directions for b >0. It has been shown that these sources are non-Gaussian and likely to be independent, thereby satisfying requirements for ICA [2]. Also as multiple fibers or tracts are likely to cross over a small neighborhood of voxels (assumed 10 in this work) with different mixing ratios, multiple sources would be mixed in multiple sensors satisfying another ICA requirement. Assuming a symmetric rank-2 tensor to model individual fibers, whose eigen values were generated randomly from the mean and standard deviation of PCA estimates of known single fibers (high FA) in the corpus callosum, simulation and experimental studies were conducted to compare the performance of a multi-tensor model and ICA for two or three randomly oriented fibers. Diffusion data were generated from one b=0 and 25 gradient directions at b=1000s/mm2 with Rician noise added (SNR=30). Simulation study results for two-fibers not only show (**Fig. 1a**) better performance for ICA at angles >30deg, but also ICA was ~100-times faster than MTC (.023 sec compared to 2.1 sec per voxel for a Xeon Quad-core 2.66GHz workstation). The simulation study for three crossing fibers showed a mean error angle of ~15 deg with ICA. Experimental 3T MRI human DTI data acquired from 25 gradient directions at b=1000s/mm^2, 2x2x4mm^3 voxels suggest that the residual error per voxel between diffusion profile data obtained from estimated two-fibers per voxel (in voxels likely to contain two fibers, see below) and the measured data was approximately 100-times smaller in ICA than MTC (**Fig. 1b**).





The number of fibers per voxel (which is required for ICA) was estimated also by using ICA to find the orientations of assumed one, two or three fibers per voxel followed by a F-test to retain the number suggesting best match between computed and measured diffusion profiles. PCA whole-brain tractography, conducted by standard streamline approach using vector interpolation, FA ≥0.05, step size of 0.2mm, was compared to ICA streamline tractography with same step size, same FA threshold and vector interpolation. In seeds containing multiple fibers, tracking was initiated with steps along each orientation. When a voxel with multiple orientations was encountered along the path, the orientation indicating minimum deflection was selected [3].

Results and Discussion

An example of a color FA map of a slice in a human subject where a region likely to contain crossing fibers has been highlighted (white rectangle) is presented in **Fig. 2a**. The 1, 2 or 3 fiber directions estimated by ICA in this targeted region are shown in **Fig. 2b**. Conventional color-coding is used to indicate fiber directions. It is apparent that most white-matter regions where FA is suppressed due to fiber crossing now indicate two or three fibers whose recovered orientations are consistent with the apparent continuity of the crossing fibers. An example of hippocampal ROI based filtering to sort the fornix/cingulum tracts is shown in **Fig. 3a**. The Freesurfer identified left hippocampal ROI was used to sort PCA (top) and ICA (bottom) whole-brain tracts, revealing better recovery and continuity of the fornix and cingulum tracts (see arrows) with ICA in regions where multiple tracts would be mixed. Only a small portion of the cingulum is recovered even by ICA with the hippocampal ROI. Overall, better recovery of the cingulum is obvious in **Fig. 3b** where a ROI was directly placed in the mid-cingulate area. ICA (**Fig. 3b bottom**) still indicates much better recovery of tracts throughout the extent of the cingulum and connections toward frontal and temporal areas (see arrows) than PCA (**Fig. 3b top**). The proximity of corpus callosum fibers to the cingulum (**see Fig 3c**), which were mixed in the relatively large voxels of DTI data available for this work (2x2x4 mm^3), results in crossing fibers within voxels, leading to erroneous eigen vectors in PCA. These crossing fibers are apparently resolved by ICA to show better recovery.

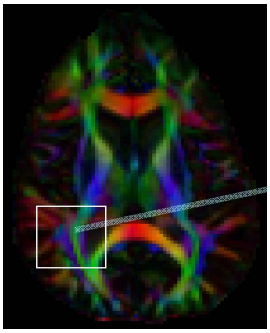


Fig. 2a: Color FA map with targeted region.

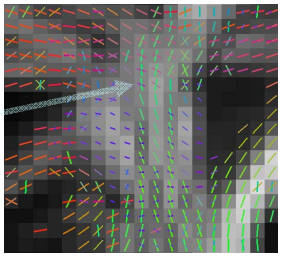


Fig. 2b: ICA estimated multi-fiber directions in targeted region.

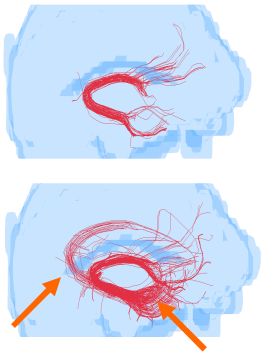


Fig. 3a: Fornix using left hippocampal ROI. (top) PCA, (bottom) ICA.

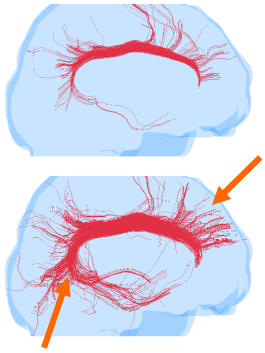


Fig. 3b: Cingulum tract using ROI in mid-cingulate region. (top) PCA, (bottom) ICA.

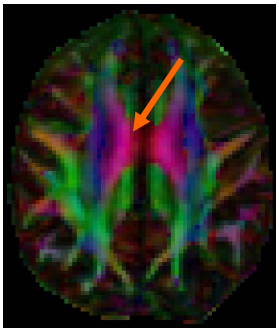


Fig. 3c: FA map showing proximity/overlap between mid-cingulum (green) and corpus callosum (red) tracts.

[1] Tuch et al., Magn Res Med, 48:577-582, 2002; **[2]** Singh and Wong, Proc ISMRM, 15:899, 2007 **[3]** Parker and Alexander, Phil Trans R Soc B 360: 893-902, 2005.