# An optimized tensor orientation strategy for non-rigid alignment of DT-MRI data

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## Introduction and Purpose

Diffusion tensor magnetic resonance imaging (DT-MRI, or DTI), recently introduced by Basser et al., provides a unique way to investigate the microstructure of biological tissues [1]. Compared to the alignment of scalar images, the coregistration of DTI is particularly challenging because of the multi-dimensionality of the data on the one hand, and the need for tensor realignment with the underlying microstructure on the other hand. Some DTI coregistration techniques circumvent the need for an iterative tensor reorientation (TR) by aligning scalar images derived from the DTI data sets. Park et al. demonstrated that the use of orientational information improves the image correspondence after coregistration. This method implies the need for an iterative TR, which is computationally intensive and introduces inaccuracies. In this study, mutual information (MI) is used as a criterion for image correspondence. Therefore, multimodal images, such as the orientational information that is derived from DTI, can be aligned, thereby avoiding the need for an iterative TR. Ever since Alexander et al. raised the TR issue, their proposed TR strategies are applied widely [2]. The `finite strain' (FS) tensor reorientation method decomposes the transformation matrix in a deformation and a rotation component. Only the latter is then used to reorient the tensors. Shearing, non-uniform scaling and stretching factors affect the orientation as well, but they do not contribute to the finite strain TR. These factors are taken into account in the `preservation of principal direction' (PPD) strategy. Alexander et al. tested both TR techniques for affine deformations on real and synthetic data. The purpose of this study is to investigate the effect of the different TR approaches in the case of non-rigid coregistrations, based on the high dimensional viscous fluid model [3]. The results that are displayed in this abstract originate from a coregistration on the fractional anisotropy maps, but using orientational information, such as the diffusion tensor elements or the diffusion weighted images, showed similar results.

## Methods

*Experiment I*: In a first stage, the inaccuracies introduced by both TR methods are studied using a synthetic DTI software phantom. A straight synthetic fibre bundle was deformed with different sinusoidally shaped deformation fields. Thereafter, TR was performed with the FS and the PPD method. A second fibre bundle was introduced, following a sinus with exactly the same frequency and amplitude compared with the deformation fields. The tensors of this second bundle follow their underlying microstructure and can therefore be regarded as ground-truth. The tensor orientations of the deformed bundle after TR are then compared with this ground-truth.

*Experiment II*: A real, human DTI data set is deformed with a known deformation field. Thereafter, both images are coregistered, followed by a TR. In contrast to *Experiment I*, the TR is now based on an imperfect deformation field that is derived after coregistration. Therefore, the effect of local, small misregistrations on the tensor alignment can be evaluated.

*Experiment III*: Because small misregistrations, which hardly affect the spatial coregistration result can cause large inaccuracies in the tensor alignment, a Gaussian smoothing of the final deformation field is performed. This will not affect the spatial alignment, but only the TR and thus tensor correspondence.

## Results

*Experiment I*: In Figure 1 (A) and (C), the results after deformation of a straight fibre bundle to a sinusoidal shaped one are displayed for a FS and a PPD TR, in blue and green respectively. The ground-truth orientation of the tensors is displayed in red (B). For each voxel, the first eigenvector of the ground-truth is compared with the first eigenvector after TR with the FS approach (D), and with the PPD method (E). (F) and (G) offer a closer look at the differences between all first eigenvectors. The angle between the tensors after TR and the ground-truth is measured for all voxels, and the results are shown in (H) for the FS, and in (I) for the PPD approach.

*Experiment II*: Five known deformation field were applied to a DTI dataset. Thereafter, all five were coregistered to the original data-set. In Figure 2, the orientations of the first eigenvector are displayed in the corpus callosum (CC). In (A) the FA map of the CC is shown, and in (B) the first eigenvectors of the target image (red) and the deformed image (green is after PPD, blue after FS) are displayed. After zooming in (C), it is clear that the result after FS approximates the ground-truth in a better way, compared to the PPD result. The angle difference of the first eigenvectors of the deformed tensors and the reference image tensors is calculated and displayed in (D).

*Experiment III*: Different isotropic Gaussian smoothing kernels were used to filter the deformation field. Note that this will not influence the coregistration result itself, since it is applied after the floating image is deformed to the reference image. The jacobian matrix of this filtered deformation field is calculated and used to reorient the tensors. In Figure 3 (A), the effect of different levels of Rician noise on the coregistration result is shown. The same study was performed with different Gaussian smoothing kernels, and the effect of the kernel width is displayed in (B) for a noise level σ of 22. It is clear that especially the PPD reorientation results are improved by filtering the deformation field and from a kernel width of 2 voxels on, the PPD method outperforms the FS approach. The same noise study was done with a smoothing kernel of 3 voxels, of which the results are shown in (C). Note the large improvement of tensor similarity after a simple Gaussian smoothing of the deformation field.

## Discussion and conclusions

In this work, we evaluated different TR methods under non-rigid conditions. We demonstrated that the PPD approach clearly outperforms the FS method in the case of perfectly known and smooth deformation fields. However, even in this theoretical case, the PPD method is not perfect, due to interpolation artefacts. In addition to this, we showed that the PPD approach is more sensitive to local misregistrations, compared to the FS method. It results in an overall better tensor alignment after coregistration when the FS approach is used. This can be explained by the fact that misregistrations contain more non-uniform scaling and stretching factors, and less rotational components. This is furthermore validated by our last experiment, where Gaussian smoothing kernels filtered out the small misregistrations. This reduction of local inaccuracies in the deformation field especially improved the PPD results, as expected (from 20° to 8°!).

## References

[1]Basser et al,*Biophys J* **66**, p.259-267, 1994; [2]Alexander et al,*IEEE trans on Med Im* **20**, p.1131-39,2001;[3]Van Hecke et al, *ESMRMB*, pp. 191-192, Poland, 2006.

Fig. 1

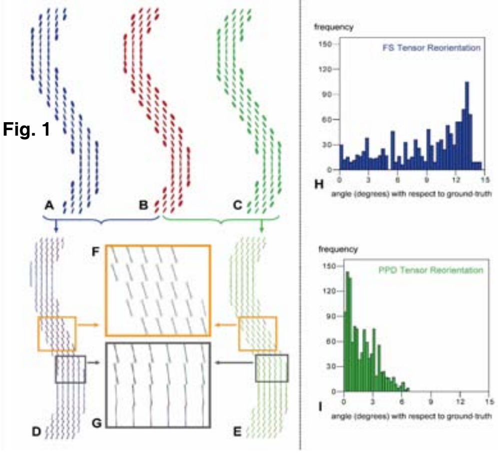

Fig. 2

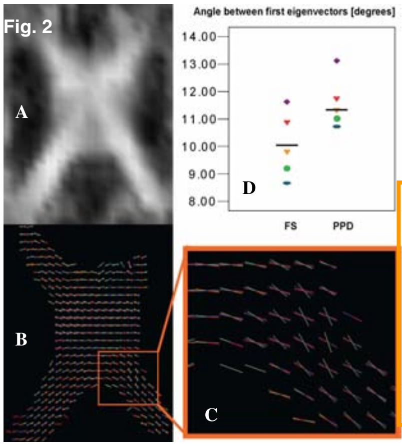

Fig. 3