

Evaluation of Anisotropic Filtering for DTI as a Function of SNR

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Introduction

Diffusion tensor imaging (DTI) measures are very sensitive to noise [1]. These noise effects are even more increased as the spatial resolution of DTI is increased. Therefore, it may be desirable to use image-processing methods that will reduce noise effects in DTI. An anisotropic Gaussian filtering based on the diffusion tensor in DTI was recently proposed for preferential image blurring along the white matter tracts directions, which minimizes partial volume averaging artifacts [2]. In this study, we further improved the anisotropic Gaussian filtering by taking a higher power of diffusion tensor to accentuate the anisotropy, and evaluated the performance with higher spatial resolution DTI data with various SNR levels.

Methods

Data and gold standard images: A single-shot spin echo EPI sequence with diffusion-tensor encoding (12 directions (optimized using minimum energy criterion [3], $b=1000s/mm^2$), was used to get 12 sets (identical slice locations, voxels = $0.84 \times 0.84 \times 1.8mm$, 23 cm FOV, 54 slices) of the whole brain DTI data from a single subject. "Gold standard" FA was obtained by averaging all 12 sets of diffusion weighted images. Various SNR levels (10-32) of data were derived from the twelve data sets.

Isotropic versus Anisotropic Kernel Smoothing: Anisotropic Gaussian kernel based on a powered tensor \bar{D}^p , which is achieved by multiplying \bar{D} by itself p times is formulated as $K_i(r) = \frac{\exp(-r(\bar{D}^p)^{-1}r/4t)}{(4\pi)^{n/2}(\det \bar{D}^p)^{1/2}}$, where \bar{D} is diffusion tensor. We tested $p=3$ in this

study. Both anisotropic kernel smoothing and isotropic Gaussian kernel, which was provided by $K_i(r)$ with $\bar{D} = I$ (identity matrix), were applied to DW images of each DTI set. \bar{D} in the kernel is normalized by the mean of the trace to regularize a kernel size regardless of diffusion amplitudes. Different effective kernel widths were investigated by iterative application of the filter up to 10 times with an optimum $t = 0.8$, which was determined empirically. The FA maps were evaluated at each level of smoothing. The root mean square error (RMSE) was estimated by $RMSE_i = \sqrt{\langle \sum (\tilde{x} - \hat{x}_i)^2 \rangle}$

Results

For the anisotropic filter, the RMSE of lower SNR data (SNR 10 and SNR 14) was minimized for the 4th and 2nd iterations, respectively, and otherwise at the first iteration for all other SNR levels (Figure 2 - solid lines). For the lowest SNR, Isotropic Gaussian smoothing reached the minimum RMSE after the first iteration and was more effective than the anisotropic filter at these SNR levels (Figure 2 - dashed lines). At other SNR levels, isotropic filtering performed equivalent to or worse than the anisotropic Gaussian filter. FA maps in Fig1 (the 2nd ~ 5th row) are displayed at each minimum RMSE point. The isotropic filter appeared to introduce more error in and around the corpus callosum.

Discussion and Conclusions

Except for the most noisy image data (SNR = 10), the anisotropic filter performed better than the isotropic filter. The reason for the anisotropic filter performing less optimally at low SNR is because the filter kernel is derived from the data, which itself is very noisy. As the SNR was increased, the anisotropic filters were more optimal and were less prone to blurring and other overfiltering effects. The study also demonstrates that with data at moderately high SNR, filtering can easily introduce more errors than are removed. In conclusion, the results from this study demonstrate that anisotropic filtering can effectively reduce errors in DTI data as long as they are applied properly.

Fig 1

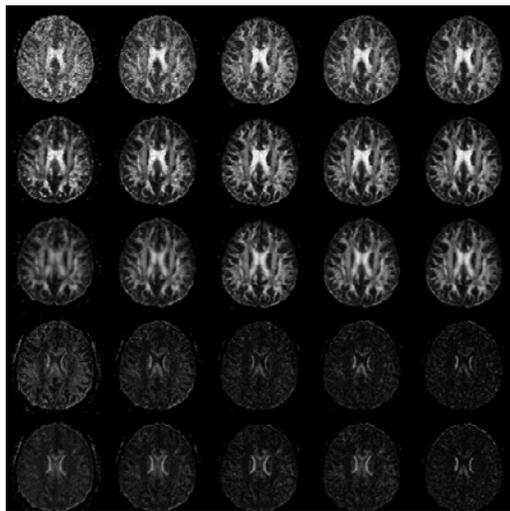
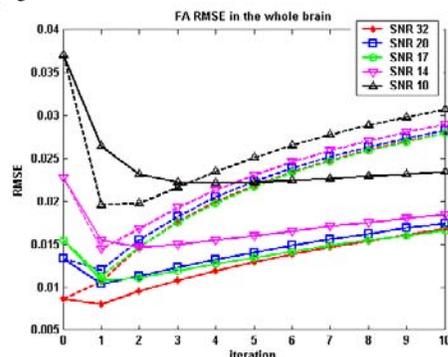


Fig1: Maps of smoothed FA, RMSE of FA at the iteration where the minimum RMSE was achieved for each data. Columns left to right: SNR 10,14 17, 20, and 32 data. The rows from top to bottom: unfiltered, anisotropically smoothed, isotropically smoothed, RMSE of anisotropically smoothed FA, RMSE of isotropically smoothed FA maps

Fig 2



Reference

- [1] Pierpaoli, C. et al, 1996. MRM. 36, 893-906.
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- [3] Hasan K.M. et al 2001 JMIR. 13:769-780.