A NOVEL ALGORITHM FOR THE CORRECTION OF EDDY CURRENT DISTORTION IN DIFFUSION WEIGHTED IMAGING DATA

W. Liu[1,2], G. Yang[1], Z. Zhou[2], Y. Zhou[1], G. Li[1], B. S. Peterson[2], and D. Xu[1,2]

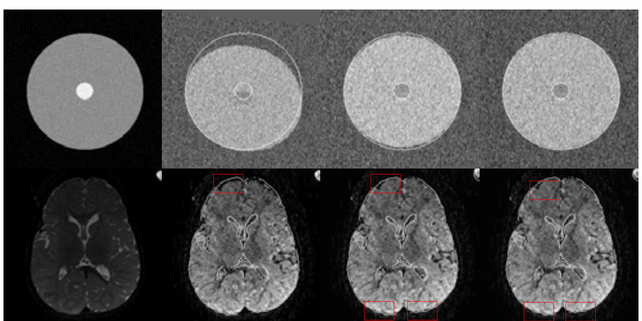
[1]Physics, FMRI Unit, East China Normal University, Shanghai, China, People's Republic of, [2]Psychiatry, MRI Unit, Columbia University, New York, New York, United States

Introduction

Diffusion Tensor Imaging (DTI) is a powerful magnetic resonance imaging technique for characterizing the diffusion of water in living tissue. DTI is particularly useful in studying the structure of nerve fibers in the brain. However, the power of providing such insight can be seriously impaired if the distortions introduced by eddy currents cannot be corrected properly when employing echo-planar imaging (EPI) sequences with fast switching gradients. Various methods have been proposed to solve this problem, among which one of the most popularly used approaches is a post-processing algorithm, Iterative Cross Correlation (ICC)[1]. However, ICC has inherent difficulties in dealing with diffusion-weighted images (DWI) acquired at b-values higher than 300 s/mm^2, because DWI signals attenuate dramatically in the cerebral ventricles, which contain cerebrospinal fluid (CSF). The contrast of DWI data acquired there differ greatly from contrast in the baseline images that are usually used as reference images, thereby making the calculation of the cross correlation in ICC extremely unreliable. Many remedies have been proposed to overcome this problem when using ICC, including the use of an additional set of gradients of opposite polarity to estimate the distortion[2], and employing a FLAIR sequence to suppress signals from CSF[3]. Both of these methods require acquisition of additional imaging data, increasing an already lengthy scan time. Moreover, the inaccuracy in estimating the correction derived from the ICC algorithm, to a great extent, dues to the amount of large changes in image contrast, or the CSF portion of the image. Therefore, excluding the CSF in the image from the coregistration, particularly in the ventricles that contain the largest portion of CSF in the image, should improve the performance of ICC. This approach would have the advantage of not requiring the acquisition of additional imaging data. Adding the use of mutual information (MI) [4] to this approach should further improve the accuracy of ICC.

Materials and Methods

Two experiments were employed to validate our algorithm. In the first, we used simulated data to assess whether our new algorithm can effectively estimate the distortion in raw DWI data. We simulated a DW image with differing levels of noise and differing amounts of *MTS* distortion (*M*: scaling, *T*: translation, *S*: shear) (Eq.1), producing synthetic imaging data with varying signal-to-noise ratios (SNRs). We simulated the structure of the ventricles using a spherical area with variations in contrast in the central portion of the image. In the second experiment, we used a set of real DWI data to verify that our algorithm could first effectively correct distortion and to demonstrate that reconstructed tensors using this algorithm would have fewer ill-conditioned tensors than would those generated using conventional ICC. This DWI dataset was acquired using an EPI sequence on a 3-Tesla GE MRI scanner along 11 gradient directions at a b-value = 1000 s/mm^2, and 3 baseline images acquired without application of a diffusion gradient. Other imaging parameters were: TR=17000ms, TE=minimal (~77 ms), FOV=240mm, matrix size=132×128, number of excitations=2, slice thickness=2.5mm at 68 slice locations with no gaps.



(a) (b) (c) (d)

Figure 1. A comparison of distortion correction using different approaches. First Row: The simulated dataset; Second Row: The real dataset. (a)Reference image; (b)Distorted image (*M,T,S* were 0.9,0.2,-0.08 respectively); (c)Correction of (b) using ICC; (d) Correction of (b) using our proposed. The red rectangles indicate visually notable differences.

The method begins with an initial estimation of the *MTS* values using conventional ICC. It performs a rough initial correction of the distorted DWI. The silhouette of the ventricles is then used to mask out CSF in the subsequent estimated distortion of the DWI data. The correlation between the reference column and the scaled distorted column is calculated using the so-called Entropy Correlation Coefficient (ECC) [5] (Eq. 2), rather than using the normalized cross-correlation function of the conventional ICC algorithm [1]. A bisquare estimator [6] is employed as a fitting criterion for a more robust estimation of *T, S.*

$$\begin{aligned} Y' &= MY + T + SX \\ &= MY + T'(X) \end{aligned} \quad (1)$$

$$ECC(M,T') = \frac{2\cdot I(Cr,Cd)}{H(Cr)+H(Cd)} \quad (2)$$

$$I(Cr,Cd) = H(Cr) + H(Cd) - H(Cr,Cd)$$

Where *M* is a uniform scaling in the phase-encoding direction *Y*, *T* is a shear paralleling to *Y* in the frequency-encoding direction *X*. *S* is a uniform translation along *Y*, produced in the slice-encoding direction *Z*. *T'(x)* is a distance translated along *Y*, described as the straight line related to *X; Y'* is the eddy current induced distortion model. *Cr* and *Cd* are the corresponding columns in the reference and the distorted images; *I(•)* is the MI, and *H(•)* is the entropy[5]. We counted the number of ill-conditioned tensors in the reconstructed DTI based on the corrected DWI and compared with the number of such tensors in DTI generated using conventional ICC and FSL (FMRIB Diffusion Toolbox, http://fsl.fmrib.ox. ac.uk/fsl/fdt/).

Results

By superimposing the contour of the reference data to the DWI data before and after correction, we compared the corrections of eddy-current distortions using our method and conventional ICC. Corrected images using our method in both simulated and real datasets matched the reference images perfectly, whereas residual distortions remained when using ICC (Fig. 1). The number of ill-conditioned tensors in the reconstructed DTIs were also substantially fewer using our method (Table 1).

Discussion

Our method improved the performance of ICC by minimizing the disturbance in coregistration introduced by the ventricles and CSF. Although segmentation of the ventricles is therefore necessary using our method, this can be achieved easily using any of numerous software tools that are freely and widely available. Segmentation of the ventricles need not be very precise, because any reduction in the disturbances caused by CSF will benefit the accuracy of the estimation of distortion, although undoubtedly an automated and precise identification of the ventricles is preferred.

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	No Correction	ICC	FSL	Our Method
Ill Tensors %	1.6403%	1.8066%	1.5000%	1.3105%

Table 1. A comparison of valid tensors in the DTIs based on DWIs of different strategies of distortion correction. Our method provided the best result, while some other method may increase the number of ill-conditioned tensors (non-positive definite).

References

[1]Haselgrove et al.(1996), Magn. Reson. Med. **45**.960 –964.
[2]Nils Bodammer et al. (2004), Magn. Reson. Med. **51**.188-193.
[3]Bastin et al. (1999), Magn.Reson.Imag.**17**.1011-1024
[4]Nilesh et al. (2006), Magn. Reson. Med. **56**.310-316
[5]Maes et al. (1998), Ph.D. thesis
[6]Tukey et al.(1977),Addison-Wesley Publishers, Cy.