Improved accuracy of motion and affine eddy current distortion correction in high b-value diffusion weighted imaging using brain mask based weighting functions

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Introduction: Eddy currents in the conducting surfaces of the gradient coils and subject motion cause affine distortions in diffusion weighted image (DWI) sequences. Affine image registration is a widely used method to correct these errors, where one diffusion unweighted image is chosen as the registration target for all other volumes in the sequence. A commonly employed affine registration method is the eddy_correct script in FSL which is based on registering every image in the dataset to one diffusion unweighted image (the template) using the tool FLIRT[1]. For high b-value image sequences the eddy_correct method artificially expands the diffusion unweighted volumes with scaling factors greater than unity which leads to misregistration. These artificial expansions are more profound in high signal from the scalp vanishes and the outer CSF boundary is expanded to match the scalp boundary of the template. Other mask based methods have been proposed for this issue[2], but are potentially computationally expensive. The current study proposes a modification to the eddy_correct pipeline that avoids these artificial expansions for high *b*-value images by removing the scalp signal from the template by including a reference-space brain mask-derived weighting on the cost function.

Methods: Our modified eddy_correct creates a brain mask-based weighting function using the following steps: 1) Compute brain mask of reference volume with BET [3], 2) erode and then smooth the brain mask with spherical and Gaussian kernels, respectively. We then apply the existing eddy_correct registration protocol by sequentially registering every volume in the dataset with the template using FLIRT, but adding the weight image as the argument for the –refweight option. In some cases nonsensical scaling (above 20% expansion or contraction) and implausible translation parameters are estimated due to the decreased support of the weighting function. For these cases we iteratively dilate the weighting function and repeat the registration until the scaling and translation values are reasonable. Images that fail to register after 5 iterations should be excluded from the dataset. We evaluate the existing eddy_correct pipeline and our method with both the correlation ratio (default) and mutual information cost functions on a cohort of 143 healthy adolescent volunteers from the Victorian Infant Collaborative Studies (VICS).

Results: Figure 1 shows one diffusion weighted volume registered to the template comparing all methods. This panel shows results that are representative of the differences between the methods. Both of the eddy_correct methods exhibit misregistration at the frontal and occipital extremities due to AP expansion. In contrast, our method (correlation ratio) shrinks the diffusion weighted image in the AP and LR dimensions but our method (Mutual Information) aligns the AP borders correctly. Figure 2 shows aggregate results for the scaling values of the transformation matrices across the cohort. For the low b-value data all methods perform similarly with the means expansions varying between 1-2%. In the high *b*-value data, however, the expansion of the diffusion weighted images by the original eddy_correct method is more severe (5%) and more pronounced compared to the scaling values of the diffusion unweighted images. Using mutual information as the cost function improves the eddy_correct scaling values in the IS and LR dimensions but not the AP dimension. For both cost functions, our modified method reduces average excess scaling values for the diffusion weighted images across all three dimensions in the high *b*-value case. The mutual information cost function produced the least variation in scaling values across volumes in the high b-value case for our method.

Discussion and Conclusions: We have presented a novel modification to the eddy_correct pipeline to improve the results of motion and eddy current distortion correction in DWI processing. We showed that the effect of artificial scaling is more profound in high b-value images compared to low b-value images. Our method decreases excess scaling at high b-values while registration results at low b-values are largely unaffected. Mutual information should be used for registration of diffusion weighted to diffusion unweighted images. More accurate affine registration will reduce partial volume contamination and there are implications for the accuracy of tensor calculations and crossing fibre algorithms. The method is efficient; taking only 20-30 seconds per volume and is parallelizable. Any researcher performing DWI processing will benefit from this method.

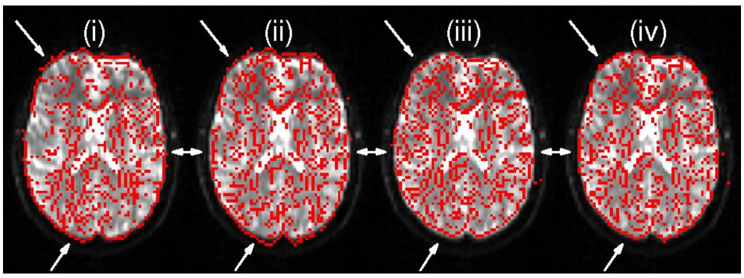

Figure 2: Visual comparison of registration results by method (i) eddy_correct, (ii) eddy_correct (Mutual Information), (iii) Our Method (Correlation Ratio), and (iv) Our Method (Mutual Information). Each panel shows the reference image in the background with the intensity edges of the registered images overlaid in red. The arrows highlight that our method corrects the misregistration of the diffusion weighted images at the brain

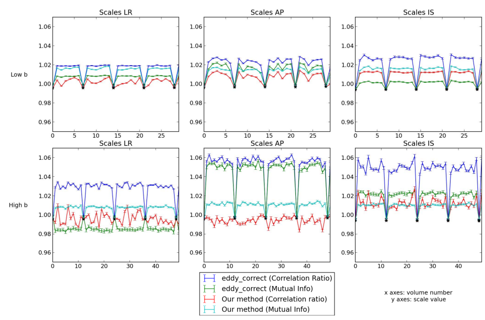

Figure 2: Mean scaling amounts in each Cartesian dimension for each volume for the low b-value (top panels) images and the high b-value images (bottom panels). The error bars show the standard error of the mean for each volume. The stars denote the diffusion unweighted images.

References:
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