Quantitative evaluation of eddy-current and motion correction techniques for diffusion-weighted MRI

Synopsis

It is necessary to perform correction of eddy-current and motion artefacts before analysing DW-MR data, but none of the commonly used correction techniques have been evaluated quantitatively. Here we apply a recently proposed simulation framework to evaluate four correction techniques. We found the three techniques that register to a b=0 image (Eddy_correct, ACID, ExploreDTI) perform worse then a technique that registers to predicted DWIs (eddy). Furthermore, we found that one of the most commonly used methods for registration to b=0, eddy_correct, performs significantly worse than the other methods considered.

Introduction

This work makes use of a recently proposed simulation framework [1] to quantitatively evaluate methods for correcting eddy-current (EC) and motion artefacts in DW-MRI. EC and motion artefacts introduce misalignments into DW-MR datasets, which adversely impact the quality of information obtained from them. This is made worse by the increasingly common acquisition of multi-shell datasets. Such acquisitions tend to involve higher b-values and longer scan times, which increases the severity of EC and motion artefacts. Most often these artefacts are corrected using freely available post-processing techniques but there are no systematic, quantitative comparisons of these. Recently, a novel framework was developed that enables the simulation of realistic DW-MR datasets with artefacts, enabling the validation of correction techniques. Here we apply this framework to evaluate the quality of correction obtained by four of the most commonly used software packages.

Methods

Data: A DW-MR dataset with artefacts was simulated, according to the method in [1]. It consisted of 32/64 directions with b=700/2000s/mm^2, 12 b=0 images, TR/TE = 7500/109 ms, dimensions 72/86/55 with isotropic voxel size 2.5mm. Diffusion directions were distributed isotropically on the sphere. Severe artefacts were simulated: large, linear EC and a randomly selected rotation of up to ±5° about each axis, translations of up to ±5mm along each axis. Noise was added to create datasets with SNR=20 and 40.

Techniques tested: We tested four commonly used software packages. Three perform registration to a b=0 image: FSL's **eddy_correct** [2] uses full 12 dof affine registration, **ACID** [5] performs a constrained 9 dof registration and **ExploreDTI** [4] registers to b=0 in order to optimise the parameters of an EC and motion specific model (see [6]). The fourth method, FSL's **eddy** [3], registers each volume to a model-free prediction of how it should look. Each method was used with its default settings to correct the simulated dataset. For eddy_correct and ExploreDTI, final resampling was changed to use spline interpolation to match that used in eddy and ACID.

Evaluation strategy: Quality of correction was assessed quantitatively by evaluating the displacement fields predicted by each method. The ground truth displacement field, ψ^T, describes a mapping from undistorted to distorted space and is obtained from the simulation framework. Each method predicts its best mapping from distorted to undistorted space, ψ^P. Combining these gives us a field, ψ^E, which describes where each voxel in undistorted space is moved to after correction:

$$\psi^E = \psi^T \circ \psi^P$$

where o is the composition operator. A zero error field indicates perfect correction. Additionally, the impact of correction was assessed by fitting the DT and NODDI [7] models to corrected and 'ground truth' datasets, simulated without any artefacts. The resultant parameter maps were compared visually.

Results & Discussion

Figure 1 compares the mean error fields for each method. The three methods that perform registration to b=0 have larger errors than the method that does not (eddy), and they also display larger increases in error with increasing b-value. Eddy_correct performs significantly worse than the other two methods that register to b=0. The reason for this is made clear in Figure 2, which shows the spatial distribution of these errors. It highlights that eddy_correct is overscaling each DWI along the x-, y- and z- directions, whilst ACID and ExploreDTI are constrained to only allow scaling along the y-axis (typically the phase-encode axis, which is affected by eddy-current distortions). They also reveal that whilst ExploreDTI leads to smaller mean errors than ACID, the errors have larger variance. This could be because ACID performs direct registration to b=0, whilst ExploreDTI optimises for parameters in a physics-based EC model. Figure 3 demonstrates the impact that the choice of correction method has on estimation of microstructure. Use of eddy_correct leads to large errors in estimation of DT and NODDI metrics. Results for eddy and ExploreDTI are comparable whilst those from ACID slightly worse, most notably in the genu of the corpus callosum.

Conclusions

We used simulations to quantitatively compare four methods for correcting EC and motion artefacts. We demonstrated that the three methods that perform registration to b=0 provide worse correction than the method that avoids this, eddy. We further showed that of the three registration to b=0 methods, eddy_correct provides very poor correction. This is important given that eddy_correct is likely the most widely used correction method. We note that eddy has more stringent data requirements than the other three methods, and our results indicate that ExploreDTI could provide the best alternative when these requirements are not met.

Acknowledgements

MG is supported by the EPSRC (EP/L504889/1) and the EPSRC Centre for Doctoral Training (EP/L016478/1). HZ is supported by the EPSRC (EP/L022680/1), the MRC (MR/L011530/1) and the Royal Academy of Engineering Research Exchanges with China and India. ID is supported by the Leverhulme Trust. MG and HZ are additionally supported by the Royal Society International Exchange Scheme with China.

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Figures:

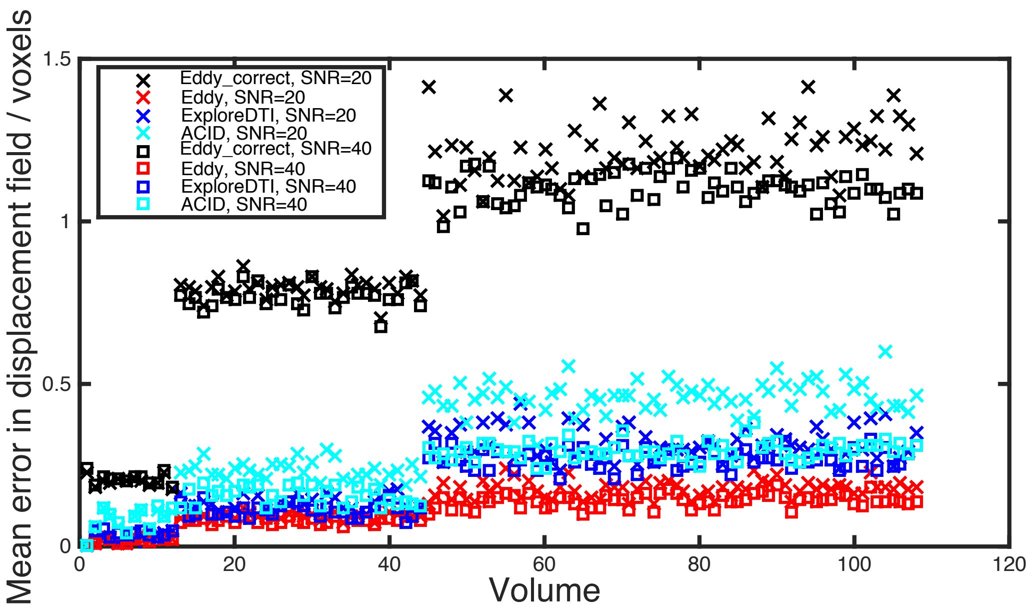

Figure 1: Mean error field over the brain, evaluated for each volume. Volumes are arranged by b-value so that the first 12 are b=0, next 32 are b=700 and final 64 are b=2000.

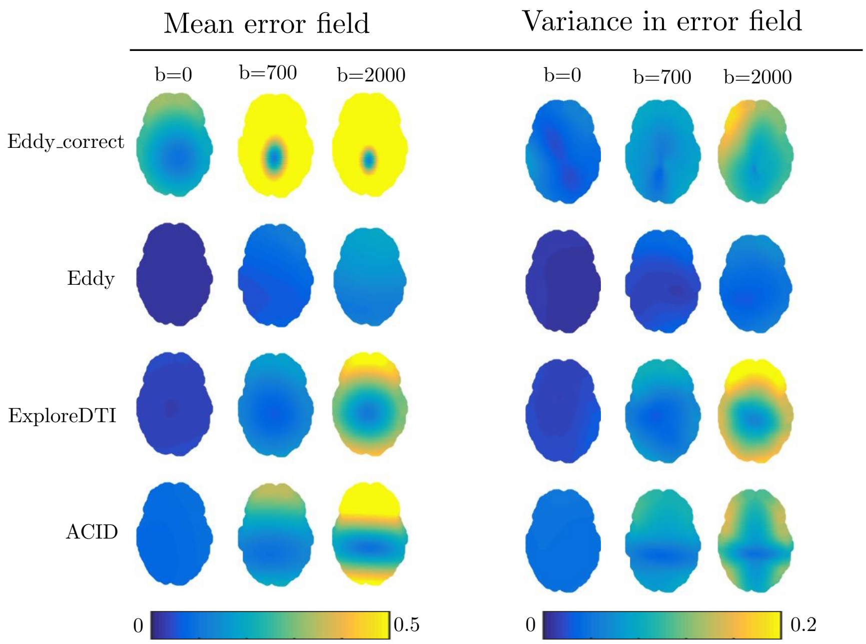

Figure 2: Spatial plots of the mean error field over every volume at a given b-value for SNR=40, and the variance in this error field, shown for one axial slice.

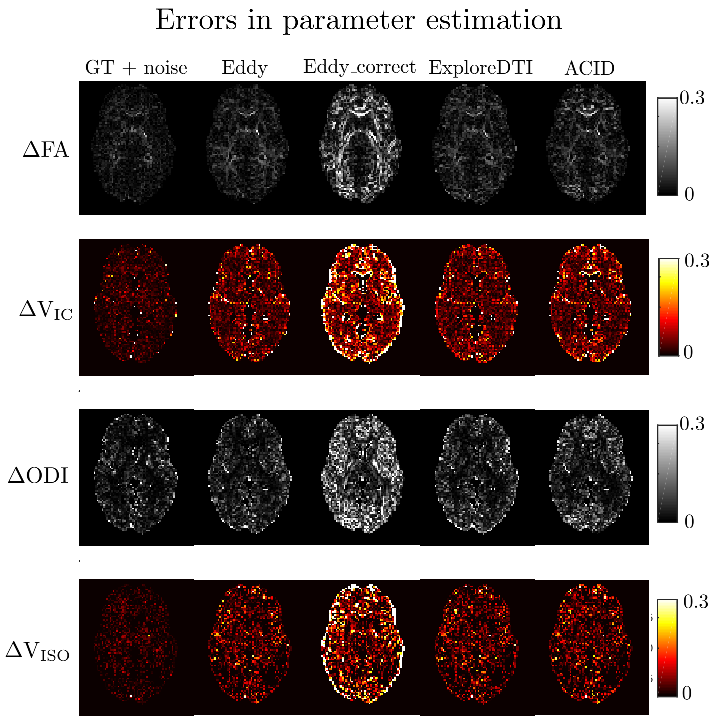

Figure 3: Absolute errors in parameter maps at SNR=40, obtained by subtraction from parameters obtained from a noise-free, artefact-free dataset. Parameters shown are fractional anisotropy (FA) from the DT, intracellular volume fraction (V_{IC}), orientation dispersion index (ODI) and isotropic volume fraction (V_{ISO}) from the NODDI model.