A comprehensive approach for correcting motion and distortion in diffusion weighted MRI

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SYNOPSIS:

We present a method for removing artifacts related to patient motion and eddy-current induced image distortions in DW-MRI. The images are corrected for motion and distortion simultaneously using a well-established registration technique. Subject motion is modeled using a 3D rigid body transformation while image distortion is modeled using a general solution for eddy-current induced fields inside the magnet. The DW-MRI dataset can at the same time be rigidly aligned to a standard template. Thus our robust post-processing method can be used to simultaneously remove motion and distortion related artifacts as well as to position the dataset in a standardized orientation.

INTRODUCTION:

Image misalignment can be a significant source of artifacts in data analysis and it reduces the clinical and biological utility of the dataset. Though post-acquisition methods to remove image distortion have existed for some time [1], until recently, the problem of patient motion during DW-MRI acquisitions was commonly ignored [2]. The method we propose achieves two objectives simultaneously and automatically: motion and distortion correction of the DW-MRI dataset as well as the positioning of the dataset in a standardized orientation, all with just one image interpolation step.

METHODS:

The image alignment procedure works as follows. First a sample image from the DW-MRI dataset is chosen to be a reference image $T(\mathbf{x})$. Since we desire the reference image to be virtually free from eddy-current induced distortions, the image acquired with least amount of diffusion weighting is used as reference. The reference image is rigidly aligned to a standard template using a well-established image registration technique [3]. The remaining images of the DW-MRI datasets are then aligned one at a time to the chosen reference image using the method described below.

A DW image $S(\mathbf{x})$ is registered to a reference image $T(\mathbf{x})$ by choosing spatial transformation $f:\mathbf{x}\rightarrow\Re^3$ such that $I(S(f(\mathbf{x})),T(\mathbf{x}))$, where $I(\cdot,\cdot)$ is the normalized mutual information [3], is maximized. The spatial transformation *f* is composed of two parts: $f(\mathbf{x})=d(m(\mathbf{x}))$. Function *m* is a 3D rigid body transformation and it accounts for subject motion. Function *d* corresponds to the image distortion component. The image distortion model is a series expansion solution (up to order 2) of Maxwell's equations for eddy-current induced fields inside the magnet, assuming no internal sources. If significant head motion is present in a given $S(\mathbf{x})$, the b-matrix for that image is reoriented accordingly. If significant image distortions are encountered in $S(\mathbf{x})$, the intensity values of the image are readjusted according to the Jacobian of the transformation *d*.

RESULTS:

The distortion model was validated by measuring the distortion in DW images of a cylindrical phantom. The cutoff at order 2 in distortion model *d* produced a reasonable approximation to the distortions present in our imaging system. The images below display relative anisotropy maps computed from a diffusion tensor fit [4] of the DW-MRI dataset before and after motion and distortion correction. Anisotropy around the edges of the brain is significantly reduced after correction. The χ^2 error between the diffusion tensor model and the DW-MRI data is reduced by more than 50% after motion and distortion correction. Principal component analysis of the dataset also indicates the presence of fewer significant signal sources after correction with our approach.

DISCUSSION & CONCLUSIONS:

Results show our correction procedure significantly reduced misalignment artifacts in sample DW-MRI datasets. In our experience, head motion is the primary source of image misalignment in prolonged DW-MRI acquisitions in which an appropriate gradient pre-emphasis scheme has been used. Note that DW images with diffusion b-values of about 1100 s mm^{-2} were used in our experiments. Thus our correction scheme is expected to align well DW images acquired with b-values of 1100 s mm^{-2} or less.

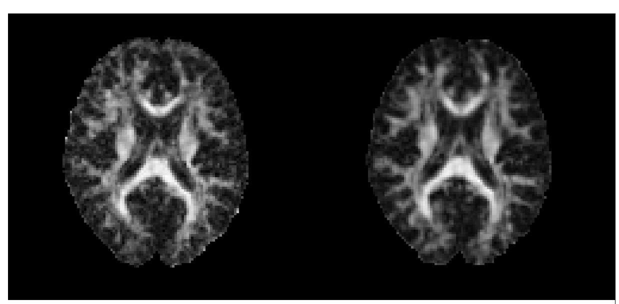

Figure 1: relative anisotropy images before (left) and after (right) motion and distortion correction.

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