Registration-Based Distortion and Intensity Correction in fMRI

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Introduction:

It is well known that spatial variations of the main magnetic field can cause large geometric distortions along the phase-encode direction of echo planar images (EPI) [1]. In fMRI, these distortions in the EPI data can lead to local shifts of 6-9mm [5] in inferior slices and signal pile-up [6]. Approaches to correcting distortions caused by field inhomogeneities include field mapping [5, 3] and non-linear registration with an undistorted reference image (usually a T1- or T2- weighted) [4, 1]. We previously developed a method for correcting distortion in the EPI images used in diffusion weighted imaging (DWI) [1]. In that work, we estimated a correction field by non-rigidly registering the EPI to the T1 image with deformation restricted to the phase-encode direction of the EPI image. Here, we build on this concept to develop a distortion correction method for fMRI.

Methods:

Our method estimates a deformation field that maps a subject's fMRI data to their anatomy, based on a T1-weighted image collected during the same session. As in Bhushan et al [1], we restrict this deformation to the phase-encode direction of the fMRI (distortion is an order of magnitude greater in the phase-encode direction than in the frequency-encode direction). Therefore the first step of the algorithm is to use the multi-resolution, mutual information method described in Thevenaz et al [8] to compute a rigid transformation that maps the T1 image data to the space of the first time point volume in the fMRI time series. We then use this transform to resample the T1 image to the fMRI space.

We next estimate the inverse distortion field - modeled as a tricubic B-spline - using a multi-resolution, nonlinear registration process to maximize the mutual information between the corrected EPI and the resampled T1. Because magnetic fields - and therefore the distortion - are necessarily smooth, we use a thin-plate spline regularizer to penalize high bending energy. Inhomogeneities can cause the signal from different spatial positions to be erroneously mapped to the same voxel, thus inducing signal intensity changes. This change in intensity is related to the derivative of the distortion field at the voxel [5]. Our algorithm therefore optimizes the deformation field to correct both the intensity and geometric distortion effects of field inhomogeneities in fMRI images.

Inhomogeneities caused by subject physiology shift with subject motion. We account for subject motion by registering each fMRI time point volume to the first time point using a rigid body transformation computed using a normalized correlation metric [7]. We then use these transformations to remap the estimated deformation field to the space of each time point and apply the distortion correction in the native space of each image. We then apply the inverse transformation to the time point to bring the data back into the same space of the corrected reference image, producing a series of images that have been corrected for both geometric distortion and subject motion. The fMRI time series may then be processed using conventional fMRI processing software.

Results:

We performed distortion correction on 11 subjects with 5 fMRI sessions each. Within this pilot group, we found similar distortion within each subject, but varied levels of distortion between subjects. Because of air/bone boundaries near the frontal and temporal lobes there was much greater distortion in these areas, whereas parietal and occipital regions tended to be less distorted. Figure 1 shows an example of our method applied to one of these sets of images.

Conclusions:

We have developed a method for performing non-rigid distortion and intensity correction in fMRI based on estimating the distortion field in fMRI EPI images relative to a T1-anatomical scan. In future work, we plan to explore the effects of motion on the distortion field. We will also analyze the effect of our distortion correction method on task-based fMRI analysis.

Modeling and Analysis Methods:

Motion Correction and Preprocessing

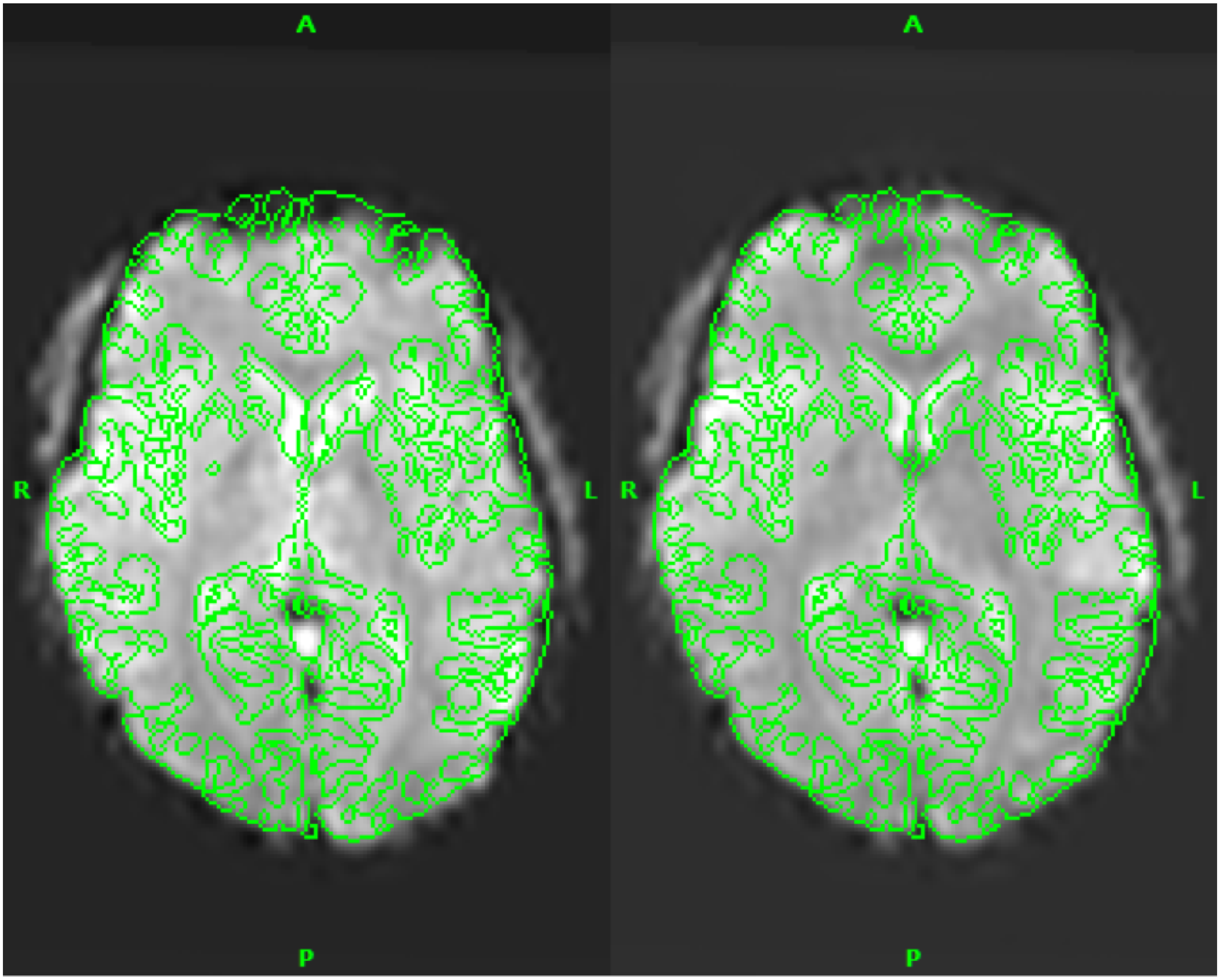

Figure 1. Comparison of (left) original EPI and (right) distortion corrected EPI relative to an edge map computed from the corresponding T1 MRI (green outline). The EPI volumes are shown resampled to the space of the T1 MRI.

Abstract Information

Would you accept an oral presentation if your abstract is selected for an oral session?

Yes

Please indicate below if your study was a "resting state" or "task-activation" study.

Task-activation

Healthy subjects only or patients (note that patient studies may also involve healthy subjects):

Healthy subjects

Internal Review Board (IRB) or Animal Use and Care Committee (AUCC) Approval. Please indicate approval below. Please note: Failure to have IRB or AUCC approval, if applicable will lead to automatic rejection of abstract.

Yes, I have IRB or AUCC approval

Please indicate which method was used in your research:

Functional MRI

Structural MRI

For human MRI, what field strength scanner do you use?

3.0T

What post processing software packages do you use?

Other, Please list - BrainSuite

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