Automatic Geometric Distortion Correction for Single-Shot Echo Planar Imaging

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Introduction

Single-shot echo planar imaging (EPI) suffers from spatial and intensity distortions caused by B_0 field inhomogeneities. For comparison with anatomical MRI scans, undistorted images are highly desirable. Various methods to correct geometric distortions have been presented [1-8]. Here, we focus on a method recently introduced by Holland et al. [8] that involves a displacement mapping scan based on two EPI scans with opposed phase encoding polarities together with a fast nonlinear alignment procedure to determine the displacement map. We demonstrate a fully automatic version of the method implemented on various Siemens MRI scanners.

Methods

The method proposed by Holland et al. [1] has been implemented on the 1.5 T Avanto, 3 T Tim Trio and 7 T (Siemens, Erlangen, Germany). It consists of a short displacement mapping scan based on a single-shot spin-echo EPI scan with two measurements with forward and reverse phase-encoding followed by a distortion-matched imaging scan. The following imaging scan types based on gradient-echo and spin-echo EPI have been implemented: BOLD, PACE, DTI/HARDI/QBI/DSI, and ASL. Calculation of the displacement map is done automatically online at the end of the mapping scan. Data from subsequent imaging scans with distortion-matched protocols are automatically unwarped online on the scanner during image reconstruction.

All experiments were performed on a 3 T Tim Trio (Siemens, Erlangen, Germany) using a 32-channel head coil. The proposed method was used to image 10 subjects. Acquisition parameters for the BOLD displacement mapping scan were as follows: TR 5310 ms, TE 80 ms, FoV 216 mm, 47 slices, 3.0 mm slice thickness, no gap, matrix size 72×72 (image pixel size 3.0 mm × 3.0 mm), bandwidth 2240 Hz/px, 2 measurements with forward and reverse phase encoding, scan time 16 s. Acquisition parameters for the BOLD scan were identical but for: TR 3000 ms, TE 30 ms, 160 measurements, inline motion correction, scan time 8:12 min:s. Acquisition parameters for the DTI displacement mapping scan were as follows: TR 9550 ms, TE 80 ms, FoV 237 mm, 79 slices, 1.85 mm slice thickness, no gap, matrix size 128×128 (image pixel size 1.85 mm × 1.85 mm), bandwidth 1396 Hz/px, 6/8 phase partial Fourier, acceleration factor 2 using generalized auto-calibrating partially parallel acquisitions (GRAPPA) [9], 2 measurements with forward and reverse phase encoding, scan time 57 s. Acquisition parameters for the DTI scan were identical but for: TR 9970 ms, TE 84 ms, 10 non diffusion-weighted volumes, 60 diffusion gradient directions, b-value 700 s/mm2, scan time 12:09 min:s. For anatomical comparison, multi-echo MPRAGE [10] scans have been acquired with the following parameters: TR 2530 ms, TEs 1.7 ms, 3.6 ms, 5.5 ms, 7.3 ms, TI 1200 ms, FoV 230 mm, 192 slices per slab, 0.9 mm slice thickness, no gap, matrix size 256×256 (image pixel size 0.9 mm × 0.9 mm), bandwidth 651 Hz/px, scan time 6:03 min:s. The four echoes were root-mean-square averaged. Difference maps were calculated between the images acquired with opposed phase encoding polarities, before and after unwarping, to check the quality of the distortion correction.

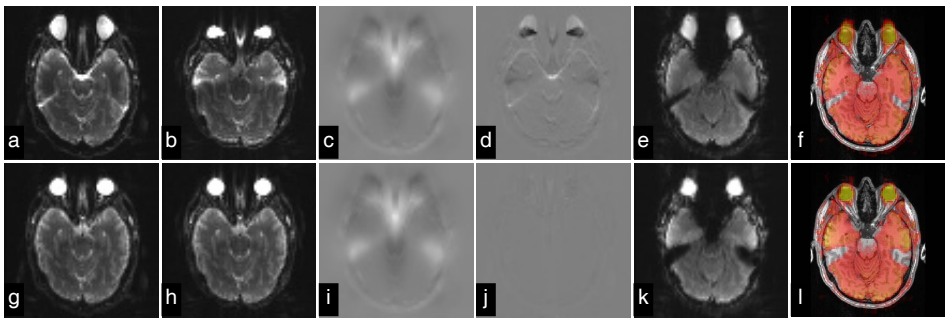

Figure 1*: Data from displacement scan and BOLD acquisition as well as overlay onto the MEMPRAGE data. a) forward, b) reverse phase encoding polarity, c) displacement map, d) difference between a and b, e) original BOLD data, f) original BOLD data overlaid on MEMPRAGE, g) unwarped forward, h) unwarped reverse phase encoding polarity, i) displacement map (same as c), j) difference between g and h, k) unwarped BOLD data, h) unwarped BOLD data overlaid on MEMPRAGE.*

Results and Conclusion

Automatic calculation of displacement maps and unwarping of imaging data worked well in all subjects. Figure 1 shows an example of the acquired and automatically processed data from one of the BOLD scans. Figure 2 shows the same data from one of the DTI scans. After unwarping, forward and reverse phase encoded images are almost identical as demonstrated in the difference images (j) compared to the clearly visible differences before unwarping (d). BOLD and DTI data shows much better match to the anatomical data MEMPRAGE data after unwarping. In summary, we demonstrated a fully automatic procedure to correct for geometric distortions in single-shot EPI for a wide range of applications.

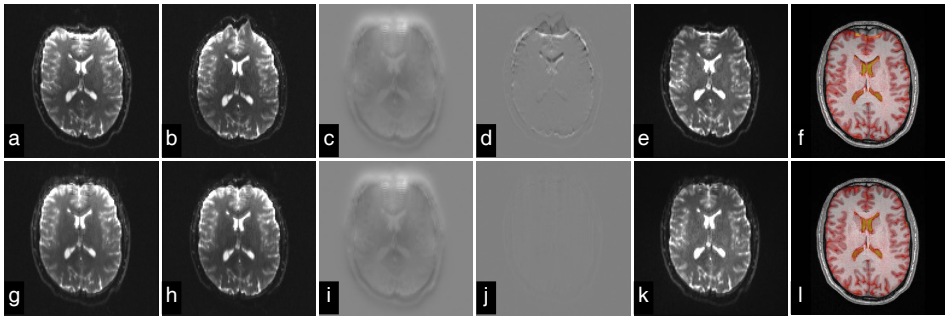

Figure 2*: Same data as in Figure 1 but from the DTI scan (non diffusion encoded images shown).*

Acknowledgments

This research was carried out at the Athinoula A. Martinos Center for Biomedical Imaging at the Massachusetts General Hospital, using resources provided by the Center for Functional Neuroimaging Technologies, P41RR14075, a P41 Regional Resource supported by the Biomedical Technology Program of the National Center for Research Resources (NCRR), National Institutes of Health. This study was supported by the National Multiple Sclerosis Society (NMSS RG 4281-A-1).

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