Reference-free Distortion Correction for EPI by Flipped k-space Segments (DICOFLIP)

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TARGET AUDIENCE: People interested high resolution Diffusion Weighted and Echo Planar Imaging

Introduction and Purpose: Diffusion weighted magnetic resonance imaging (DWI) data is usually acquired with single-shot echo-planar imaging (EPI). However, spatial resolution is limited and off-resonance effects cause distortion artefacts, even when parallel imaging is incorporated. Multi-shot acquisition methods can partially solve these issues, but are susceptible to phase differences between different shots, in particular in DWI. Recently, a reconstruction technique called multiplexed sensitivity encoding (MUSE) [1] was introduced, which makes the phases of the different shots consistent by a simple post processing step, without any use navigators. In this work we combine this technique with an interleaved bottom-up/top-down traversal of k-space of the individual k-space segments to completely remove susceptibility induced distortions.

Method: DWI data is obtained with an interleaved segmented EPI pulse sequence (using 2 and 4 segments). [TR: 2s, $TE_{2,4seg}$: 114/77ms, b: 1000s/mm^2, 6 directions, matrix 128×128×5, voxel 1.6×1.6×2 mm] For the very initial MUSE segment-wise reconstruction one non-diffusion weighted image with equal k-space traversal directions is acquired to compute the coil-sensitivities. Then, for every slice and weighting direction, the first segment of k-space is flipped in phase-direction; hence, also the susceptibility induced distortions are flipped.

Following MUSE we reconstruct each segment separately using SENSE. This allows determining the phase of each segment which can then be combined with the coil-sensitivities. Once the MUSE-phase corrected coil-sensitivities are computed and the fieldmap is estimated from the separately reconstructed segments, we can formulate the full forward-operator as follows:

$$S_{j,l}(k_x, k_y) = \int c_{j,l}(r) e^{-sg(l) i\omega(r) k_x - i(sg(l) k_x r_x + k_y r_y)} \rho(r) dr^3$$

Where $S_{j,l}$ is the signal coming from the j-th coil and l-th segment. The term $sg(l)$ denotes the sign indicating bottom-up/top-down traversal. The sensitivities $c_{j,l}(r)$ are the modified coil-sensitivities (following MUSE) calculated from the j-th coil and l-th segment. The FSL-topup tool [2] was used to estimate a fieldmap $\omega(r)$from the bottom-up and top-down image. Actually, one could do this for each individual image, or e.g., just from the initial b=0 scan, we decided for the latter. The inversion of the signal equation was done by a simple CG approach without any regularization.

Results: In Figure 1 we show reconstructions from two slices of the measurement using 2 interleaves. First, each segment reconstructed independently without any correction is shown, then the images corrected via topup. Finally, the result of our new approach is shown for the B0 and one diffusion weighted image. Additionally, a close-up view of the frontal region is shown comparing topup and our approach.

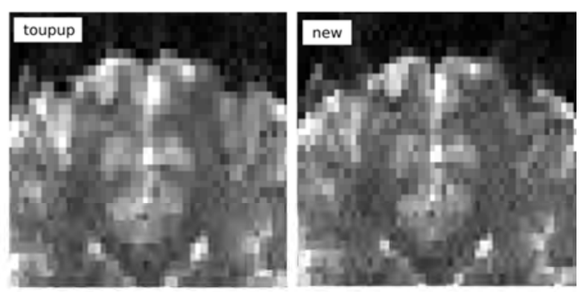
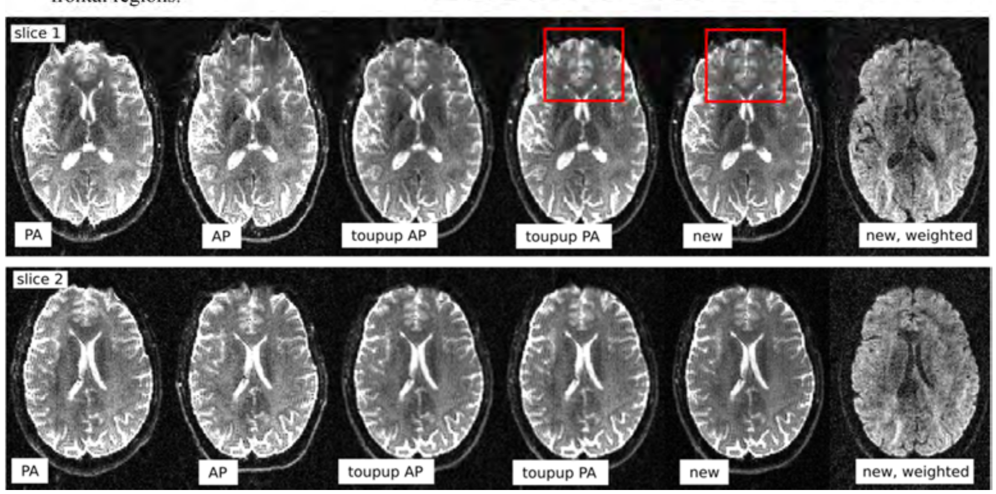


Figure 1: Reconstruction from two slices are shown together with closeups of the frontal regions.



Discussion: We presented a novel EPI acquisition scheme which includes off-resonance information such that a distortion correction is possible without any reference scan. Note that, the segmented EPI already decreases off-resonance effects due to smaller echo times; therefore distortions are less, but still present as shown in the Figure. While topup can quite nicely recover the displacement field (or fieldmap), the close-up view shows how the image-space based warping strongly affects the noise characteristics and smoothes the deformed regions. In contrast our new approach keeps the noise characteristics, because all corrections are included in the early reconstruction. Additionally, our approach can benefit from the advantages of the MUSE approach, which eliminates phase artifacts and allows high-resolution DWI.

References: [1] A robust multi-shot scan strategy for high-resolution diffusion weighted MRI enabled by multiplexed sensitivity-encoding (MUSE) N. Chen, A. Guidon, H. Chang, A. Song, Neuroimage 2013, 72, 41-47, [2] How to correct susceptibility distortions in spin-echo echo-planar images: application to diffusion tensor imaging, J. Andersson, S. Skare, J. Ashburner, Neuroimage 2003,20,2,870-888