Correct Ghosting and Distortion Artifacts in EPI by Phase Labeling for Additional Coordinate Encoding (PLACE)

Q-S. Xiang[1], F. Q. Ye[2]

[1]Department of Radiology, University of British Columbia, Vancouver, BC, Canada, [2]Neurophysiology Imaging Facility, National Institute of Mental Health, NIH, Bethesda, MD, United States

Introduction Echo-Planar-Imaging (EPI) suffers from two major artifacts: (i) N/2 ghost caused by data inconsistency between odd and even echoes; (ii) geometry and intensity distortion due to signal miss-mapping along phase encoding (PE) direction. A few N/2 deghosting methods have been developed, typically using additional reference scans [1,2] with varing degree of success. Many distortion correction methods have also been proposed, including field mapping [3] with 2 image acquisitions, and more sophisticated PSF [4] and k-space phasing with extended data acquisitions [5,6]. In this work, we propose a simple method that corrects for either artifacts by acquiring 2 images, or both artifacts simultanously with 3 images. The method uses Phase Labeling for Additional Coordinate Encoding and thus is termed PLACE.

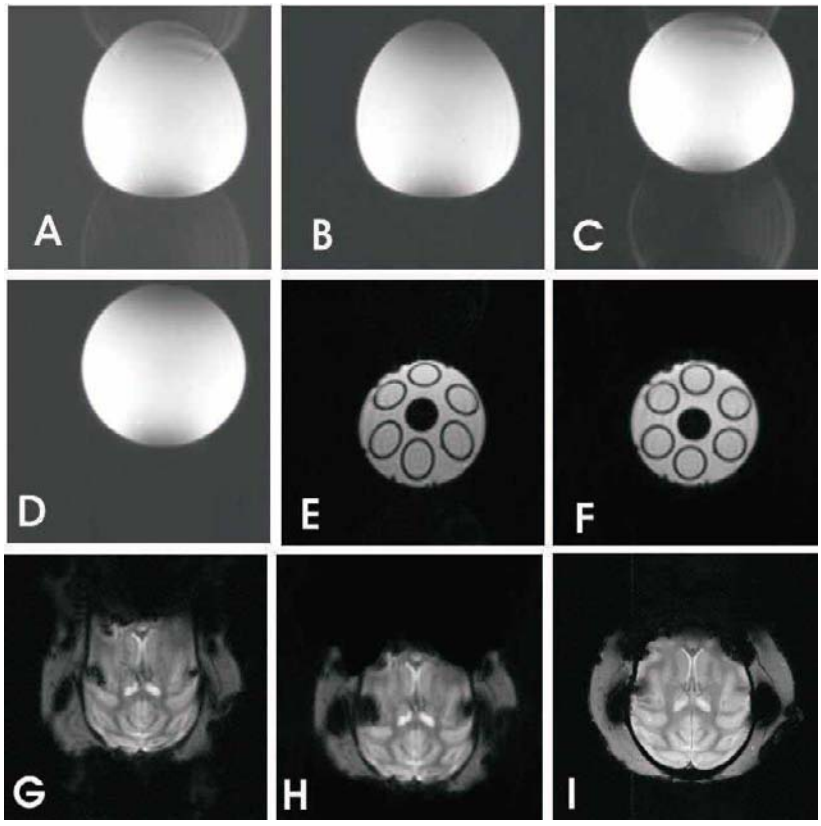
Methods Phantom and animal experiments were performed on a 4.7T Brucker scanner. Two complex images I_1 and I_2 are acquired with 2 nearly identical EPI sequences. The 2 sequences differ only by an additional PE gradient application, with a small area equal to 1 or 2 normal "blips", generating a phase twist between the 2 images along y-direction. Therefore, there is a phase rotation for each voxel depending on where the voxel was originally located in the scanner. The parametrers for EPI were: 2mm slice, 128x128 mm^2 FOV, 128x128 matrix size, sampling bandwidth 200KHz, TR 2000ms, TE 30ms. Four scenarios are considered.

(1) For N/2 deghosting only. The additional PE gradient has an area of 1 normal blip, creating a phase ramp within $(-\pi,\pi)$ range across the entire filed-of-view (FOV). This corresponds to a phase rotation of π radians for any N/2 ghost components relative to the overlapping image component since they are from 2 voxels located FOV/2 apart. By applying a phase ramp within $(-\pi,\pi)$ range across the FOV, the 2 complex images can be essentially "phase aligned" and simply averaged to produce an image with highly suppressed N/2 ghost.

(2) For undistortion only. If the N/2 ghost is not present, the above data can also be used for distortion correction, since the correct y-coordinate for each pixel in the undistorted space is encoded in the phase difference between the 2 complex images as, $y = 0.5\ FOV\ Arg\ (I_1 I_2^*)/\pi$. To achieve intensity restoration, sub-pixel mapping is used by expanding the PE dimension from 128 to 12800 pixels. The expanded complex image $I_1 I_2^*$ is heavily smoothed in 2D after an ideal linear phase ramp is removed, resulting in a displacement map for continous warping. The final result is obtained by rebinning the undistorted image into its normal size of 128 pixels along PE direction.

(3) For undistortion in presense of N/2 ghost. The procedure is similar to (2) except now the additional PE gradient has an area of 2 blips, making the y-coordinate phase labeling insensitive to N/2 ghost, since the N/2 ghost will rotate by nearly 2π relative to the overlapping image component. Unique warping can be achieved as long as no voxel has displaced by more than FOV/2.

(4) For both N/2 deghosting and undistortion. Three images I_1 , I_2 , and I_3 are acquired with additional PE gradients of areas equal to 0, 1, and 2 blips. Two deghosted images can be obtained first by combining I_1 and I_2, as well as I_2 and I_3 using procedures described in (1). The two deghosted images can then be combined for undistortion according to (2).



Results Figures (A-D) are images from a spherical phantom. A is one of the acquired images with both N/2 ghost and distortion; B is only deghosted with 2 images differing by 1 blip; C is only undistorted with 2 images differing by 2 blips; D is both deghosted and undistorted with 3 images using 0, 1, and 2 blips. E and F are distorted and corrected images from a phantom containing circular tubes. G and H are distorted and corrected images from a transverse head scan of a monkey with head implant; I is acquired with FLASH sequence as a gold standard. These results demonstrate the effectiveness of PLACE for both deghosting and undistortion.

Discussion The sequences have similar effects for eddy current and concomitant gradient since they have identical timing. The phase difference map for displacement is well behaved without phase wrap that is often problematic for field mapping methods. Smoothing the complex image rather than phase image is simpler and more robust as it self-regulates the background noise through magnutide weighting. The 2 or 3 images can also be used as reference scans to produce "ghost phase map"[2] or displacement map for deghosting and undistortion of every single image in a time series.

References

[1] X Hu, TH Le, MRM, 36,166-171, 1996
[2] NK Chen, AM Wyrwicz, MRM, 51, 1247-1253, 2004
[3] P Jezzard, RS Balaban, MRM, 34, 65-73, 1995
[4] MD Robson *et al*, MRM, 38,733-740, 1997
[5] JY Chiou *et al*, IEEE-TMI, 22,200-205, 2003
[6] H Zeng *et al*, MRM, 52, 1373-1378, 2004