Embedded PLACE Correction for Geometric Distortion and N/2 Ghosting in Single-Shot EPI

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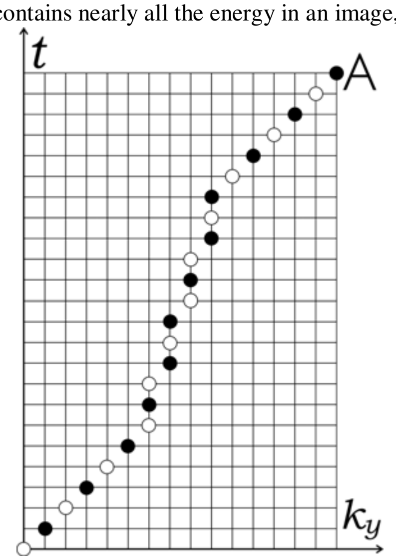
Introduction Echo-Planar Imaging (EPI) is vulnerable to two major artifacts, known as N/2 ghosting and geometric distortion. A number of techniques have been proposed to correct for either but not both artifacts [1-9]. Phase Labeling for Additional Coordinate Encoding (PLACE) has recently been demonstrated to be able to correct for both artifacts [10]. The original PLACE is simple but requires 2 or 3 excitations to address either or both artifacts respectively. It can also be used as reference scans for correcting subsequent acquisitions if motion is negligible. In this work, we present a new version of instant PLACE (iPLACE) that is capable of correcting both artifacts simultaneously within a single RF excitation.

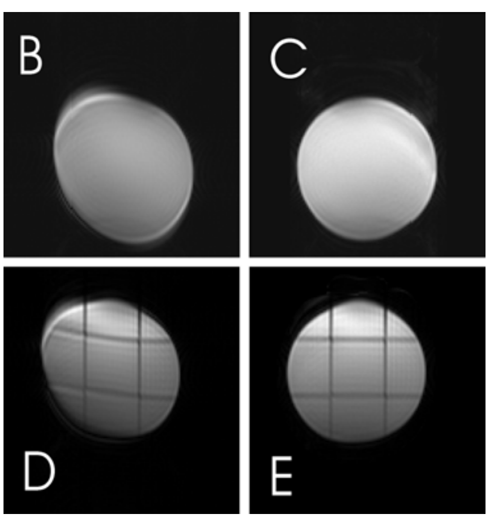
Methods Phantom experiments were performed on a 4.7T Bruker scanner. Offset current was introduced in a 2nd order shim coil to generate B_0 field errors leading to geometric distortion. A standard blipped EPI sequence was moderately modified to collect each of the central 16 lines in k-space repeatedly for 3 times. This was readily achievable by removing 2 out of 3 blips, or keeping only every 3rd blip near the k-space center. The k_y-t space coverage [10] after this modification is schematically illustrated in Figure (A) with 4 central k-space lines acquired 3 times, where the solid and open circles indicate k-space lines acquired with positive and negative readout gradient. Note the k_y advancement is 3 times slower near k-space center than peripheral parts. As such, the low-resolution component of the image will have 3 times more geometric distortion than the "edges", causing blur as a result of miss-registration between the two components [9]. Reconstruction was performed offline with the following two steps.

<u>(i) N/2 Deghosting</u> At each k_y step near central k-space, let us denote the repeatedly acquired 3 signal lines as (1,2,3). They can be reorganized into two groups, denoted as (1,2) and (2,3) respectively. Clearly, each group contains a pair of both solid and open circles as shown in Figure (A). When the two data points in each group are averaged, N/2 ghost will be eliminated because now the signal modulation at Nyquist rate is averaged out. Therefore, two low-resolution images, both free from N/2 ghost, can be reconstructed from the two groups of data. Since the central k-space contains nearly all the energy in an image, this process would suppress more than 90% of the ghost in the final image. The two low-resolution images were used to find a displacement map as described below, and also further averaged and combined with the "edges" to form an "uncorrected" image I.



<u>(ii) Distortion Correction</u> Two deghosted low-resolution images were compared in phase, after low-pass filtering or smoothing to avoid possible ringing from truncation artifact. This phase difference recorded the displacement Δy of each pixel in the *distorted* space (x', y'). It was used to map Δy itself onto the un-distorted space (x,y) to form a registered displacement map, by warping the Δy map in a similar manner as described in Ref [10]. Assuming the ideal image to be recovered is I_0, and the uncorrected image is I. For each column along the y-direction, the two images are related by $I = AI_0$. The operator A is a combination of several matrix operators given by $A = F^{-1}(H_1FP_1 + LFP_0 + H_2FP_2)$, where F and F^{-1} represent the forward and inverse Fourier transforms; L is a low-pass filter; H_1 and H_2 are two high-pass filters for the upper and lower part of the k-space respectively; P_0, P_1, and P_2 are matrices that are derivable from the registered displacement map. Once the matrix A is obtained, its pseudo-inverse A^{-1} can be found (e.g. as conjugate-transpose), and subsequently applied to the uncorrected image I to yield a final restored image I_0. This procedure is repeated for all columns to restore the entire 2D image.

Results Figure (B) is magnitude of an uncorrected image I after step (i), in which the N/2 ghosting was well suppressed, but distortion and blur (upper-left corner) are visible. Figure (C) is magnitude of the final image found as $I_0 = A^{-1}I$. All artifacts, (i.e. N/2 ghosting, geometric distortion, and blur) are well suppressed. The image of a spherical phantom now does appear circular. Figures (D) and (E) are similar results as those in (B) and (C), except 4 tagging lines were imposed on the otherwise uniform phantom. The 2 horizontal tagging lines were distorted in (D) but straightened in (E).



Discussion Instant Phase Labeling for Additional Coordinate Encoding (iPLACE) is developed and successfully demonstrated to be effective by phantom experiments on a 4.7T scanner. Compared with the original PLACE [10], iPLACE is more time efficient and allows simultaneous and instantaneous suppression of both N/2 ghosting and geometric distortion artifacts in single-shot EPI.

References

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