A Modified Reversed Gradient Method using the Displacement Map Concept for Geometric Distortion Correction in EPI

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Introduction

In echo-planar imaging (EPI), static magnetic field inhomogeneities lead to geometric and intensity distortions within an MR image. A common method achieves off-resonance correction by collecting an extra field map [1]. Another option relies on using gradient with reversed polarity that produces distortion in opposite direction, from which the information on the difference in spatial displacements is then used to correct for distortion [2]. The reversed gradient (RG) method is, however, problematic in regions with low signals because of a lack of information on distortions [3]. In this work, we proposed a modified reversed gradient method using the concept of displacement map to solve this problem.

Theory

In reversed gradient method, two images are acquired showing different spatial displacements y_1 in image i_1 and y_2 in image i_2 with reversed phase-encoding gradient. The true position of the pixel is given by

$$y = \frac{y_1 + y_2}{2} \qquad (1)$$

, and with true intensity

$$i(y) = \frac{2 i_1(y_1) i_2(y_2)}{i_1(y_1) + i_2(y_2)} \qquad (2).$$

The matching pair y_1 and y_2 can be found from pixels satisfying

$$\int_{y_{01}}^{y_1} i_1(\tau_1)d\tau_1 = \int_{y_{02}}^{y_2} i_2(\tau_2)d\tau_2 \qquad (3).$$

It is simpler to work backwards by stepping through pixel locations in the corrected image matrix (y) to search for corresponding values y_1 and y_2 having equal line integrals (Eq.3). In low signal regions, however, Eq.3 can always be satisfied, causing erroneous estimates of y_1 and y_2. In this work, we assume that the variation of field inhomogeneities is slow, such that the pixel displacement is a spatially smooth function. This assumption allows a modification of the pixel-by-pixel displacement map using 2D polynomial surface fitting followed by a low-pass filter, with the low signal regions eliminated using a mask. The new displacement map can then be used to correct geometrical and intensity distortion from i_1 and i_2. The flow chart is shown in Fig.1.

Material and methods

We collected phantom and human brain data on a 3.0T MRI scanner (Philips Achieva, Best, the Netherlands). The single shot EPI scanning protocol consisted of the parameters: Flip angle 90 deg, TE 120ms, TR 1650ms, NEX 6, FOV 24cm*24cm, slice thickness 5mm, 256*256 imaging matrix.

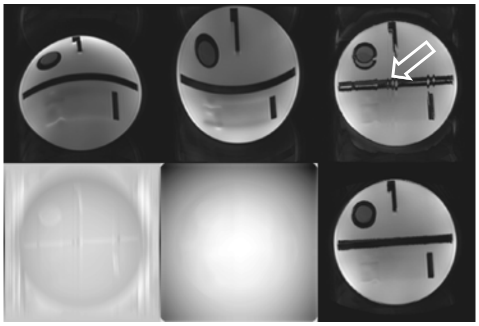

Figure 2. Phantom images acquired with opposite phase gradient polarities showing distortions along opposite direction (a,b), RG corrected image (c), original displacement map (d), re-computational displacement map (e), and modified RG corrected image using re-computed displacement map (f).

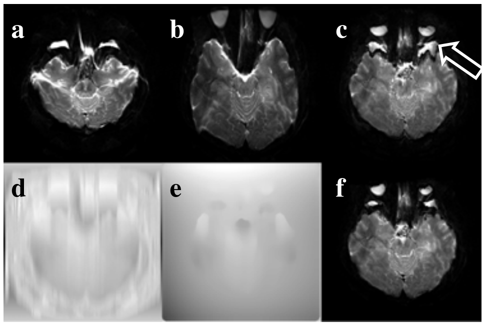

Figure 3. Human brain images acquired with opposite phase gradient polarities showing distortions along opposite direction (a,b), RG corrected image (c), original displacement map (d), re-computational displacement map (e), and modified RG corrected image using re-computed displacement map (f).

Acquired two images with distortion in opposite direction use reversed gradient.

↓

Used Eq. (3) to find y_1 and y_2 pair, then used Eqs. (1) & (2) to compute correct image

↓

Computed displacement map

↓

Used mask to remove displacement map of black part

↓

Used 2D polynomial surface fitting to compute new displacement map, and then smooth by filter.

↓

Used new displacement map to correct pair of distortion images i_1 and i_2

Figure 1. Flow chart of modified reversed gradient to improve correction in low signal regions.

Results

The results phantom and human brain of modified reversed gradient method are shown in Figs.2 and 3. The corrected images without re-computing the displacement maps (Figs.1c & 2c) still showed failed correction at low signal regions (arrows). The re-computed displacement maps (Figs.1e & 2e) are smooth compared with the original displacement maps (Figs.1d & 2d), resulting in improved corrections from our modified RG method (Figs.1f & 2f).

Discussion

The results from our study show that geometric and intensity distortions correction using RG indeed benefits from the re-computed displacement map through effectively reduced artifacts in low signal regions. The modified RG method employing 2D polynomial surface fitting is also computationally economic than field map correction. Another important advantage of modified RG method is that it also corrects EPI distortions arising from eddy current effects as long as the distortions are opposite in the two images, whereas off-resonance corrections using field map do not take eddy current effects into account. The corrected EPI images show good preservation of quality even near the skull base.

Conclusion

The modified RG method reduces EPI distortions and helps obtaining additional correction at low signal regions. Our modified scheme uses 2D surface fitting to smooth the displacement map, it hence has advantages of less computing time with eddy current correction capability. We therefore conclude that the modified reversed gradient method is an effective approach for correction of EPI geometric and intensity distortions.

Reference

[1] Jezzard P, et al, MRM, 34:65 (1995). [2] Chang H, et al, IEEE Trans. Med. Imag, 11:319 (1992). [3] Kannengiesser SAR, et al, MRM, 42:585 (1999).