EPI Undistortion Using an Echo Spacing Fitting Method

X. Liu[1], J. Zhong[2]

[1]Electrical and Computer Engineering, University of Rochester, Rochester, New York, United States, [2]Departments of Radiology and Biomedical Engineering, University of Rochester, Rochester, New York, United States

Introduction

In MR imaging, the fidelity of image reconstruction relies on the homogeneity of the static magnetic field, which is not always achievable in many cases because of the imperfection of the magnet system or the susceptibility difference between different tissue. As a widely used fast MR imaging method in fMRI and DTI, Echo planar imaging (EPI) suffers more geometry and intensity distortions because of its inherently long acquisition window in phase encoding direction. The well-known fieldmap correction method [1] works well for most geometry correction but it performs poorly in intensity correction. Chang et. al. [2] proposed a gradient-reversal undistortion method which successfully corrects both the geometry and intensity distortion induced by field inhomogeneity. In this work, we propose an Echo Spacing Fitting (ESF) EPI undistortion method algorithm using two or more images collected with different echo spacing time and phase gradient direction. It can be shown that Chang's phase-reversal undistortion method is a special case of ESF method.

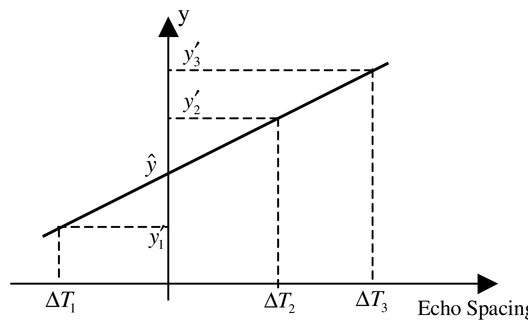

Figure 1. Calculate the estimated undistorted coordinates from distorted coordinates in images collected with different echo spacing.

Theory and Method

In 2D FFT MR imaging method, the signal sampled in k-space in the presence of field inhomogeneity is: $s(k_x, k_y) \approx \iint \rho(x,y) \cdot \exp\left[-i\{k_x \cdot x + k_y[y + \gamma\Delta B_0(x,y)\Delta T / \Delta k_y]\}\right]dxdy$ (1), where ρ(x,y) is the spin density distribution function, $\Delta B_0(x,y)$ is the field inhomogeneity, ΔT is the echo spacing time, and Δk_y is the distance between two k_y line in k-space and equal to the reciprocal of image resolution in y direction. From above equation, the distorted pixels coordinate is: $y' = y + \gamma\Delta B_0(x,y)\Delta T / \Delta k_y$ (2), y is the 'correct' coordinate in image without distortion. The distorted image intensity is: $I'(y') = I(y)dy/dy'$ (3). The pixel displacement is proportional to field inhomogeneity and echo spacing. When the echo spacing is fixed, we can correct the distorted image with the knowledge of field inhomogeneity. That's how the field map correction method works. If we collect two or more images of the same slice with different echo spacing time and with assumption that the acquisition is motion free (i.e. the field inhomogeneity is the same), we can use the linear relation between pixel displacement and echo spacing to find out the undistorted image (Fig. 1). It is straightforward from above equations that the estimated undistorted image can be calculated from two distorted images with different echo spacing as follows: $\hat{y} = \frac{y_2'\Delta T_1 - y_1'\Delta T_2}{\Delta T_1 - \Delta T_2}$ (4) and $\hat{I}(\hat{y}) = \frac{I_1'(y_1')I_2'(y_2')(\Delta T_1 - \Delta T_2)}{I_1'(y_1')\Delta T_1 - I_2'(y_2')\Delta T_2}$ (5), here y_1' and y_2' is the corresponding pairs in images with different echo spacing. If we treat the reverse of phase gradient as choosing negative echo spacing value, that is when $\Delta T_2 = -\Delta T_1$, the resulting ESF is exactly the same as Chang's reversal-gradient method.

The ACR phantom and human volunteer brains were scanned using an SE EPI sequence on a Siemens 3T Trio scanner (Fig.2a, 2b and Fig.2d, 2e). The measurement parameters for the two sets of images were all the same except using different echo-spacing time and phase encoding direction. In-plane resolution was 128×128. TE was 105ms. The images were resized by a factor of 3 using a bicubic interpolation method to increase the matching accuracy. Corresponding pairs in two images were found using integral method with a local pixel adjustment algorithm. From the corresponding pairs we restored the undistorted coordinates and intensities from distorted images using equation (4) and equation (5). Gaussian smoothing was applied to the voxel displacement map based on the fact that the field inhomogeneity is mostly low frequency. The algorithm was applied from the either edge of the brain along the phase encoding direction. The results were averaged to increase SNR.

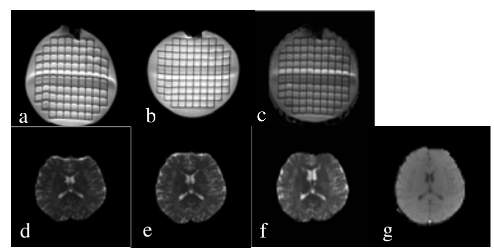

Figure 2. a) Phantom image with ESP (echo spacing)=1.4ms, PE (phase encoding) direction A to P. b) Phantom image with ESP=0.7ms, PE direction P to A. c) Corrected phantom image. d) Brain image with ESP=1.34ms, PE direction A to P. e) Brain image with ESP=0.6ms, PE direction A to P. f) Corrected brain image g) GRE anatomical image.

Result and Discussion

Fig. 2c shows the corrected phantom image, which can be seen with both the shape and intensity well restored. The twisted grid in both distorted images were corrected. In brain images, the shape and intensity in front lobe area were distorted due to compressing in Fig. 2d and Fig. 2e. Fig. 2f shows the corrected brain image. The distortion was well corrected. In this abstract, we showed the correction using two images with different echo spacing and phase encoding gradient direction. If three or more images are collected with different echo spacing and gradient direction, a linear fitting according to equation (2) can be used to estimate pixel position and nonlinear fitting can be used according to equation (3) to estimate intensity. More accurate correction is expected, but with acquisition time penalty using this method.

Reference

[1] P. Jezzard, et. al., MRM 34, 65-73 (1995) [2] H.Chang and J. Fitzpatrick, IEEE Trans Med. Imag.,11(3) , 319-329 (1992)100