A New Method To Correct Distortions In Echo Planar Imaging

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Introduction: Echo planar imaging (EPI) is the leading rapid imaging technique in MR. However, its widespread adoption is limited by the large intensity variations and geometric distortions which can arise due to the accumulation of phase errors during the long acquisition of multiple gradient echoes. These distortions severely limit the practical uses of EPI, especially at high field. A new method is described that can correct these errors. This method uses two or more reference images that are prephased along the phase-encoding direction, enabling the distortion along that direction to be calculated, and corrected. It also avoids the difficulties of phase unwrapping used in field-mapping methods. Results using this method for phantoms and human heads at 3T demonstrate the efficacy of this method.

Method: In EPI, given an original image $\rho_0(x_0,y_0)$, the distorted image due to the off-resonance effects can be expressed as [1]

$$\rho_o(x_o,y_o) \longrightarrow \rho(x,y) = \frac{\rho_0(x-\delta x_0, y-\delta y_0)}{J(x,y,x_0,y_0)}, \quad (1)$$

Here $x = x_0 + \delta x_0$, $y = y_0 + \delta y_0$ and δx_0 and δy_0 are the distortions, in each of the in-plane directions, and $J(x,y,x_0,y_0)$ is the Jacobian. Since δx_0 (in the frequency direction) is small compared with δy_0 in EPI, we only consider δy_0. Now if we prephase the image with a gradient pulse such as to add an extra phase expressed as $\exp(i2\pi n\, k_1 y_0)$, where n is an integer, and k_1 is constant, we obtain a new image which is $\exp(i2\pi n\, k_1 y_0)\,\rho_o(x_o,y_o)$. Then we have:

$$\exp(i2\pi n\, k_1 y_0)\,\rho_o(x_o,y_o) \longrightarrow \rho_n(x,y) = \frac{\rho_0(x-\delta x_0, y-\delta y_0)}{J(x,y,x_0,y_0)} \exp(i2\pi n k_1 (y-\delta y_0)) \quad (2)$$

Dividing (2) by (1), we get:

$$\frac{\rho_n(x,y)}{\rho(x,y)} \exp(-i2\pi n\, k_1 y) = \exp(i2\pi n\, k_1 \delta y_0) \quad (3)$$

thus:

$$n\,\delta y_0 = \mathrm{Arg}\left(\frac{\rho_n(x,y)}{\rho(x,y)} \exp(i2\pi n\, k_1 y)\right)/(2\pi k_1) \quad (4)$$

Thus repeating the experiment with multiple values of n, we can obtain an estimate of δy_0 and use that to correct the image.
A phantom and head were imaged on a GE 3T MR Scanner using a spin-echo EPI sequence, with a matrix size of 128x128, TE=170ms for the phantom and 60ms for the head, FOV = 24cm, BW = +/-62.5 kHz, for the brain.

Results: Fig. 1 shows the n δy as a function of n at a point in the center of phantom for an experiment with eight scans (n=-4…+4). Fig. 2 shows the phantom and human imaging results. The first column contains standard spin echo images, the second column shows distorted (i.e., uncorrected spin echo EPI images, and the last column show the images corrected using our new method (using only two reference scans with n = +1,-1).

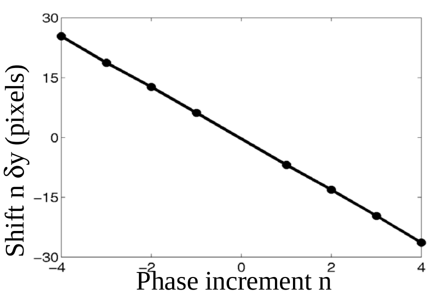

Fig. 1

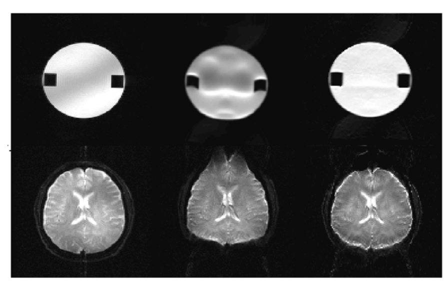

Fig. 2

Discussion: This new method avoids the difficulties of phase unwrapping of field mapping methods by applying only small gradient pulses to prephase the data in a known manner. It also can correct the distortion from eddy currents. Results using this new method with phantoms and human head scans at 3T demonstrate the effectiveness of the method in correcting distortions in spin echo EPI.

Reference:1. H. Chang, J. M, Fitzpatrick, IEEE Trans on Med Imag. Vol. 11, No.3, 1992.