Point Spread Function Map for Distortion Correction with Double EPI Readout Acquisition Strategy at 3T

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Background field inhomogeneity causes geometric distortion in echo planar imaging (EPI) MR images. Point spread function (PSF) mapping method has been proposed to correct for the geometric distortion. The currentPSF mapping technique needs an extra 2-3 min of scan time to acquire a PSF map, based on prevalent EPI acquisition parameters used in fMRI studies. Moreover, when a subject moves between the PSF mapping scanning and the real imaging scan, the PSF map would not be accurate to be used to correct for geometric distortion. Though EPI using parallel imaging acquisition can alleviate the distortion problem, it is at the cost of SNR. In this study, we aim to develop a simultaneous PSF mapping correction method without lengthening data acquisition time.

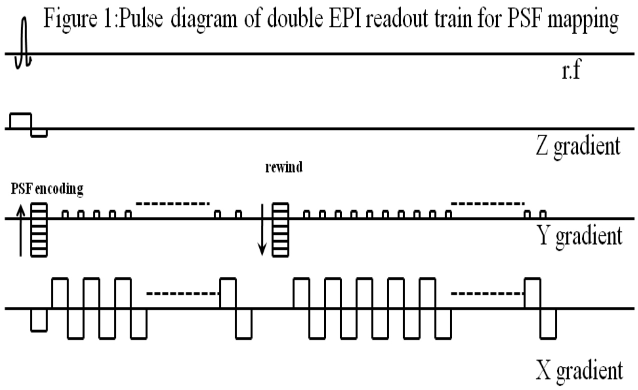
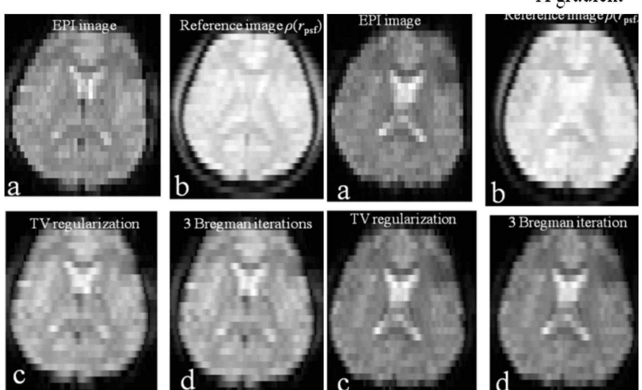


Figure 1:Pulse diagram of double EPI readout train for PSF mapping



5/8 partial acquisition 8/8 full acquisition
Figure 2 a.EPI image b reference image $\rho(r_{\mathrm{psf}})$; c: TV regularization d. 3 Bregman iterations

Methods: For a typical functional MRI scan (fMRI), TE is usually chosen around 27-40 msec to achieve sufficient sensitivity to blood oxygenation level dependence contrast (BOLD). This range of TE in a gradient echo EPI sequence usually leave some unused time from RF excitation pulse to the true imaging readout. We proposed to utilize this idle time by inserting a PSF echo before the imaging readout. Over the course of the entire fMRI acquisition (usually has 60 or more repetitions), the full PSF echo can be encoded by stepping through a PSF encoding table along phase encoding direction every repetition. By doing it, no additional time is needed. Moreover, since the PSF echo was acquired simultaneously with the true imaging echo, this approach is relatively insensitive to motion. The pulse sequence diagram of this dual EPI readout train is shown in the Figure 1. Two human subjects were scanned on a Siemens 3 T Allegra MRI. The first readout train with PSF map encoding used two acquisition schemes: The first scheme was the full readout train matrix size 64×64. The second scheme was the reduced phase encoding resolution 5/8 of the full acquisition (matrix size = 64×40) to minimize TE. The second readout echo for EPI image was full acquisition with a matrix size 64×64. FOV = 240mm × 240mm, TR = 3 s, slice thickness = 4.0 mm, number of slices = 24, receiver bandwidth = ± 89.3kHz, echo spacing = 0.43 ms. PSF FOV = 120 mm, number of PSF encodings = 64. For the full first echo acquisition, TE for the PSF encoding = 16 ms; TE of EPI image = 44 ms; for 5/8 partial acquisition, TE of the PSF encoding = 11 ms; TE of EPI = 32 ms. The PSF map H and the undistorted reference image $\rho(r_{psf})$ (Fig2b) were processed as described previously[1]. The Total Variation (TV) regularization with Bregman iteration was applied to the PSF map for regularized inverse solution[2]. The cost function f_k, ($f_k = arg\{||g+v_{k-1}-Hf||^2+\lambda^2||f||_{TV}\}$) was minimized, such that $||f||_{TV} = \sum(\mathrm{sqrt}(f_x^2+f_y^2))$, $v_k = v_{k-1}+g-Hf_{k-1}$ for $k>0$, $v_0=0$. The first Bergman iteration is equivalent to the TV regularization, $\lambda^2 = 1$, Bregman iterations = 3; each Bregman iteration has 30 fixed-points iterations.

Results: The EPI image of the brain is distorted (Fig 2a), the right side looks bulged while the left side compressed, and is sheared to the left. The embedded PSF correction method described herein successfully corrects the distortions observed in Fig 2a. Both full and partial (5/8) PSF corrections are able to restore brain geometry in the image (Fig 2c). However, although quality of the image obtained using 5/8 partial acquisition is comparable to that of the full acquisition more Gibbs ring are apparent in $\rho(r_{psf})$ image in 5/8 acquisition mode, as expected. By applying an appropriate Bregman iteration regularization protocol to this correction method image contrast may be improved (Fig 2d).

Conclusions: Using a dual echo to simultaneously acquire PSF and imaging echo, we are able to correct for geometric distortion in EPI images without lengthening data acquisition time. In this study, a PSF echo was inserted before the imaging echo by taking advantage of the idle time between the RF excitation pulse and the imaging echo. In sequences that there is not enough time to acquire a PSF echo before imaging echo, the PSF echo can be acquired after the imaging echo. Under this situation, same correction scheme can be applied. The only difference is that the latter approach might have a lower SNR in PSF mapping. With the rapidly expanding interest in utilizing ultra high field system in fMRI study, our approach can offer an unique solution to the geometric distortion problem at little cost.

1. Zeng, H. and R.T. Constable, *Image distortion correction in EPI: comparison of field mapping with point spread function mapping*, in *Magn Reson Med*. 2002. p. 137-46.
2. Liu, B., et al., *Regularized sensitivity encoding (SENSE) reconstruction using Bregman iterations.* Magn Reson Med, 2009. **61**(1): p. 145-52.