Distortion Correction for Echo Planar MR Imaging using the Point Spread Function (PSF) Map with Bregman Iteration

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Abstract:

Point Spread Function (PSF) mapping techniques have shown promise for geometric distortion correction in Echo Planar Imaging (EPI)(1), where the distortion information is mapped by applying additional phase encoding gradients with a constant time (PSF encoding). Cai et al(2) introduced the inverse solution of the PSF map with the Tikhonov regularization method for EPI distortion correction. The smoothness penalty in the Tikhonov regularization causes it sensitive to the aliasing artifact in its reconstructed image and fine textile structure blurring. Here we apply the total variation (TV) regularization with Bregman iteration method(3) to the PSF map in which the penalty term is adaptively updated based on the Bregman distance, which is immune to the above effects. The proposed approach compared with the Tikhonov regularization methods were evaluated at 3.0T with human subjects while at 9.4T with rats.

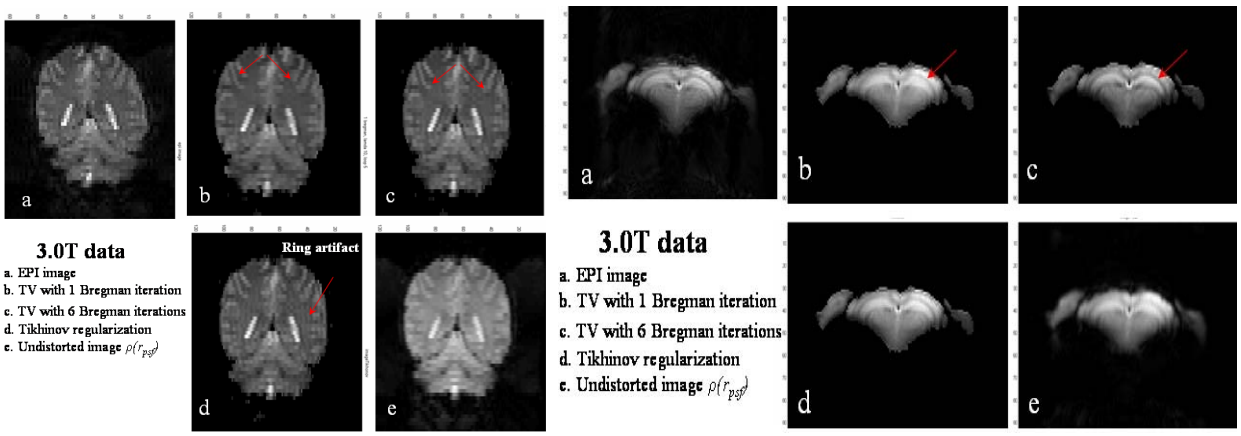
Methods:

Human Studies at 3.0T: One healthy normal volunteer was scanned on the Siemens 3.0T scanner, after obtaining written informed consent. Shimming was carefully adjusted according to the vendors' procedures. A gradient echo EPI sequence was employed with the imaging parameters: coronary plane, phase encoding L-R direction, FOV = 240mm×240mm, TR = 2500ms, slice thickness = 4.0mm, number of slices = 15, receiver bandwidth = ±62.5kHz, matrix size = 64×64, and TE = 25ms. The PSF encoding direction was identical to the phase encoding in EPI. Acquisition parameters for the PSF technique were FOV = 120 mm (half of the phase encoding FOV) and number of PSF encodings = 64. Total PSF acquisition time was 160s.

Animal Studies at 9.4T: The animal studies were performed on a Bruker BioSpec 9.4T spectrometer after receiving approval from the Institutional Animal Care and Use Committee. To boost the SNR, a receive-only surface coil was used. Shimming was performed according to Bruker's FASTMAP protocol. The gradient echo EPI acquisition parameters were, axis plane, phase encoding A-P direction, FOV = 28mm×28mm, TE = 24ms, TR = 2500ms, slice thickness = 1.0mm, number of slices = 8, receiver bandwidth = ±100kHz, and matrix size = 128×64. The PSF encoding direction was identical to the phase encoding in EPI. Acquisition parameters for the PSF technique were FOV = 14 mm and number of the PSF encodings = 64, average = 4; total acquisition time for PSF map was 640s.

Post-Processing: The PSF map H , the undistorted reference image $\rho(r_{psf})$ were processed based on the approaches reported in reference (1); For the Tikhonov regularization method, the cost function $arg\{||g-Hf||^2+\lambda^2||f||^2\}$ was minimized, in which g is the distorted EPI image, f is the distortion corrected image, and λ^2 is the regularization parameter. We chose $\lambda^2 = 0.6$ in our study. For TV regularization with nth Bregman iteration method, the cost function $f_k = arg\{||g+v_{k-1}-Hf||^2+\lambda^2||f||_{TV}\}$ was minimized, in which $v_k = v_{k-1}+g-Hf_k$ for $k>0$, $v_0=0$. The first Bergman iteration is equivalent to the TV regularization. We empirically used $\lambda^2 = 10$ in human data and $\lambda^2 = 300$ in animal data, 6 Bregman iterations were used; each Bregman iteration has 30 fixed-point iterations.

Results:



The data show that the distortion is corrected in both Tikhonov and TV regularization with Bregman iteration method. The robustness of TV regularization method against the aliasing artifacts is more appreciable in the human data, which is indicated by the red arrow in the Tikhonov regularization method(Figure d). Compared with the TV regularization method, the fine detail structure is maintained in the Bregman iteration, which shows better contrast between gray matter cortex and white matter in both human and animal data.

Conclusion:

The TV regularization with Bregman iteration can be successfully applied to PSF mapping technique for distortion correction. It is robust to the aliasing artifact reconstructed in Tikhonov regularization method. With Bregman iterations, the loss of the fine textile structure in TV regularization can be alleviated and better contrast is maintained.

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