Digital Tuning to Suppress Ghost Artifacts in EPI by Minimization of Total Variation

F. Q. Ye[1], and Q-S. Xiang[2]

[1]Neurophysiology Imaging Facility, National Institute of Mental Health, NIH, Bethesda, MD, United States, [2]Department of Radiology, University of British Columbia, Vancouver, BC, Canada

Introduction

Echo-planar imaging (EPI) is widely used in functional MRI studies, most often in single-shot form. Interleaved multi-segment EPI becomes desirable when higher spatial resolution and less geometric distortion are crucial. However, interleaved EPI is more susceptible to ghost artifacts. The first major cause of ghost artifacts is even-odd echo data discrepancy, mainly due to gradient eddy current. It corresponds to the familiar N/2 ghost seen in the single-shot EPI. Several post processing methods exist for the N/2 ghost correction, by performing phase correction based on information that is derived either from reference scans [1-3] or from the ghosted image itself [4-6]. The second major cause of ghost artifacts is inter-segment data discrepancy due to hardware instability, subject motion, and field fluctuation due to physiological motion. The ghosts are similar to but spatially shifted from the even-odd echo ghosts. Navigators can be added in EPI sequences to measure the inter-segment discrepancy. The information is then used in image reconstruction for ghost suppression [7]. We propose a digital tuning approach to suppress both types of ghost artifacts altogether. The method uses minimization of total variation (MiniTV) which has been recently shown capable of reconstructing a compressible digital image from a small number of random linear measurements [8].

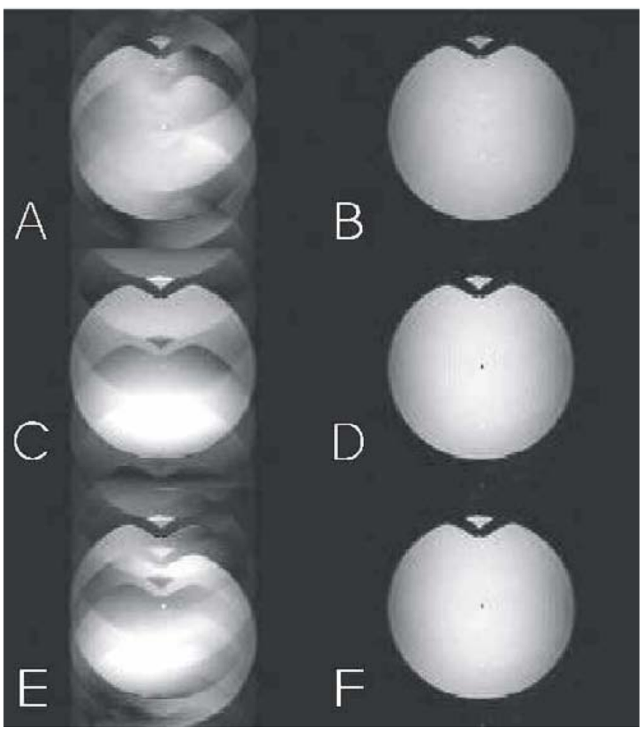
Methods

Single-shot and multi-segment raw data from an off-center axial plane were acquired with a standard gradient-echo EPI sequence on a 4.7T Bruker scanner. FOV=128x96 mm^2, matrix size= 128x96, sweeping bandwidth =200KHz. Severe ghost artifacts were deliberately induced by choosing poor pre-emphasis setting, and by small changes of Z^2 shim between subsequent EPI segments.

Image reconstruction was done offline with or without digital tuning. Our modeling of EPI data discrepancy was restricted to zero and first order phase modulation. For inter-segment tuning, it assumed that phase in one segment (the first segment) was correct while phase in other segments needed correction. Phase correction was done in time domain, involving two tuning parameters for each segment. For even-odd echo tuning, k_x lines were first sorted into even and odd echo groups, then Fourier transformed along x direction. It assumed that phase in one group (odd echo) was correct while phase in the other group needed correction. Zero and first order phase correction was done along x direction in the x-k_y space. After both inter-echo and inter-segment phase correction, a magnitude image was reconstructed. Across this image, total variation (TV) was computed as the l_1 norm of its gradient. Minimization of total variation (MiniTV) gave the optimal tuning parameter set which was then used to reconstruct the final image. The program was written in IDL language (ITT Visual Information Solutions, Boulder CO). A library routine was used for multidimensional minimization with the downhill simplex method.

Result and Discussion

Ghost artifacts in single-shot or multi-segment EPI images are consistently suppressed with the proposed digital tuning approach. Examples from the 4-segment data are shown in the figures: ghost artifacts due to poor pre-emphasis setting (A) are suppressed after digital tuning (B); ghost artifacts due to inter-segment Z^2 shim change (C) are suppressed after digital tuning (D); ghost artifacts due to both poor pre-emphasis setting and Z^2 shim change (E) are suppressed after digital tuning (F).



To reconstruct one image it takes fraction of a second for single-shot data (two tuning parameters) and about 4 seconds for 4-segment data (eight tuning parameters).

Our digital tuning incorporates into image reconstruction the simple phase correction procedures which are widely used in artifact correction. The advantage of our approach is that it does not require any extra experimental data from reference scans or navigators for determining phase discrepancy. It is fully automated and can be used on existing old data sets. Digital tuning by MiniTV exploits statistical characteristics common to most images, and it should be useful in guiding MRI artifact suppression and image reconstruction, as demonstrated in this work.

References

[1] Bruder H., et al, MRM (1992) 23:311-323.
[2] Hu X. and Le T.H., MRM (1996) 36:166-171.
[3] Chen N. and Wyrwicz A.M., MRM (2004) 51:1247-1253.
[4] Buomocore M.H. and Gao L., MRM (1997) 38:89-100.
[5] Hennel F., JMR (1998) 134:206-213.
[6] Buomocore M.H. and Zhu D.C., MRM (2001) 45:96-108.
[7] Pfeuffer J., et al, MRM (2002) 47:344-353.
[8] Candes E., et al, IEEE Trans. Inf. Theory (2006) 52:489-509