EPI Ghost Correction with LTI *k*-space Trajectory Estimation

N. O. Addy[1], H. H. Wu[1,2], and D. G. Nishimura[1]
[1]Electrical Engineering, Stanford University, Stanford, CA, United States, [2]Cardiovascular Medicine, Stanford University, Stanford, CA, United States

Introduction: Echo planar imaging (EPI) is commonly used to rapidly acquire MR images in applications seeking to analyze dynamic physiological information such as functional MRI and diffusion-weighted imaging. As with other non-conventional trajectories, specific knowledge of the location of sampled *k*-space data points is required to reconstruct high fidelity images. Gradient amplifier nonlinearities, timing errors, and the eddy-current-based magnetic fields affect the desired gradient field, causing deviations in the location of sampled *k*-space points. For blipped EPI trajectories, these deviations create a misalignment of echoes and result in ghosting artifacts. Solutions exist to correct for the deviations with a reference scan (1) or careful tuning of echo timing (2,3). Trajectory estimation with a linear model of the gradient system has previously been used to correct for spiral and circular EPI trajectories (4). This work presents a method to correct for ghosting artifacts in blipped EPI by estimating trajectories achieved on the scanner with a high bandwidth, linear time-invariant (LTI) model without the use of an additional reference scan or manual measurement of gradient delays.

Method: Experiments were performed on a 1.5 T GE Excite scanner with maximum gradient strength 40 mT/m and maximum slew rate 150 mT/m/s. Trajectories were measured based on the technique by Duyn et al. (5) to obtain a reference of the actual trajectories achieved on the scanner. Sequence parameters were: 2 mm thick slices at locations ±3 and ±1 cm, ±125 kHz receiver bandwidth. TE/TR for the interleaved trajectory were 23/200 ms and 60/400 ms for the single-shot trajectory. The LTI model of the gradient system was characterized using the response of a 20 kHz bandwidth chirp waveform (6). Estimates were calculated by convolution with the resulting impulse responses. To simplify the estimation process, gradient waveforms were designed in MATLAB®. Both trajectories were designed for a 24×24 cm^2 field of view. The 30 interleaf trajectory was designed for a 240×240 matrix size with echo train length 8 and 13.4 ms duration. The single-shot trajectory was designed for a 64×64 matrix size and 52.8 ms duration. GRE images were acquired with TE = 8.5/28.2 ms (interleaved/single-shot), TR = 200 ms, 80° flip angle, and 5 mm slice thickness.

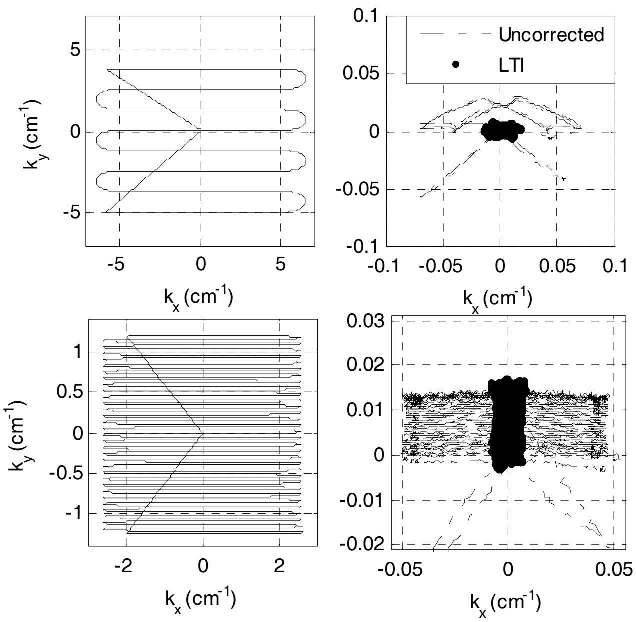

Figure 1. *k*-space trajectories (left) and deviations from measured trajectory (right) for uncorrected and LTI trajectories for interleaved (top) and single-shot trajectories (bottom).

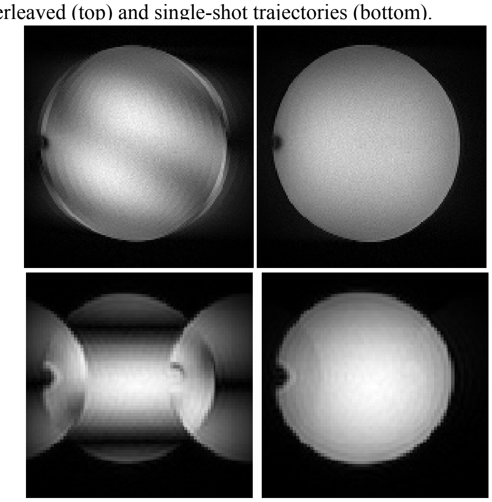

Figure 2. Reconstructed EPI images using uncorrected (left) and LTI estimated (right) trajectories for interleaved (top) and single-shot (bottom) trajectories. Phase encode direction is L/R.

Results: Figure 1 shows the ability of the LTI model to largely reduce *k*-space trajectory deviations from the measured trajectory. Figure 2 shows EPI images with and without correction. The ghosts seen in the phase-encode direction are removed in the corrected images, although for the single-shot trajectory, a faint ghosting artifact is seen on the left side of the image with correction.

Conclusion: It was shown in this work that the simple LTI characterization of the gradient system was able to correct for timing errors, reducing ghosting artifacts in both single-shot and interleaved EP trajectories. The LTI model provides a more time-efficient trajectory independent solution than reference scans which must be repeated for each scan and can suffer from inter-scan motion.

References: [1] Bruder et al., MRM, 23:311-23, 1992. [2] Butts et al., MRM, 31:67-72, 1994. [3] Reeder et al., MRM, 41:87-94, 1999. [4] Kerr et al., Proc. 4th ISMRM, p. 364, 1996. [5] Duyn et al., JMR, 132 :150-3, 1998. [6] Addy et al., Proc. 17th ISMRM, p. 3068, 2009.