# Reference-less EPI ghost correction in real-time cardiac MRI

**J-F. Nielsen[1], Y-C. Kim[1], and K. S. Nayak[1]**
[1]Electrical Engineering, University of Southern California, Los Angeles, California, United States

**Introduction:** Echo-planar imaging (EPI) is sensitive to data inconsistencies between odd and even phase-encode lines. Image-domain phase errors are typically estimated from 1D or 2D reference scans obtained prior to image acquisition [1,2], and are scan-plane dependent. In real-time EPI, it is desirable to avoid reference scans (which interrupt imaging) when a scan-plane change occurs. Kim *et al*. recently introduced an 'alternating' EPI acquisition scheme [3] (see Fig. 1(a)), and used SENSE to recover ghost-free images. In this work, we apply and evaluate two reference-less EPI ghost correction schemes based on alternating EPI, and demonstrate that these schemes provide effective ghost suppression in real-time cardiac EPI, without the need to "use" a parallel imaging factor of 2.

**Methods:** Phantom and in-vivo experiments were performed on a GE Signa 3T EXCITE HD system (40 mT/m gradient amplitude; 150 T/m/s slew rate) using the RTHawk real-time imaging system [4], and an 8-channel cardiac receive coil array. Multi-shot real-time EPI data was acquired using the 'double-alternating' readout scheme [3]. Image phase-errors arising from odd/even data inconsistencies were estimated from the current and the previous time-frames, and were used to reconstruct the current time-frame. Two reconstruction schemes were implemented and compared:

*2D correction*: First, left-right (LR) only and right-left (RL) only full-FOV images were reconstructed as shown in Fig. 1(b), using the two most recent time frames. A smooth phase map $\theta(x,y)$ was calculated by complex division of these two images, followed by low-pass filtering (the low-pass filtering operation is not shown in Fig. 1). This 2D phase map was then used to solve directly for the un-aliased pixel values for the current time frame in the manner described by Chen *et al* [2]. This has the advantage that arbitrary 2D phase-error patterns can be corrected for, including non-linear phase-errors along the phase-encode direction. However, a potential disadvantage of this approach is that certain phase-error patterns can cause singularities ("spikes") in the image.

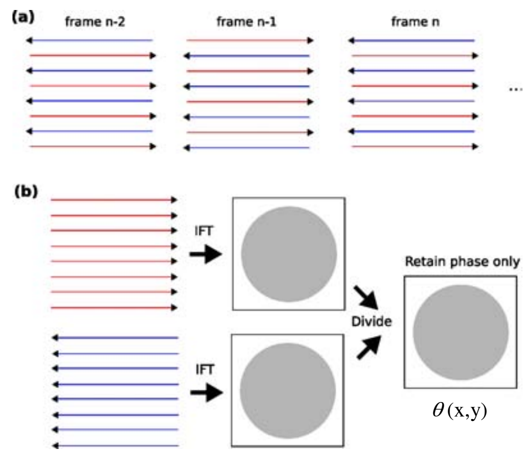


Fig. 1. (a) Alternating EPI data acquisition scheme. (b) Calculation of a 2D odd/even phase-error map. LR (red) lines and RL (blue) lines are drawn from the two most recent time-frames. Using these two data sets, a full-FOV 2D odd/even phase-error map $\theta(x,y)$ is calculated, which is then used for subsequent 2D correction. The processing steps for calculating a 1D phase-error map used for 1D correction are identical, except that the images are projected (not shown) onto the readout axis prior to performing the complex division.

*1D correction*: To avoid the possibility of image singularities, we also implemented a non-linear 1D correction. Again, LR only and RL only full-FOV images were reconstructed as shown in Fig. 1(b), However, prior to image division, each image was projected onto the x-axis (readout direction), to produce two 1D images. These images are equivalent to the inverse FT of the central (ky = 0) LR and RL k-space lines. These two images were then divided to produce a 1D phase-error map. Finally, the phase image was smoothed, and the resulting phase was added to the (aliased) image reconstructed from the RL phase-encode lines from the current time frame. This corrected RL image was then added to the LR image from the current time frame to produce the final image.

**Results:** Fig. 2 shows phantom results obtained at an oblique scan plane. The un-corrected EPI image shows strong ghosting, which is mostly removed when reconstructing the images using the proposed techniques. In Fig. 2, the 2D correction scheme is slightly more effective in removing the ghost pointed to by the white arrow. Additional phantom data (not shown) reveals that the 1D method is relatively sensitive to scan plane orientation, and is less effective when gradient/DAQ time delays along x and y are highly anisotropic (as evidenced by strong linear phase variation along y). Fig. 3 shows a frame from a real-time cardiac movie using interleaved double-alternating circular EPI [3] (3 shots; 25 cm FOV; voxel size 3.1x3.1x5 mm$^3$; readout duration 13 ms; TE/TR = 10/20 ms; 60 ms total imaging time per frame), and demonstrates adequate ghost suppression for both methods.

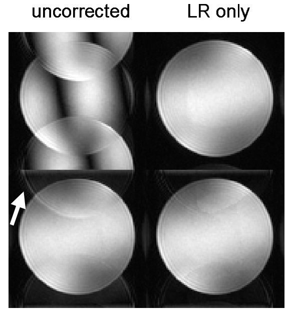


Fig. 2. EPI images of a water-filled phantom (oblique scan).

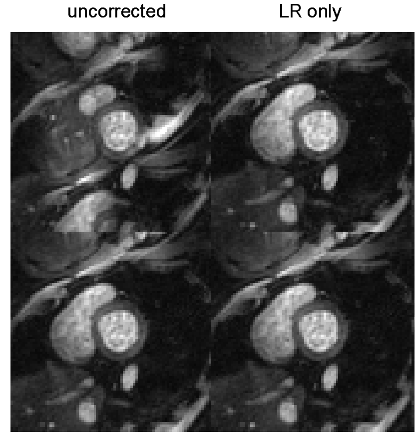


Fig. 3. One frame from a real-time cardiac EPI acquisition (short-axis view), reconstructed using the proposed methods. Both 1D and 2D correction produces adequate ghost suppression.

**Conclusion:** Fully automatic and reference-less ghost suppression in real-time EPI is possible when using an alternating acquisition scheme, combined with 1D or 2D phase-error correction. The proposed methods are simple to implement, and are fast enough for application to real-time echo-planar cardiac imaging.

**References:** [1] Hu *et al*, MRM 1996;36:166-171, [2] Chen *et al*, MRM 2004;51:1247-1253, [3] Kim *et al*, Proc. ISMRM 14th Scientific Meeting (2006), p 2350, [4] Santos *et al*, Proc. IEEE EMBS, 26$^{th}$ Annual Meeting.