Real-Time Oblique Echo-Planar Imaging: Ghosting Artifact Reduction in Arbitrary Scan Orientations

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Introduction: In echo-planar imaging (EPI), ghosting artifacts due to gradient timing errors can be corrected if the scan plane is on axis. Oblique scan planes pose additional considerations in ghosting correction, and conventional methods solve them by measuring gradient time delays and then re-designing readout gradients [1, 4]. We present a new ghosting artifact reduction method that does not require gradient time delay information to achieve oblique EPI correction. The method is useful in real-time cardiac imaging, where the scan plane is changed frequently. It adopts a double-alternating EPI readout of which traversal in k-space alternates at every phase-encoding level and at every frame. With this readout scheme, sensitivity encoding (SENSE) [2] is used to recover full field-of-view (FOV) images, and sensitivity maps are updated on-the-fly similar to TSENSE [3]. Importantly, they are almost ghost free, but have lower temporal resolution. Phantom and cardiac in-vivo results indicate that the method makes real-time EPI robust against changes in scan plane orientation.

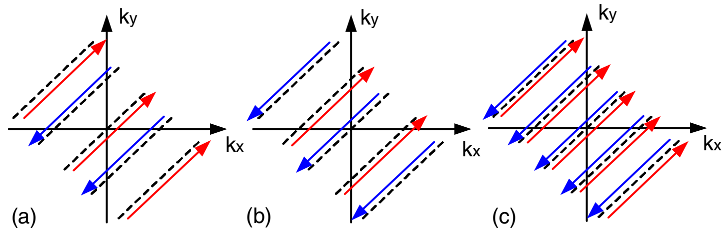

Fig. 1. In oblique EPI scans with asymmetric gradient delays, acquired raw data represent samples on the red and blue lines, not on the intended dashed black lines. (a): odd frame. (b): even frame. (c): When (a) and (b) are combined, the blue lines become uniformly spaced with 1/FOV interval along logical phase-encoding direction, and so forth for the red lines.

Methods: Fig. 1(a) illustrates that for asymmetric gradient delays in x and y, the red lines shift to right and the blue lines (traversal direction opposite to the red) shift to left with respect to the intended k-space locations (dashed black). Therefore, the red and blue lines combined are not uniformly spaced, and this causes distortions in reconstructed images [4]. However, it is noted that the red (or blue) lines keep uniform spacing. We propose a double-alternating method shown in Fig. 2. From the two frames n-2 and n-1, we reconstruct sensitivity maps from the red and blue lines separately to prevent any echo-misalignment problems and preserve uniform spacing between the lines. In the next frame, n, we apply SENSE reconstruction separately to the red and blue lines. The resulting two full FOV images differ not in magnitude but in phase, and taking root sum-of-squares eliminates distortions in phase and increases SNR.

Our method was tested on GE Signa 3T scanner. Real-time uniform phantom and in-vivo cardiac experiments were performed. The in-vivo data without gating and breath-holding were acquired with 8-channel cardiac array coil. Three interleaves were combined as shown in Fig. 3 to reconstruct one image with 25 cm FOV. Spectral spatial excitation pulse was used [5]. Images with 3.1 mm spatial resolution were reconstructed every 60 ms of temporal resolution.

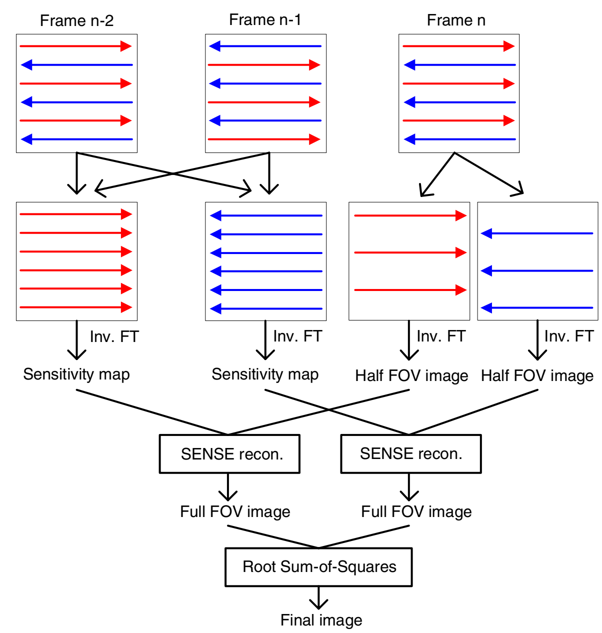

Fig. 2. Flow chart of our ghosting reduction method.

Results and Discussion: In columns (1) and (2) of Fig. 4, our method reduces ghosting artifacts for both on-axis and oblique slice. Aligning echoes works well for on-axis, but it produces ghosting for oblique slice. In (3) and (4) of Fig. 4, our method produces almost no ghosting in doubly-oblique short-axis view and its rotation. For all scan orientations considered, although they are not included here, our method reduced ghosting artifacts significantly. Since sensitivity maps were updated from the adjacent frames, it worked well even during frequent scan orientation changes. However, cardiac motion and flow can degrade its performance, because sensitivity maps have lower temporal resolution by a factor of 2.

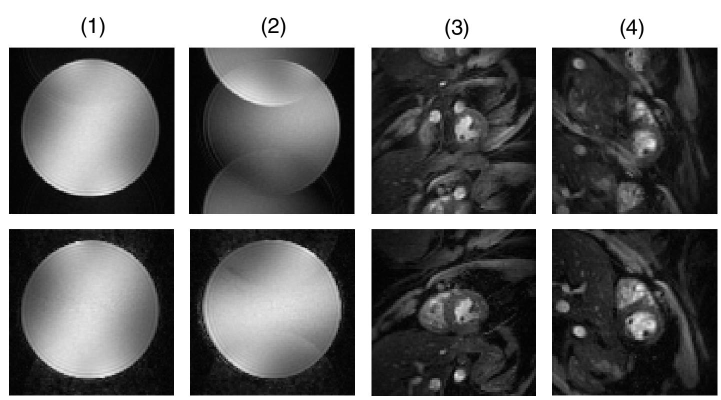

Fig. 4. (Top) Ghosting correction by aligning echoes (Bottom) Ghosting correction using our method. Column (1): uniform cylinder phantom (on-axis). (2): oblique slice. (3): doubly-oblique short-axis view. (4): rotated with respect to (3).

References: [1] Reeder et al., MRM, 41:87-94, 1999 [2] Pruessmann et al., MRM, 42:952-962, 1999 [3] Kellman et al., MRM, 45:846-852, 2001 [4] Gatehouse et al., ISMRM, p1481, 1996 [5] Nayak et al., MRM, 51:655-660, 2004

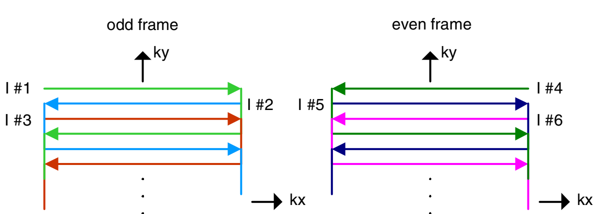

Fig. 3. Double-alternating EPI trajectory used in cardiac study. The interleaf order is shown.