Robust Elimination of EPI Nyquist Ghosts via Spatial and Temporal Encoding

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Introduction: Nyquist ghosts are an inherent artifact in echo planar imaging (EPI). Many methods have been proposed to correct for them, with various strengths and weaknesses. Here, we propose a fusion of previous spatial [1] and temporal [2] encoding methods to achieve the goal of self-referenced ghost elimination with very low temporal latency.

Methods: Our approach follows from the method described by Kim, et al, [3]. The notable changes are shown by the gray boxes in Fig. 1, where we employ PLACE [2] to achieve improved Nyquist ghost suppression.

Specifically, we employ readout gradients that alternate in polarity for each volume. To reconstruct images in the sequence, two frames of temporally encoded data are interleaved and coherently combined to determine parallel MR imaging (pMRI) reconstruction coefficients. We employ GRAPPA here, although SENSE could be used as well. Interleaving positive/negative readout data from two frames *should* yield images free of Nyquist ghosts. We have found, however, that this is not true in the presence of scanner/magnetic field instability. As noted by the authors of PLACE, if one phase-aligns, via Ψ, the negative readout image, I'_n, to the positive readout image, I'_p, then residual ghosts will in-fact cancel. This cancellation can negatively impact imaging applications such as perfusion, yet it greatly improves the pMRI calibration data quality [4]. To form images with no adverse signal cancellation, odd and even lines from a single time point are separated, and pMRI reconstruction with GRAPPA is performed on each set. These two images are then phase-aligned and summed to produce the full-sampled and Nyquist ghost corrected coil data. The final image may be formed by combining the coil data coherently, [5] or with root sum-of-squares.

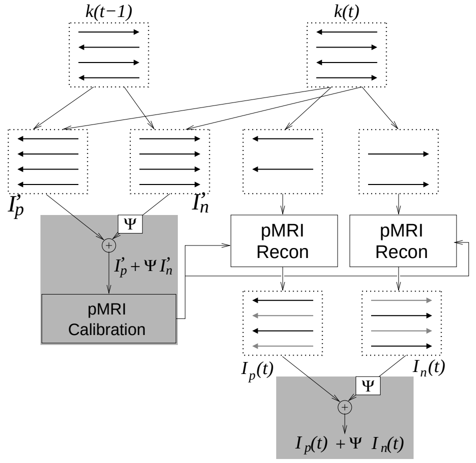

Fig 1: Data processing flow diagram. Note that the dashed boxes represent a multi-coil set of data.

Below, we compare this *ghost elimination via spatial and temporal encoding* (GESTE) approach to three alternate methods. Ahn & Cho static [6] employs a reference data prescan to estimate the linear shift between odd and even kspace lines. Ahn & Cho dynamic [7] employs similar data at each image time point, via an extended echo train. The method of Kim, et al, [3], employs a strategy similar to Fig 1, yet computes separate coil sensitivity maps for both I'_p and I'_n, which can be susceptible to Nyquist ghosting. A second difference is that the coil images, $I_p(t)$ and $I_n(t)$, are combined non-coherently using a root-sum-of-squares. In contrast, we find that a coherent combination of these images further suppresses residual ghost and pMRI artifacts.

Results: 124 EPI images were acquired on a 1.5T GE scanner with known heating issues that cause magnetic field drift. Imaging parameters were: TR/TE= 2500 msec / 55.1 msec (f=1x); slice thickness= 8 mm; FOV= 28 cm; image size= 128 x 128.

Fig. 2 shows reconstructions of one EPI image frame for each of the four different methods. Nyquist ghost levels were measured as the ratio of root-sum-of-squares signal, $(\Sigma|I(x,y)|^2)^{1/2}$ with $\{x,y \in A\}$, measured in each of two boxes: one over the tissue region, and one in the signal-void region. The values of this ratio are plotted in Fig 3, over the course of the image sequence. In the presence of field drift, a visible increase in the ghosting level appears in the static method, ([6] top line of Fig 3).

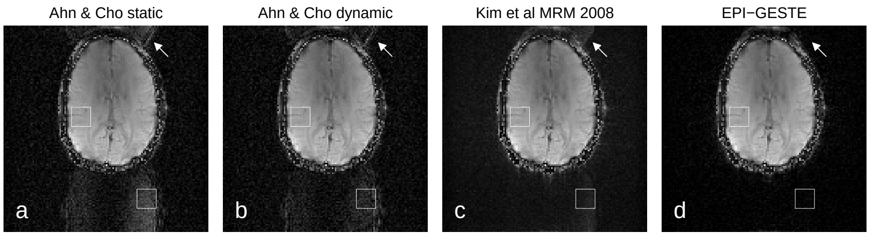

Fig 2: Example images from the four ghost correction methods. Noise in the signal void region has been amplified 10-times to improve ghost visibility.

Although adjusting the ghost correction dynamically can remove the drift trend, ([7] 2nd line from top), greater ghost suppression can be seen when pMRI is employed ([3], 3rd line from top). Our approach to use PLACE instead of the non-coherent combinations of Kim et al [3] yields significantly lower ghosting levels (bottom line).

Discussion: Our approach demonstrates superior ghost suppression compared to a variety of previous methods. As a self-referenced method, it is robust to scanner variations, such as field drift shown here, and suitable for imaging situations that involve acquisition changes such as real-time imaging and PROPELLER methods.

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References: [1] Kellman, McVeigh. NMRB 2006;19:352–361. [2] Xiang, Ye. MRM 2007; 57:731–741. [3] Kim et al. JMRI 2008;27:239–245. [4] Hoge et al. *Proc ISMRM* 2009; 2720. [5] Buehrer et al. *Proc ISMRM*. 2009; 759. [6] Ahn, Cho. IEEE TMI 1987;6:32–36. [7] Jesmanowicz et al. *Proc SMRM* 1993; 1239.

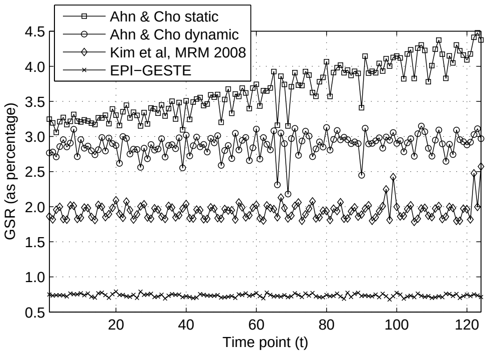

Fig 3: Performance comparison of four ghost correction methods, in the presence of field drift.