Phase constraints for parallel imaging with PEPI

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Introduction: Pretty easy parallel imaging (PEPI) is a fast reconstruction method for undersampled non-Cartesian data using multiple coils [1]. One major advantage is the computational requirements are scalable to 3-D imaging [2]. Partial Fourier or phase constrained imaging has been applied to various parallel imaging techniques, to further reduce aliasing artifacts [3, 4] . This study applied a phase constraint to the PEPI iteration to attain greater reduction factors of acquisitions, providing general application of partial Fourier to non-Cartesian parallel imaging.

Theory: In parallel imaging, estimation of coil maps are necessary to reconstruct undersampled data (either implicitly or explicitly). In practice, coil maps also contain phase from the imaged object. Image phase can be accurately approximated as slowly varying [4]. When image phase and coil phase are removed, a purely real image should remain, which exhibits symmetry in k-space. This symmetry allows reduction in sampling requirements. Residual phase from inaccuracies in phase maps will corrupt the symmetry. While some methods penalize for residual phase, PEPI projects the iterative solution onto spaces consistent with a constraint (similar to POCS). The phase constraint can be implemented by projecting the solution onto a purely real answer, using either the magnitude or the remaining real part of the phase corrected image.

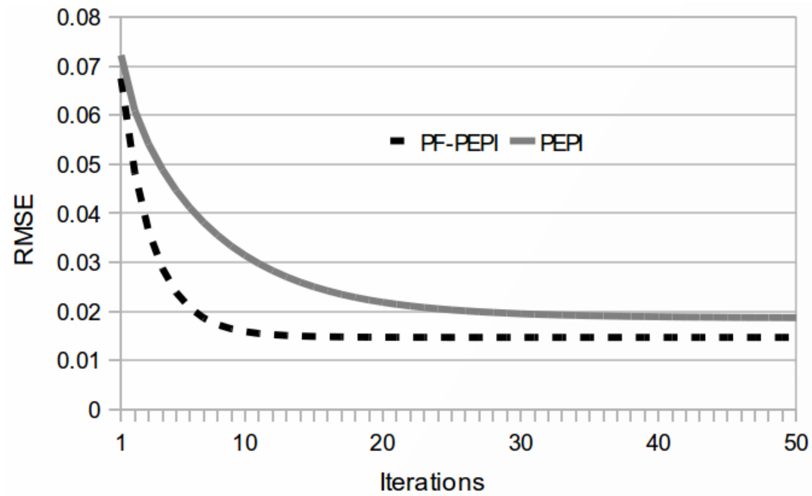

Figure 1: Graph of the root mean squared error for a simulated image (8 coils with R = 3) with respect to iteration number. The standard PEPI iteration converges in over 30 iterations. With the addition of a phase constraint to PEPI (PF-PEPI), the algorithm will converge in less than 10 iterations. PF-PEPI converges to a better solution.

Methods: A simulated dataset was synthesized to characterize the convergence behavior of PEPI with and without a phase constraint (60x60 image with R=3 using 8 coils). The PEPI algorithm with a phase constraint converged in fewer iterations (less than a third) and to a better solution than did standard PEPI (Fig. 1). Also, phantom data were collected for a 436x436 image using a dual density spiral (fully sampled interior for coil map estimation) undersampled by a factor of 2. Single channel data were collected to illustrate the advantage of the proposed method (twelve channels were reduced to one prior to PEPI). Because there is only single channel data, standard PEPI is ill-conditioned to reduce the aliasing in the undersampled dataset, Fig. 2 (b). PEPI was also implemented with the phase constraint using either the magnitude or positive real parts. Both phase constrained versions provided reduced aliasing, as seen in Fig. 2 (c, d).

Discussion: The application of phase constraints allows the usage of PEPI with single channel data. Because of computational requirements of PEPI, this method can easily be extended to provide fast 3-D non-Cartesian imaging with reduced sampling requirements for both parallel and non-parallel data. The phase constraint also speeds up the convergence behavior of PEPI.

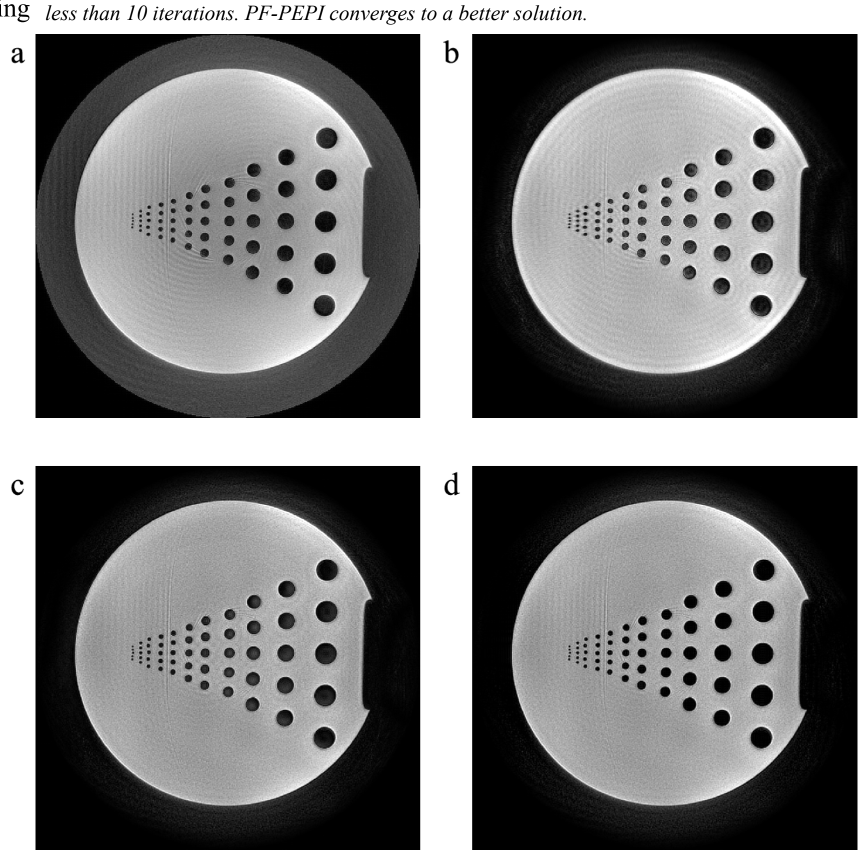

Figure 2: An undersampled (R=2) image using single coil data. The conventional reconstruction (a) exhibits considerable aliasing artifact. The standard PEPI iteration (b) is ill-conditioned for this image as it removes much of the aliasing at the expense of blurring. The addition of phase constraint (c, d) removes aliasing while preserving resolution. During the iteration, the phase constraint is applied by using the magnitude of the signal (c) or by dropping the imaginary and negative components (d).

References: [1] Pipe. 2009. In *Proc. of the ISMRM*, 2722. Honolulu, USA. [2] Zwart and Pipe. 2010. In *Proc. of the ISMRM*, 2894. Stockholm, Sweden. [3] Samsonov et al. 2004. *MRM* 52: 1397-406. [4] Bydder and Robson. 2005. *MRM* 53: 1393-401.

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