Self-calibrated radial sampling parallel imaging reconstruction with iterative k-x estimation

Yi-Cheng Hsu[1], Ying-Hua Chu[1], and Fa-Hsuan Lin[1]
[1]*Institute of Biomedical Engineering, National Taiwan University, Taipei, Taiwan*

TARGET AUDIENCE Scientists interested in parallel imaging acquisition and reconstruction.

PURPOSE Reducing data acquisition time with minimal image quality degradation is critically important in MRI for scientific and clinical purposes. Fast imaging can improve patient's comfort, reduce motion artifact, or allow delineating important physiological information with high temporal resolution. Radial *k*-space sampling trajectory is one method of fast imaging[1]. This acquisition strategy has been applied to fast cardiac imaging such that data acquisition can be completed in single breath hold[2]. Combining radial sampling acquisition with parallel imaging (pMRI) can further reduce the data acquisition time. Previously, Cartesian GRAPPA has been modified for accelerated radial sampling[3]. The densely sampled *k*-space center in radial sampling allows self-calibrated reconstructions without any additional reference scan in image domain[4] and *k*-space[5]. However, different radial coordinates should use different GRAPPA weights, because the *k*-space lattice structures are not shift invariant.

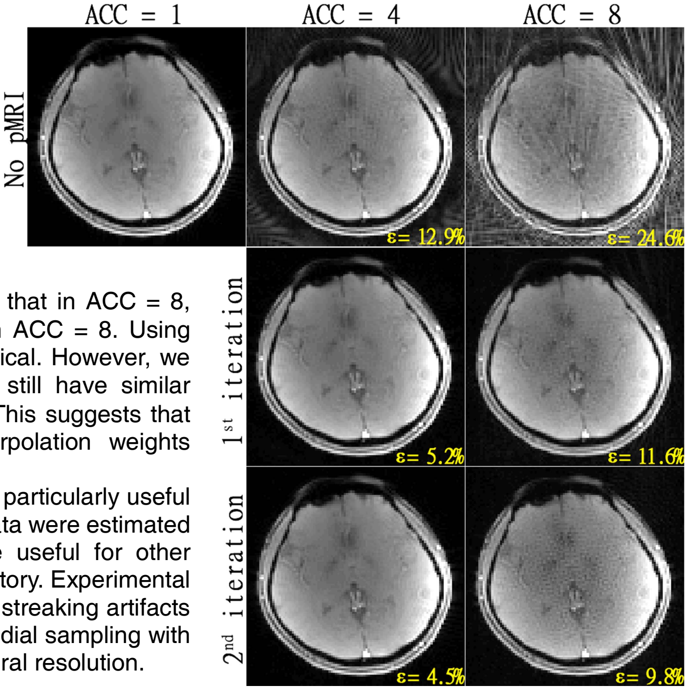
In theory, the best GRAPPA weights can be estimated if coil sensitivities are known[6]. Importantly, coil sensitivity information was significantly preserved in radially sampled data because the *k*-space center was densely sampled. Here, we propose an iterative *k-x* method to first estimate weights to reconstruct missing *k*-space data points using individually reconstructed coil images from the under-sampled data. Once missing *k*-space data were estimated, individually reconstructed coil images used in the last estimation were replaced by coil images in this reconstruction for the next iteration. Our empirical results show that our method can successfully reconstruct human brain images with 2 mm spatial resolution and minimal streaking artifacts using 22 radial projections.

METHODS Using an *N*-channel array, the coil image, C_i^0 at channel *i* were first reconstructed by under-sampled data using filtered back projection. For each missing *k*-space point at (k_x, k_y) in channel *j* can be interpolated from sampled *k*-space data $\mathbf{k}_m$ at ($k_x+\delta k_{x,m}$, $k_y+\delta k_{y,m}$) in channel *i*, where *i* = 1…*N* and *m* = 1…*M*. *M* denotes the size sampled *k*-space data used to estimate one missing *k*-space data point. The best interpolation weight, $w_{i,m}$, can be estimated by minimizing an l_2 norm of the difference in spatial domain:

$$w_{i,m} = \arg\min_{w_{i,m}} \left\| C_j^o(x,y)e^{i(k_x x + k_y\, y)} - \sum_{i=1,m=1}^{i=N,m=M} w_{i,m} C_i^0(x,y) e^{i((k_x+\delta k_x^m)x + (k_y+\delta k_y^m)\,y)} \right\|_2 = \arg\min_{w_{i,m}} \left\| C_j^0(x,y) - \sum_{i=1,m=1}^{i=N,m=M} w_{i,m} C_i^0(x,y) e^{i(\delta k_x^m x + \delta k_y^m\, y)} \right\|_2 .$$

After $w_{i,m}$ was estimated, missing *k*-space data were calculated by interpolation. We only interpolated necessary *k*-space data points to satisfy the Nyquist sampling criterion. After interpolation, new images C_j^1 were reconstructed again using filtered back projection. C_j^1 can replace C_j^0 to repeat the *k*-space data interpolation.

Fully sampled data (ACC = 1) were acquired using a pulse sequence with a radial sampling trajectory (flip angle = 25°, TR = 50 ms, TE = 10 ms, 2 mm resolution, 202 mm x 202 mm FOV, 5mm slice thickness, and 180 projections with 1° increment). Four-fold (ACC = 4) and 8-fold (ACC = 8) accelerated data used 45 and 22 projections, respectively. Our reconstructions used *M* = 6. We calculated percentage error ε to quantify the reconstruction performance. Experiments were performed on a 3T system (Skyra, Siemens) using a 32-channel head coil array (*N* = 32).



RESULTS The top row in the figure shows the reconstructed images, which show clear streaking artifacts in ACC = 4 and ACC = 8. After the 1st iteration, the reconstructed image using 4-fold accelerated data and our method shows the similar quality to the fully sampled image. The streaking artifact for the 8-fold accelerated was reduced but noisy at the image center. Both 4-fold and 8-fold reconstructions shows no clear improvement visually in the 2nd iteration. However, the percentage errors were improved: ε = 5.2% → 4.5% (ACC = 4) and ε = 11.6% → 9.8% (ACC = 8).

DISCUSSION The percentage error ε in ACC = 4 is roughly 50% of that in ACC = 8, because the amount of acquired data in ACC = 4 is twice of that in ACC = 8. Using under-sampled data for interpolation weights estimation may be skeptical. However, we used full sampled images for interpolation weights estimation and still have similar percentage errors (ε= 4.5% in ACC = 4 and ε= 9.4% in ACC = 8). This suggests that errors are not dominated by using under-sampled data for interpolation weights estimation, but rather the size and locations of $\mathbf{k}_m$.

CONCLUSION We proposed a self-calibrated parallel imaging method particularly useful for radial sampling. The interpolation weights for the missing *k*-space data were estimated directly from the under-sampled coil images. This method may be useful for other trajectories with densely sampled *k*-space center, such as a spiral trajectory. Experimental results show human brain images with 2 mm spatial resolution and no streaking artifacts using only 22 radial projections. This method may be integrated with radial sampling with projections in golden-angle increments to provide dynamic spatiotemporal resolution.

REFERENCES

1 Lustig, M., et al., IEEE, 2008. **25**(2): p. 72-82.
2 Peters, D.C., et al., Journal of Magnetic Resonance Imaging, 2004. **20**(3): p. 411-416.
3 Griswold, M.A., et al., Proc. Intl. Soc. Mag. Reson. Med., 2003: p. 2349.
4 Yeh, E.N., et al., Magnetic Resonance in Medicine, 2005. **54**(1): p. 1-8.
5 Arunachalam, A., A. Samsonov, and W.F. Block, Magn Reson Med, 2007. **57**(5): p. 931-8..
6 Sodickson, D.K. and W.J. Manning, Magn Reson Med, 1997. **38**(4): p. 591-603.