Reducing Off-Resonance Artifacts in O-space Imaging

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$$m(x,y)^{(k)} = m(x,y)^{(k-1)} + \lambda(x,y)\,\frac{s_i - E(x,y)_i \cdot m(x,y)^{(k-1)}}{\|E(x,y)_i\|^2} \cdot E^*(x,y)_i$$

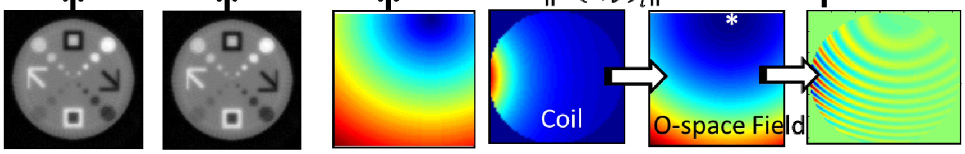

Figure 1: ART reconstruction for O-space, modified to use spatially varying λ(x,y) to reduce off-resonance artifacts. The O-space field and the resulting encoding matrix, Ei, show that encoding is not strong in the CP neighborhood—resulting in sensitivity to off-resonance near the CP. In the modified ART, for each CP, the image estimate in the neighborhood of the CP (asterisk) is not updated, via the spatial filter λ(x,y).

Target Audience: Parallel and iterative reconstruction and non-linear imaging communities.

Introduction: Here we analyze off-resonance effects in O-space imaging (1-3). In O-space, the z2 non-linear gradient, along with x and y linear gradients generate fields of the form $G=Gz2\ (x-x_0)^2 + (y-y_0)^2$ where (x_0,y_0) is the center-placement (CP) of the quadratic field, which is rotated around the edge of the FOV, to perform the role of "phase-encodings" in O-space. In Figure 1, the ART algorithm for reconstructing O-space is shown, based on the O-space field. The field has a low magnetic field gradient (i.e. Hz/pixel) in the neighborhood of the CP (asterisk). Therefore off-resonant spins in the CP location will be inaccurately encoded based on their frequency. Previous work has investigated off-resonance, and the incorporation of field maps into the reconstruction to reduce off-resonance (4). Here we present a reconstruction-based solution to reduce off-resonance artifacts, without field mapping.

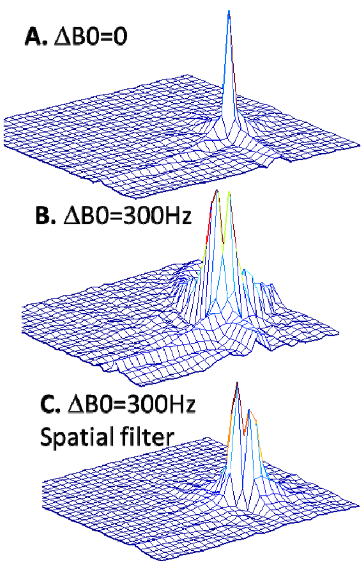

Figure 2: PSF analysis shows improvement with the spatial filter λ(x,y) (zoomed views).

Methods: Simulations were performed in Matlab, using 128 readout, with 128 CPs placed at radii= FOV/2, with a 390 Hz/pixel bandwidth. Synthetic data was generated and then reconstructed using iterative ART (1). To simulate off-resonance effects, we included into the raw data signal a new term reflecting a global off-resonance phase accumulation: $\varphi(t) = \Delta B0 \cdot t$, where t is time during readout. A modified ART reconstruction was investigated in simulations and phantom MR imaging (Figure 1). This modification is based on the insight that the spatial encoding magnetic field has little information, and significant off-resonance error, in the location around the CP because the magnetic field is not varying strongly in that location. Therefore in the iterative ART algorithm, for each CP, the image estimate was not updated in the neighborhood of the CP. This is easily achieved by using a spatially varying λ(x,y) designed for each CP, as shown in Figure 1, which illustrates the filter which varies as the distance from the image pixel location to CP, since at locations near the CP, the Hz/pix is small, and off-resonance error is high.

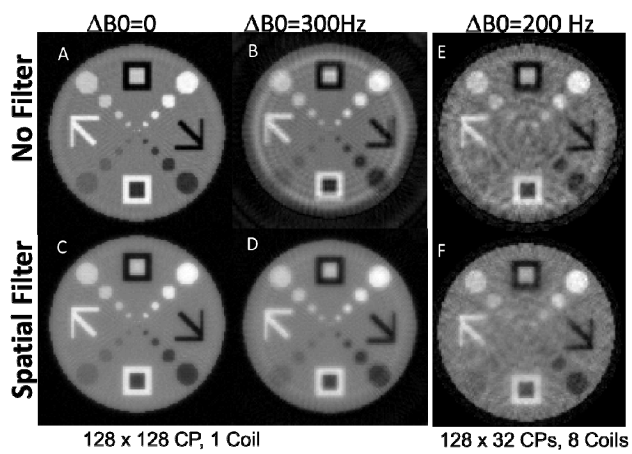

Figure 1: Simulation results. Spatial filtering improves images with off-resonance (D), but does not affect image with no off-resonance present (C). (E-F) Simulation for 8 coils, R=4.

Results: The PSF for an off-center point is shown in Fig. 2, with and without off-resonance, and spatial filtering. Figure 3 shows that images are improved in the presence of off-resonance (128 x 128 CPs, 1 coil), using the spatial filter. Accelerated imaging is also shown (128 x 32 CPs, 8coils, Figure 2,E,F).

Conclusions: O-space imaging is sensitive to off-resonance, but this sensitivity is reduced by spatial filtering of raw data most affected by off-resonance errors.

References: 1) Stockmann JP et al. MRM 2010. 2) Galiana et al. MRM 2012. 3) Tam LK et al. MRM 2012. 4) Stockmann JP, ISMRM 2010, 549.