Linear Off-resonance Correction for Partial-k-Space 3D Spiral Imaging

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Introduction 3D "stack of spiral" scans of large or multiple volumes can benefit significantly from slice-by-slice off-resonance correction when the field inhomogeneity varies enough that linear shimming is insufficient. When higher temporal resolution or shorter scan times are desired, partial k-space acquisition can be used in the phase-encoding (z) direction followed by a homodyne reconstruction [1]. The homodyne reconstruction begins in k_x,k_y,k_z or x,y,k_z space and ends in x,y,z space. Slice-by-slice off-resonance correction must be performed in k_x,k_y,z space. Therefore, the off-resonance correction and the partial k-space reconstruction are not separable, but they can be combined by performing the steps in the appropriate order, as we demonstrate here. Because off-resonance correction is performed on each slice individually, we can also correct for an arbitrary (i.e. not necessarily linear) gradient in z. We present a modified homodyne algorithm with off-resonance correction for partial 3D spiral data sets.

Methods Two low-resolution complex images are collected with different echo times for each slice with the fat and water signals in phase (ΔTE=4.5ms at 1.5T) with short, single-shot spiral readouts and symmetric, low-resolution k_z planes. The phase difference between the images is used to calculate a field map for each slice, which is approximated with constant and linear terms [2]. Figure 1 shows the modified homodyne algorithm. An $IFFT_z$ is performed on both the symmetric k-space data and the weighted partial k-space data. The k-space trajectory is modified to compensate for off-resonance [2], then used to grid both the symmetric and weighted data before each are Fourier transformed in k_x/k_y. Finally, the weighted partial k-space data is demodulated by the phase of the symmetric reference, and the real-part taken as in standard homodyne reconstruction.

Images were acquired using a 3D stack of spirals trajectory and RF-spoiling with TR/TE=30/9 ms and a water-only slab excitation on a GE Excite 12.0 scanner. In phantoms, we used a 17-interleave spiral, 20x20 cm FOV, 0.7x0.7 mm^2 resolution in-plane, 32 slices, 2mm thickness, and a 30º flip angle with linear shims. In a breast patient, rapid 3D images used a 9-interleave spiral, 20x20 cm FOV, 1.1x1.1 mm^2 resolution in-plane, 32 slices, 3mm thickness, and a 40º flip angle with linear shims for a 10-second frame rate. Finally, in a volunteer, we used a 17-interleave spiral with a 36x36 cm FOV, 1.3x1.3mm^2 in-plane resolution, 32 slices and a 15º flip angle with linear shims for a 15-second scan time.

Results Figure 2 shows phantom data reconstructed using full k-space data (a), using the standard homodyne algorithm (b), and using homodyne with field-map correction (c). The image with off-resonance correction is sharper, particularly in the higher resolution features, as indicated by the arrows. Figure 3 shows the corresponding images for patient breast data where the most noticeable improvement is in the thickness of the skin. Figure 4 shows the corresponding images for abdominal volunteer data. The organs are more clearly delineated in the corrected image. For each of these data sets, the field map correction (c) produces sharper edges compared to reconstructions that do not employ field map correction, even when used in conjunction with linear shimming. The observed SNR does not differ significantly between the three images.

Discussion In this algorithm, the off-resonance correction is applied by adjusting the k-space trajectories and gridding within the partial k-space reconstruction. Multi-frequency reconstruction [2] would allow for partial k-space reconstruction and off-resonance correction to be performed independently, but would be significantly more computationally intensive than the algorithm described above. The modified homodyne algorithm should provide shorter scan times and reduced blurring due to off-resonance with greater computational efficiency than the multi-frequency reconstruction.

Conclusion We have demonstrated a simple procedure to combine linear off-resonance correction with homodyne reconstruction for partial k-space 3D spiral data acquisitions. This algorithm should prove to be very useful in studies where the field inhomogeneity is considerable across the imaging volume and linear shimming is unlikely to sufficiently correct the local gradients.

References

[1] Noll, et al., IEEE TMI, MI-10(2), 154, (1991).
[2] Irarrazabal, et al., MRM 35(2):278-82 (1996).

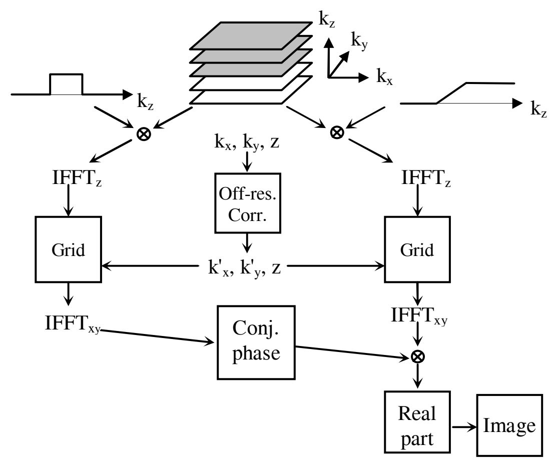

Figure 1 – Homodyne algorithm with Field Correction

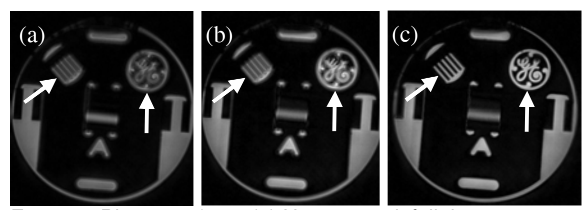

Figure 2: Phantom data. (a) Uncorrected, full k-space, (b) Uncorrected, 5/8 k-space, (c) Corrected, 5/8 k-space

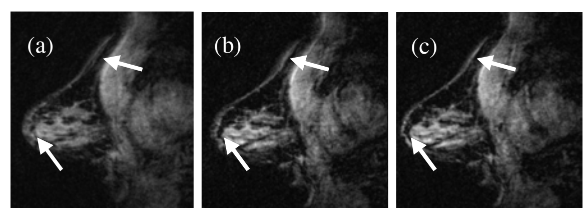

Figure 3: Unilateral patient breast data. (a) Uncorrected, full k-space, (b) Uncorrected, 5/8 k-space, (c) Corrected, 5/8 k-space

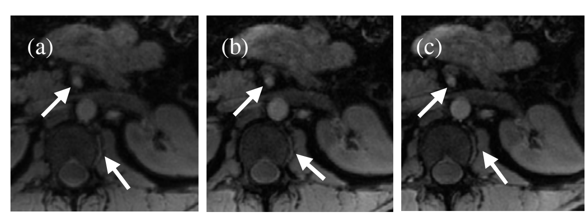

Figure 4: Section of abdominal data, showing spine and kidney. (a) Uncorrected, full k-space, (b) Uncorrected, 5/8 k-space, (c) Corrected, 5/8 k-space

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