Homodyne Reconstruction for Single-Echo Dixon Imaging

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Target Audience: ISMRM members with interest in reconstruction of single-echo Dixon images acquired with partial Fourier sampling.

Purpose: Dixon-based methods for fat suppression have the advantage of avoiding errors by accounting for main magnetic field inhomogeneities (ΔB_0) during the separation of the fat and water signals. Additionally, when applied to contrast enhanced MR angiography (CE-MRA), Dixon methods have been shown to demonstrate improved signal-to-noise ratio compared to background suppression via subtraction[1,2]. Typically, complex data acquired from multiple echoes is used to simultaneously estimate complex water and fat signals and the "nuisance" parameter that accounts for ΔB_0. Acquiring multiple echoes, however, comes at the cost of extended scan time. Partial Fourier techniques with homodyne reconstruction[3,4] have been applied to multi-echo Dixon and can reduce scan time by a factor of almost two. Single-echo Dixon techniques avoid extending the scan time, but require that nuisance parameters be known *a priori* from either a calibration scan or a "virtual shimming" procedure[5–7]. To our knowledge, partial Fourier sampling has not yet been applied to single-echo Dixon imaging. The purpose of this work is to theoretically derive and experimentally demonstrate partial Fourier single-echo Dixon with homodyne reconstruction.

Methods: *Theory:* Single-echo Dixon imaging assumes that both the water (W) and the fat (F) signals are real and have known initial phase ϕ_0 as shown in Equation 1. The time-dependent ΔB_0-induced phase $\phi(t)$ and chemical shift-induced phase $\theta(t)$ are also assumed known. To obtain real-valued W and F, a phase constrained reconstruction[8] was used for fully-sampled data (Equation 2). The matrix A is a generalized phase matrix with terms from chemical shift and "nuisance" phase. In the case of partial Fourier sampling and homodyne reconstruction, Equation 3 was derived and used. The second term of Equation 3 is the "blurring" term described by Noll et al.[9] and is negligible when the phase is slowly varying. Equation 4 ignores the "blurring" term and is identical to the standard homodyne process, except i) this process is performed within the framework of the phase constrained reconstruction and ii) instead of lumped phase, the matrix A separates phase due to chemical shift and nuisance parameters.

$$S(t) = \left(W + Fe^{i\theta(t)}\right)e^{i(\phi(t)+\phi_0)} \qquad (1)$$

$$\begin{bmatrix} W \\ F \end{bmatrix} = [Re\{A^*A\}]^{-1} Re\{A^*S\}, \quad A = e^{i(\phi(t)+\phi_0)}[1 \; e^{i\theta(t)}] \qquad (2)$$

$$\begin{bmatrix} W \\ F \end{bmatrix} = [Re\{A^*A\}]^{-1}\left[Re\left\{A^*\mathcal{F}^{-1}\left(I_{LP}+2I_{HP_A}\right)\mathcal{F}S\right\} + Re\left\{A^*\mathcal{F}^{-1}\left(I_{HP_B}-I_{HP_A}\right)\mathcal{F}S\right\}\right] \qquad (3)$$

$$\begin{bmatrix} W \\ F \end{bmatrix} \approx [Re\{A^*A\}]^{-1} Re\left\{A^*\mathcal{F}^{-1}\left(I_{LP}+2I_{HP_A}\right)\mathcal{F}S\right\} \qquad (4)$$

Phantom Experiments: A fat-water phantom was constructed to simulate an abdomen (bovine gelatin) with subcutaneous fat (vegetable shortening) and an enhanced abdominal aorta (~0.4 mmol gadolinium-doped bovine gelatin). Fully-sampled axial images were acquired with a birdcage coil at 3.0T (GE, Waukesha, WI) with the following scan parameters: $TE_1/TE_2/TR$=2.3/3.5/6.5msec, α=18°, BW=±62.5kHz, FOV=22×22×9cm, Matrix=224×224×60. Images acquired at TE_1 and TE_2 were used to estimate $\phi(t)$ and ϕ_0 using a two-point Dixon method[10]. A fully-sampled single-echo image was acquired with identical parameters except: TE/TR=2.8/6.5msec. Phase-constrained Dixon reconstruction was performed on i) fully-sampled, ii) retrospectively undersampled and zero filled, and iii) retrospectively homodyne filtered single-echo images. The homodyne filter used in this work is shown in Figure 1 (acceleration = 1.88). To determine whether the "blurring" term is negligible in this application, both the first ("object") term and the second ("blurring") term of Equation 3 were reconstructed.

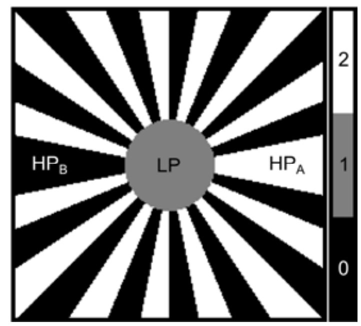

Figure 1: The homodyne filter used to retrospectively undersample the data.

Results: Axial slices from the phantom study are shown in Figure 2. Water images from the single-echo Dixon reconstruction show good fat suppression when fully sampled (a), zero filled (b), and reconstructed with homodyne processing (c). The corresponding fat images (e-g) depict the vegetable shortening layer of the phantom very well with only slight water signal leakage within the gadolinium-doped gelatin. The "blurring" term is shown in (d) and (h).

Discussion: The single-echo Dixon reconstruction with zero filling shows noticeable blurring compared to the fully-sampled image. Homodyne processing sharpens the image and shows good fat suppression and minimal artifacts. Due to the homodyne filter used, the undersampling artifacts resemble those from a projection reconstruction. These artifacts can potentially be reduced by using a more random high-pass region or with an iterative approach to partial Fourier reconstruction (e.g. POCS). In the phantom used here, the "blurring" term of Equation 3 is small compared to the object term. Future work will investigate the use of this method in vivo and in conjunction with parallel imaging.

Conclusion: A homodyne reconstruction for single-echo Dixon imaging with partial Fourier sampling has been presented. This processing is performed within the framework of a phase constrained reconstruction and accomplishes the fat-water separation and homodyne phase correction in a single step. Partial Fourier sampling plus homodyne processing can reduce scan time by a factor of almost 2 and when combined with other acceleration strategies (parallel imaging) shows promise for time-resolved Dixon imaging for dynamic applications such as CE-MRA.

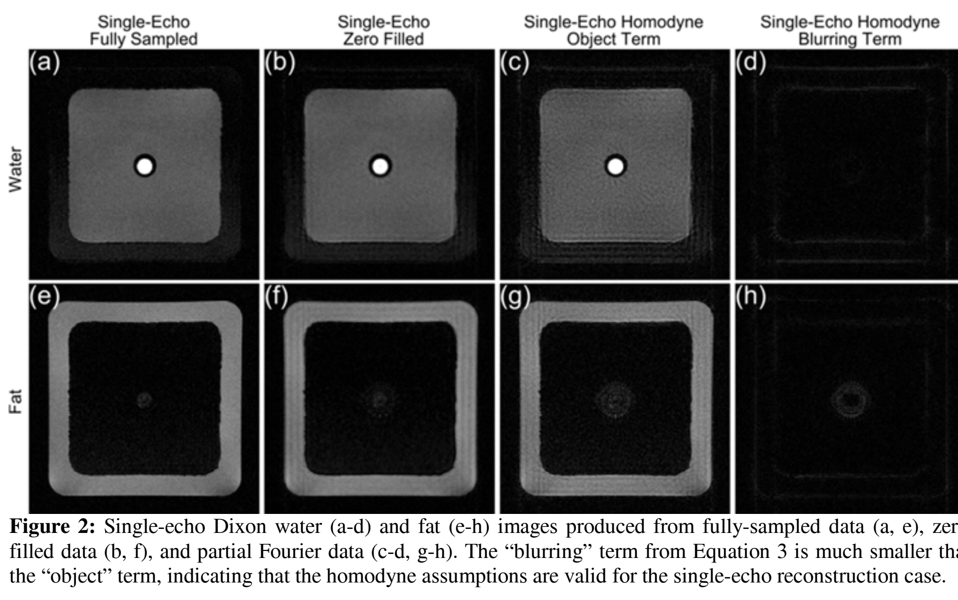

Figure 2: Single-echo Dixon water (a-d) and fat (e-h) images produced from fully-sampled data (a, e), zero-filled data (b, f), and partial Fourier data (c-d, g-h). The "blurring" term from Equation 3 is much smaller than the "object" term, indicating that the homodyne assumptions are valid for the single-echo reconstruction case.

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