Acceleration of IDEAL Water-Fat Imaging using Compressed Sensing

S. D. Sharma[1], H. H. Hu[1], and K. S. Nayak[1]
[1]Department of Electrical Engineering, University of Southern California, Los Angeles, CA, United States

Introduction: IDEAL is an iterative technique for separating water and fat signals on a per-*voxel* basis [1]. Water-fat imaging plays an important role in many clinical applications, including high-spatial-resolution 3D knee imaging to characterize bone marrow and cartilage [2], and 3D whole-abdomen imaging to quantify fat in adipose tissue depots and organs [3]. However, the long scan times required increase susceptibility to motion artifacts. Thus, water-fat imaging applications can significantly benefit from data acceleration. In this work, we reformulate the IDEAL algorithm to estimate water and fat signals on a whole-image basis [4], and present an approach to integrate Compressed Sensing (CS) [5] into the accelerated water-fat separation framework [6]. We demonstrate up to 3x acceleration using CS-IDEAL.

Theory: Each iteration of the IDEAL reconstruction solves two least-squares (LS) problems: 1) water and fat signal estimation, and 2) estimation of the current iteration's field map error. We reformulate these LS problems in Equations 1 and 2. The vector k represents the acquired k-space data from all TEs and all coils, Φ is the Fourier sampling operator, Ψ represents a function of the image field map estimate, C denotes the coil sensitivity maps, A is

$$\min_{c_w, c_f} \left\| k - \Phi\Psi CADc \right\|_2^2 + \lambda_1 \left[\left| c_w \right|_1 + \left| c_f \right|_1 \right] \quad (1)$$

$$\min_{\Delta\psi} \left\| e - By \right\|_2^2 + \lambda_2 \left| \Delta\psi \right|_{FD} \quad (2)$$

the water-fat chemical-shift coefficient matrix, D represents a sparsifying transform and c are its coefficients such that c_w and c_f are the water and fat transform coefficients. In Equation 2, the vector e denotes the difference between the true and the estimated k-space signals, B represents the error-modeling matrix [1], and y is a matrix of field map error ($\Delta\psi$), water signal error, and fat signal error. FD denotes the finite-difference operator. By solving these problems on a whole-image-basis, we are able to leverage presumed compressibility of both water and fat images as well as the field map error to regularize our underdetermined system of equations.

Method and Results: We used a variable-density retrospective sampling scheme and the Daubechies4 wavelet transform to compress both the water and fat images [7]. **Phantom:** We verified this method on a 256x256 water-fat phantom using an oblique coronal slice that spanned the fat fraction spectrum. Figure 1 shows line profiles of the estimated fat fractions using conventional IDEAL and CS-IDEAL with 2x and 3x acceleration. Both CS-IDEAL reconstructions agree quite well with the IDEAL estimation. **In vivo:** We applied this technique to a 256x256 sagittal knee slice. Figure 2 shows field maps, fat fraction maps, and the fat fraction difference map for IDEAL and CS-IDEAL (3x). The bone marrow regions outlined in Figure 2e have high fat fractions. In these regions, the average absolute fat fraction difference between IDEAL and CS-IDEAL is only 2.7%. At tissue interfaces, some large fat fraction differences did occur due to unreliable field map estimates in both IDEAL and CS-IDEAL.

Conclusion: We have demonstrated accelerated water-fat imaging by reformulating the IDEAL algorithm and solving the problem via CS on a whole-image basis. One limitation of the present framework is the lack of consideration for T2*-decay. This remains as future work.

References: [1] Reeder et al., MRM 2004; [2] Kijowski et al., JMRI, 2009; [3] Winkelmann et al., MAGMA, 2006; [4] Hernando et al., MRM 2008; [5] Candes et al., IEEE IT 2004; [6] Lustig et al., ISMRM 2009; [7] Lustig MRM 2007;
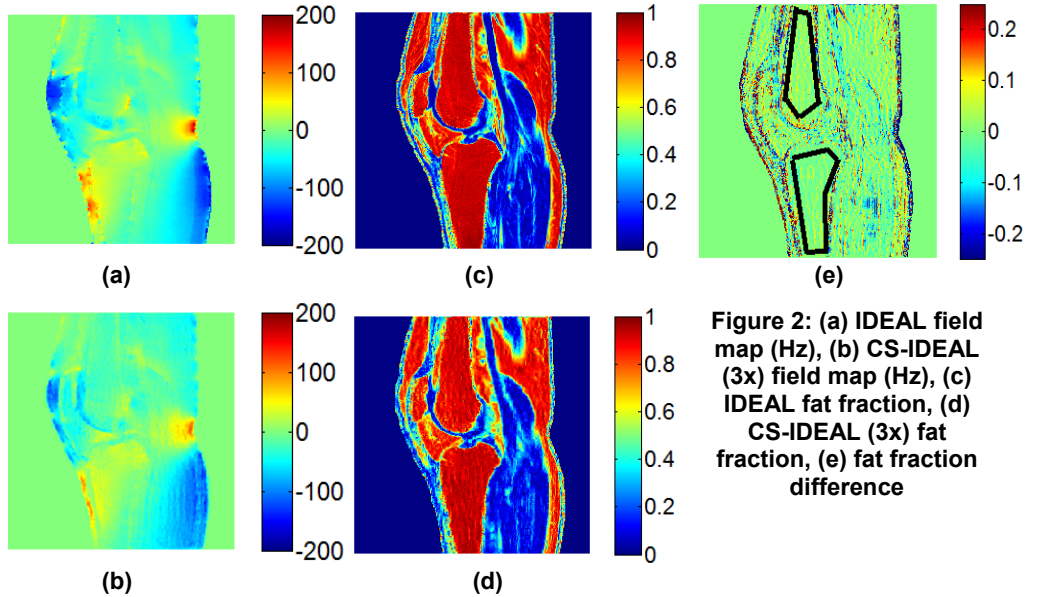
(a)

(c)

(e)

(b)

(d)

Figure 2: (a) IDEAL field map (Hz), (b) CS-IDEAL (3x) field map (Hz), (c) IDEAL fat fraction, (d) CS-IDEAL (3x) fat fraction, (e) fat fraction difference
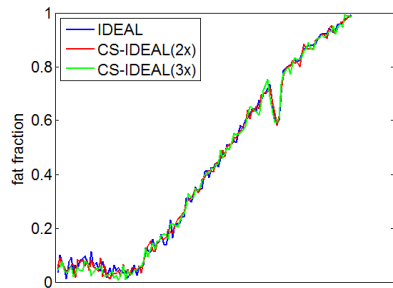

Figure 1: fat fraction line profile along water-fat interface