Acceleration of IDEAL Water-Fat Imaging using Compressed Sensing

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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, \( \Phi \) is the Fourier sampling operator, \( \Psi \) represents a function of the image field map estimate, \( C \) denotes the coil sensitivity maps, \( A \) is 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.