Accelerated Water-Fat Imaging Using Restricted Subspace Fieldmap Estimation

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Introduction: Water-fat separation techniques based on multi-echo methods play an important role in several clinical applications because they can reliably separate water and fat signals in the presence of B_0-field inhomogeneity. However, multi-echo methods require longer scan times as compared to single-echo imaging. Therefore, an accelerated imaging technique is desirable to reduce the length of these methods. This work proposes a new approach for water-fat separation from undersampled data acquisitions. The typical voxel-independent (VI) model is generalized to consider estimation of the entire water, fat, field map, and R2* **images** directly from the undersampled k-space data. An IDEAL-like algorithm is used to iterate between water-fat estimation and field map update [1]. Unlike previous works [2], region-growing (RG) is not used for field map estimation.

Theory: Equation 1 presents the model that relates the undersampled k-space measurements k at echo time t_n to the unknown water image (ρ_w), fat image (ρ_f), and field map/R2* image (ψ). The variable Φ denotes the undersampled Fourier transform, d_n is a complex-valued quantity that represents the chemical shift of fat relative to water, and the symbol $\otimes$ denotes point-wise multiplication.

$$k(t_n) = \Phi\left[\rho_w + \rho_f \otimes d_n\right] \otimes e^{j2\pi\psi t_n} \quad (1)$$

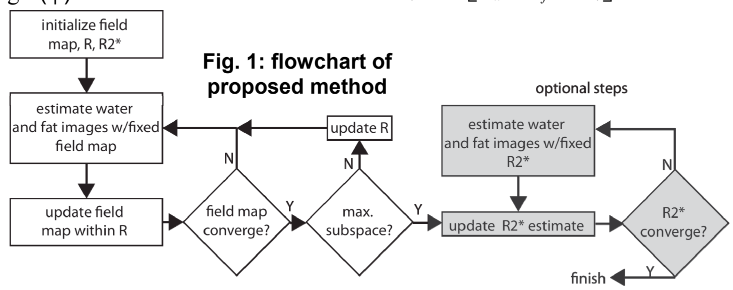

Fig. 1: flowchart of proposed method

Water-Fat Estimation: Guided by the theory of compressed sensing [3], the water and fat images are estimated by including a ℓ_1-penalty on their respective wavelet coefficients. Field Map Estimation: Updating the field map estimate is not straightforward since the least-squares cost function with fully-sampled data is non-convex with respect to the field map image. Motivated by the work of Tsao and Jiang [4], this work proposes to restrict the dimension of the linear subspace, R, in which the field map estimate is updated. The subspace dimension is successively increased to allow for a more accurate field map estimate, but it never reaches the full dimension of the field map image. Further, the linear functions that span the subspace are created as shifted versions of *tri(x/a)*, where '*a*' depends on the subspace dimension.

R2* Estimation: R2* estimation is performed after the field map has been finally estimated. The field map is held fixed and the water-fat images and R2* images are iteratively estimated using an ℓ_1-penalty on the water-fat estimates and a finite-difference penalty on the R2* estimate to promote a piecewise-linear result. See flowchart in Figure 1 for a summary of the approach.

Methods and Results: Data were collected on a 3T Signa EXCITE HDx System (GE Healthcare, Waukesha, WI) using an investigational six-echo IDEAL spoiled-gradient-echo (SPGR) sequence. The data were retrospectively undersampled using a variable-density scheme that fully-sampled the central $1/8^{th}$ phase-encoding lines. Images were reconstructed using voxel-independent IDEAL [1] and/or an in-house implementation of IDEAL with region-growing [2], and the proposed method. All processing was done in Matlab (The Mathworks, Inc, Natick, MA).

Ankle: Figure 2 shows water, fat, and field map results of a 256x256 sagittal slice. The data were acquired using a single-channel coil with TE_1 = 1.548 ms and ΔTE = 0.866 ms. The white arrows in Fig. 2 highlight incomplete water-fat separation caused by erroneous field map estimates. The proposed approach at 2x correctly separated the water and fat signals.

Abdomen: Figure 3 shows field map, R2*, and fat fraction estimates of a 256x256 axial slice. The data were acquired using an eight-channel torso coil with TE_1 = 1.272 ms and ΔTE = 1.002 ms. Liver measurements were made within a ROI denoted by the white dashed line in the R2* images. The average R2* was 35.13 and 32.44 ms^{-1} and average fat fraction was 1.88 and 3.48% for the RG and proposed approach, respectively.

Discussion: The proposed approach avoids the local minima that plague voxel-independent methods. Further, the need for region-growing/merging techniques, which rely heavily on seed pixels and connected signal regions, is avoided. By solving **entire images instead of individual voxels**, sparsity of water, fat, and R2* images can be exploited and the field map can be resolved in a reduced-dimensional space for accurate estimation from undersampled data.

References: [1] Reeder et al. MRM 2005; [2] Yu et al. MRM 2005; [3] Candes et al. IEEE IT 2004 [4] Tsao et al., ISMRM 2008.

Fig. 2

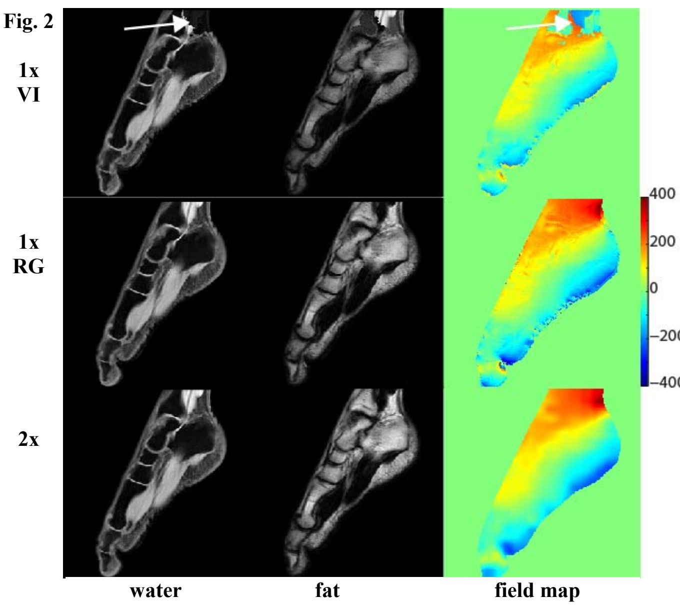

Fig. 3