Robust two-point Dixon water/fat separation using graph cut algorithm

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Target audience: Researchers interested in two-point Dixon water/fat separation.

Purpose: To perform two-point Dixon water/fat separation with flexible echo times that is robust to large field inhomogeneity.

Methods: The signal equations for the two-point Dixon method can be written as [1-3] $s = (W + Fc_1)P_a$, $s_2 = (W + Fc_2)P_aP$, where $s_{1,2}$ are the measured complex signals, W and F are the real non-negative water and fat signals, $c_{1,2}$ are constants computed from the water/fat spectra and echo times, $P_a = e^{i\phi_1}$ is the phasor at the first echo and $P = e^{i(\phi_2-\phi_1)}$ is the phasor due to the field inhomogeneity accumulated between the two echoes. For each voxel, W and F can be computed algebraically if P is known. From the signal equations, two candidate solutions of P can be computed. Thus the key of any two-point Dixon method is to determine the phasor P. Typical methods include utilizing local average of the phasors [2] or global optimization with smoothness constraint [3].

In our method, the spatial smoothness of the field inhomogeneity is imposed explicitly as an energy minimization over binary labels on each voxel. To improve the robustness of the water/fat separation, we 1) identify low SNR voxels and replace their P candidates with locally smoothed values, 2) create a candidate map A by taking the phasor P with the smaller phase in absolute value, and the map B with the alternative choice of phasor. Part of A will serve as a bias to guide the energy minimization. The energy function takes the form $\min_{\{K_i\}} E = \min_{\{K_i\}} \lambda \sum_i m_i D_i(K_i) + \sum_{\langle i,j \rangle} w_{ij} V_{ij}(K_i, K_j)$
where the first (unary) term creates a bias towards a partially smooth initial guess and the second (binary) term imposes the smoothness on the P candidates over the whole image stack. The labels K_i take values of 0 or 1 for each of two choices for P. In the first term, $D_i(K_i) = -M_i$ if $K_i = 0$ and $D_i(K_i) = 0$ if $K_i = 1$, where M_i is the SNR of the voxel. The mask $m = \{m_i\}$ is obtained by identifying a smooth region in A, by selecting those voxels whose gradient falls below a preset threshold τ_∇: $\max\{|\partial_x A|, |\partial_y A|, |\partial_z A|\} < \tau_\nabla$. The second term penalized the difference between neighboring voxels: $V_{ij}(1,0) = |B_i - A_j|^2$, $V_{ij}(0,0) = |A_i - A_j|^2$, etc. The construction is similar to that used in Ref. [5]. In our construction, the edge term V_{ij} (defined for each pair of neighbouring pixels $\langle i,j \rangle$) is not sub-modular making the minimization problem is NP-hard [4]. We use the Quadratic Pseudo-Boolean Optimization (QPBO) algorithm to solve the problem. Fig 1 shows a flow chart of our method.

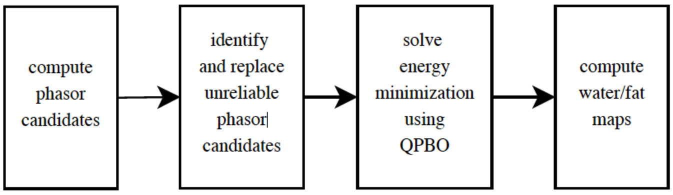

Figure 1. Flow chart of the proposed method.

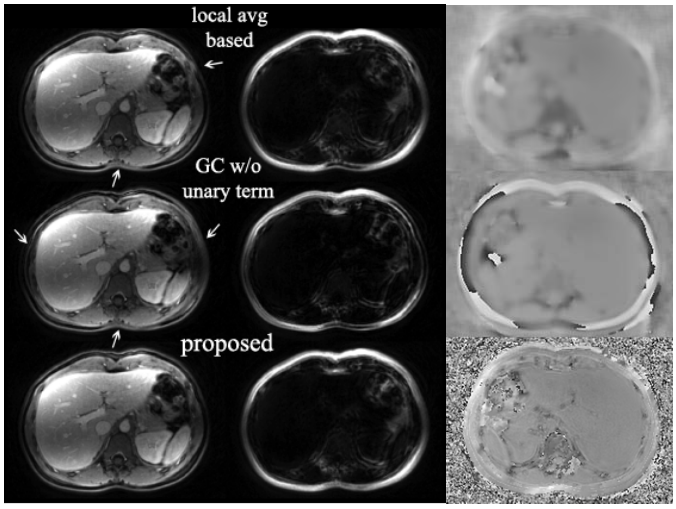

Figure 2. Water maps (first column), fat maps (second column) and field maps (third column) calculated from local average based method (first row) [2], graphcut optimization without unary term (second row) [3] and the proposed method. Discontinuities in the field maps result in water/fat swaps, as indicated by arrows.

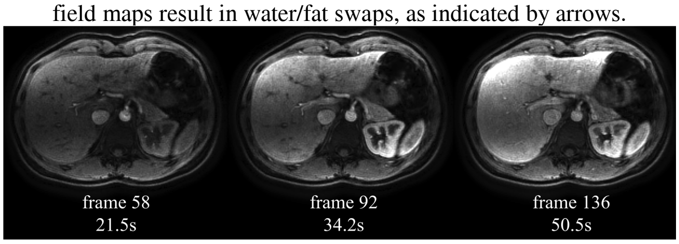

Figure 3. Water images of the dynamical liver data with contrast enhancement using the proposed method at 1.5T. 140 temporal frames were constructed for the 51 second scan.

Contrast enhanced dynamic liver data were acquired in 3 healthy volunteers on a 1.5T scanner (GE Healthcare, Waukesha, WI). A single dose (0.1mmol/kg) of Magnevist (Bayer Healthcare) was injected at 2ml/s, followed by a 20ml saline flush. Imaging parameters were: 48 leaves fully sampled (13s), 256×256×20 acquisition matrix, ±62.5kHz bandwidth, flip angle 15°, TE1/TE2=0.7/2.8ms, voxel size 1.37×1.37×5mm, TR=8ms. Images were reconstructed for each leaf using TRACER[5], leading to nominal frame rate of ~4frames/s. Non-contrast enhanced liver data were acquired in 8 healthy volunteers on 1.5T scanner (GE Healthcare, Waukesha, WI) with the same imaging parameters.

Results: Water and fat maps from one healthy subject are shown methods are shown in Fig. 2. Water maps of the dynamic liver imaging with contrast enhancement are shown in Fig. 3, which correspond to the arterial, portal venous and delayed phases.

Discussion: The preliminary data in this work demonstrated the feasibility of robust water/fat separation with two-point Dixon method with flexible echo times using a complex phasor pre-processing step combined with an efficient global voxel labelling algorithm. Robust water/fat separation of the proposed method was achieved in all frames of the dynamic liver imaging data with contrast enhancement.

Conclusion: The proposed two-point Dixon water/fat separation method with flexible echo times was shown to provide robust water/fat separation in liver data at 1.5T, including in dynamic imaging after contrast injection. Water-fat swap artefacts near air/tissue interfaces were effectively suppressed.

References [1]. Ma 2008. JMRI (28) 543-558; [2]. Eggers et al. 2011. MRM (65) 96-107; [3]. Berglund et al. 2011. MRM (65) 994-1004; [4]. Kolmogorov et al. 2004. IEEE TPAMI (26) 147-159; [5]. Dong et.al. 2014 IEEE TMI, in press, DOI: 10.1109/TMI.2014.2361764 [6]. Xu et al. 2013. MRM (69) 370-381.