Joint Inference of Field Inhomogeneities with Fat Likelihood Estimation from Three Echoes

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Introduction: Robust multi-echo water-fat separation at high field remains challenging in the presence of long echo-spacing and large field inhomogeneities. Recent work by Yu et al. [1] greatly improves the robustness of field map estimation by computing *a priori* fat likelihood. However, obtaining reliable fat likelihood requires rather long echo train (6 echoes) to observe the signal difference arisen from single-peak water model and multiple-peak fat model. In this work, we demonstrates that inconclusive fat likelihood estimation from three echoes can be effecitively combined with field map smoothness via a joint inference algorithm, which enables robust water-fat separation in challenging imaging scenarios at 3T.

Theory: The signal S_i received at echo time TE_i is
$S_i = \left(W + F\sum_l \alpha_l e^{j2\pi\Delta f_l TE_i}\right)e^{j2\pi\psi TE_i}$,
where Δf_l are the chemical shift between water W and the l^{th} spectral component of fat F. Given the multi-peak fat parameters α_l and Δf_l, we can compute the least-squares fitting error J_ψ as the function of the unknown field inhomogeneity ψ [2]. Two smallest local minima of J_ψ at ψ_W and ψ_F are located within one spectral FOV $[0, 1/\Delta TE]$, where ψ_W and ψ_F results in water-dominant and fat-dominant separation results, respectively. Denote their corresponding fitting errors as J_W and J_F; *a priori* fat likelihood P_F is given by $J_W/(J_W + J_F)$.
The larger the water-fitting error J_W as compared to the fat-fitting error J_F, the more likely the fat is dominant (Fig. 1a). However, J_W and J_F can be very close when estimated from three echoes using the multi-peak fat modelling, especially for voxels containing water-fat mixture (Fig. 1b). Similar J_W and J_F results in inconclusive fat likelihood (i.e., $P_F \approx 0.5$), which imposes challenges on resolving the correct field inhomogeneity.

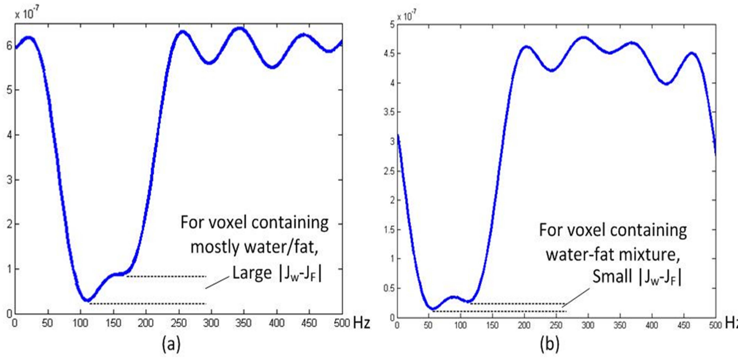

Fig. 1: Multi-peak least-squares fitting errors of (a) a voxel containing mostly water/fat and (b) a voxel containing water-fat mixture. Multi-peak fat modelling easily differentiate voxels containing pure water/fat, but is less certain in determining fat dominance in those containing water-fat mixture.

Methods and Results: For each voxel, ψ_F, ψ_W and their spectral replicas are considered feasible field map values, which are assigned with the corresponding *a priori* likelihood P_F or $1 - P_F$. An interaction potential V_{pq} is exchanged between two neighboring voxels p and q on their feasible field map values ψ_p and ψ_q:

$$V_{pq} \propto P_{\psi_p} P_{\psi_q} \exp(-(\psi_p - \psi_q)^2), \quad (1)$$

which blends both the difference between two feasible values and their *a priori* likelihood. The interactive potential between ψ_p and ψ_q is large when both *a priori* likelihoods are close to 1 and the difference between two values is small. More importantly, the interaction potential enables a voxel with strong *a priori* likelihood to exert influence on its neighboring voxels with less conclusive *a priori* likelihood. The interaction potential is embedded in a soft-decision message from p and q at the t^{th} iteration

$$m^t_{p\to q}(\psi_q) = \sum_{\psi_p}\left(V_{pq}\prod_{s\in\aleph(p)\setminus q} m^{t-1}_{s\to p}(\psi_p)\right), \quad (2)$$

where $\aleph(p)\setminus q$ denotes the set of pixels neighboring to p other than q. By exchanging the soft-decision messages between voxels, the algorithm jointly infer the most likely field map values across the whole image grids [3].

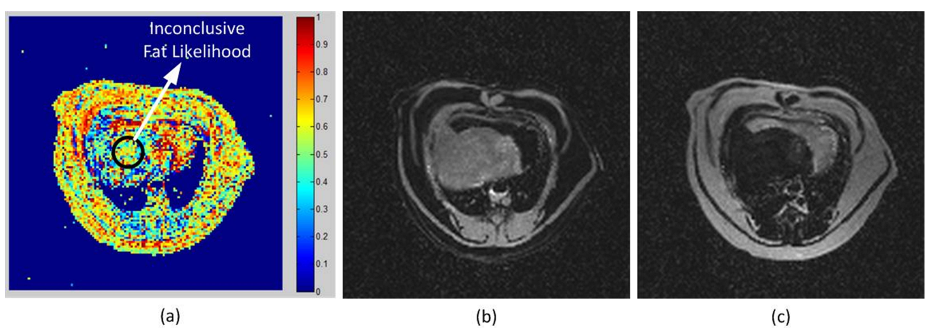

Fig. 2: (a) A prori fat likelihood of a obses cat liver study estimated from three echoes. The black circle encloses a fatty liver region, of which a priori fat likelihoods are inconclusive. The proposed technique effectively combines the fat likelihood with the smoothness constraint to achieve uniform separation of (b) water and (c) fat.

A multi-echo SPGR sequence was used to perform liver studies on 11 obese cats using a body matrix coil and a spine coil on a Siemens Tim Trio 3T scanner. The images were acquired with respiratory gating and 2 ms ΔTE, 5^o flip angle, 128x128 matrix size, 20x20 cm^2 FOV. Fig. 2a shows that subcutaneous fat has very strong fat likelihood estimate (i.e., $P_F \approx 1$), while some regions in the fatty liver have inconclusive fat likelihood estimates (P_F fluctuates around 0.5 inside the black circle). In spite of inconclusive fat likelihood estimates, the proposed inference algorithm achieves uniform water-fat separation for all studies. The sample separation results are shown in Fig. 2b and c.

Conclusion: This work presents a joint inference algorithm which effectively combines the field map smoothness constraint and the fat likelihood estimated from three echoes. This technique is potentially useful for motion-sensitive applications, such as liver fat quantification.

References: [1] Yu et al. MRM; doi: 10.1002/mrm.23087 [2] Lu et al. MRM 2008;60:236-44 [3] Lu et al. TMI 2011;30:1417-26