3D Mapping of T2* and B0 Inhomogeneities for Water/Fat Separation

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Target Audience: This work targets researchers in Dixon-based water/fat separation in all anatomies.

Introduction: MRI Dixon based techniques [1] have shown the ability to non-invasively quantify fat by producing separate images for fat and water components. However, a successful separation is severely hindered by the presence of B_0 inhomogeneities that can swap the fat and water components in their respective images [2]. Most of the techniques proposed in the literature perform slice-by-slice reconstruction, relying on the fact that the field map should be smooth throughout the field of view. In fact, B_0 inhomogeneities vary smoothly in 3D. In other words, considering inter-slice smooth variations of field map should help enforcing an additional smoothness prior on the reconstruction process. Recently, we proposed a 2D labeling approach [3, 4] for field map estimation that was more efficient than the commonly-used IDEAL-based region growing technique [2, 5]. In this work, we extend this approach to 3D, taking advantage of the 3D smoothness of the magnetic field. Moreover, T_2^* decay was integrated in the approach, which is necessary for 1) obtaining an accurate fat fraction map [6], 2) avoiding fat/water swaps by providing a more accurate signal model. We tested our technique on 3D data of NAFLD patients as well as 2 datasets of healthy volunteers acquired at 3.0 Tesla.

Methods: By considering the T_2^* effect in the signal equation, a cost function can be derived as follows: $\Gamma_v(\varphi, R_2^*) \coloneqq \left\|(\mathrm{AA}^\dagger - I).\Psi_v{}^{-1}(\varphi\,, R_2^*).\mathrm{S}_v\right\|_2$, where $\mathrm{A}_{N\mathrm{x}2}$ is an Nx2 matrix $s.t$: $\mathrm{A}_n = [1 \quad \sum_{m=1}^{M} \alpha_m . e^{i2\pi\,\delta_m\,t_n}]$, t_n denotes the echo-time (TE) ($n = 1, \dots, N$) of the acquired signal, M is the number of fat peaks in the fat spectrum; δ_m is the frequency of the m-th peak with its corresponding amplitude α_m (Hz), such that $\sum_{m=1}^{M} \alpha_m = 1$; $\Psi_v(\varphi, R_2^*, t_n) = diag\left(e^{i\,(2\pi\,\varphi_v + iR_{2v}^*)t_\mathrm{n}}\right)$, φ_v (Hz) is the local frequency offset at voxel v and S_v denotes the signal acquired from a voxel v. A calibrated fat spectrum model [6] was used, where the main fat peak is at ~ 420 Hz, relative to the water peak at 3T. The labeling approach estimates the field map in two steps [3, 4]. The role of the first stage is avoiding fat/water swaps by 'labeling' each pixel with an approximate frequency offset – the so called labeling stage. The second stage performs T_2^*-IDEAL, employing the coarse field map of the first stage as initial estimate for the iterative process. By extending the labeling stage into 3D, the smoothness of the field map in all directions is considered. The entire volume is therefore divided into independent regions, each labeled with a certain field map value. The labeled volume is employed in the 3D T_2^*-IDEAL reconstruction as described in [3, 4], from which fat and water volumes are obtained simultaneously with a 3D R_2^* map.

Results: Data were acquired from 2 healthy volunteers and 2 NAFLD patients with 3D IDEAL-SPGR sequence using 8-coil array on 3T (Discovery MR 750, GE Healthcare, Waukesha, WI). Volumetric field maps and R_2^* maps were successfully reconstructed for all datasets from which fat and water volumes were subsequently obtained. Figure 1 shows the results of a 2D slice from a NAFLD patient, with the R_2^* map, clearly showing the presence of iron overload in the liver. Data shown were acquired with TE/ΔTE/TR = 1.064/0.852/7.484 msec, bandwidth = 558.047 Hz/pixel and flip angle = 5º.

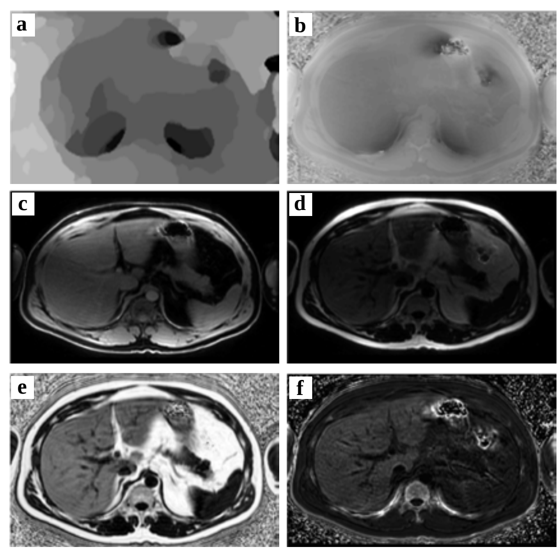

Figure 1: (a) Initial estimate of field map, (b) Final field map, (c) Water, (d) Fat, (e) Fat fraction, (f) R_2^* map

Discussion: The labeling approach was extended to 3D to take advantage of the actual 3D field map smoothness embedded in the acquisition. However, fat/water swaps could still appear at the inferior and superior slices of the axially-acquired 3D volumes as those are, intuitively, subject to more inhomogeneities. A solution to this problem might be to apply a spatially varying smoothness prior that allows greater variation in the B_0 field at the extremities of the imaged volume. While the labeling stage provides an initial estimate for the field map only, we nevertheless found it necessary to consider the T_2^* decay in the cost function of this stage to avoid fat/water swaps in some cases (not shown here).

Conclusion: We have demonstrated a 3D approach for field map estimation which takes into account the 3D smoothness property of the B0 magnetic field. We have also integrated T_2^* effect into the labeling approach, necessary for accurate fat quantification.

References: [1] Ma, *JMRI*, 2008, 28:543. [2] Yu *et al.*, *MRM*, 2005, 54:1032. [3] Soliman *et al.*, *ISMRM*, 2012, 2508. [4] Soliman *et al.*, *MICCAI*, 2012, LNCS 7511:519. [5] Reeder *et al.*, *MRM*, 2005:636. [6] Yu *et al.*, *MRM*, 2008, 60:1122.