# A joint estimation method for two-point water/fat imaging with regularized field map

D. Hernando[1], P. Kellman[2], and Z-P. Liang[1]

[1]Electrical and Computer Engineering, University of Illinois, Urbana, IL, United States, [2]National Institutes of Health, Bethesda, MD, United States

## INTRODUCTION

A recently developed joint estimation method for water/fat separation, based on a penalized maximum likelihood (PML) formulation and graph cuts optimization, is able to perform robustly in the presence of large $B_0$ field inhomogeneities [1]. This method requires the acquisition of at least three images with different TE shifts, because the water and fat components of the signal are allowed to have different initial phases [2]. However, 2-point methods can be advantageous in terms of acquisition time [3,4,5]. In this work, we adapt the joint estimation framework for 2-point acquisitions and demonstrate its performance using simulations, phantom results and in vivo data.

## METHODS

In a chemical shift-encoded acquisition (e.g., multi-echo GRE), we can model the signal at voxel q and TE shift t as:

$$s_q(t) = [W + F\exp(i2\pi f_F t)]\exp(i(\varphi + 2\pi f_B t)) \qquad \text{Eq. 1}$$

where $W$ and $F$ are the (real-valued) amplitudes of water and fat, respectively, $f_F$ is the fat resonance offset (e.g., -220Hz at 1.5T), $\varphi$ is the initial phase and $f_B$ is the frequency offset due to local $B_0$ field inhomogeneity. In this model, there are two unknown linear parameters ($W$ and $F$), and two unknown nonlinear parameters ($\varphi$ and $f_B$). The presence of $\varphi$ complicates direct application of the regularized estimation method proposed in [1]. However, if one of the TE shifts ($t_1$) is acquired in-phase, i.e., $\exp(i2\pi f_F t_1)=1$, then we can remove the phase parameter from the in-phase image [5]. Denoting $\varphi_1=\varphi+2\pi f_F t_1$ and rewriting Eq. 1 as $s_q(t) = [W+F\exp(i2\pi f_F t)]\exp(i(\varphi_1+2\pi f_B(t-t_1)))$, then we estimate $\varphi_1$ as the phase of $s_q(t_1)$.

Given the phase $\varphi_1$, the signal model becomes a function of two linear parameters and one nonlinear parameter. This allows us to apply a regularized formulation to jointly estimate the complete water/fat images and field map ($\mathbf{W},\mathbf{F},\mathbf{f_B}$):

$$\arg\min_{\mathbf{W},\mathbf{F},\mathbf{f_B}} \sum_q R_q(W_q, F_q, f_{B,q}) + \mu \sum_{q,j\in\delta_q} w_{q,j}(f_{B,q} - f_{B,j})^2 \qquad \text{Eq. 2}$$

where $R_q$ is the sum-of squares of the difference between signal model (given $\varphi_1$) and measured signal at voxel $q$; $\delta_q$ is the 8-neighborhood of voxel $q$; $\mu$ and $w_{q,j}$ control the regularization. Eq. 2 can be effectively optimized using variable projection and graph cuts [1].

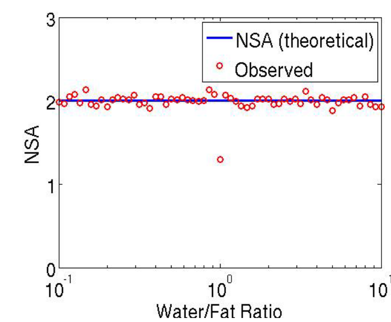


**Figure 1.** NSA as a function of water/fat ratio.

## RESULTS AND DISCUSSION

Figure 1 shows the theoretical effective number of signal averages (NSA) [5,6] achievable with an in-phase/opposed-phase acquisition, as well as simulation results over a range of water/fat ratios. Interestingly, the proposed method matches the theoretical NSA for nearly all water/fat ratios, despite the fact that the initial phase is estimated only from the in-phase image.

Figure 2 shows phantom 2-point separation results from a simple oil/water phantom, in the presence of relatively large field inhomogeneities (> $f_F$). Figure 3 shows an in vivo acquisition in a patient with a large lipoma, comparing the results from the proposed 2-point method with a 3-point acquisition (relative phases π, 2π, 3π). Note the close agreement in the results from the two techniques throughout the field of view.

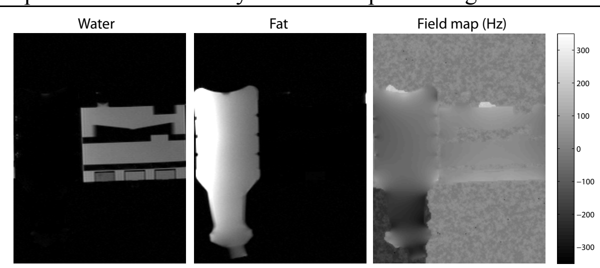


**Figure 2.** Results on a simple phantom consisting of an oil bottle and a water container.

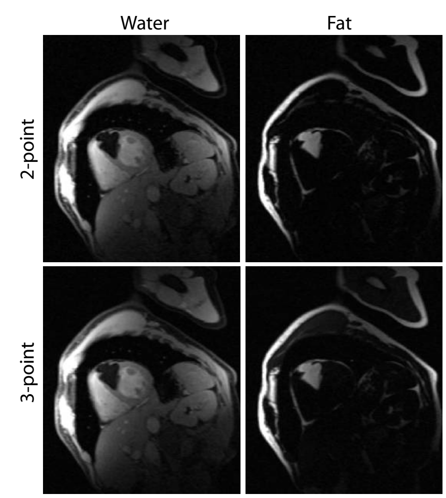


**Figure 3.** Results for an in vivo cardiac acquisition (patient with large lipoma) using the proposed 2-point method and a 3-point method.

The proposed 2-point method can in principle be applied with a variety of choices of TE shifts, as long as one of the images is in-phase. However, the NSA performance deteriorates for choices very different from in-phase/opposed-phase [5]. Also, T2* decay parameters cannot be directly estimated using the proposed 2-point method (since there is not sufficient data to estimate an additional unknown parameter), but if T2* decay rates are known from a separate acquisition, they can be included in Eq. 1. Similarly, a pre-calibrated multi-peak fat model can be used to estimate $W$ and $F$ once the field map is estimated with the proposed method.

## CONCLUSION

Reliable 2-point water fat separation can be performed using a joint estimation approach, based on an approximated PML formulation and a graph cut solution. This method results in good noise properties and the ability to handle large $B_0$ field inhomogeneities.

**REFERENCES:** [1] Hernando et al., ISMRM 2009, p. 459. [2] Reeder et al., MRM 51:35-45, 2004. [3] Ma J, MRM 52:415-419, 2004. [4] Ma J, JMRI 28:543-558, 2008. [5] Xiang QS, MRM 56:572-584, 2006. [6] Pineda A et al., MRM 54:625-635.