Analytical Three-point Water-fat Imaging with Multi-peak Fat Model

Dinghui Wang and James G. Pipe

Neuroimaging Research, Barrow Neurological Institute, Phoenix, AZ, United States

Introduction: The multi-point analytical approach of water-fat imaging [1] is more tolerant to artifacts such as blurring in spiral imaging than two-point Dixon method. By adjusting uneven TE increments, this approach extracts $B_0$ inhomogeneity (a “field map”) without spatial phase unwrapping. However, because of the symmetry between water and fat in the signal model, this method heavily relies on region growing from the interface of water and fat to resolve pure water or pure fat voxels [2]. Inspired by the incorporation of multi-peak fat spectral models in water-fat imaging, e.g. [3-5], we propose an analytical three-point water-fat Dixon method to work with multi-peak fat model.

Methods: The signal model of the image at echo time $t_n$ ($n = 1, 2, 3$) is

$$S_n = (W + c_n F) e^{i(2\pi n \Delta B_0 t_n + \phi)}$$

(Eq. 1)

with $c_n = \sum_{m} w_m e^{i(2\pi \Delta f_m t_n)}, \sum_{m} w_m = 1$.

Real unknowns $W$, $F$ and $\Delta B_0$ are water, fat, and the field map, respectively. $\Delta f_m$'s and $w_m$'s are the known chemical shifts and weights of a multi-peak spectral fat model [6]. $\phi$ and $\theta$ are other unknown systematic phase errors. Similar to [2], we first obtain two possible solutions for $W$ and $F$ by solving quadratic equations of $W$ and $F$. Then two sets of corresponding values of $\Delta B_0$ are determined by linear regression. We select the $\Delta B_0$ that has the lower RMS error of the linear fitting when the difference of the RMS errors is significant. For pure water or pure fat voxels, the signal model of Eq. 1 degrades to the one used in two-point Dixon method [4]. Hence, two more strategies are exploited to initially identify $\Delta B_0$ for those voxels. First, as explained in [5], an ellipse represents the quadratic equation of $W$ and $F$ at each TE. In the noiseless case, there is only one common point of all three ellipses from the two sets of possible solutions. Fig. 1 shows one example for pure water voxels. Therefore, we choose the solution cluster with the smaller standard deviation to identity $\Delta B_0$. Second, we linearly fit $\Delta B_0$ using values of $W$ and $F$ computed from TE1 and TE3. The correct $\Delta B_0$ value tends to have the lower RMS.

We define the regions of reliable initial guesses of $\Delta B_0$ according to measures, such as image SNR and difference of RMS errors, as seeds. A local iteration and region-growing algorithm [2] then extracts the $\Delta B_0$ for the whole 3D volume. The smoothed and extrapolated field map is then utilized to separate and deblur fat and water [7].

Results: Data were acquired using spherical distributed spirals [8] on a 3T Philips Ingenia scanner. Some results are sown in Fig.2. The field map $\Delta B_0$ was correctly resolved for most voxels at the initial identification stage (Fig.2).

Conclusions: Utilizing a known multi-peak fat model, the presented analytical three-point Dixon approach is capable of resolving the correct field map for a substantial portion of voxels if the TE points are selected such that the magnitude of fat fluctuates significantly. The efficiency and the robustness of the subsequent post-processing can be enhanced for such TE combinations.

Acknowledgement: This work was funded by Philips Healthcare.