Joint Water-fat Separation and Deblurring with Spiral In-out Sampling

Dinghui Wang[1], Zhiqiang Li[1], Ryan K. Robison[1], Nicholas R. Zwart[1], Michael Schär[1,2], and James G. Pipe[1]
[1]Neuroimaging Research, Barrow Neurological Institute, Phoenix, AZ, United States, [2]Philips Healthcare, Cleveland, OH, United States

Introduction

Spiral imaging with in-out trajectories is efficient for spin echo and T_2^* weighted sequences. Two images can be reconstructed from the spiral-in and spiral-out parts respectively. These two images can then be combined to increase signal to noise ratio or utilized to extract new information. Based on previous work in [1], we propose an iterative approach to simultaneously separate and deblur water and fat using these images.

Theory

Similar to the notation in [1], the blurring is formulated as

$$\tilde{B}^H \tilde{g} = \tilde{B}^H \tilde{B} \tilde{f}, \quad \text{(Eq.1)}$$

where $\tilde{g} = \begin{bmatrix} g_{in} \\ g_{out} \end{bmatrix}$ are the collected images, $\tilde{B} = \begin{bmatrix} B_{inW} & B_{inF} \\ B_{outW} & B_{outF} \end{bmatrix}$ represents the blurring process, $\tilde{f} = \begin{bmatrix} f_{Water} \\ f_{Fat} \end{bmatrix}$ are the water and fat images. H denotes the conjugate transpose. $\tilde{B}$ is calculated from an known field map of B_0 inhomogeneity. Eq. 1 is solved by a conjugate gradient approach [1]. The 'blur' and the 'deblur' processes are implemented by spatially varying convolutions.

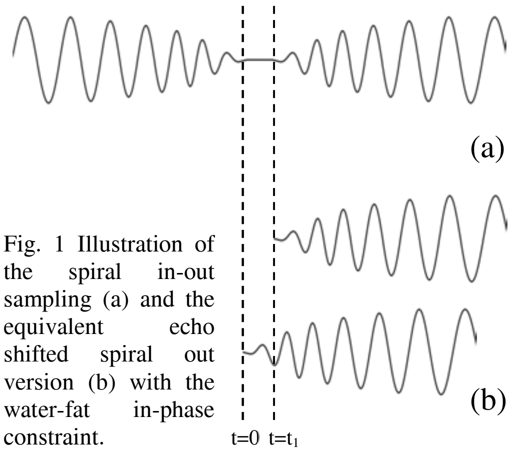

Fig. 1 Illustration of the spiral in-out sampling (a) and the equivalent echo shifted spiral out version (b) with the water-fat in-phase constraint.

Methods

A schematic plot of the spiral in-out readout waveform is shown in Fig.1 (a). A short duration is inserted between the spiral-in and the spiral-out parts for better water-fat separation. The time delay between the sampling points of spiral-in and spiral-out parts that are at the same k-space loaction varies as the k-space radius changes. As a result, different spatial frequences converge at different rates, which can cause ringing artifacts. If water and fat are both real at time $t = 0$, with a minor modification as $\tilde{g} = [g_{in}^* \quad g_{out}]^T$, the problem can be seen as an analogy to the echo shifted spiral-out sampling (Fig.1 (b)). To implement this modified appoach, we assume that water and fat are in phase at time 0. A slowly varying phase map is estimated from $\tilde{f}$ computed without the water-fat in-phase constraint. This phase is eliminated from $\tilde{g}$. $\tilde{f}$ is then recaculated with the water-fat in-phase constraint.

Results and Discussion

We tested the proposed approach with data of a canola oil-water phantom and in-vivo data acquired on a 3T Philips Ingenia scanner. The duration between the spiral-in and the spiral-out parts was 0.7 ms. The phantom data were collected with gradient echo stack of spirals (SOS). The data were corrected for B_0 eddy currents before reconstruction [2]. The in-vivo experiment was performed using a turbo spin echo SOS sequence. In both experiments, a field map was obtained [3] from a separate gradient echo SOS data set. The time for the iterative approach was around 1- 2 min per coil. We can see the ringing artifacts along sharp boundaries of the water and fat images (Fig.2 (c-d) and Fig.3 (c)). The water-fat in-phase constraint removed these artifacts (Fig. 3 (e)).

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References [1] E. Aboussouan and J. G. Pipe, ISMRM 20: 2413, 2012. [2] E. K. Brodsky *et al*, MRM 69:509-515, 2013. [3] D. Wang and J. G. Pipe, ISMRM 20: 364, 2012.

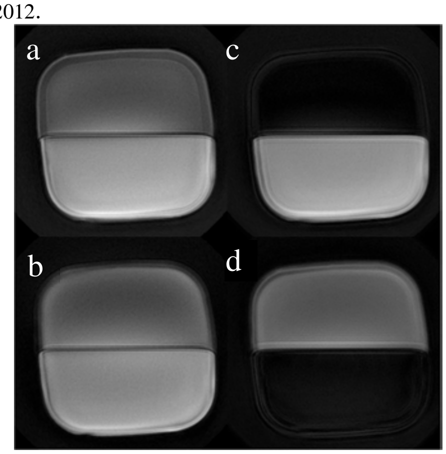

Fig. 2 Results of the phantom data without water-fat in-phase constraint. (a) (b) Original spiral-in and spiral-out images. (c) (d) water and fat. ADC = 6.2 ms, $1 \times 1 \times 3$ mm res, 250×250 mtx.

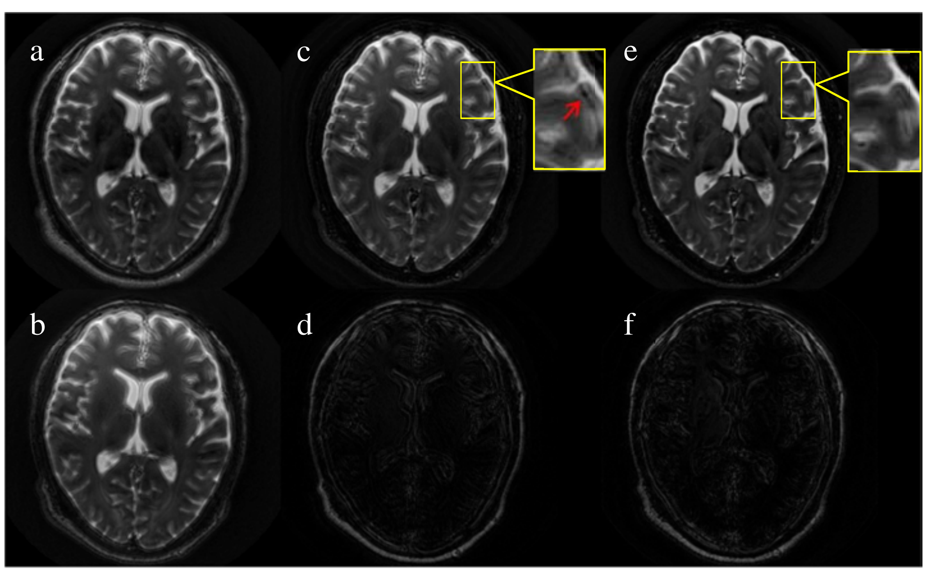

Fig. 3 Results of in-vivo data. (a) (b) Original spiral-in and spiral-out images. (c) (d) Water and fat reconstructed without the water-fat in-phase constraint. (e)(f) Water and fat reconstructed with the water-fat in-phase constraint. Note that the ringing artifacts (pointed to by an arrow) in (c) is absent in (e). Imaging parameters: ADC = 7.1 ms, $1 \times 1 \times 3$ mm res, 300×300 mtx.