A dynamic R2*-and-field-map-corrected imaging for single shot rosette trajectories

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Introduction

The rosette trajectory is known for the spectral selectivity, which was used to selectively reconstruct different chemical species or multiple slices with different resonant frequencies [1,2]. However, the spectral selectivity causes difficulty in the image reconstruction when there is main field inhomogeneity. The conventional iterative reconstruction [3], which uses pre-estimated field maps, often fails to reconstruct images properly, because the rosette trajectory is more sensitive to the errors in the field map than other fast single shot trajectories such as spiral. In this work, we present a robust reconstruction method that can reconstruct R2*-and-field-map corrected (and R2* weighted) images from low accuracy field maps. Beyond the robust dynamic field map correction, the proposed method produces a more accurate field map from the phase of reconstructed images. A human experiment results are presented.

Theory

The MR signal is segmented in time into L contiguous segments. Assuming there is negligible signal decay from R2*, the signal for l'th segment can be written as

$$S_l(t) \approx \int m_l(\vec{r}) e^{-i\omega(\vec{r})t} e^{-i2\pi\vec{k}(t)\cdot\vec{r}} d\vec{r}, \quad TE_l \le t < TE_{l+1}, \text{ and } l = 1,\ldots,L, \tag{1}$$

where $m_l(\vec{r}) = m_0(\vec{r}) e^{-R_2^* TE_l}$ is the R2* weighted magnetization at the l'th segment, and $\omega(\vec{r})$ is the field map. The discrete signal equation can be rewritten from the equation (1) as

$$\begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_L \end{bmatrix} = \begin{bmatrix} A_1 & & & \\ & A_2 & & \\ & & \ddots & \\ & & & A_L \end{bmatrix} \begin{bmatrix} M_1 \\ M_2 \\ \vdots \\ M_L \end{bmatrix}, \text{ where } [A_l]_{ij} = e^{-i\omega(\vec{r}_j)(t_i + TE_l)} e^{-i2\pi\vec{k}(t_i + TE_l)\cdot\vec{r}_j}, \text{ and } [M_l]_i = m_l(\vec{r}_j). \tag{2}$$

The images M_l 's can be reconstructed by minimizing the following cost function using conjugate gradient

$$\phi = \sum_{l=1}^{L} \left\| Y_l - A_l X_l \right\|^2 + \beta \sum_{l=1}^{L} \left\| C X_l \right\|^2 + \gamma \sum_{l=2}^{L-1} \left\| M_{l-1} - 2M_l + M_{L+1} \right\|^2, \tag{3}$$

where the pre-estimated low accuracy field map is used in the segmented system matrix A_l, and β and γ are the spatial and temporal regularization terms respectively. The third term in the equation (3) plays key role in the segmented reconstruction by providing *a priori* information on the temporal evolution of M_l's. It should be noted that, without the temporal regularization, a direct reconstruction of each image M_l from Y_l would result in severe undersampling artifacts since each segment is only about 2ms long. From the phase of the images M_l, we can estimate the refined field map by log-linear fitting.

Method

This approach is demonstrated using human data from a GE 3T scanner. The scan parameters were TR=2s, TE=5ms, slice thickness=3mm, FOV=24cm. The parameters for rosette trajectory were the azimuthal frequency ω1=1.087kHz, the slow angular frequency ω2=113.22Hz, and the total length of the acquisition = 44.4ms. The reconstruction parameters were the number of segments L=24, β=0.5 and γ=400. The initial low accuracy field map was estimated using the low resolution images from two delayed acquisitions, where the redundant samples were excluded in the reconstruction of the low resolution images.

For the comparison, the images were iteratively reconstructed [3] using no field map, low accuracy field map and the higher accuracy field map estimated using the proposed method.

Results

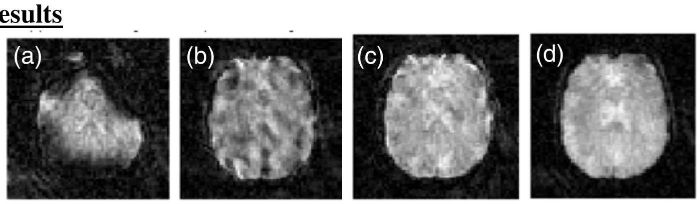

Figure 1. (a) No field map correction (b) field-map-corrected image using the low accuracy field map (c) field-map-corrected image using the high accuracy field map from the proposed method (d) R2*-and-field-map corrected image (M_{12}) from the proposed method

Discussion

The proposed reconstruction was more robust to the field map error than the conventional iterative reconstruction, while it can also provide an updated field map from the phase of M_l's. Since each segment was about 2ms long, the reconstructed images were also R2* corrected. The spatial and temporal regularization parameters were determined through simulations, and the optimal values varied according to the number of rosette petals per data segment. Unlike the previously proposed method by Lee et.al.[4], the proposed method does not require a pre-estimate of R2* map. The accuracy of the field map could be improved if the estimated field map is used again as the initial field map in the proposed method. However, the convergence of such iteration is not guaranteed. The method is also applicable to other refocusing trajectories such as projection reconstruction (PR), and it is readily extendable to multi-shot imaging methods.

References
(1) Noll, IEEE Tran. Med. Imag. 16:372 (2) Noll et. al., MRM, 39:709 (3) Sutton et.al., IEEE Tran. Med. Imag. 22:178 (4) Lee et.al., Proc. 10th ISMRM, p2128

Acknowledgement : This work is funded by NIH R01DA015410-01.