Efficient Deblurring by Iterative Reconstruction for Spiral-in-out Imaging

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Introduction

To address the signal loss due to the susceptibility differences at the air/tissue interfaces, several methods have been proposed to minimize the intra-voxel phase dispersion and recover the lost signal. Among them, the combination of spiral-in and spiral-out sequences [1, 2] has been proven effective and efficient in improving image quality. However, due to the long read out window of these single shot acquisitions in the presence of large field inhomogeneity, the off-resonance effect can be severe which would induce noticeable blurring artifact in the final images. The conventional method to de-blur the images includes measuring a field map using extra scans and reconstructing images based on the region-specific frequencies [3], which tends to be time consuming even if a coarse field map is used. In this abstract we propose to use the intrinsic field map from the spiral in and out acquisitions and an iterative reconstruction method [4] to correct the off-resonance effect.

Methods

The pulse sequence was constructed to play out the spiral-in and spiral-out waveforms sequentially with a 2 ms gap, resulting in a 2 ms TE difference for the spiral-in and spiral-out images. After phase unwrapping, the field map $\Delta B(x, y)$ was determined from the phase differences of these two images.

After the field map estimation, we employed an iterative reconstruction method [4] to remove the blurring artifact. This method allows better results than the conventional techniques, such as multiple-frequency or time segmentation, by taking abrupt field changes into account. In a linear system, $S = \boldsymbol{H} f$, where S is sampled signal, $\boldsymbol{H}$ is point spread function and f is the object. Generally f can be determined by the least square approach, $f_{est} = (H^t H)^{-1} H^t S$. However, if the matrix $\boldsymbol{H}$ is too large, the inverse of $\boldsymbol{H}$ is difficult to compute, and therefore f_{est} needs to be estimated iteratively. The basic equation for an iterative method can be written as $f^{k+1} = f^k + a^k H^t (S - Hf^k)$, where a is scale factor, and k is iteration number. In this abstract, each image at location p is represented by

$$f_p^{k+1} = f_p^k + (S_j - \sum_{m=0}^{P-1} e^{i2\pi k_j x_m} f_m^k e^{i\varphi_m j}) e^{-i2\pi k_j x_m}$$

where f_p is the unknown image at location p *[0… P-1]*; f^0 of all 0 is used for the initial iteration; φ_m is the phase map; $\varphi_m j$ is equal to $2\pi jfdt$; and jdt is the time increment for the k space sampling. The final image is f_p^{k+1} after the iterative calculations.

Phantom and human data were acquired on a GE 3T EXCITE scanner. A matrix of 64 x 64 was used with a FOV of 24 cm. TEs for the spiral-in and spiral-out acquisitions were 28 ms and 30 ms respectively. The read out window was 24 ms for each spiral.

Results and Discussion

Figure 1 shows the phantom results. Fig1.a is the field map calculated from the spiral-in and spiral-out images. This field map is consistent with those determined from spiral-in only or spiral-out only images. Smoothing and registration steps were carried out to reduce the spatial mismatch between the spiral-in and spiral-out images. Using this intrinsic field map, the blurring artifact seen in Fig. 1b is effectively reduced, as shown in Fig. 1c. The *in vivo* results are shown in figure 2.

A potential problem in this technique is the imperfect alignment between the spiral-in and spiral-out images because of their difference in the trajectory path in the presence of gradients errors. K-space trajectory measurement could further improve the spatial accuracy by removing the discrepancies in local distortions in the spiral-in and spiral-out acquisitions.

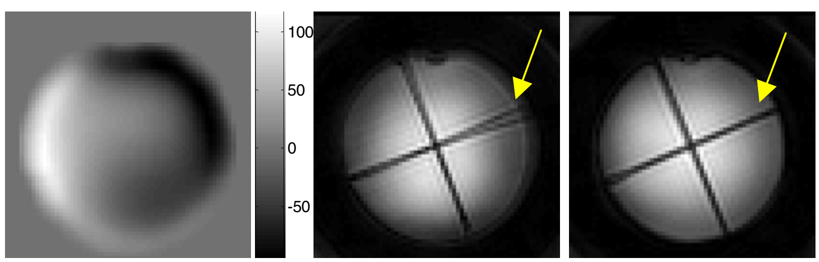

Figure 1, phantom data. a), field map from spiral-in and spiral-out images. b), spiral-in-out image before image correction. c), spiral-in-out image after deblurring.

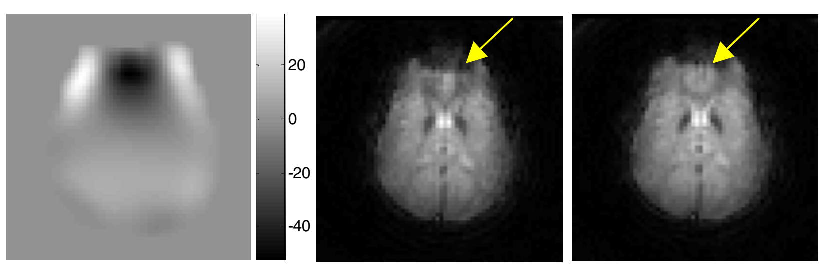

Figure 2, *in vivo* data. a), field map from spiral-in and spiral-out images. b), spiral-in-out image before image correction. c), spiral-in-out image after deblurring.

Conclusion

This work demonstrates that efficient deblurring results can be achieved for spiral-in and spiral-out acquisitions without any time penalty. The final images with efficient blurring artifact reduction and effective signal recovery at areas with large susceptibility differences (e.g. ventral brain regions) can be highly valuable for functional MRI research.

Reference

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