Partial Fourier Spiral Reconstruction under Consideration of Off-resonance Effects

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Introduction

A Partial Fourier Spiral Reconstruction (PFSR) algorithm has recently been proposed as an efficient reconstruction technique for partially acquired spiral data [1]. In this technique, k-space data are acquired using variable density spiral (VDS) trajectories. While the Nyquist criterion is satisfied in the central portion of k-space, the outer regions are undersampled to reduce the data acquisition time. During image reconstruction, acquired k-space data are distributed to a large rescaled matrix and iterative procedures are performed with three constraints imposed at each iteration: (i) finite-support constraint in image domain, (ii) phase constraint (PC) in image domain, and (iii) data-consistency constraint in Fourier domain. This algorithm is a simple extension of the previously proposed Projections Onto Convex Sets (POCS) method described for rectilinear sampling methods [2] to spiral sampling techniques via the Iterative Next Neighbor re-Gridding (INNG) algorithm [3]. The quality of the image reconstructed using the PFSR algorithm depends on the accuracy of the estimated image phase map. The image phase map is usually obtained from the low resolution image reconstructed from the central k-space data. However, the phase map obtained using this estimation method is sometimes not accurate and hence the image reconstructed using the PFSR algorithm sometimes shows little improvement from that reconstructed using standard k-space gridding. Furthermore, off-resonance correction is often required in spiral imaging. However, effective off-resonance correction may not be achieved if the phase map is inaccurate because of a poor estimate of the PC. In this study, a new approach is presented for partial Fourier spiral reconstruction. The newly proposed technique is similar to the original PFSR algorithm, yet a PC is not imposed on the reconstructed image. Instead, an extended finite-support constraint (EFSC) is imposed in the image domain at each iteration. The effectiveness of off-resonance correction has also been compared between the PFSR algorithm with PC and that with EFSC.

Methods

A flow chart of the PFSR algorithm is shown in Fig.1. Here, *s* is a scaling factor and *N* x *N* is the target grid matrix size. In the PFSR algorithm, acquired k-space data are first distributed to a large rescaled *sN* x *sN* matrix (a). An inverse Fourier transform (IFT) is performed on matrix (a), leading to a reconstructed image in the central *N* x *N* region, as shown in (b). Zeros are set outside the central *N* x *N* region, as indicated in matrix (c). In the PFSR algorithm with PC [1], the following constraint is imposed on the central *N* x *N* region in matrix (c):

$I_{new} = |I_{old}|\cdot\exp(i\phi_e)$ [Eq.1],

where I_{old} and I_{new} represent the image values before and after PC, respectively. On the other hand, in the newly proposed PFSR algorithm with EFSC, the following constraint is imposed on the central *N* x *N* region in matrix (c):

$I_{new} = I_{old} \cdot M$ [Eq. 2],

where *M* is an image mask (i.e., *M* is defined to be 0 for the background and 1 for the object region. *M* can be created using the same procedure as described in ref.[4]). For both the PFSR algorithm with PC and that with EFSC, matrix (c) is Fourier transformed to obtain the updated data matrix, as shown in (d). The original data are inserted at the k-space data locations where the original k-space data exist to impose the data-consistency constraint, as indicated in matrix (e). An IFT is performed on matrix (e). The updated image shows up in the central *N* x *N* region again. The procedures (the loop (b) → (c) → (d) → (e) → (b) (surrounded by the dashed line in Fig.1)) are repeated until the difference between the updated image (b) and image (b) at the previous iteration becomes sufficiently small.

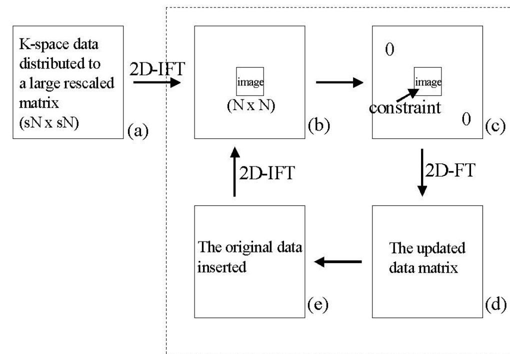

Fig.1. Flow chart of PFSR algorithm

In-vivo head images were acquired using VDS trajectories. The Nyquist criterion was satisfied within the central circular region with radius 30% of k_{max}. Only 50% of the data at the Nyquist limit were acquired in the outer k-space regions. TE/TR were set to 6.0/31.0ms, and the slice thickness was 10mm. Images were reconstructed using both the PFSR algorithm with PC and that with EFSC. In the PFSR algorithm with PC, a floating point POCS method was used [2]. In each algorithm, 100 iterations were performed with *s*=4. Off-resonance blurring artifact corrections were performed on both images using BRORC [5]. An image was also reconstructed using the next neighbor re-gridding algorithm [6] as a standard reconstruction method.

Results

Figure 2 shows the reconstructed images (a: standard reconstruction; b: PFSR with PC after off-resonance correction; c: PFSR with EFSC after off-resonance correction). Aliasing artifacts resulting from undersampling are observed for the entire region in image (a). The aliasing artifacts are effectively reduced in both images (b) and (c). However, loss of resolution is observed for wide regions of the brain in image (b). These artifacts were introduced after off-resonance correction. In contrast, off-resonance blurring correction is effectively performed without introducing artifacts in image (c).

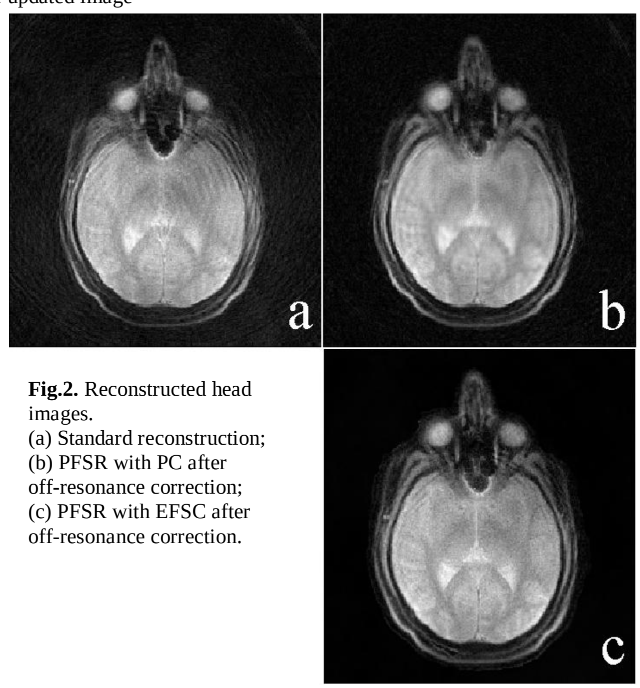

Fig.2. Reconstructed head images.
(a) Standard reconstruction;
(b) PFSR with PC after off-resonance correction;
(c) PFSR with EFSC after off-resonance correction.

Discussion and Conclusions

The performance of the PFSR algorithm with PC depends on the accuracy of the estimated phase map. However, it is often difficult to make accurate phase estimations. Furthermore, inaccurate PC disrupts the image phase and therefore often introduces artifacts after off-resonance correction. In contrast, the newly proposed PFSR algorithm with EFSC significantly reduces aliasing artifacts while allowing effective off-resonance correction following image reconstruction. Although the PFSR algorithm with EFSC requires a well defined image background void of signal, object regions are usually limited to parts of the prescribed field-of-view in most imaging applications. Despite the fact that VD spirals provide further reduction in acquisition time, off-resonance blurring artifacts often still remain since the degree of blurring is determined by spiral readout durations. Therefore, off-resonance artifact correction is often required for the images acquired using spiral trajectories. The newly proposed PFSR with EFSC has a significant advantage over that with PC since it enables effective off-resonance correction as well as reduction of aliasing artifacts.

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