Spiral MR Reconstruction Using FOCUSS

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Introduction: Spiral data acquisition has gained in popularity over the past decade since it has several advantages over rectilinear acquisition methods. These advantages include short acquisition time and reduced sensitivity to flow artifacts. In spiral imaging, k-space data are efficiently collected along spiral trajectories during relatively long readout. Since the total number of TR cycles of spiral acquisition is usually significantly reduced from that of rectilinear acquisition, the total scan time can be reduced. However, further reduction of acquisition time would be desirable since it helps to reduce artifacts due to motion and/or off-resonance effects. Spiral sampling method using fewer spiral interleaves can achieve shorter acquisition time although the images are often affected by aliasing artifacts. Recent advancement of parallel imaging techniques enables us to reconstruct images with reduced aliasing artifacts [1]. Alternative approaches to reduce aliasing artifacts are to modify reconstruction methods taking advantage of specifically designed regularizations and/or constraints. Recently, the focal underdetermined system solver (FOCUSS) that was originally proposed for electro- and magneto- encephalogram has successfully been adapted to angularly undersampled projection reconstruction (PR) in MRI [2]. PR-FOCUSS is an iteration algorithm that uses conjugate gradient (CG) method. A primary difference between FOCUSS and conventional CG method is that FOCUSS uses an image weighting matrix as a constraint and updates the weighting matrix during iterations. Images reconstructed using PR-FOCUSS are of high quality when compared with those using conventional CG method [2]. In this study, we show that FOCUSS can be extended to spiral trajectories. The newly proposed method is referred to as 'Spiral FOCUSS'. When data are acquired using spiral trajectories with reduced interleaves, images reconstructed using Spiral FOCUSS substantially reduce aliasing artifacts from those reconstructed using conventional gridding [3]. Since PR-FOCUSS capitalizes on back-projection and reprojection [2], the algorithm of PR-FOCUSS could only be applied to radial k-space trajectories. However, since Spiral FOCUSS takes advantage of iterative next neighbor gridding (INNG) [4], k-space data are simply distributed to oversampled matrices and hence cumbersome convolution-based gridding is not required. Therefore, the algorithm of Spiral FOCUSS can essentially be applied to general non-uniform sampling methods. Spiral FOCUSS is a new, useful technique that reconstructs high-quality images from spiral data with reduced interleaves, thereby enabling us to further reduce scan time of spiral imaging.

Methods: FOCUSS can be formulated as: min $|q|^2$ s.t. $AWq = y$, where y is acquired data, W is an image weighting matrix, and A represents Fourier transform (FT). The solution q is to be computed using CG method with W updated during iterations. The reconstructed image x can be expressed as $x=Wq$. Procedures of FOCUSS are summarized in ref.[2]. In Spiral FOCUSS, INNG is utilized to efficiently perform CG algorithm on non-uniformly sampled data. Figure 1 shows a flow chart of Spiral FOCUSS. In Fig.1, small and large squares indicate $N \times N$ and $sN \times sN$ matrices, respectively, where N is the target reconstructed image size and s is a scaling factor of oversampled matrices [4]. An initial image estimate x_0 is obtained after inverse FT is performed on the data that are distributed to an oversampled matrix of zeros. CG algorithm starts with W_1, a gradient g^0, d^0 and q_l^0 (zero matrix), as indicated in Fig.1. α_n and β_n are computed using W_l, g^n, g^{n+1} and d^n, as described in ref.[2]. For each l, a CG loop (surrounded by dashed lines) is repeated until q_l^n is converged. An updated image is computed as $x_l = W_l\, q_l^{n+1}$. Therefore, a weighting matrix can also be updated for the next, i.e. (l+1)-th, iteration.

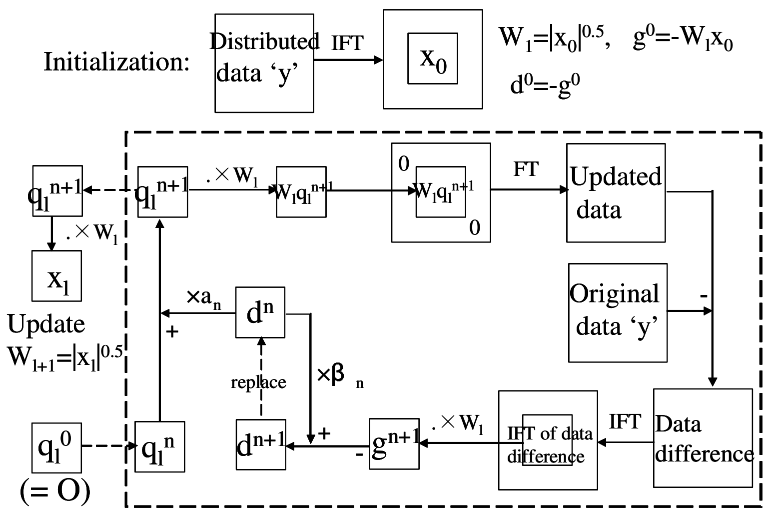

Figure 1. A flow chart of Spiral FOCUSS

MR experiments were performed to test Spiral FOCUSS using a 1.5 Tesla Siemens Sonata Scanner. Axial abdominal images were acquired from an asymptomatic volunteer. The spiral trajectories used in this experiment consisted of six interleaves. The acquired data satisfied approximately 50 % of the Nyquist limit. TE/TR=7.5/30.0ms, FOV=300mm. Images were reconstructed using the conventional gridding, Spiral FOCUSS, and CG-INNG algorithm [5]. For each of Spiral FOCUSS and CG-INNG, s = 8, N = 256, and the total number of iterations were 40. An image was also reconstructed from the data acquired with 12 interleaved spiral trajectories (the Nyquist criterion fulfilled) using conventional gridding for comparison.

Results: Figure 2 (a-c) shows images reconstructed from the data acquired with six interleaves using (a) conventional gridding, (b) Spiral FOCUSS, and (c) CG-INNG algorithm. Figure 2 (d) is an image reconstructed from the data acquired with 12 interleaves. Aliasing artifacts observed in image (a) are significantly reduced in image (b) while substantial artifacts remain in image (c).

Discussion and Conclusions: As seen in Fig.2(b,c), although both Spiral FOCUSS and CG-INNG use CG, only CG does not help to reduce aliasing artifacts. When Fig.2(b) are compared with (d), (b) shows intensity variations, as observed in the liver. We suppose that the intensity variations resulted from data errors of low frequency k-space. Spiral trajectories with reduced interleaves violate the Nyquist criterion in the central k-space. Therefore, artifacts that originate from low frequency data often appear in the images and are usually difficult to remove. However, this type of artifacts can considerably be reduced if variable density (VD) spiral trajectories are used (the results not shown). VD spirals densely sample only at the k-space center and therefore the total acquisition time needs to be slightly extended. The newly proposed Spiral FOCUSS is a quite useful reconstruction technique for undersampled spiral trajectories. It permits faster spiral acquisition while maintaining image quality. Furthermore, Spiral FOCUSS can readily be combined with parallel imaging methods, thereby enabling even faster acquisition.

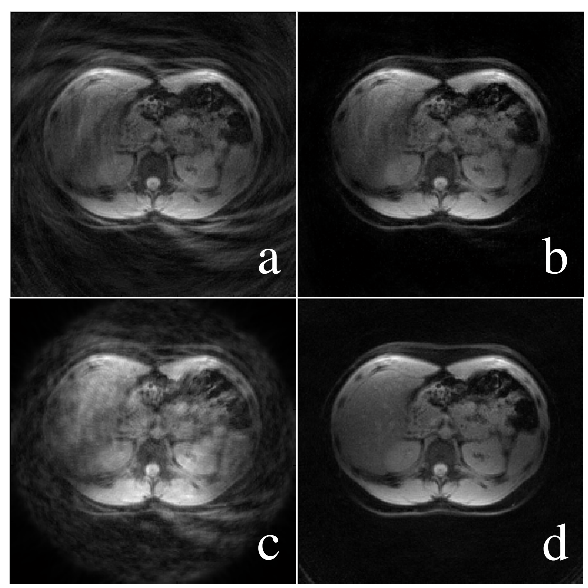

Fig.2. Reconstructed images

Acknowledgements: Siemens Medical Solutions.

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