A Reconstruction Algorithm of Parallel Imaging with High Reduction Factor in SPACE RIP

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Introduction

SPACE RIP (Sensitivity Profiles from an Array of Coils for Encoding and Reconstruction In Parallel)[1] is in the family of parallel acquisition schemes such as sensitivity encoding (SENSE)[2]. The technique permits the arbitrary choice of the set of k-space phase encoding lines used in the reconstruction, hence allowing optimal selection of encoding lines. Generally, in parallel imaging, the reconstructed image quality is degraded as the reduction factor increases. In this study, a method is presented in order to improve the reconstructed image quality when the reduction factor is high (i.e. when it is close to the number of channels in phased array coil) by choosing optimal phase encoding lines and adding the Tikhonov regularization[3] technique in the conventional SPACE RIP reconstruction.

Methods

SPACE RIP reconstruction takes the Fourier transform of the k-space signal along the x direction (read-out direction) to yield the phase modulated projection of the sensitivity-weighted image onto the x axis. The resultant expression can be converted to matrix form for each position x along the horizontal direction of the image [1]. This equation form permits the arbitrary choice of the set of k-space lines.

$$S_k(G_y^g, x) = \sum_{n=1}^{N} \rho(x,n) W_k(x,n) e^{i\gamma(G_y^g n\tau)} \Rightarrow \mathbf{S} = \mathbf{W}\boldsymbol{\rho}$$

where S_k is k-space signal after 1D Fourier Transform along x direction of the k^{th} channel, G_y is the phase encoding gradient, W_k is Sensitivity value of the k^{th} channel, and ρ is the image domain signal. Solving the matrix equation is in general an ill-posed problem. In order to enabling stable and robust reconstruction at high reduction factor, Tikhonov regularization technique was used. An explicit solution of the equation is given by:

$$\boldsymbol{\rho} = \left(\mathbf{W}^T\mathbf{W} + \lambda^2\mathbf{I}^T\mathbf{I}\right)^{-1}\mathbf{W}^T\mathbf{S}$$

where $\mathbf{I}$ is an identity matrix and λ^2 is a well-chosen regularization parameter. For this study, we set λ^2 as one. Phantom and human brain data were acquired with 4-channel phased array coil at 3T scanner where the matrix dimension was 128×128. The parallel imaging experiments were performed for reduction factor 2, 3 and 4 which means 64, 43, and 32 phase encoding lines were used in the reconstruction, respectively. When reduction factor was 2 or 3, SPACE RIP with only regularization was used in reconstruction, but, when reduction factor was 4, (theoretically maximum value when 4-channel coil was used) the optimal phase encoding scheme as well as regularization were used in SPACE RIP reconstruction. The schematics to determine the optimal phase encoding line are described in Fig. 1.

1. Since most information of a natural image concentrates on the low frequency band, it is efficient that more phase encoding lines are assigned to the low frequency band than the high frequency band. At first, Fourier transform was applied to the reference data (Fig. 1(a), and take only magnitude component) to obtain the frequency signal (Fig. 1(b)).
2. Half of the column sum of this signal was taken due to bilateral symmetry (Fig. 1(d)).
3. After smoothing the obtained signal, equal spaced sampling along the y-axis yields the corresponding sampling points along the x-axis. On the base of the position of these points, the optimal phase encoding lines were determined.

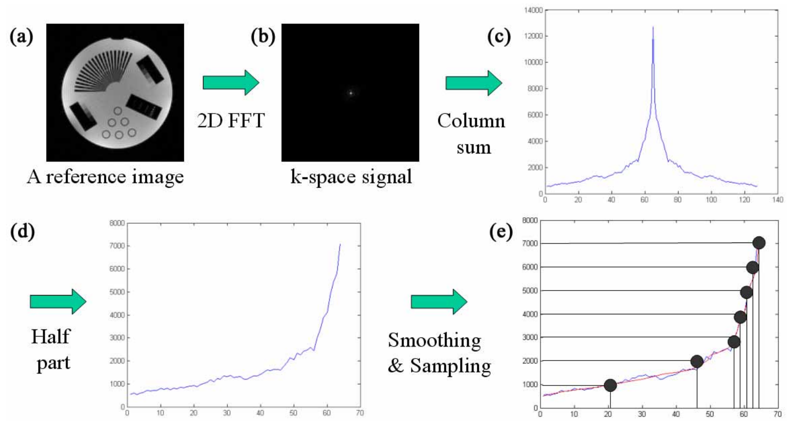

Fig. 1 **(a)** A reference image, **(b)** k-space signal of Fig. a, **(c)** Column sum of Fig. b , **(d)** Half part of Fig. c **(e)** Smoothing of Fig. d and sampling. Blue line: the line of Fig. d, Red line: Smoothing result of the blue line.

Results

The first column of Fig. 2(a) shows the reference images for 3 slices of phantom. The second, third, and last column of Fig. 2(a) show the reconstructed images from the proposed method when reduction factor was 2, 3, and 4, respectively. Same analysis for human brain data is also shown in Fig. 2(b). As shown in the figures, the images were well reconstructed even if the reduction factor was four. Fig. 2(c) and (d) shows the equal-spaced phase encoding lines (used at reduction factor 2 and 3) and optimal phase encoding lines (used at reduction factor 4), respectively.

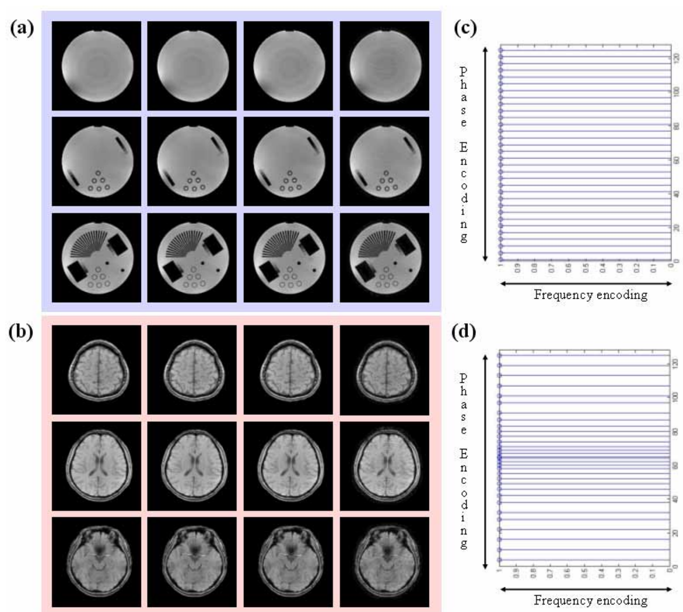

Fig. 2 **(a)** The reconstructed images of phantom, **(b)** The reconstructed images of human brain, **(c)** Equal-spaced phase encoding lines, **(d)** Proposed-spaced phase encoding lines

Conclusion

The proposed method could reconstruct the images with quite good quality when the reduction factor is high in parallel imaging.

References

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