Wavelet based multiscale selection CS reconstruction for multi-contrast MR images

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Introduction

Magnetic resonance images (MRI) can provide several different contrast images for the same subject by adjusting different MR scanning parameters, such as repetition time (TR) or echo time (TE) etc., and using different pulse sequences. Proton-density (PD), T_1, T_2, and T_2* weighted images are the most common examples of the different contrast MR images. More than one type of images are routinely acquired for proper diagnosis. However, the multiple acquisitions of several contrast images require long scanning time, which is the main obstacle in MRI, compared to other imaging modalities such as computed tomography (CT). In this study, we propose a multimode compressed sensing (CS) framework to reduce the total scanning time by undersampling the k-space data of each contrast (mode) image and reconstructing artifact-minimized images. Three different T_2* weighted images at different echo times were considered as multimode images for this study. Technically, the reduced sampling invokes under-determined problem in the numerical computation. Therefore, we propose a wavelet based multiscale selection CS technique to alleviate the computational artifact, i.e., aliasing, on undersampled k-space multimode images. Since the multimode images have common information, multimode CS improves the reconstruction performance better than the individual mode CS reconstruction. Wavelet based multiscale selection can suppress the aliasing effect, and preserve the modal information. An MIT group studied a Bayesian CS method [1], however, the computation time may not encourage for a compact system. In our studies, the running time of the proposed wavelet multimode CS is presented as a minute, which is promising for agile and compact applications.

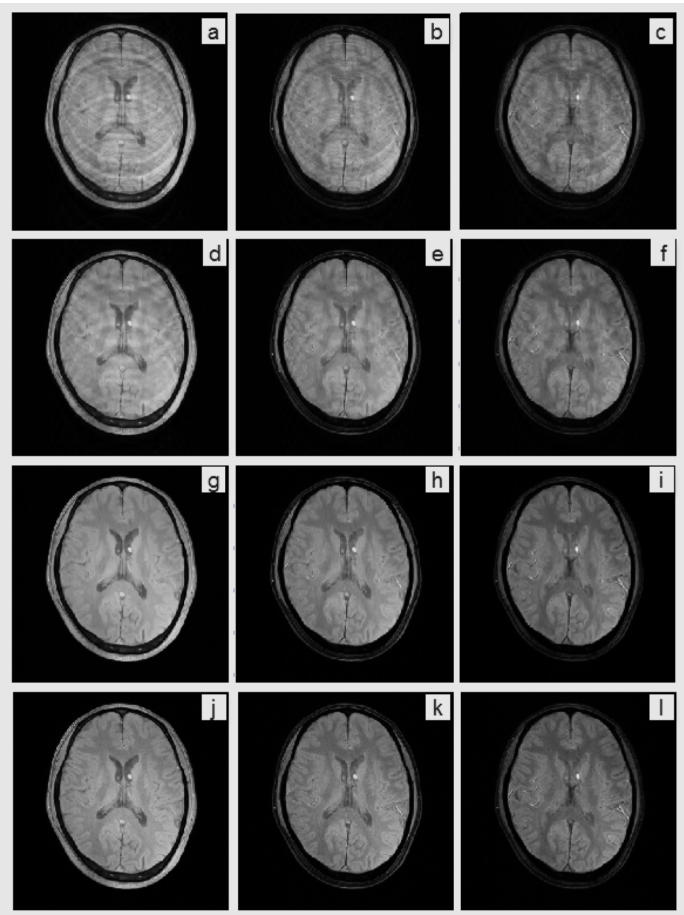

Fig1. Three mode reconstruction with 256×256 pixel image data : (a)-(c) inverse Fourier transform of undersampled k-space data for three modes, (d)-(f) individually CS processed reconstructions on 28% undersampled data (RMSEs: 5.4%, 4.5%, and 4.3%), (g)-(i) wavelet multimode CS reconstructions on the same undersampled data (RMSEs: 1.9%, 2.1%, and 2.3%), and (j)-(l) reconstructions on the fully sampled data for three modal images. Note the wavelet based multimode CS reconstructions suppressed distinct aliasing effects that are observed in the individually CS processed reconstruction.

Methods

The CS method solves underdetermined inverse problems. In a mathematical model, the least square term minimizes estimation residues and the TV regularization term constrains possible solutions in image space [2].

$$x^* = \arg\min_x \|x\|_{TV} + \lambda \|Hx - y\|_2^2$$
$$H = MF^{-1}RF$$
$$M = W^{-1}SW,$$

$$\begin{bmatrix} A_L^{LH} \\ A_L^{LH} \\ A_L^{LH} \end{bmatrix} = \sum_{m=1}^{3} \begin{bmatrix} A(m)_L^{LH} \\ A(m)_L^{HL} \\ A(m)_L^{HH} \end{bmatrix},$$

where the system matrix H forward projects the original data x. The sampling matrix R under-samples the original data x in k-space. In the image space, the individual modes are enhanced by the multiscale selection method. Wavelet multiscale selection keeps the modal image features, and replaces the corrupted features by common information of multi-modal images. For the common information, the wavelet multiscale coefficients are averaged over the modes. Note the variable *m*

$$\begin{bmatrix} S(m)_L^{LH} \\ S(m)_L^{HL} \\ S(m)_L^{HH} \end{bmatrix} = \begin{cases} \begin{bmatrix} M(m)_L^{LH} \\ M(m)_L^{HL} \\ M(m)_L^{HH} \end{bmatrix}, & \begin{aligned} &\sum_{k=1}^3 |S(m)_L^k| + \sum_{k=1}^3 |S(m)_{L+1}^k| \\ &\quad > \sum_{k=1}^3 |A_L^k| + \sum_{k=1}^3 |A_{L+1}^k| \end{aligned} \\ \begin{bmatrix} A_L^{LH} \\ A_L^{LH} \\ A_L^{HH} \end{bmatrix}, & otherwise\,. \end{cases},$$

indicates the mode index, and the superscripts {LH, HL, HH} respectively denote the low-high, high-low, and high-high coefficients in the wavelet decompositions [3]. Then the modal coefficients M are compared to the averaged coefficients A at the mode *m* and the level L. Three wavelet levels are used in the reconstruction.

Once the multi-scale selection is done, the selected images are plugged back into the CS framework.

Results

Fig1.(a)-(c) show the inverse Fourier transforms of 28% undersampled k-space data. An undersampling code was designed to collect a certain band of center frequencies and randomly sampled high frequencies. The same sampling design was applied to the three modes. In the figures, the features of individual modes are severely corrupted by aliasing. Fig1.(d)-(f) and (g)-(i) compare the individually CS reconstruction and the wavelet multimode CS reconstruction : the former still shows aliasing effects. The latter suppresses the computational artifacts improving the image quality from 5% RMSE (d-f) to 2% RMSE (g-i) because of the wavelet based multiscale selection.

Conclusion and Discussion

This study shows the feasibility of the multimode CS reconstruction method in a compact form for fast acquisition and reconstruction of multiple contrast images. The wavelet based multi-scale selection can effectively reduce aliasing artifacts caused by the undersampling, and enhance the multimode images in the relatively short running time.

Reference [1] B. Bilgic et al., MRM 66(6):1601-15, 2011. [2] S. Lim et al., Applied Optics 50(34):H75-H86, 2011. [3] V. Petrovic et al., Proc. SPIE 3719:319-326, 1999.

Acknowledgement This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2012-0008577).