Interpolated Compressed Sensing MR Image Reconstruction in Phase Encoding for the Brain

Yong Pang[1], Daniel B. Vigneron[1,2], and Xiaoliang Zhang[1,2]

[1]*Dept of Radiology and Biomedical Imaging, University of California San Francisco, San Francisco, CA, United States,* [2]*UCSF/UC Berkeley Joint Graduate Group in Bioengineering, San Francisco & Berkeley, CA, United States*

Introduction: Developed from compressed sensing MRI which is able to reduce the acquisition time and raw data size by significantly undersampling the *k*-space [1, 2], interpolated Compressed Sensing (iCS) method demonstrates the capabilities in reducing the image error and increase the contrast to noise ratio (CNR) for multi-slice two-dimensional (2D) MR imaging [3]. In this work, we designed the iCS method in phase encoding direction to facilitate its practical implementation for brain imaging on clinical MR scanners. Compared with 2D iCS, iCS method in phase encoding direction should have lower requirements to system gradients on the slew rate and maximum amplitude. This may also have a potential to improve the imaging quality due to better accuracy of gradient fields and acquisition trajectory. In-vivo MR of human brain has been used to investigate the feasibility of the proposed method.

Theory and method: In multi-slice two-dimensional MR imaging it is potential to increase the CNR and image quality by interpolating the missed k-space data of one slice by using phase encoding k-space lines from another slice multiplied by a weighting function, while keep the original raw data of the slice unchanged. Following is the reconstruction strategy:

1. Variable-density sampling scheme and Mote-Carlo incoherent sampling strategy were firstly used to undersample the *k*-space samples in the phase encoding direction for each slice;
2. The k-space sampling of the two slices were compared;
3. The k-space lines from one slice was multiplied by the weighting function and interpolated into the k-space of the neighboring slice to estimate the missed phase-encoding lines;
4. Non-linear conjugated gradient was used to perform image reconstruction using the interpolated k-space.

Fig.1 shows the diagram of the proposed method. To investigate the feasibility of the proposed method, a healthy human brain was used in in-vivo MR imaging at GE whole body 7T scanner. The undersampling rate is 1/20 for each even slice while 1/4 for each odd slice as shown in Fig.2. Each odd slice is used to estimate the missed k-space lines of the neighboring even slice.

Results: Fig.2 shows brain MR image on sagittal plane by using phase encoding direction interpolated CS reconstruction. The first row is the images reconstructed from full k-space data for reference; the second and third rows are the images reconstructed using the original compressed sensing and the proposed method. The 3 columns are the reconstructed images, image error maps and the CNR point by point. The image error is evaluated by using:

$$IE = \sqrt{\sum_j \frac{(I_j^{Ref} - I_j^{us})^2}{(I_j^{Ref})^2}} \quad (1),$$

where I^{Ref} represents the signal intensity of the jth pixel in the full k-space reference image, and I^{us} represents the signal intensity of the jth pixel in the undersampled images using conventional CS or phase encoding iCS [3] methods. It is demonstrated that the image error has been decreased while the CNR has been greatly improved by using the phase encoding iCS.

Conclusions and discussions: The phase encoding iCS reconstruction method, capable of providing improved CNR and reduced image error in multi-slice imaging, has been designed and tested in this work to facilitate the practical implementation of the iCS method. By limiting the random sampling in phase encoding direction, the sparse Cartesian k-space trajectory doesn't need fast varying gradient waveforms therefore make it much easier to be implemented to meet standard gradient coil slew rate and maximum amplitude.

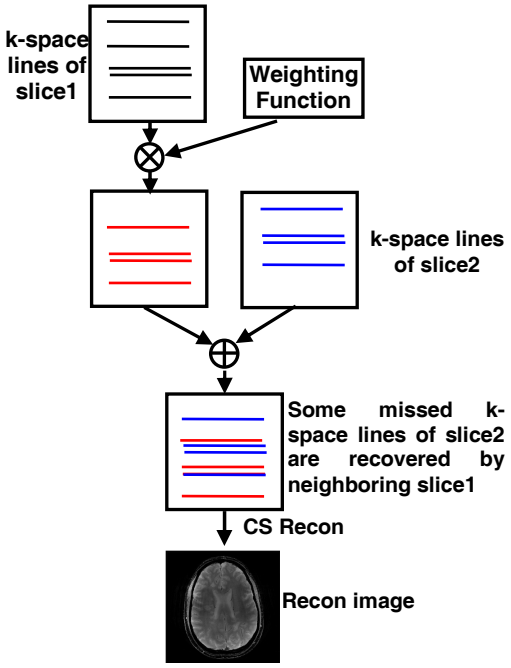

Fig.1 Diagram of the proposed iCS method in phase encoding direction.

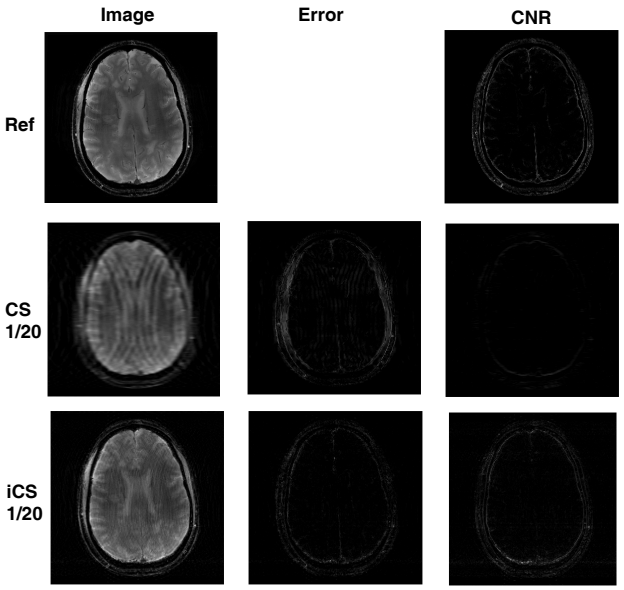

Fig.2 In-vivo MR images of human brain in sagittal plane. The 1st row are reference images reconstructed from full k-space; the 2nd row are images reconstructed using CS at 1/20 undersampled rate; the 3rd row are images reconstructed using proposed iCS method at the same rate. The 1st column is the reconstructed image, the 2nd column is the image error map of the images reconstructed from CS and iCS, the 3rd column is the CNR point by point. It is demonstrated that the SNR can be greatly improved.

References: [1] Lustig M, et al, Magn Reson Med 2007; 58: 1182-1195. [2] Jung H, et al, Magn Reson Med 2009; 61: 103-116. [3] Pang Y, et al, Plos ONE 2013; 8(2): e56098. doi:10.1371/journal.pone.0056098.