Multi-dimension Random Phase Encoding for Chemical Shift Imaging

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INTRODUCTION: MR chemical shift imaging (CSI) requires efficient suppression of intervoxel signal contamination and reducing the measurement time [1]. To this end, a random under-sampled k-space CSI sequence is proposed. The core of the proposal is a modification of the traditional 2D-CSI sequence that uses randomly generated phase encoding gradients between the slice-selection and refocusing pulses. This method is inspired by the recent exploitation [2, 3] of sparse MRI image reconstruction using a randomly under-sampled k-space dataset. In this study the spatial response function and the metabolite map (NAA map) of random under-sampling are demonstrated and compared with those of weighted low resolution sampling.

THEORY: 2D signals can be represented by a few transform coefficients [4]. In the case of SCI, only a few Fourier transform coefficients are needed to represent the image. Random sampling has been shown to be an efficient approach to acquire these sparse coefficients in less time [2, 3]. Sparse images can be recovered by solving the optimization constraints [2]: $minimize\ ||\phi c||_1\ s.t.\ ||MFc - y||_2 < \varepsilon$. Here y is the MRI measurement, F is the Fourier transform matrix, M is the random sampling matrix and ε controls the trade off between the noise level and the reconstruction time. The CSI sequence is compatible with random sampling because the X-axis and the Y-axis phase-encoding gradients are applied between the 90 and 180 pulses and no phase encoding is needed during readout, which enables independent sampling in the two directions of k-space shown in Fig.1.a. During MRI, limited sampling of high frequency components introduce contamination artifacts where a sharp edge is reconstructed with Gibb's ringing. With properly designed random sampling trajectories that cover both the low and high frequency areas of k-space, random sampling will recover the high and low frequency image components.

METHODS: The proposed random phase encoding SCI trajectory fully samples in the spectral dimension and partially samples k-space as shown in Fig.1b. Images are reconstructed by the conjugated gradient method [2]. **Sampling trajectory:** A random two direction phase-encode Cartesian acquisition was simulated with reconstruction matrix size ranging from 16*16 to 64*64 as done by Lustig *et al.*[2]. **SRF:** Fig.2a is the input point object. We applied two different sampling strategies in k-space, one is variable density random sampling with iterated reconstruction as described above, and another is uniform sampling in the center rectangular area of k-space with zero filling as done by Scheenen *et al.* [1]. To simulate measurement uncertainty, white noise (0.25 times of amplitude of data) was added in k-space as shown in Fig.2d. **Metabolite map:** We extract the simulation data from 2DiCSI (websit columbia.edu/3dicsi). The parameters of the raw data were: repetition time = 1000ms, thickness = 15mm, matrix size = 16*16 and field of view = 240*240mm. We added two spectrally uniform points in the image to test contamination in the measurement (shown in Fig. 3). Metabolite maps were constructed from the N-Acey1 Aspartate (NAA) peak with under sampling factors spanning 70% to 35% using random sampling and weighted low resolution sampling.

RESULTS AND DISCUSSION: Figs. 2 and 4 illustrate the simulated SRF and the metabolite map reconstructed with two test points. In Fig.2, the SRF results of random sampling (b, e) and weighted low resolution (c, f) illustrate the shape of the reconstructed pixel and the contamination it produces outside the central maximum intensity. Note random sampling produces less contamination in neighboring pixels. We also simulate the above two methods in the noisy environment in Fig. 2e and Fig.2f. Again, random sampling produces less contamination, even when compared to the original noisy input in Fig. 1d. In Fig.4, two test points on the top left of each map show the intervoxel contamination. Note that two test points can still be resolved after randomly undersampling at 35% of k-space data, while the weighted low resolution method causes the two points to merge with less undersampling (in Fig4.e to h). For random sampling (Fig. 4 a to c), the original image is reconstructed well. For weighted sampling (Fig. 4 f to h), reconstruction error is increased for higher under sampling factor. The reason why Fig.2.b and Fig.4 a to c recovered the input image well because the sampling abided by the restricted isometry property [4]. Random sampling can reduce the effects of noise because noise is incoherent with the sampling matrix. However, for large under sampling factors, 35% for example (in Fig.4.d), some details in the picture are different from the original. We note that even though random sampling seems to perform better than weighted sampling in these simulations, the reconstruction costs are significantly increased. Further research should be done to develop an efficient sparse transform basis for CSI data. With a better transform function, it may be possible to achieve better under sampling factors and shorter measurement times.

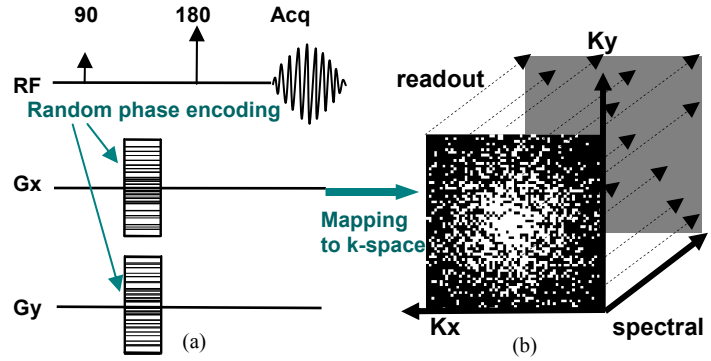

Fig 1: (a) Random two phase encoding CSI, (b) random sampling in k-space and readout in spectral direction. The k space is randomly sampled while the spectrum direction is full sampled. Sampling density increases from periphery to center. Size of sampling matrix is 64*64.

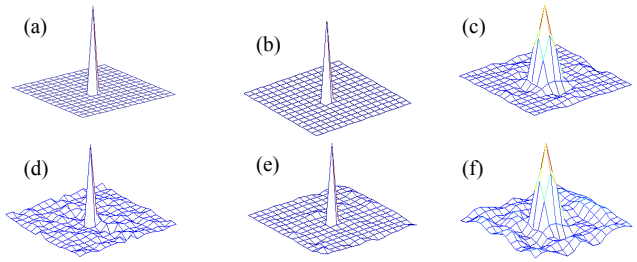

Fig 2: Spatial response function: (a) input point object, (b) random sampling, (c) weighted low resolution sampling, (d) to (f) is the same as (a) to (c) except noise is added in k-space to simulate measurement error.

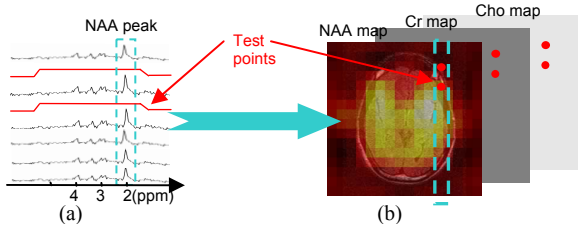

Fig 3: NAA distribution map (with color) human brain CSI image and (b) NAA peak in the spectrum (a). Two signals (red color) added for to test contamination. The distance between two test points is one pixel.

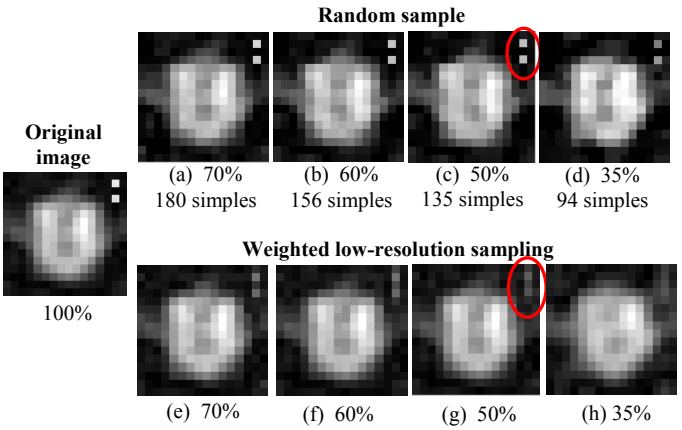

Fig 4: CSI of human brain, NAA map. (a) to (d), random sampling under sampling factor from 70% to 35%. (e) to (h), weighted low resolution sampling, under sampling from 70% to 35%.

REFERENCES: 1. Tom W.J. Scheenen, et. Magn Reson Med, 2004:52:80–88; **2.** M. Lustig, et. Magn Reson Med 2007:58(6):1182-1195; **3.** HongJung, et. Magn Reson Med. 2009; **4.** V. R. Baraniuk, IEEE Signal Processing Magazine, 2007.