Acceleration of Chemical-Shift Imaging by Applying True 3D Compressed Sensing

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Introduction:

Chemical-shift imaging (CSI) has long been considered the gold standard method for *in-vivo* metabolite imaging. After slice selection, 2D-CSI is acquired with two spatial phase encodings and a free induced decay (fid) in the third dimension. A typical 16x16 phase encoding requires 256 RF excitations and a minimum acquisition time of 20s. For hyperpolarized ^{13}C metabolic imaging, it is very desirable to reduce the number of RF excitations and acquisition time in order to acquire kinetic information about tissue metabolism during the lifetime of the hyperpolarized agent with multi-phase CSI. For single channel acquisition, compressed sensing offers some advantages. A “slice-by-slice” 2D compressed sensing reconstruction would be difficult to obtain satisfactory spectroscopy along the fid dimension. In this work, we have adopted the principle of 3D compressed sensing method [1] into CSI. The results demonstrate that when the entire CSI data set is treated as one single object, compressed sensing can be satisfactorily applied to spectroscopic CSI.

Methods:

A four metabolite (lactate, alanine, formic acid, bicarbonate, all C_1-^{13}C labeled) phantom was imaged using CSI sequence on a 3T GEHC MR750w scanner (GE Healthcare, Waukesha, Wisconsin) with a single channel (birdcage) ^{1}H/^{13}C dual tuned rat size coil. 16x16 spatial phase encoding and spectrum length of 256 points were acquired. Sparseness of the k-space data was applied in two phase encoding directions to obtain a total reduction rate of 5x, 3x, 2.5x and 2x corresponding to 20%, 33%, 40% and 50%, respectively, of fully sampled data. Figure 1 shows the proton reference image of the phantom, a reduction matrix (R=2.5) and a symbolic 3D Wavelet object. Conjugate Gradient method [2] was used for argmin{ $\|\Phi m\text{-}k\|_2 + \lambda TV(m) + \alpha\|\Psi m\|_1$} compressed sensing optimization. All variables and operators in the optimization process are in true 3D format for full 3D compressed sensing reconstruction. The compressed sensing reconstruction process was performed off-line using a Matlab script.

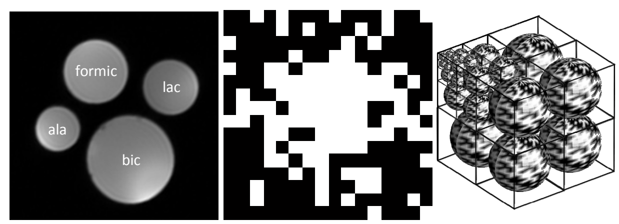

Fig. 1 *Left*: reference proton image; *middle*: R=2.5 phase encoding matrix; *right*: symbolic 3D Wavelet objects.

Result and Discussion:

Figure 2 shows the normalized root of mean square error as a function of sampling rate. Figure 3 shows the reconstructed CSI with 3D compressed sensing method. For a reduction factor of 2 (R=2, with 50% of full data) the compressed sensing reconstructed CSI with normalized root mean square error nRMS = 0.0016 is visually identical to the reference. Minor artifacts appeared with further reduction factors up to R=5 but this still reflects a significant time and excitation saving for CSI acquisition (80%). However in the R=10 case with a 10% sampling rate, the errors became large and many artifacts appear.

The common 2D compressed sensing methods would be difficult for CSI acceleration because many “slices” contain only “flat noise” without sparse structure. True 3D compressed sensing is demonstrated to be a feasible method for CSI acceleration.

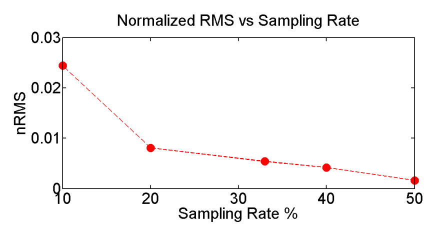

Fig. 2 Normalized RMS vs sampling rate; 10%, 20%, 33%, 40 and 50% correspond to R=10, 5, 3, 2.5 and 2 respectively.

Conclusion:

This compressed sensing acceleration mechanism is being implemented into the CSI RF sequence for real-time phase encoding reduction.

References:

[1] J-X Wang, ISMRM 2012, 2181; [2] YH Dai & Y Yuan, Journal of Computational Mathematics, Vol.20(6), 2002

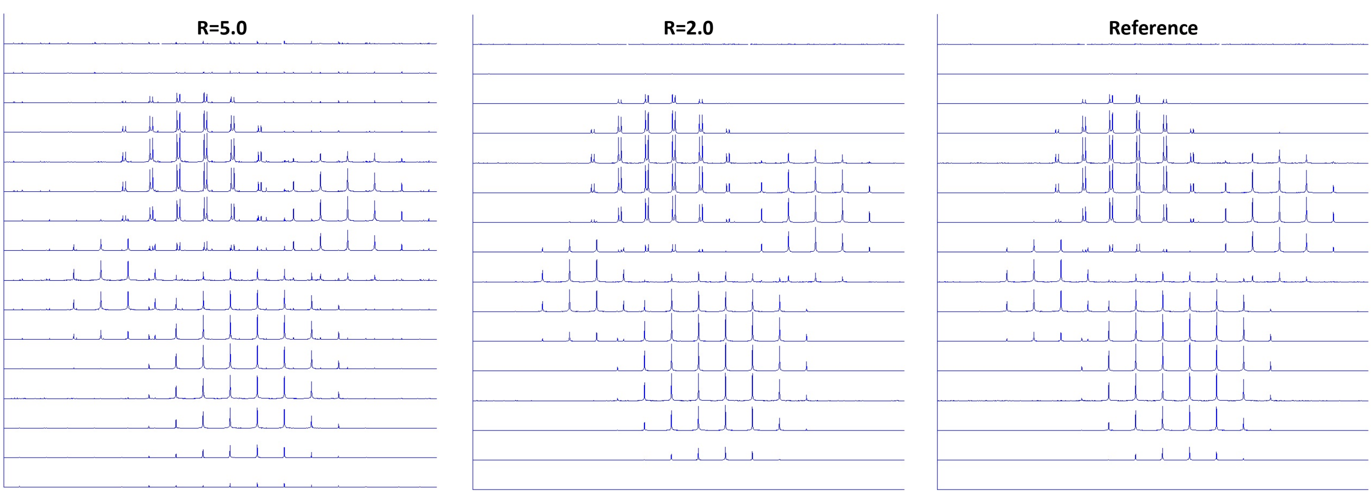

Fig. 3 Single channel 3D-CS reconstructed CSI which consists of 16x16 spectra with R=5 (20% of full data), R=2 (50% of full data) and the full data reconstructed CSI.