Combination of Compressed Sensing and SENSE for 1H MRSI: An Initial Result

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Introduction

Compressed sensing (CS) and parallel imaging are immerging techniques that allow acquiring signals at lower rates than Nyquist frequency and recovering full signal utilizing nonlinear reconstruction algorithms [1,2]. In recent years, studies on the combination of the two techniques, such CS MRI [3] and SENSE [2], have been reported to achieve higher acceleration rates than can either of them individually and thereby, significantly reduce scan times of anatomical MRI. To the best of our knowledge, however, no application of this combined technique on proton MRSI was reported. In this work, we proposed a highly accelerated high resolution proton MRSI technique by combining SENSE and CS.

Methods and Materials

SENSE and CS The SENSE reconstruction was carried out by solving the linear equation $C\rho = b$, where C is an n×r sensitivity matrix with n as the number of coils and r the SENSE acceleration rate, ρ is a r×1 vector denoting the image values at the r pixels, and b is an n×1column vector representing the aliased signals picked up by the coil elements. The major procedures of CS entail sparsifying transform and image reconstruction. Sparsifying transform was performed using discrete wavelet transform with a threshold T and image reconstruction was carried out by solving the following constrained optimization problem: $\min \|\Psi x\|_1, s.t. \|F_u Px - y\|_2 < \varepsilon$ and $x = Sx$, where $\|.\|_i$ l_i-norm, ψ denotes the sparse transform matrix, F_u denotes the undersampled Fourier transform, x denotes the estimated signal or image, y denotes the measured k-space data, and ε controls the fidelity of the reconstruction to the measured data. Specifically, S is a matrix with diagonal elements set to 1 in the locations that correspond to the region of support (ROS) and zero elsewhere.

Fig. 1. CS-SENSE sampling pattern. Points in white are the sampled PE steps.

MRSI Data We acquired MRSI data from human volunteers on a whole body 3T scanner (Signa 3T HDx, GE Healthcare, Waukesha, WI) using a multiple 2D MRSI sequence [4]. The parameters were: TR/TE =1000/144ms; SW=2 kHz; PE=50 x 50; Full echo data points = 512; FOV = 24cm x 24 cm; Slice number = 2; Thickness/spacing = 10/2mm. SENSE acquisition was simulated from the fully sampled k-space data by down-sampling in one phase encoding (PE) direction with an acceleration rate of 2, and CS acquisition was simulated using a variable sampling scheme [3] in the SENSE-downsampled k-space, with an acceleration factor of 1.96. The total acceleration factor was 2×1.96 = 3.92. Sensitivity maps for SENSE were first generated from the fully sampled localizer images (256x256x2) [2] and then degraded to the in-plane resolution of 50x50.

MRSI Reconstruction Spatial reconstructions were performed by the CS and SENSE procedures consecutively on each frame (50x50) at each point of the FID. Then, spectral reconstruction was performed by inverse FFT. The algorithm was written in Matlab©.

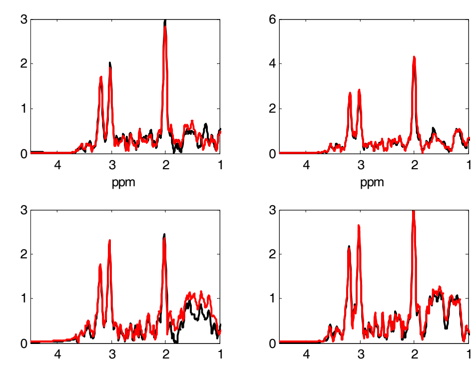

Fig. 2. Comparison of original (black) and reconstructed (red) spectra from a 2x2-voxel region. Spectra are shown in magnitude mode.

Results and Discussion

The original full k-space sampling points were in an inscribed circle in a 50x50 square [4]. A CS-SENSE sampling pattern in the k-space is shown in Fig. 1. The mean absolute error (MAE) over all points is 0.0149 and the mean square error (MSE) is $7.2\text{x}10^{-4}$. An example of comparisons of original and reconstructed spectra from a 2x2-voxel region is shown in Fig. 2. We postulated that the following two reasons might attribute to the applicability of CS to MRSI: (1) the residual water signal, on which the metabolite signals are superimposed, varies slowly across space and thereby, and is sparse in the transformed domain; (2) the relatively large PE matrix might favor the randomness of the sampling.

Conclusion

Our initial results demonstrated the feasibility to combine SENSE, a parallel imaging technique, with compressed sensing, a technique of sparse sampling, to achieve highly accelerated acquisition of high resolution ^{1}H MRSI. Future work may explore the potential of the combined technique for MRSI with both high temporal and high spatial resolution, without trading-off one for another.

References

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