Parallel Spectroscopic Imaging Reconstruction with Arbitrary Trajectories using k-Space Sparse Matrices (KSPA)

M. Gu[1], C. Liu[1], and D. Spielman[1]
[1]Radiology, Stanford University, Stanford, California, United States

Introduction
The major limitation of volumetric MRSI is the long scan times required to acquire data in both spatial and spectral dimensions. Fast imaging techniques using non-Cartesian k-space trajectories, e.g. spiral, have been implemented to reduce scan times. The scan time can be further reduced by acquiring partial k-space data with multiple receiving coils and reconstruct using the knowledge of each coil's sensitivity profile. With k-space data on a Cartesian grid, reconstruction can be achieved using image-domain based SENSE algorithm or k-space-domain based GRAPPA algorithm [1,2]. For non-Cartesian k-space data, image-domain based iterative SENSE algorithm or k-space-domain based PARS algorithm can be used for the reconstruction [3,4]. Although effective, these non-Cartesian k-space data reconstruction methods suffer from long computing times. In this work, we propose a parallel MRSI reconstruction method with arbitrary trajectories using k-space sparse matrices (KSPA) [5]. The algorithm achieves reduced computing times and memory requirements by taking advantage of the compactness of the convolution kernel defined by the coil sensitivity. Reconstruction using this algorithm is demonstrated using undersampled spiral k-space data from an in-vivo study with different reduction factors.

Methods
Suppose data are acquired at *nk* sampling locations in k-space with *nc* receiving coils. The KSPA algorithm formulates the reconstruction problem as a linear system: $d=Gm$, where d is a column vector in the size of $nc \times nk$, stacked with the k-space data acquired by all coils and m is a column vector of the size N^2, with the Cartesian k-space value to be estimated. G is a coefficient matrix composed of coil sensitivity spectrally interpolated at arbitrary k-space locations. The reconstruction problem can be solved by finding a pseudo-inversion matrix G^+ of the coefficient matrix G as $G^+=(G^HG)^+G^H$. The direct computation of G^+ requires prohibitively large storage and a long computing time. Exploiting the sparsity of the coefficient matrix G, KSPA algorithm solves G^+ by finding a sparse approximate inverse $(G^HG)^+$ by solving N_b^2 independent least squares problems for each row of (G^HG), where N_b is the number of block into which k-space is divided, and $N_b<<N$.

The coil sensitivity maps required for the KSPA reconstruction are estimated in two steps. First, the raw sensitivity map of each coil is estimated by dividing the coil water image with the sum-of-squares water image. Second, a 2D thin-plate spline fitting is computed on both the real and imaginary parts of the sensitivity map independently to obtain a smoothed sensitivity map.

To encode chemical shift information, fast MRSI with spiral k-space trajectories samples data points on repeated spiral trajectories as shown in Figure 1. With the KSPA algorithm, the reconstruction matrix is calculated using k-space data on the first spiral trajectory and then applied to k-space data on the remaining spiral trajectories to estimate the fully sampled k-space data on repeated Cartesian grids. Since the reconstruction matrix only needs to be computed once, significant reconstruction time can be reduced.

Results
Data were collected at 1.5T using a General Electric (G.E. Medical Systems, Milwaukee, WI) scanner with an 8-channel phased-array head coil. PRESS-based RF pulses were used for localization and excitation with TE/TR=144/1500ms, 32cm FOV, 64x64x256 matrix size, 0.5cc voxels, 8 NEX and 13 minute acquisition. The high resolution structural image and the spectra of representative voxels reconstructed with fully sampled k-space data and undersampled k-space data with reduction factors of 1.5, 2 and 2.5 are shown in Figure 2. The reconstruction with 64x64x256 matrix size using KSPA takes 3 minutes on a 1.5GHz Pentium PC compare to 20 minute reconstruction using iterative SENSE algorithm.

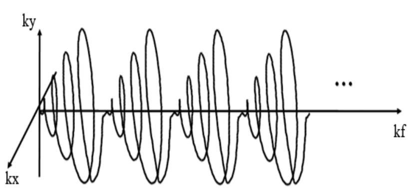

Figure 1. Repeated spiral k-Space trajectories for MRSI encoding.

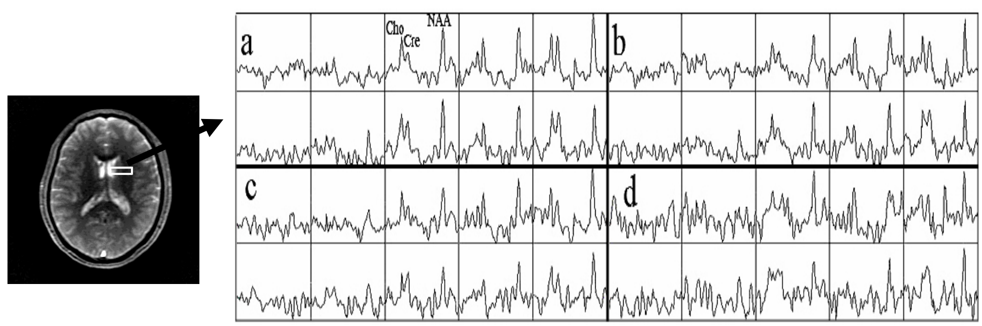

Figure 2. Spectra from representative voxels with different reduction factors. Reduction factors are 1, 1.5, 2, 2.5 for subplot a, b, c, d respectively.

Conclusion
Parallel spectroscopic imaging reconstruction with arbitrary trajectories using KSPA algorithm was implemented and tested in vivo using MRSI with spiral k-space trajectories. Spectra very similar to that reconstructed using fully sampled k-space data are obtained using KSPA MRSI reconstruction with different reduction factors. The algorithm demonstrates its flexibility of reconstruction using undersampled data on arbitrary k-space trajectories and its efficiency with significantly reduced computing time compare to iterative SENSE and PARS algorithms.

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