High resolution MRSI using compartmental low rank algorithm: demonstration using undersampled EPSI

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Synopsis: Improved spatial resolution is needed for MRSI. In this work we propose an algorithm which provides a comprehensive and automatic approach to recover high resolution metabolite maps from highly undersampled acquisitions; the improved spatial resolution translates to improved spectral quality and reduced leakage artifacts. The proposed algorithm is also quite flexible and can be readily used in a variety of sequences, including EPSI, CSI, and spirals acquisition schemes.

Purpose: Conventional MRSI schemes that rely on Nyquist sampling are fundamentally limited by the achievable spatial resolution. The low spatial resolution often results in B_0 induced spectral distortions and spectral leakage from extracranial lipids and unsuppressed water, which makes the interpretation of MRSI data challenging. Experimental lipid suppression schemes (e.g outer volume suppression, inversion recovery) have limited ability in eliminating the leakage artifacts, at the typically low spatial resolution of conventional MRSI. Novel acquisition schemes and reconstruction algorithms are urgently needed to overcome these challenges.

Methods: We introduce a novel compartmental low rank algorithm, coupled with variable density undersampled k-space acquisition, to considerably improve the spatial resolution of the metabolites. The reconstruction from undersampled data is made well posed by low-rank priors on the extracranial lipid and metabolite compartments, which are further constrained to be mutually orthogonal. The spatio-temporal MRSI signal is represented as the linear combination of the metabolite signal γ_M and the extracranial lipid signal γ_L:

$$\gamma(\mathbf{r},t) = \gamma_{\rm M}(\mathbf{r},t) + \gamma_{\rm L}(\mathbf{r},t), \qquad [1]$$

where $\mathbf{r}$ and t are the spatial and temporal dimensions, respectively. We assume these signals to be spatially disjoint and restricted to the spatial regions Ω_M and Ω_L, respectively. Since the spectral support and relaxation properties of the metabolites and lipids are strikingly different, they can be safely assumed to be mutually orthogonal (i.e, $\langle \gamma_M(\mathbf{r}_1,t), \gamma_L(\mathbf{r}_2,t)\rangle = 0; \forall \mathbf{r}_1 \in \Omega_1; \mathbf{r}_2 \in \Omega_2$) (**?**). We exploit this orthogonality property to minimize lipid leakage artifacts; we do not rely on elaborate spectral priors as in (**? ?**), hence this method is more robust to field inhomogeneity variations in the extracranial regions. Since the recovery of the metabolites and lipids from highly under-sampled and heavily noisy data is highly ill-posed, we propose to use compartmental low-rank priors to make the problem well posed. We formulate the recovery as:

$$\{\mathbf{\Gamma}_{\rm M}, \mathbf{\Gamma}_{\rm L}\} \;=\; \arg\min_{\mathbf{\Gamma}_{\rm M},\mathbf{\Gamma}_{\rm L}} \underbrace{\|\mathcal{A}(\mathbf{\Gamma}) - \mathbf{b}\|^2}_{\text{data consistency}} \;+\; \underbrace{\lambda_1\|\mathbf{\Gamma}_{\rm M}\|_* \;+\; \lambda_2\|\mathbf{\Gamma}_{\rm L}\|_*}_{\text{low-rank priors}} + \underbrace{\beta\,\|\mathbf{\Gamma}_{\rm M}\mathbf{\Gamma}_{\rm L}^H\|^2}_{\text{orthogonality prior}} \;.$$

Here, $\mathcal{A}$ is the forward model consisting of field inhomogeneity shifts, coil sensitivity encoding, and (non)-uniform Fourier transform, while $\mathbf{b}$ is the hybrid k-space data collected using EPSI.

A volunteer was scanned with a GE MR750W 3T scanner at the University of Iowa using a 32-channel head coil. We relied on a hybrid EPSI acquisition scheme consisting of (a) a 32x32 sampled EPSI data with 8 averages for improved SNR and (b) a 96×96 sampled EPSI dataset with only one average. The readout bandwidth of both datasets is 600 Hz. The hybrid k-space data is constructed by retaining the low resolution part from (a) and only the high resolution part from (b). The total data acquisition time, including water reference acquisition for eddy current correction and sensitivity estimation, was 12 mins. We also considered undersampling the high-resolution data with factor x2 and x4 respectively which correspond to scan times of 9.5 mins and 8 mins respectively. Water is removed using HSVD from the hybrid k-space data.

Results: Data is collected on a single axial slice of FOV = 24 cm,slice thickness of 1 cm at TR/TE = 800/100 ms. 8 OVS bands are used for lipid suppression. Figure 1 shows the peak integral images of NAA maps for IFFT reconstruction of the low resolution (32×32) data, high resolution (96×96) data and the hybrid data in the top row . The bottom row shows the reconstruction using the proposed method for the fully sampled, and undersampled data. All maps are reconstructed to a grid size of 96×96. The IFFT reconstructions show lipid leakage near the skull for the low resolution and hybrid data whereas the SNR of the high resolution map is highly compromised. The proposed method produces high resolution maps with high quality details like low signal in ventricles. As is evident from the maps the high resolution details are intact even for undersampled recovery.

The spectra coresponding to the maps are shown in Figure 2. The low resolution data and the hybrid data show lipid leakage in the pixels close to the skull whereas the high resolution data has very low SNR. The representative spectra for the proposed method however, eliminate lipid leakage and recover and denoised.

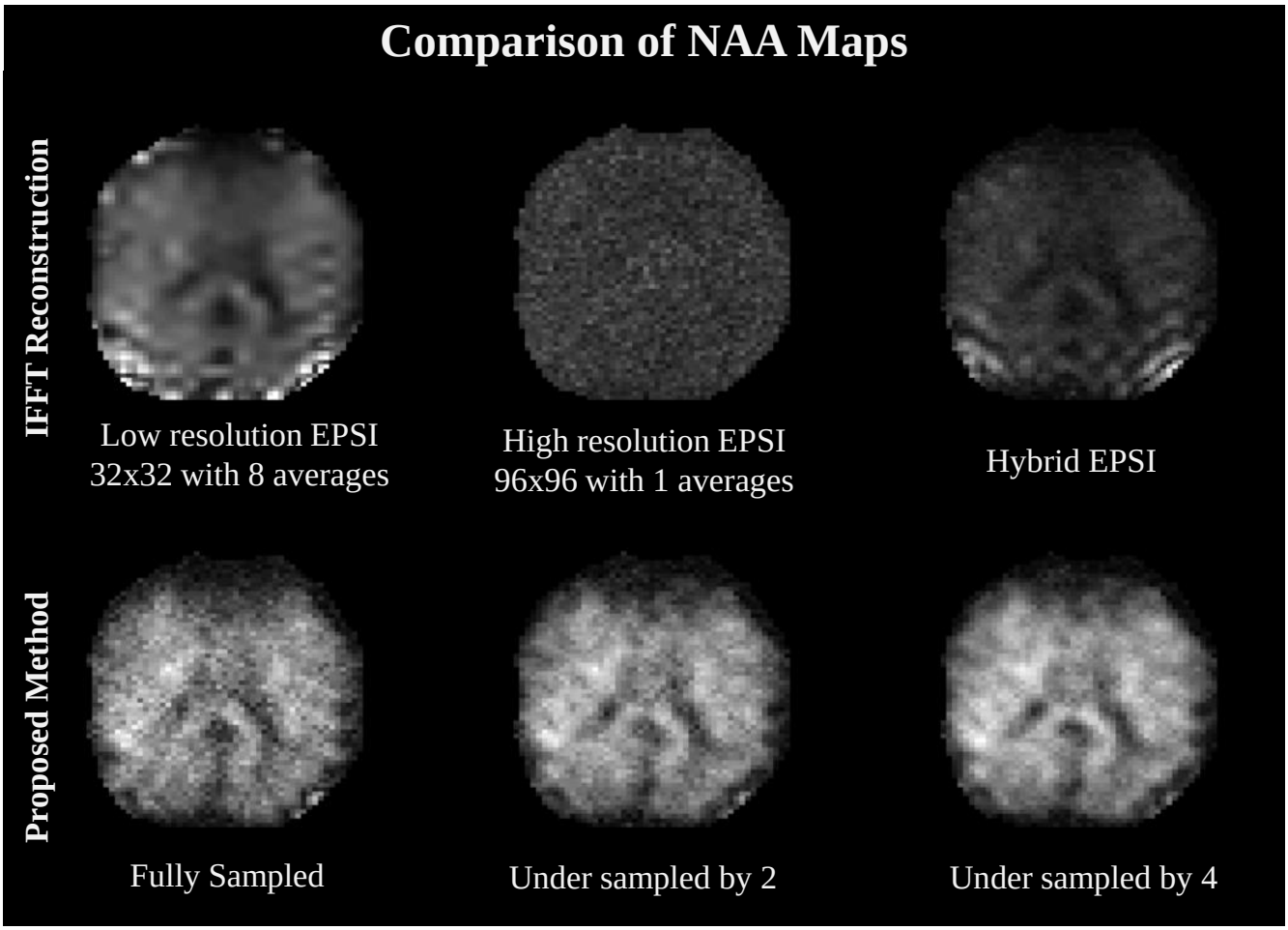

Figure 1: Comparison of NAA maps: The top row shows NAA maps from IFFT reconstruction of EPSI data and the bottom row shows reconstructed maps using the proposed method at different undersampling factors. The EPSI data has lipid leakage at low resolution and is highly noisy at high resolution. The proposed method recovers high resolution maps with reduced spectral leakage artifacts.

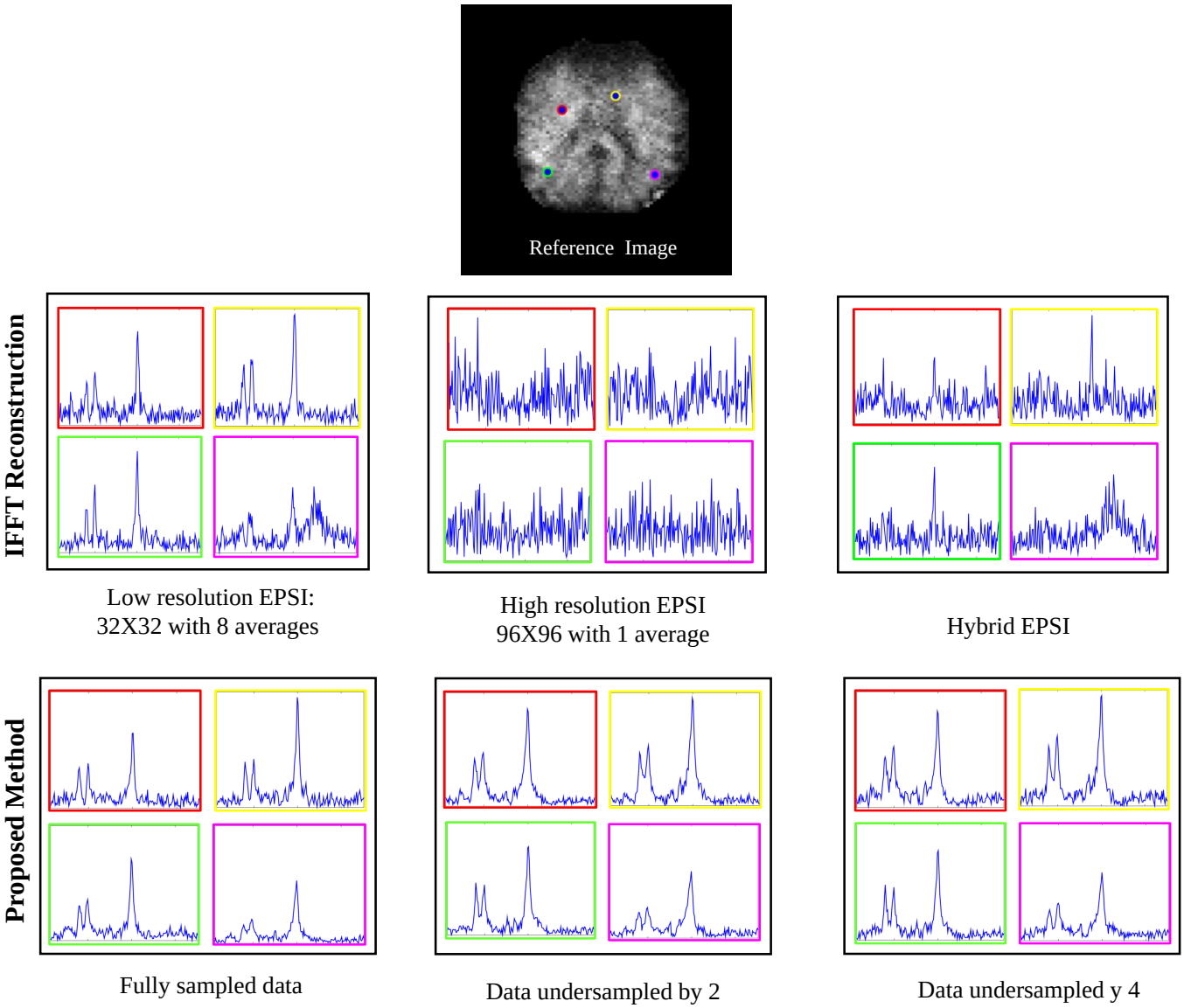

Figure 2: Comparison of spectra, from locations marked in the refernce image: The top row shows IFFT reconstruction of the EPSI data and the bottom row shows reconstructed spectra using the proposed method at different undersampling factors. The spectra are denoised and the lipid leakage is eliminated.

Conclusion: We demonstrated a method for recovering high resolution MRSI data from undersampled measurements using different acquisition methods. The proposed method reduced lipid leakage artifacts and due to low rank modeling recovers high resolution maps from undersampled data. The maps can greatly improve with added spectral quantification.