

MRS Sparse-FFT: Reducing Acquisition Time and Artifacts for In Vivo 2D Correlation Spectroscopy

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Target Audience: Developers of fast reconstruction algorithms that exploit sparsity; Scientists interested in 2D spectroscopy applications in vivo.

Purpose: 2D Correlation Spectroscopy (COSY) allows the unambiguous assignment of NMR signals in crowded spectra and as such can be used in vivo to detect and disentangle the spectral overlap of metabolites. Several methods were demonstrated to acquire localized COSY spectra in vivo [1, 2] and showed great utility in detecting new molecular biomarkers of disease [3, 4]. Despite its potential, the in vivo use of 2D COSY is not largely spread due to several challenges. These are related to the acquisition of the additional frequency dimension (f1), which requires significant encoding time and suffers from truncation artifacts that may obscure cross-diagonal peaks. Here, we present results towards reducing the acquisition time and truncation artifacts in f1 dimension of 2D COSY using recently developed algorithms for the sparse Fourier transform [5, 6].

Methods: We propose adapting sparse-FFT algorithms [5, 6], which are optimized for the reconstruction of sparse signals in the Fourier domain. The 2D COSY spectrum is sparse, and hence lends itself naturally to such an approach. We designed a sparse-FFT algorithm customized for 2D MR spectroscopy. The algorithm has two components: 1) a sparse sampling scheme, and 2) a technique for suppression of truncation artifacts of large diagonal peaks. Instead of taking consecutive increments along the t1-dimension, the algorithm takes subsamples of the time domain signal along t1 and uses filtering techniques described in [5] to recover the positions and values of the peaks in the frequency domain. This allows the algorithm to reduce the number of samples needed along the t1-dimension. To suppress the f1 ringing of diagonal peaks, we leverage techniques from the sparse-FFT to estimate fractional frequencies that fall between two points on the standard FFT grid, and which characterize the spectrum of ringing tails stemming from diagonal peaks. Given these fractional frequencies, we reconstruct and subtract the ringing tail and thus remove a large portion of the artifacts. We performed experiments on a whole-body 3T MR scanner (Tim Trio Siemens, Erlangen). We used the COSY-LASER sequence (TR = 1.5 s, TE = 30 ms) [2] to acquire 2D COSY spectra on 3 volunteers and a brain phantom. The sparse-FFT was performed using 60 t1 increments on volunteers, and 64 t1 increments on brain phantom. For comparison with a large-size FFT however, we acquire the t1 evolution time with 160 and 180 consecutive t1 increments on volunteers and phantom, respectively.

Results: We demonstrate that by using sparse-FFT we can: 1) reduce the measurement time by almost a factor of three (160/60=2.7 and 180/64=2.8), 2) eliminate the t1 truncation artifacts resulting from the ringing tails of the diagonal, and 3) improve the SNR and resolution of cross-peaks. Comparing with a full-size FFT, we reduce average FWHM (Full Width at Half Maximum) of cross-peaks by 40% for in vivo and 25% for phantom; we also improve signal-to-artifacts ratio by 14dB for in vivo and 8dB for phantom. We also compare sparse-FFT with a conventional FFT algorithm that uses the first 60 samples (64 for phantom) and Compressed Sensing (CS) that uses 60 random samples (64 for phantom). We allow Full-FFT, FFT (N1=60 and 64), and Compressed Sensing to benefit from q sine windowing and linear prediction to improve cross-peaks and reduce the t1 artifacts. The results are summarized in Figures 1-4.

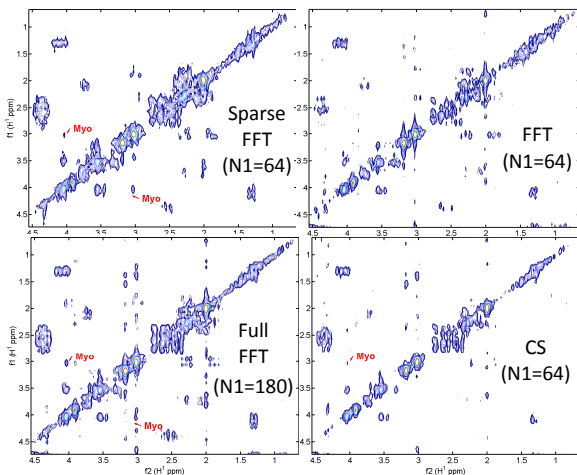


Figure 1. Phantom Data (Myo is labeled for reference)

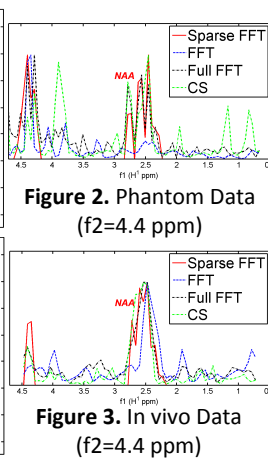


Figure 2. Phantom Data (f2=4.4 ppm)

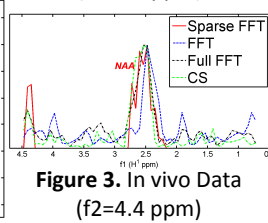


Figure 3. In vivo Data (f2=4.4 ppm)

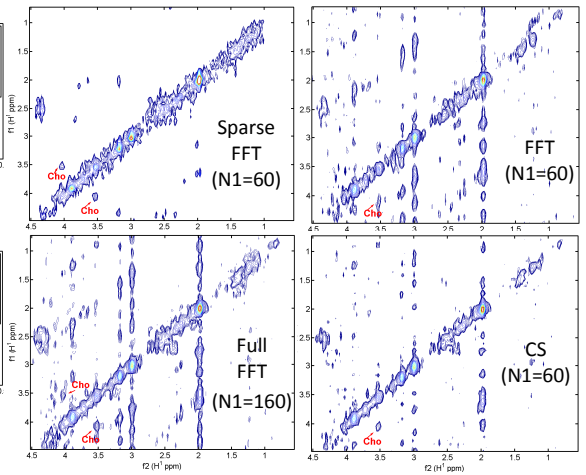


Figure 4. In vivo Data (Cho is labeled for reference)

Discussion & Conclusion: Our preliminary results indicate that sparse-FFT is useful for reducing acquisition time and reducing truncation artifacts in 2D COSY spectra. Sparse-FFT is also superior to Compressed Sensing in terms of reducing the f1 ringing and enhancing the SNR. Typically, 2D COSY spectra reconstructed with conventional FFT use windowing functions such as q sine and linear prediction to improve cross-peaks and reduce the t1 artifacts. However, q sine windowing may selectively enhance only some of the cross-peaks, while linear prediction may reduce the SNR and introduce spiking artifacts. Sparse-FFT is less biased in finding the cross-peaks and may provide a more robust method in dealing with the limitation of in vivo COSY. However, further validation and development is mandatory for routine clinical applications.

References: [1] M. A. Thomas et al., *Magn. Reson. Med.*, vol. 46, pp. 58-67, 2001. [2] O. C. Andronesi, S. Ramadan, C. E. Mountford, and A. G. Sorensen, *Magn. Reson. Med.*, vol. 64, pp. 1542-1556, 2010. [3] O. C. Andronesi, G. S. Kim, E. Gerstner, T. Batchelor, A. A. Tzika, V. R. Fantin, M. G. Vander Heiden, and A. G. Sorensen, *Science Translational Medicine*, vol. 4, p. 116ra4, 2012. [4] A. Elkhaled, L. E. Jalbert, J. J. Phillips, H. A. I. Yoshihara, R. Parvataneni, R. Srinivasan, G. Bourne, M. S. Berger, S. M. Chang, S. Cha, and S. J. Nelson, *Science Translational Medicine*, vol. 4, p. 116ra5, 2012. [5] Hassanieh H, Indyk P., Katabi D., and Price E. STOC 2012. [6] Hassanieh H, Indyk P., Katabi D., and Price E. SODA 2012.