Compressed Sensing with Prior Information for Time-Resolved TurboSPI

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Introduction: Compressed sensing allows MR images to be recovered from highly undersampled k-space using a non-linear reconstruction, significantly accelerating their acquisition [1]. The degree to which an image can be accelerated without artefacts or loss of information depends heavily on the data sparsity, either in the image domain or a suitable transform domain. Incorporating prior information about the target image can assist in reconstruction, if differences between the target image and the prior information are sparse, and time-resolved data are well-suited to such reconstruction due to their common support. It has recently been shown [2] that using the known support of one time point, such as a fully-sampled image preceding a dynamic acquisition, can be used to reconstruct subsequent points in a time series, even at higher undersampling factors than the sparsity of the data would normally permit.

TurboSPI is a multi-echo single point imaging sequence that acquires several hundred time points centered on the spin echo peak at each sampled k-space location, with no readout gradient. The result is an image series that allows high temporal resolution R_2* relaxometry [3], which we are now evaluating for longitudinal cell tracking applications *in vivo*, for which high acceleration is required. If a readout gradient is applied, the TurboSPI sequence becomes equivalent to Fast Spin Echo (FSE) and a single image corresponding to the TurboSPI volume at t=TE can be acquired rapidly. Earlier work [4] used this FSE image to prescribe optimal sampling patterns, as previously described for SPI sequences [5], and also to provide the initial condition of the reconstruction. In this work we use the FSE image as prior information to constrain and guide the reconstruction of the t=TE volume, which can in turn be used to guide adjacent time points, eventually reconstructing the entire 4D time series.

Methods: All data were acquired on a 3T horizontal bore MRI system with an Agilent DirectDrive console, using a homebuilt quadrature RF coil with a 5cm i.d. Images were acquired of a rat abdomen *ex vivo*, to allow a fully sampled TurboSPI acquisition to be obtained (scan time 10 hours 15 minutes) as well as images with undersampling factors ranging from 3 to 30. Acquisitions used a 192x192x32 matrix, 55x55x25mm FOV, 20mm slab excitation, TR=250ms, TE=8ms, ETL=8 with fat signal suppressed by a 10ms saturation pulse before each excitation. For TurboSPI acquisitions, 256 time points were acquired at each sampled k-space location at a sampling rate of 50 kHz, covering a 5ms window about the spin echo center. An FSE image with readout gradient on was acquired using 4 signal averages in 13 minutes. This FSE image was used to prescribe undersampling patterns, with the magnitude of the FSE k-space used as a probability density function [5].

Reconstruction of undersampled data was performed using code in Matlab (The Mathworks, Natick MA) based on the SparseMRI library [1] and the modified-CS approach of Vaswani and Lu [2]. Two approaches to the use of prior information were considered, though in both cases the FSE template image provides prior information for the TurboSPI volume at t=TE, and subsequent TurboSPI volumes are guided by previously-reconstructed, temporally adjacent volumes. In the first approach the sparsifying transform was the difference from the template image, while in the second approach the sparsifying transform was a 3D wavelet transform, and the sparse components corresponding to the known support of the template image (top 5% of components sorted by intensity) were held fixed using modified-CS. Image quality was assessed by computing the normalized root mean square error (nRMSE) between the reconstructed and fully-sampled data.

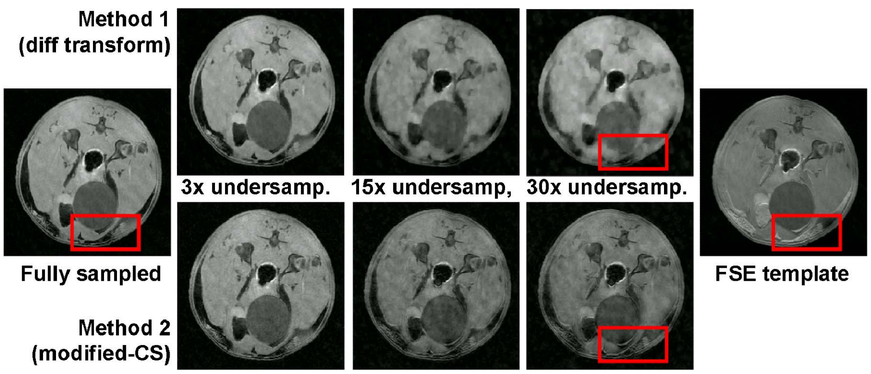

Figure 1. TurboSPI images reconstructed from data acquired with varying undersampling factors, using a difference transform (method 1, top row) or a wavelet transform with fixed support (method 2, bottom row). CS-reconstructed images are from t=9.5ms, with the fully-sampled t=9.5ms point at left and the FSE template image (from t=TE=8ms) at right. The red box denotes an example of FSE template contrast increasingly influencing the modified-CS reconstruction at higher undersampling factors.

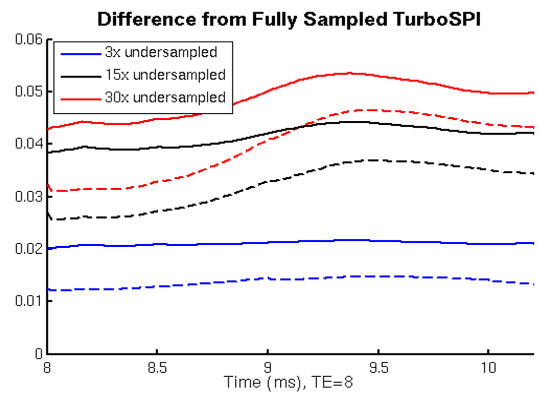

Figure 2. nRMSE between reconstructed images and fully-sampled data, for three different undersampling factors. Dashed lines: method 1 (difference transform). Solid lines: method 2 (modified-CS)

Results and Discussion: Figure 1 shows TurboSPI images reconstructed using various undersampling factors, as well as the corresponding fully-sampled data and the FSE template image. The difference-transform approach offers suitable reconstruction quality throughout the time series for low undersampling factors, but performs less effectively as the undersampling factor increases, leading to increased blurring and loss of contrast. The modified-CS method retains small details even at higher undersampling factors, and the overall contrast matches that of the fully sampled data throughout the time course; however, as undersampling increases, the reconstructed images begin to more closely resemble the FSE image in terms of smaller details and fine contrast. For example, the red boxes in Figure 1 highlight an area where contrast from the FSE image, which is slightly different from TurboSPI, appears in the modified-CS reconstruction but not the difference-transform reconstruction. This underscores the importance of having a FSE image of high quality and with parameters identical to the TurboSPI dataset it is intended to guide.

As shown in Figure 2, the nRMSE of reconstructed images increases with undersampling factor, and is largest for those volumes with contrast most different from the guide image (around t=9-9.5ms, due to destructive interference between water and unsuppressed fat signal). The nRMSE of the difference-transform method is actually slightly lower than that of the modified-CS method at all undersampling factors, which likely reflects the additional influence of the template on these images, which has an nRMSE of 0.06 compared to the fully-sampled t=TE volume. Improvements to the guide would likely have more impact on the performance of the modified-CS method. Both methods show a decrease in image SNR with time, as compared to the fully-sampled data, since residual artefact compounds from one volume to the next. We are exploring group-based reconstructions that will reconstruct multiple volumes concurrently, in an attempt to mitigate this SNR degradation. Alternative sampling schemes (such as Poisson-disk sampling with variable density prescribed by the FSE template) may also allow these artefacts to be further reduced.

Conclusions: It is possible to reconstruct TurboSPI datasets that have been significantly undersampled (by factors of up to 30) using a matched FSE template image to provide prior information that guides the reconstruction. Assuming good quality templates, the modified-CS reconstructions remain of useable quality throughout the time series, and will permit TurboSPI to be applied to *in vivo* imaging with reasonable scan durations.

References: [1] M. Lustig et.al., *MRM* 58 p.1182-1195 (2007) [2] N. Vaswani and W. Lu, IEEE Trans Signal Proc 58 p.4595-4607 (2010) [3] J. Rioux et.al., *J. Magn Reson*, submitted October 2011. [4] J. Rioux et.al., Proc. 18th ISMRM, no.4853. [52] P. Parasoglou et.al., *J. Magn Reson* 201:1 p.72-80 (2009)