Compressed sensing undersampling strategies for accelerating 3D cine MRI in mouse hearts

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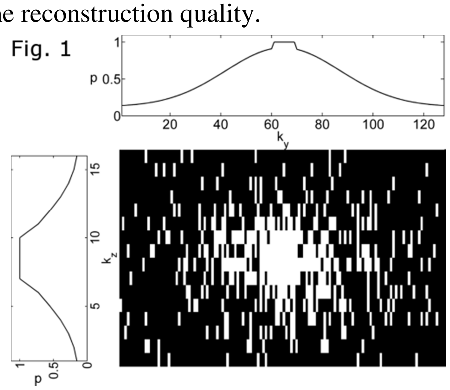
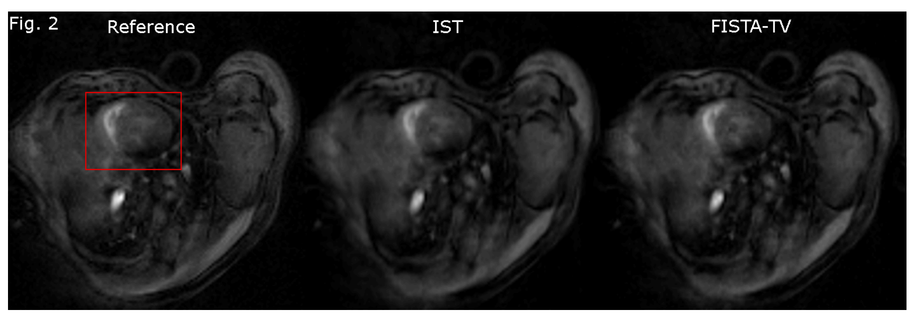
Target audience: Scientists and clinicians interested in fast cardiac MRI in mice.

Purpose: Cine magnetic resonance imaging (cine-MRI) to assess global cardiac function in surgically or genetically modified mice is typically performed using fast 2D spoiled gradient echo type sequences in combination with prospective ECG- and (optional) respiratory-gating. Conversely, 3D techniques provide improved signal-to-noise, which could be utilized to increase spatial resolution and therefore aid studies, where for example isotropic voxel sizes are essential. While such an approach would eliminate the need for planning the imaging slab in short-axis orientation, it may potentially increase the acquisition time significantly necessitating the need for dedicated acceleration techniques. The additional phase encoding direction holds the potential of higher acceleration factors when applying compressed sensing strategies, as undersampling artifacts may be distributed more incoherently compared to 2D acquisitions. The aim of this study was to investigate two different compressed sensing [1] algorithms as an approach to accelerate 3D cine-MRI in mice at 9.4T.

Methods: Cine-MRI was performed on a horizontal 9.4T MR system comprising a VNMRS DDR2 console (Agilent, Santa Clara, US), a 1000 mT/m gradient system and a quadrature driven birdcage coil (id 33mm – Rapid Biomedical, Germany) optimised for cardiac application in three C57Bl6 mice. A retrospectively gated 3D FLASH imaging sequence was implemented [2] (TE/TR=1.1/4.6ms, 128x128x16, 32 frames, 10 repetitions, 25.6x25.6x12mm, 8mm slab thickness, navigator slice thickness 1mm; total acquisition time: ~50mins). Fully sampled data sets were then reconstructed consisting of 30 frames, which were subjected to undersampling (by factors 3 to 15) in offline post-processing by randomly selecting phase encoding steps from the two phase encoding directions (k_y/k_z) of the fully acquired data set. The sampling scheme approximated a Gaussian density distribution with maximum density at low frequencies and was varied across the whole cycle of all acquired cine-frames. The center of k-space was fully sampled throughout all frames (Fig. 1). These datasets were then subjected to an iterative soft thresholding algorithm [3] exploiting spatio-temporal sparsity [4] (IST) as well as to a fast iterative shrinkage-thresholding algorithm for linear inverse problems [5] with an additional total variation constraint (FISTA-TV), promising improved image recovery for high acceleration factors. The RMSE to the fully sampled reference was determined for each acceleration factor R within the region of the heart in order to estimate the reconstruction quality.





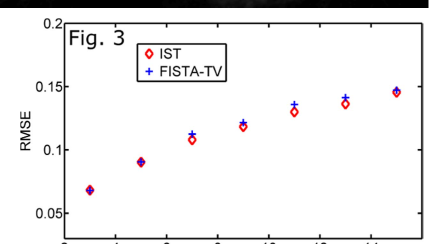


Fig.1: Sampling pattern in k_y-k_z-direction exemplarily for one time frame. The plots show the sampling probability p. Fig. 2: Results of the image reconstruction using the fully sampled dataset as well as the compressed sensing reconstructions of the undersampled ones (R=10). Fig. 3: RMSE-values within the red box (Fig. 2) for different degrees of acceleration R.

Results: Figure 2 shows a mid-ventricular slice for the end-systolic frame both for the fully sampled reference and the compressed sensing reconstructions of 10-fold undersampled datasets. The visual grading of the image quality was constant throughout all partitions and timeframes. Except for a slight blurring, the compressed sensing reconstructions resulted in a comparable image quality as obtained for the reference. The RMSE is similar for the two algorithms throughout all degrees of undersampling.

Discussion & Conclusion: Our study demonstrates that compressed sensing enables drastic time savings in high resolution 3D cine imaging in mouse hearts. Both IST and FISTA-TV resulted in acceptable RMSE-values even for R=15. Future work will improve spatial resolution and aims to investigate the impact of undersampling/compressed sensing on the temporal / spatial resolution and finally on the accuracy of global cardiac functional parameters.

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