A GPU Implementation of Compressed Sensing Reconstruction of 3D Radial (kooshball) Acquisition for High-Resolution Cardiac MRI

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Introduction

3D radial (kooshball) trajectory allows high isotropic resolution with superior motion and flow properties. However, it suffers from long acquisition and reconstruction time. While highly undersampled kooshball is more forgiving in terms of artifacts than Cartesian, the streaking artifacts could impact the clinical interpretation. Compressed sensing (CS) [1] has potential to remove these artifacts; however the heavy computation of the CS reconstruction has been the limiting factor of its application. Recently graphical processing units (GPU) have become available which potentially can mitigate this limitation. In this study, we investigated the utility of a GPU-accelerated CS reconstruction for whole heart anatomical imaging with isotropic resolution.

Materials and Methods

The kooshball trajectory [2] has \( N_i \) interleaves, and \( N_p \) projections in each interleaf. Interleaves are rotated versions of the first interleaf around \( k_z \)-axis (Figure 1). The MR signal is formulated as \( y = Ax \), where \( y \) is the acquired k-space samples, \( x \) is the desired image, and \( A \) is the encoding matrix. \( A \) can be regarded as the reverse steps of conventional gridding reconstruction [3] without density compensation. An image \( x \) is reconstructed from the k-space data by solving \( \arg \min_x \|y-Ax\|^2 + \lambda \|x\|_1 \) iteratively, where the \( l_1 \) norm of the image coefficient is used for regularization [4]. The iterative process is demonstrated in Figure 2. CS reconstruction was implemented in CUDA on GPU and C++ to compare the reconstruction time.

![Figure 1: A kooshball trajectory.](image)

All scans were performed on a 1.5T Philips (Achieva) magnet with 5-ch cardiac coils using free breathing ECG-triggered SSFP sequences. Whole heart kooshball data sets with sampling densities 7, 12, 24, and 36% were acquired to evaluate the image quality of CS reconstruction. The scan parameters are: TR/TE/\( \alpha \) = 3.9/1.94/60°, resolution = (1.4mm\(^3\)), FOV = (240mm\(^3\)). Whole heart data sets with resolution = (1.3mm\(^3\)), FOV = (256mm\(^3\)), sampling densities 10-40% were scanned for measuring the reconstruction time. A phantom data set with resolution = (1.3mm\(^3\)), FOV = (226mm\(^3\)), and 7.5% of sampling was used to observe the convergence property of the iterative CS reconstruction method.

Results

Figure 3 shows an example slice of phantom image with different number of iterations to investigate the convergence property of the CS algorithm. The streaking artifacts are gradually removed while the image becomes slightly more blurry up to 500 iterations. After additional 2500 iterations the image looks more refined with improved sharpness and preserved edges.

![Figure 3: CS reconstruction of a phantom (sampling density = 7.5%) with different number of iterations. Streaking artifacts are gradually removed with some blurring up to 500 iterations. With additional iterations the streaking artifacts are suppressed with improved sharpness.](image)

![Table 1: Average time required in one iteration of the CS reconstruction with CUDA and C++, and associated speedup (SU) for different sampling densities (10-40%). CUDA yields 34.3-53.9 times SU compared to C++ implementation. (\( N_i \): # sample/projection, \( N_p \): # projection/interleaf, \( N_s \): # interleaves).](table)

![Figure 4: Example slices of axial and sagittal views from 3D whole heart images reconstructed by conventional gridding algorithm and iterative CS method for different sampling densities. CS provides improved image quality for low sampling densities.](image)

Conclusions

GPU implementation reduces the duration of a CS reconstruction of a typical 3D kooshball data of the heart with 34-54 times speedup. This allowed us to investigate the utility of CS in reducing the scan time by decreasing the sampling density. Initial results show superior CS-reconstructed images at lower sampling density when compared with conventional gridding.

References


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