How to stack the stars: a variable center-dense k-space trajectory for 3D MRI

Benjamin Paul Berman[1], Zhitao Li[2], Maria I. Altbach[3], Jean-Phillipe Galons[3], Diego R. Martin[3], Bin Dong[4], Puneet Sharma[3], Bobby T. Kalb[3], and Ali Bilgin[2,5]
[1]*Applied Mathematics, University of Arizona, Tucson, Arizona, United States,* [2]*Electrical and Computer Engineering, University of Arizona, Tucson, Arizona, United States,* [3]*Medical Imaging, University of Arizona, Tucson, Arizona, United States,* [4]*Mathematics, University of Arizona, Tucson, Arizona, United States,* [5]*Biomedical Engineering, University of Arizona, Tucson, Arizona, United States*

Introduction: There is constant demand for high quality images and short data acquisition times for MRI. Traditionally, a choice is made for one or the other, but due to the development of compressed sensing (CS) theory, it is often possible to have both. Provided the image has a sparse representation, and the measurements are sufficiently uncorrelated, CS can be used to iteratively reconstruct high resolution images from a very small amount of data relative to the Nyquist criterion. For 3D MR imaging, various trajectories are used to undersample in Fourier space including Cartesian, radial, and cylindrical. The cylindrical trajectory – or stack-of-stars – is used for dynamic and motion sensitive 3D imaging[1]. Since CS uses a limited amount of data, it is crucial that each measurement contain as much information as possible. For MRI, this often means measuring more low frequency data. In a 2D radial trajectory, the center of Fourier space is automatically well sampled based on the radial geometry; in a 2D Cartesian trajectory, it is necessary to measure additional lines in the center. In this work, we show that the 3D stack-of-stars trajectory benefits from an extension of this center-dense sampling scheme. Rather than adding addition planes of acquisition in the low frequency region, we vary the number of radial views at each location along the stack.

Methods MR images can be reconstructed by exploiting their sparsity with respect to wavelets and total variation. A modified version of the sparseMRI[2] algorithm for 3D imaging is applied to the optimization problem $\mathbf{argmin}_x \; ||F\mathbf{x}-\mathbf{d}||_2 + \alpha \cdot ||W\mathbf{x}||_1 + \beta \cdot TV(\mathbf{x})$. Here, **x** denotes the image, **d** the acquired data; F denotes the undersampled 3D Fourier transform, W the wavelet transform (here, symmlets), and TV the total variation measure. α and β are weighting parameters. The solution is determined using an iterative backtracking line search. In order to directly compare the effects of variable density sampling, a data set obtained using a 3D VIBE pulse sequence on a 1.5T Siemens scanner was used (TE=2ms, TR=3.79ms, flip angle=10°). This dataset was retrospectively undersampled at several undersampling ratios using both uniform and center-dense stack-of-stars k-space trajectories. The undersampling fraction and total number of views was consistent between both uniform and non-uniform trajectories. In order to construct the non-uniform trajectory, a relative distribution of views was designed for dense scanning of low frequency data, and the number of lines per k_z plane was computed probabilistically. Figure 1 illustrates both acquisition schemes in k-space.

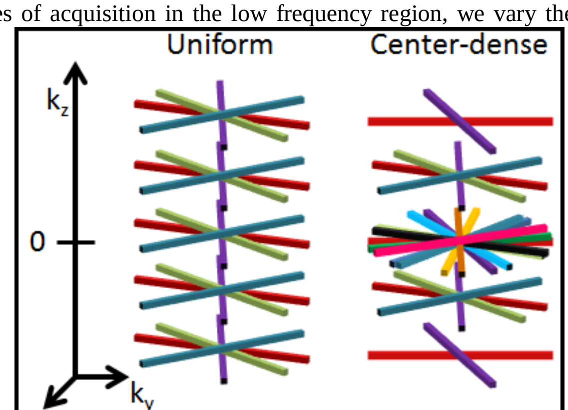

Figure 1

Results and Discussion Figure 2 shows a comparison of several 216x288x96 reconstructions from uniform and non-uniform stack-of-stars trajectories, each undersampled at fractions 1/2, 1/4, 1/6, and 1/8. The resolution along each view is fixed to 288 steps. The highlighted region of interest contains a 1cm diameter hepatocellular carcinoma (HCC, arrow) during the venous phase of a dynamic contrast enhanced image. HCCs are often hard to detect, but can be seen at all undersampling fractions for the variable density scheme. In contrast, the conspicuity of the HCC decreases significantly with increasing undersampling fraction for the uniform density scheme. For each reconstruction the structural similarity index[3] (denoted as SSIM) is measured to quantify the visual difference from the original image. The center-dense trajectory leads to a clearly visible reduction in artifacts, in addition to a much improved SSIM, when compared to a uniform stack-of-stars with the same number of radial views. The SSIM of the half-sampled variable density reconstruction suggests that it is nearly identical to the original image; the SSIM of the eighth-sampled variable is even greater than the quarter-sampled uniform due to the preservation of edges and the lack of streaking artifacts.

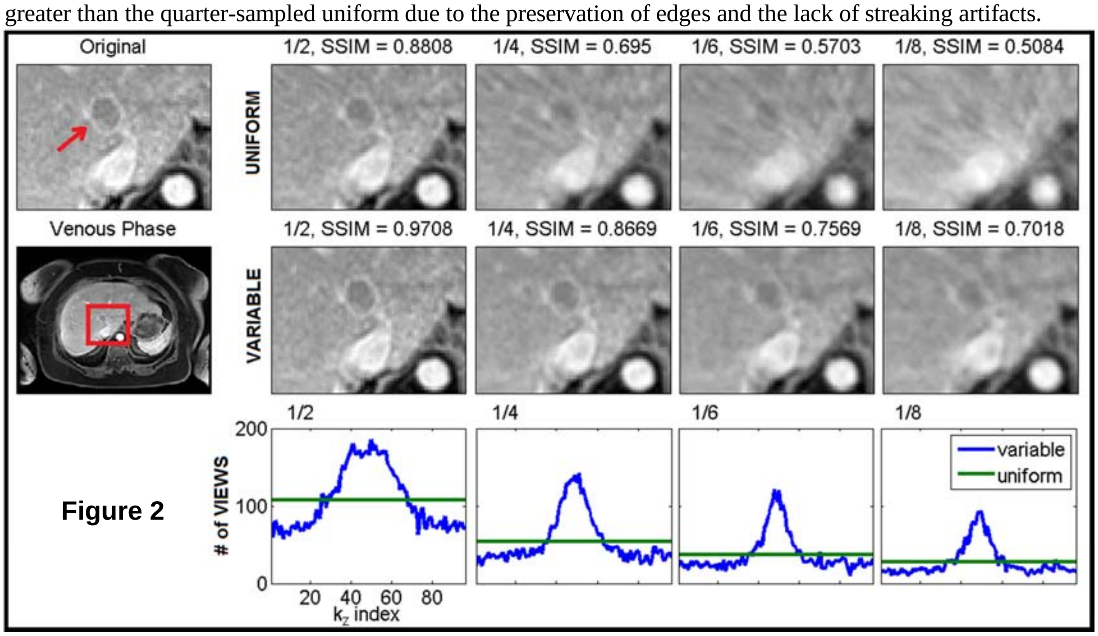

Figure 2

Conclusion Image quality for an undersampled 3D stack-of-stars can be significantly improved by increasing the number of radial views in the low frequency region of Fourier space. In the clinic, the reduction of data acquisition time with minimal loss in image quality can lead to shorter breath holds or even free breathing during the scan.

References [1] Chandarana et al., ISMRM 2012: 4206. [2] Lustig et al. MRM 58(6) 1182-1195, 2007. [3] Wang et al. IEEE TIP 13 (1) 2004.