# Highly Accelerated 3D Dynamic Imaging with Variable Density Golden Angle Stack-of-Stars Sampling

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Introduction: Dynamic contrast-enhanced (DCE) MRI is routinely used in clinical applications. In DCE MRI, it is desirable to have both high spatial and temporal resolution. High temporal resolution is needed for accurate kinetic data analysis and high spatial resolution makes it possible to identify small structures more consistently. Recently, radial DCE MRI techniques have been introduced and combined with compressed sensing (CS) to accelerate DCE MRI [1,2]. Radial trajectories provide many desirable attributes in these applications: The oversampling of the center of k-space as well as the incoherent artifacts resulting from undersampled trajectories can be exploited in CS. Radial trajectories are also known to be less sensitive to motion. A dynamic MRI technique using 3D stack-of-stars radial trajectories was recently proposed for free breathing 3D liver perfusion MRI [2]. In this work, we propose a highly accelerated 3D dynamic MRI technique which uses 3D stack-of-stars radial trajectories with non-uniform kz sampling.

Fig. 1

Methods: In golden angle radial trajectories, radial lines are rotated by the angle 111.25° to achieve relatively uniform distribution of the radial spokes at any time point and temporal window length [3]. In a 3D stack-of stars trajectory, 3D k-space is sampled radially along kx-ky and uniformly along kz. Recently, a 3D golden angle stack-of-stars trajectory was proposed [2]. In [2], one radial spoke at the same angle is acquired for each kz plane. The radial acquisition angle is then incremented by the golden angle and radial acquisition is repeated for each kz plane. Thus, radial lines acquired over any time period can be combined to reconstruct a 3D image since the golden angle sampling ensures uniform distribution of the radial spokes across kx-ky planes. Fig. 1a illustrates this trajectory when 4 radial lines are combined for each time point.
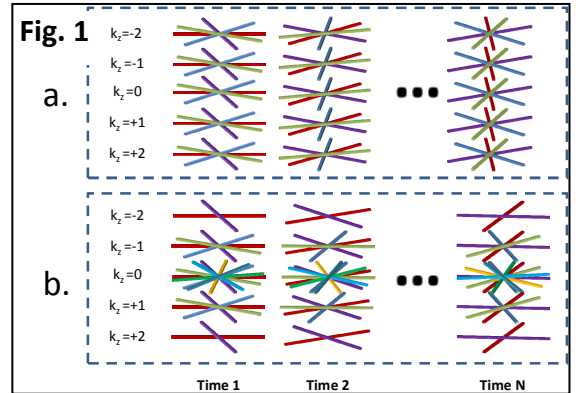
While the trajectory in Fig. 1a allows high flexibility for temporal windowing during reconstruction, it has undesirable properties along kz in terms of CS reconstruction. In CS, it is desirable to have variable density sampling with more samples at lower frequencies and less samples at higher frequencies. Such variable density schemes have been previously shown to provide significantly enhanced reconstructions in both 2D and 3D applications [4]. Thus, we propose a variable density radial stack-of-stars acquisition scheme for 3D dynamic MRI applications. In our proposed scheme, the number of radial lines acquired at each kz plane is non-uniform as illustrated in Fig 1b. To preserve the temporal flexibility enabled by golden angle increments, the acquisition angle in each kz plane is recorded individually and incremented whenever a new radial line is acquired at that kz plane. This strategy allows relatively uniform distribution of radial spokes in each kz plane regardless of the time point and temporal window used.

Experiments were performed to compare the performances of different trajectories under varying undersampling ratios. A 192×192×32×180 (x,y,z,t) renal dataset with 3mm slice thickness acquired using a dynamic 3D VIBE pulse sequence on a 1.5T Siemens scanner was retrospectively undersampled in k-space to simulate accelerated acquisitions. Images were recovered from undersampled k-space data by solving the CS reconstruction problem:

$$\arg\min_{x} \left\| Fx\text{-}y \right\|_2^2 + \lambda_1 \|Wx\|_1 + \lambda_2 TV(x)$$ where **F** denotes the undersampled Fourier transform operator, **x** denotes the image to be reconstructed, **y** denotes the undersampled k-space data, **W** denotes the wavelet transform used as the sparsifying transform, and **TV**() denotes the total variation operator. λ_1 and λ_2 are regularization parameters. A non-linear conjugate gradient algorithm was used to solve the CS problem. Note that the CS problem was solved at each time point without temporal sparsity constraints which may provide additional improvement at the expense of increased computational complexity and memory requirements.

Results and Discussion: Representative images using different k-space trajectories and undersampling ratios are shown in Fig. 2. In the figure, it can be seen that variable density kz undersampling preserves the definition of the kidneys better than uniform undersampling (arrows). A major problem in abdominal imaging is motion artifacts due to respiration. Motion correction using image registration is often applied to abdominal images prior to quantitative analysis. The enhanced edge strength obtained by variable density kz sampling should lead to better image registration.

Fig. 2 Original — 1/6 Undersampled — 1/8 Undersampled — UNIFORM — VARIABLE

Fig. 3 Artery — Kidney

The ability of the proposed variable density sampling scheme to preserve temporal fidelity is illustrated in Fig. 3. In the figure, temporal variation of intensity for two different ROIs (artery and kidney) is shown for the 1/8 undersampling ratio. The figure illustrates that the temporal characteristics obtained from this highly undersampled dataset matches very well with the original.

Conclusions: A highly accelerated volumetric dynamic MRI technique using variable density stack-of-stars 3D golden-angle radial trajectories was presented. The proposed technique can be used for 3D free breathing abdominal imaging applications to provide both high spatial and temporal resolutions.

References: [1] Bilgin, A. et al., Proc. ISMRM (2008). [2] Feng. L. et al. Proc. of ISMRM (2012). [3] Winkelmann S, IEEE TMI 26:68-76, 2007. [4] Lustig M, et al. MRM 58:1182-1195 2007.