Highly Undersampled 3D Golden Ratio Radial Imaging with Iterative Reconstruction

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Introduction

Compressed Sensing (CS) [1,2] suggests that using nonlinear reconstruction algorithms based on convex optimization an accurate signal reconstruction can be obtained from a number of samples much lower than required by the Nyquist limit. Recently, CS was demonstrated for MR imaging from undersampled data [3, 4]. Prerequisites for a good image reconstruction are the image compressibility and the incoherence of the sampling scheme. To exploit the full potential of CS, measurement samples should be acquired at random. However, random sampling of the k-space is generally impractical. Variable density sampling schemes (radial, spiral) lead to incoherent aliasing and are also advantageous because of their higher sampling density about the k-space origin, where most of the signal energy is contained. 3D variable density sampling is potentially appropriate for CS, because the noise-like aliasing is distributed within the complete volume, allowing high undersampling factors. Image reconstruction from a low number of measurements could be very useful for dynamic 3D imaging, to reduce the often long acquisition times and thus improve temporal resolution in 3D MRI.

In this work, we demonstrate the applicability of CS for 3D dynamic imaging using highly undersampled 3D radial acquisition with golden ratio profile ordering [5,6].

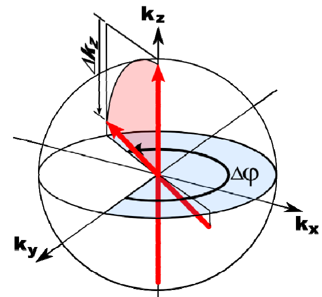

Figure 1: 2D Golden ratio increments Δkz and Δφ between subsequent radial readouts.

Methods

A 3D radial sequence [7] was applied that aims for a quasi-isotropic distribution of radial profiles in 3D k-space over the total duration of a scan as well as over an arbitrary time window extracted from a scan for dynamic imaging. This is achieved by using 2D golden ratios $\alpha = 0.4656$ and $\beta = 0.6823$ [8] to calculate the increments $\Delta kz = 2\alpha$ and $\Delta\varphi = 2\pi\beta$ (Fig. 1) for successively measured projections. The isotropic distribution of profiles over time was used to perform dynamic imaging, by reconstructing images from small sections of the data (frames), during which dynamic changes are considered to be negligible. Conventional gridding reconstruction of undersampled 3D radial data often leads to images in which the imaged object is visible, but compromised by aliasing artifacts. To improve the image quality, images for each frame were iteratively reconstructed, solving the constrained optimization problem

$$\min_m \|\Psi m\|_1 \text{ , such that } \|F_u m - y\|_2 < \varepsilon \text{ ,}$$

where Ψ is the finite difference transform, F_u is the undersampled Fourier operator, y is the data in k-space, m is the image and ε controls the fidelity between the measured data and the k-space data at each iteration step. The L1 norm of the finite difference transform is known as the total variation (TV).

To demonstrate the described approach, scanning was performed on healthy volunteers on a 1.5 T scanner (Achieva, Philips Medical Systems), using a birdcage head coil. Imaging during continuous hand motion was performed with the following parameters: an isotropic field of view (FOV) of 256 mm, TE = 4.5 ms, TR = 7.1 ms, flip angle α = 10°, matrix size 128^3, applying 2D golden section sampling. 32766 profiles were acquired, corresponding to full sampling according to the Nyquist limit. The total duration of the scan was 3 min 34s. The measured data were divided into 64 frames, measured in chronological order. Images for each frame were reconstructed with conventional gridding reconstruction and with L1 penalized iterative reconstruction. The iterative reconstruction was initialized with a zero image, 200 iterations were performed and the total duration was two hours.

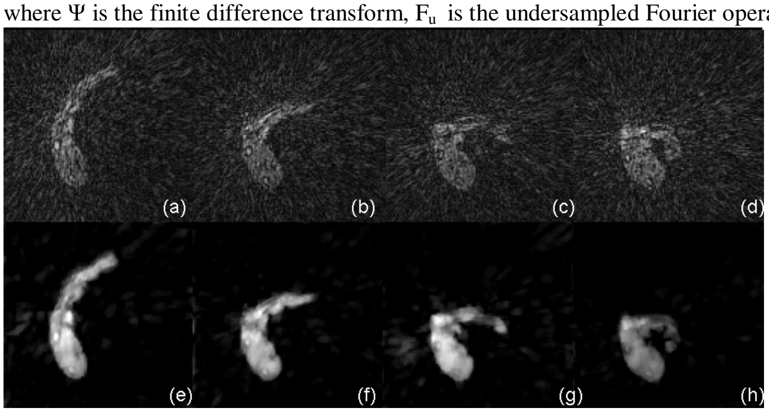

Figure 2 3D dynamic imaging of the hand. A single coronal slice extracted from the 3D data is shown for four frames (from left to right). Images, reconstructed with conventional gridding reconstruction ((a)-(d)) suffer from severe aliasing artifacts. The aliasing is significantly reduced in the iteratively reconstructed images.

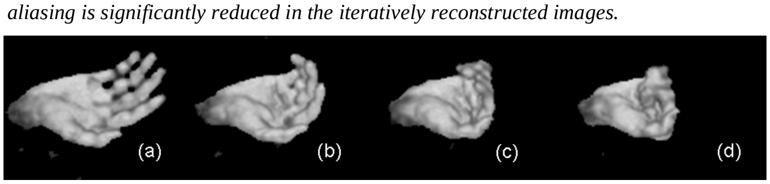

Figure3 3D surface rendered images of the hand, obtained with L1 penalized iterative reconstruction from 1/64 of the data, showing the hand motion.

Results and Discussion

Fig. 2 illustrates the results of the conventional and the iterative reconstruction. A single slice extracted from the reconstructed 3D image of the hand is shown following the hand motion at different time frames. The gridding reconstruction exhibits severe aliasing artifacts (Fig. 2 (a)-(d)). The streaking artifacts are strongly suppressed by the TV minimization reconstruction ((e)-(h)). For better visualization of the hand position in each frame a surface rendered images, obtained from the iteratively reconstructed images, are shown on Fig.3.

Conclusions

We have demonstrated the basic feasibility of CS for 3D golden ratio radial imaging. A high frame rate was achieved, allowing dynamic imaging with good temporal resolution. The described approach could be particularly useful for dynamic studies of joint motion or contrast media inflow.

References: [1] Candes E et al, IEEE Tran Info Theo 2006 52:489-509; [2] Donoho D, IEEE Tran Info Theo 2006 52: 1209-1306; [3] Lustig M. et al MRM 2007 online [4] Block K et al MRM 2007 57:1086-1098 ; [5] Winkelmann S et al, IEEE Trans Med Imag 26:68-76 [6] Chan R et al ISMRM Workshop Non Cart Imaging 2007; [7] Barger A et al, MRM 2002 48:297-305; [8] Anderson P, J of Electronic Imaging 1993: 147-54