Respiratory Phase Compressed Sensing Reconstruction using Highly Under-sampled Stack-of-stars Radial Acquisition

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Target audience:

MR researchers interested in minimizing artifact in image reconstruction using free breathing data

Purpose:

Respiratory motion causes imaging artifacts and blurring effects in upper abdominal MRI. Breath holding MR acquisition has been widely used to address this issue. However, breath holding acquisition limits the total acquisition time to tens of seconds and is challenging for patients who have difficulty holding their breath. Recently, it has been demonstrated that a self-gated stack-of-stars MRI acquisition is promising in acquiring images during free breathing[1]. In the technique, radial spokes are rebinned into several respiratory phases according to their magnitude in the center of K space, and then non-uniform fast Fourier transform (NUFFT) was utilized to reconstruct images in each respiratory phase. However, the number of radial spokes in each respiratory phase does not fulfill the Nyquist sampling rate, which might lead to severe streak artifacts. In this study, we sought to develop a compressed sensing (CS) reconstruction method that provides artifact free multiple respiratory phases 3D images using under-sampled golden angle radial acquisition.

Materials and Methods:

A golden angle 3D radial stack-of-stars spoiled gradient echo sequence with fat suppression was utilized to acquire data. The golden angle is referred to as the 111.25° angular increment between two adjacent radial spokes. During any given period of sampling time, the golden angle acquisition provides nearly uniform coverage of a 2D K space. With a consent, a 30 years-old male was scanned with the following imaging parameters: a TE/TR of 1.7/3.5 ms, a slice thickness of 3 mm, 56 partitions with a 6/8 partial Fourier acquisition with an interpolated to 112 partitions, a FOV of 36 × 36 cm^2 and a matrix size of 320×320. The total number of spokes is 2000 for each partition. Each spokes has 640 samples (2x oversampling). The imaging plane was acquired in sagittal orientation. 1005 spokes are needed to fulfill the Nyquist sampling rate. Since every radial spoke samples the k space center, the signal variation at the K space center from spoke to spoke is assumed to be caused by motion. Similar to the method proposed by Grimm[1], averaged amplitudes of three samples at the center of each radial spoke at Kz=0 was used to construct a temporal signal curve with each temporal point representing one radial spoke. Because heart beats at a higher frequency than the respiratory motion, a Gaussian lowpass filter (σ = 0.5 s) was applied to minimize signal variations induced by cardiac signal. The assumption that K-space center signal variation from spoke to spoke represents respiratory phases may not hold true in the presence of other signal variation sources. As shown in Fig. 1, the temporal signal curve shows variation at the expected respiratory frequency (20-30/min) along with a low frequency signal change. A temporal de-trending was then used to remove the slow varying single fluctuation caused by non-respiratory factors (Fig 1). After the de-trending, all spokes were grouped into 20 bins with each bin representing a respiratory phase. There are 100 spokes in each bin, which is ~10% of the Nyquist sampling rate. As expected, these highly under-sampled data result in severe streak artifacts in the reconstructed images. As shown in Fig 2, after binning the spokes into different respiratory phases, the 2D K space is no longer uniformly covered as that in the conventional golden angle acquisition. Inspired by a previous method in which temporal total variation (TV) was utilized[2], we utilized a respiratory phase TV (CS-TV_{phase}) in CS image reconstruction. The iterative CS reconstruction was performed via (1).

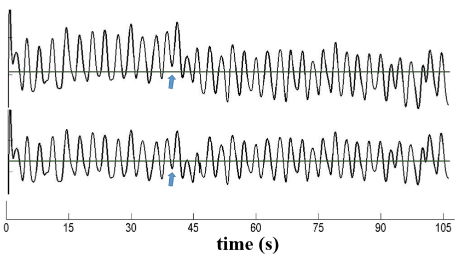

Fig. 1. Signal temporal curve before (top) and after detrending (bottom). Blue arrows marked a temporal point that were binned into different respiratory phases before and after de-trending.

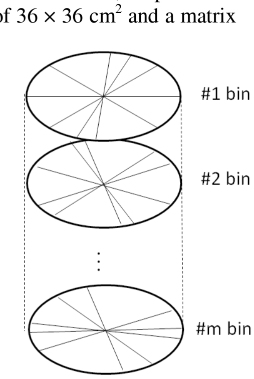

Fig. 2. Spokes scheme in each bin. m is the total number of bin.

$$minimize \quad \|FT * b1 * \rho - \mathbf{s}\|_2^2 + \lambda_{\mathrm{TV}} \|\mathrm{TV}_{Phase}(\rho)\|_1 , \qquad (1)$$

where FT is the NUFFT, b1 is the sensitivity of coil elements, ρ is the estimated image, s is the acquired k-space data, λ_{TV} is the regularization weight for the TV regularization term, and TV_{phase} can be written as,

$$\mathrm{TV}_{phase}(\rho) = \sum_{i=1}^{m-1} (\rho_i - \rho_{i-1}) \qquad (2)$$

where m is the total number of respiratory phases, ρ_i and ρ_{i-1} is the i^{th} and the $(i-1)^{th}$ respiratory phase. To compare the reconstruction performance, a CS reconstruction using an image TV (CS-TV_{image}) which is the spatial gradient of the image, while all other terms remaining the same was also used[3].

Results:

The images of NUFFT show severe streak artifacts (Fig 3, left). CS-TV_{image} reduces some of these artifacts (Fig. 3, middle). Images reconstructed using CS-TV_{phase} are free of artifacts (Fig. 3, right). High signal-to-noise and contrast-to-noise ratios are also achieved using CS-TV_{phase}.

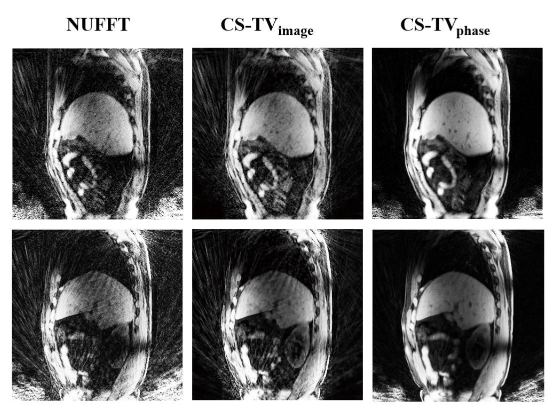

Fig. 3. Images reconstructed using NUFFT, CS-TV_{image} and CS-TV_{phase}

Conclusions:

The CS-TV_{phase} method can significantly improve the image quality in reconstructing multi- respiratory phase 3D images using a radial stack-of-stars acquisition during subject free breathing.

References:

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