Handling Motion in Sparse Reconstruction with Whiskers

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INTRODUCTION

In dynamic imaging it is often beneficial to enforce both temporal and spatial sparsity to minimize the number of sparse coefficients required to represent the object (1,2). In general, the minimum number of K-Space samples required to produce good results in sparse reconstruction is approximately four times the number of sparse coefficients (3). Patient motion that is periodic or smooth can be sparsely represented in a Wavelet-Fourier domain. Patient motion that is neither periodic nor smooth will reduce sparsity in the temporal direction and degrade the success of the sparse reconstruction. It is therefore beneficial to detect and correct as much patient motion as possible to maximize temporal sparsity and thus reduce the total number of K-Space samples required. This is accomplished using a hybrid Radial-Cartesian sampling technique called Whiskers (4). This sequence has an inherent ability to correct bulk patient motion and is well suited to non-linear sparse reconstruction.

THEORY

This work utilizes a pulse sequence named Whiskers (for the whiskers looking pattern in K-Space and lack of a clever acronym) that combines the resolution and undersampling characteristics of radial imaging with the motion correction techniques of Cartesian trajectories. The sequence acquires data near the edge of K-Space in a radial fashion (Fig. 1a) and rectilinearly near the center of K-Space (Fig. 1b). Each segment of the Whiskers sequence acquires different radial arms of K-Space but always acquires the same set of Cartesian lines at the center of K-Space. As a result, for each segment we have a low resolution image of the object which can be used to detect rigid body motion and rotation. The segmented data set is then corrected for this motion prior to reconstruction. In addition to motion, low order phase variations can be problematic in sparse reconstruction (1). This type of phase error can also be easily quantified with the Whiskers sequence and consequently corrected prior to reconstruction. The Whiskers sequence also produces nearly incoherent artifacts similar to that of a radial trajectory, making it a suitable candidate for sparse reconstruction.

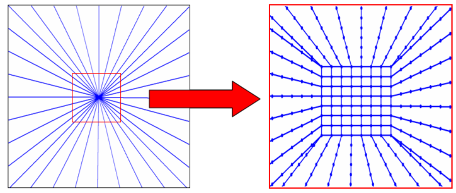

Figure 1. K-Space trajectories for one segment of a Whiskers sequence (a), with a magnified portion showing the rectilinear center (b).

METHOD

In these simulations we adopt a reconstruction method often used with KT-Sparse (2):

$$\begin{aligned} &\text{minimize} \quad \left\| \Im_t \{ W_r [m] \} \right\|_1 + \lambda \left\| \psi m \right\|_1 \\ &\text{s.t.} \quad \left\| S(\vec{k}) F\{ m(\vec{r}) \} - y(\vec{r}) \right\|_2^2 < \varepsilon \end{aligned} \quad [1]$$

The phantom used contains dynamic and static vessels, structures that have sharp edges and structures with gradual changes in contrast (Figure 2).

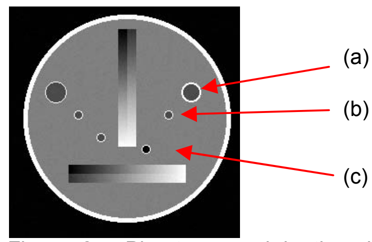

Figure 2. Phantom used in the simulations. Labels are the dynamic areas, with a vessel that is stationary but changes in size (a), a vessel that moves (b) and a vessel that moves and has a time dependent phase (c).

DISCUSSION

For the first simulation the bulk motion of the phantom has been corrected with Whiskers prior to the sparse reconstruction. As a result, the number of sparse coefficients per frame (L_0 type measure) is only about 4x256 data points. The K-Space is undersampled by a factor of 8 (we only acquire 32x256 data points for each of 15 temporal frames) and both spatial and temporal constraints are enforced in the reconstruction. Since our number of samples is about 8 times the number of sparse coefficients, we obtain good results. A difference image for one frame is shown in Fig 3a. In the second simulation the entire phantom has uncorrected rigid body motion superimposed onto the dynamic motion of the vessels. The number of sparse coefficients (using the same measure as the first simulation) is now approximately 32x256 data points. That is to say, we have as many sparse coefficients as we do sampled K-Space data points. As expected, the quality of the reconstructed image suffers (Fig 3b).

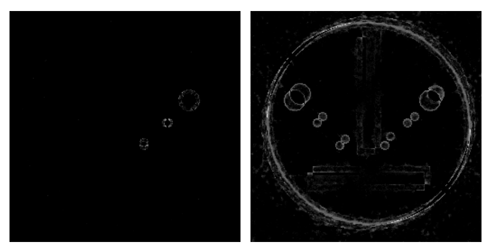

Figure 3. Difference images between a selected, fully sampled frame and the undersampled data reconstructed using sparse constraints. The error for the case where bulk motion is corrected is shown in (a) while the case with no bulk motion correction is shown in (b).

CONCLUSION

We have demonstrated that a novel Whiskers sequence is a suitable choice to be used with sparse reconstruction of undersampled data. The ability to correct for bulk motion increases temporal sparsity and reduces the number of data samples required for good results.

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