High-Resolution Dynamic Imaging with Spiral Scanning and Spatiotemporal Modeling

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INTRODUCTION:

In many dynamic MRI applications, it is desirable to acquire a time series of images from a time-varying object such as the beating heart at a high frame rate. A classical approach to achieving high frame rates is to use fast-scan methods such as the spiral methods [1, 2]. Another more recent approach is to sparsely sample (*k*, *t*)-space by taking advantage of the spatiotemporal correlation of the underlying object function [3-7]. In this paper, we integrate fast-scanning with spatiotemporal modeling to achieve higher temporal resolution. Specifically, we generalize the spatiotemporal model-based algorithm [7] to spiral trajectories, and demonstrate its effectiveness through in vivo cardiac data.

THEORY:

The basic idea of spatiotemporal model-based method [7] is that the acquired signal $d(k_i, t_j)$ can be concisely approximated by a spatiotemporal generalized series $d(k_i, t_j) = \sum_l \alpha_l(k_i)\phi_l(t_j)$ (1), where α_l and ϕ_l are coefficient and basis functions, respectively. Since the temporal and spatial variations have been completely separated into two functions, it is possible to calculate them independently. **Data acquisition**: The proposed method uses a modified interleaved spiral scanning scheme. Specifically, to increase temporal resolution, we acquire all interleaves only every *F* frames (reference frame) but only *M* interleaves for the rest frames (dynamic frame). Accordingly, the interleaves sampled in every frame can be used as the "navigation" data to determine $\phi_l(t_j)$ [7], and those sampled only in reference frame are dynamic data that determine $\alpha_l(k_i)$. **Reconstruction:** First, a $W \times NM$ matrix **S** is established using the navigation data whose entries are signals $S(t_w, k_{n,m})$ acquired at the *n*th position of the *m*th interleave in the *w*th time frame. Secondly, after applying principle component analysis to **S**, the basis function $\{\phi_p(t_w)\}_{p=1}^{P}$ can be formed by extracting the first *P* principal components. Thirdly, the series coefficient $\alpha_{n,m}(k_w)$ can be estimated by fitting the temporally sparsely sampled dynamic data with the spatiotemporal model in Eq. (1). Finally, data interpolation can be performed using Eq. (1) to estimate all the missing interleaves in the dynamic frames so that a dynamic image sequence with high resolution in both space and time is recovered. NUFFT [8] has been employed to deal with the problem of image reconstruction from non-Cartesian trajectory data.

METHOD AND RESULTS:

The dynamic data contain a 20-frame *in vivo* gated cardiac image sequence (matrix size: 256x256) sampled by a 24-interleave spiral trajectory (2286 points/interleave). The reference frames are acquired every 3 frames, and only the first interleave is sampled in each dynamic frame. The number of basis functions (*P*) was chosen to be 6. The reconstruction of the 2nd frame is given in Fig.1 (a). For comparison, the reconstruction using the sliding window method [9] is also shown in Fig.1 (b), where reduction factor is 3 and the missing interleaves for the dynamic frames were filled by the acquired interleaves in the nearest frames. To evaluate the performance of these methods, a temporal resolution improvement ratio is defined as: $\eta = 1 - (\sum_{w=1}^{W} I_{ds}(w) \Big/ (W * I_{full}))$ (2), where I_{full} is the number of interleaves for a reference frame, w is the index of time frame, and $I_{ds}(w)$ is the number of acquired interleaves for a dynamic frame. The η for the proposed method and the sliding window method are 62.29% and 66.67%, respectively. To better appreciate the improvement by the proposed method, their different images with the gold standard using the full data are also shown in (d) and (e). As can be seen, the proposed method has less swirl-artifact than the sliding window method. The improvement is also reflected in the mean-squared-error curves shown in Fig.2. The mean of sum of squared frame error is 2.03 and 2.41 for the proposed and sliding window methods, respectively.

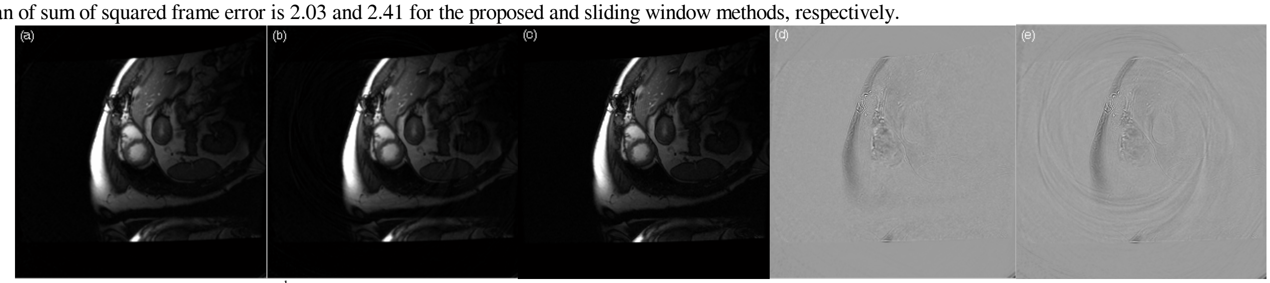

Fig. 1: Reconstructed of the 2nd frame and the error image using proposed method (a,d), and sliding window method (b,e). (c) is gold standard.

CONCLUSION:

A new dynamic MRI method integrating spiral imaging with spatiotemporal modeling has been proposed. Results show this new method outperforms the existing sliding window method in alleviating swirl artifacts. In addition, the proposed algorithm is non-iterative and computationally efficient, a desirable feature for clinical applications.

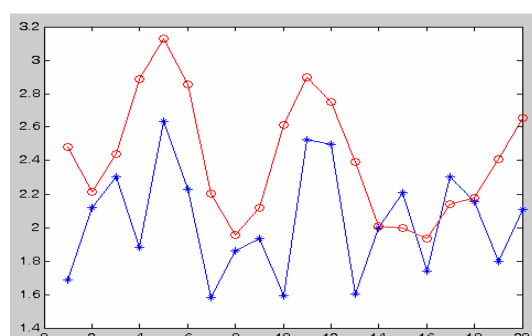

Fig.2. Mean-squared error for sliding window (o) and proposed method (*).

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