Motion-guided low-rank plus sparse (L+S) reconstruction for free-breathing dynamic MRI

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INTRODUCTION: Low-rank plus sparse (L+S) reconstruction was recently introduced as a powerful tool to reconstruct undersampled dynamic MR images with separation of background (L) and dynamic (S) components[1,2]. L+S outperforms standard compressed sensing reconstruction (based on sparsity only) and can perform background suppression without the need of subtraction. However, L+S is sensitive to respiratory motion, which causes misalignment among temporal frames and consequently the low-rank plus sparse model breaks down introducing temporal blurring in the reconstructed images. Simultaneous alignment and L+S decomposition of a series of images has previously been demonstrated for computer vision using a deformation model[3]. In this work, we bring this idea to free-breathing dynamic MRI and incorporate a non-rigid motion model in the L+S formulation to align all the frames iteratively during image reconstruction. The motion vectors are computed directly from the undersampled data and updated along with L and S. The proposed motion-guided L+S approach is tested in free-breathing dynamic imaging of the heart and abdomen.

METHODS: Dynamic images are represented in matrix form, where each column corresponds to a temporal frame. Motion-guided L+S reconstruction is performed by solving the following convex optimization problem: $[L,S] = \arg\min_{L,S} \frac{1}{2}\|EM(L+S)-d\|_2^2 + \lambda_L \|L\|_* + \lambda_S \|TS\|_1$, where E is the acquisition operator, M is the motion operator, d is the undersampled k-t data and T is a sparsifying transform for S. $\|L\|_*$ is the nuclear-norm or sum of singular values, which is used to enforce low-rank on *L*. *E* is a general linear operator that maps a dynamic image matrix to the vector of sampled k-t points. The motion operator *M* uses a deformable optical flow model (first-order Taylor series approximation) and its motion vectors are updated iteratively along with L and S employing a smoothness constraint on the motion field[4]. At each iteration, low-rank and sparsity are enforced on the registered L and S components and data consistency is enforced on the unregistered superposition L+S. The algorithm outputs the aligned background among frames in the low-rank component L and the aligned dynamic information in the sparse component S.

The method was tested on prospectively undersampled free-breathing dynamic contrast enhanced (DCE) MRI in the heart and abdomen. First-pass cardiac perfusion imaging was performed on a 3T Siemens Trio scanner using a standard 12-element body matrix coil array. 2D Cartesian perfusion data were acquired using a 192×192 matrix (FOV = 320×320 mm^2) and 40 temporal frames with 8-fold k_y-t random undersampling. DCE-MRI study in the abdomen was performed on a 3T Siemens Verio scanner using a standard 15-element body matrix coil array. 4D data were acquired using stack-of-stars sampling (radial k_x-k_y and Cartesian k_z) with 12.8-fold acceleration (20 spokes for each temporal frame). Images were reconstructed using the standard and motion-guided L+S approaches.

RESULTS: Motion-guided L+S significantly removes temporal blurring artifacts in the cardiac perfusion images compared to standard L+S (Figure 1). Temporal blurring in standard L+S is particularly visible in the myocardial wall between the left and right ventricles (arrows in Figure 1) which has lower intensity and therefore is more sensitive to leakage from other frames. Motion-guided L+S improves the visualization of contrast-enhancement of small vessels in the abdominal data set, which appear fuzzy in the standard L+S approach (Figure 2). Note that in both examples, motion is non-rigid and simple translation or rotation would not be able to effectively align the temporal frames.

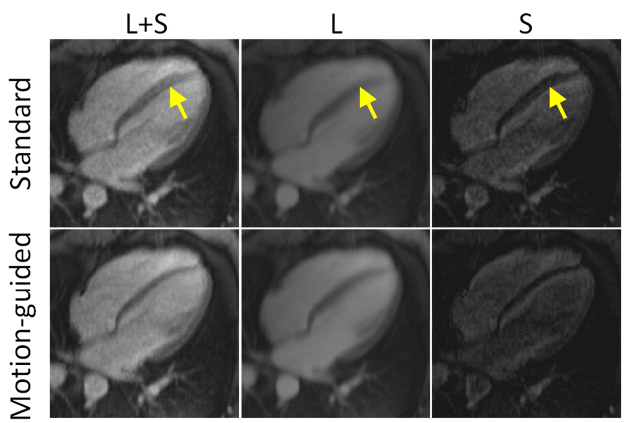

Figure 1: Standard and motion-guided L+S reconstruction of 8-fold accelerated cardiac perfusion data acquired during free-breathing. The arrows indicate temporal blurring artifacts in the standard L+S images caused by misalignment among frames.

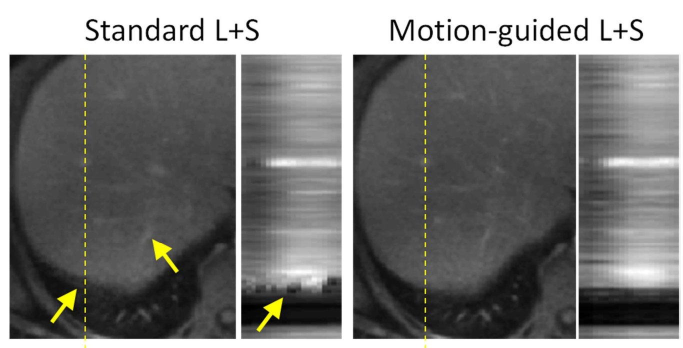

Figure 2: Liver-enhancement phase and y-t plot corresponding to the dotted vertical line for standard and motion-guided L+S reconstruction of 12.8-fold accelerated abdominal DCE radial data acquired during free-breathing. The arrows indicate temporal blurring in the standard L+S image and y-t plot, which are removed by the motion-guided L+S approach without loss of spatial resolution.

DISCUSSION: The use of a motion model in the L+S approach to register the time-series of images results in improved low-rank and sparsity conditions. Even though image registration algorithms require interpolation in the image domain, spatial resolution is preserved by the data consistency constraint. Our method does not require a reference for motion estimation and updates the motion vectors according to the reconstructed L and S components. Estimation of motion vectors from undersampled data takes advantage of the incoherent k-space sampling scheme, which produces noise-like aliasing artifacts on top of the original image without affecting significantly the motion pattern. The proposed motion-guided L+S approach may be useful for robust free-breathing dynamic MRI with separation of background and dynamic components.

REFERENCES: [1] Gao et al. ISMRM 2012; 2242. [2] Otazo et al. ISMRM Sedona Workshop 2013. [3] Peng et al. IEEE Trans Pattern Anal 2012; 34(11):2233-46. [4] Dawood et al. IEEE Trans Med Imag 2008;27(8):1164-75.