Real-Time Flow MRI with Sparse Sampling

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***Abstract*— A new constrained reconstruction method is proposed to enable real-time phase-contrast flow MRI with sparse sampling. The method is based on simultaneous low-rank and sparse modeling of the spatiotemporal characteristics of flow imaging data. Its effectiveness is illustrated in a 2D in-vivo real-time flow imaging experiment with three flow-encoding directions.**

I. Introduction

Real-time phase-contrast (PC) flow MRI is a promising technique that can overcome severe shortcomings of conventional cine-based flow MRI [1]. For example, with real-time flow MRI, (**k**, t)-space data are continuously acquired without using ECG gating and respiration control, leading to higher acquisition efficiency. Furthermore, real-time flow imaging also has the capability to resolve the beat-by-beat flow variability, which contains meaningful physiological information. However, real-time flow MRI is generally much more challenging than cine-based techniques, since (**k**, t)-space is highly undersampled. In this work, we present a new model-based reconstruction method based on simultaneous low-rank and sparse modeling to achieve high resolution real-time flow imaging.

II. Proposed Method

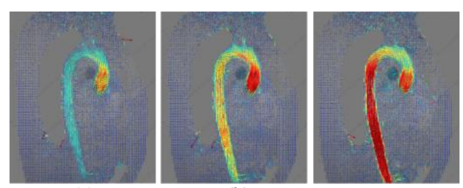
We model the spatiotemporal characteristics of flow imaging data with a parsimonious signal model, i.e., simultaneous low-rank and sparse structure, to enable reconstruction from highly undersampled data. First, low-rank modeling can be used to capture strong spatiotemporal correlation of the joint Casorati matrix $\mathbf{C}$ [2], formed by interleaving different flow-encoded image sequences. Secondly, with respect to sparse modeling, note that the complex difference, i.e., angiogram, of $\mathbf{C}$ itself has desired sparse structure, although even sparser representation can be obtained by further applying a proper spatiotemporal sparsifying transformation. Furthermore, due to quasi-periodic cardiac motion, the coefficients of the spatial-spectral representation of $\mathbf{C}$ are also approximately sparse. With the above simultaneous low-rank and sparse modeling, the reconstruction problem can be formulated as

$$\hat{\mathbf{U}}_s = \arg\min_{\mathbf{U}_s} \underbrace{\left\|\mathbf{d} - \mathbf{E}(\mathbf{U}_s\mathbf{V}_t)\right\|_2^2}_{\text{low-rank constraints}} + \underbrace{\lambda_1 \sum_{j=1}^{N_v} \left\|\mathbf{W}(\mathbf{U}_s\mathbf{V}^j - \mathbf{U}_s\mathbf{V}^1)\right\|_1}_{\text{sparsity of angiogram}} + \lambda_2 \underbrace{\left\|\mathbf{U}_s\mathbf{V}_t\mathbf{F}_t\right\|_1}_{\text{spatial-spectral sparsity}}$$

where $\mathbf{U}_s$ denotes the set of spatial coefficients to be determined, rows of $\mathbf{V}_t$ and $\mathbf{V}^j$ respectively span the temporal subspace of the joint and single Casorati matrix, $\mathbf{E}$ denotes an imaging operator, $\mathbf{W}$ denotes a spatial-temporal sparsifying transform, and λ_1 and λ_2 are two regularization parameters.

III. Results

We illustrate the performance of the proposed method for a 2D real-time flow imaging experiment, which was performed on a 3T Philips Medical Systems with 32 cardiovascular coils with isotropic spatial resolution of 2.59 mm, temporal resolution of 34.4 ms, data acquisition time of 50s, and VENC = 200 cm/s, 150 cm/s, and 150 cm/s for the feet-head (FH), anterior-posterior (AP), and right-left (RL) directions, respectively. Fig.1 shows the pathline visualization of the reconstructed velocity maps at three time points during which the blood flows through the aorta, demonstrating the high temporal resolution that the proposed method achieves.



(a) (b) (c)

Figure 1. Pathline visualization of the reconstructed real-time velocity maps at three time points, during which blood flows through the aorta.

IV. Conclusion

We have proposed a new model-based technique for real-time PC flow imaging, which achieves reconstructions with high temporal resolution at three flow encoding directions.

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