First-Pass Myocardial Perfusion Imaging with Sparse (k,t)-Space Sampling

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INTRODUCTION

Myocardial perfusion imaging is an important application of cardiac imaging with the potential to provide early detection of coronary artery disease [1] and acute transplant rejection [2], among other uses. However, temporal resolution is a major concern, especially for performing myocardial perfusion imaging experiments in rats (which have heart rates above 300 bpm). This problem has been partly addressed using fast scanning and parallel imaging methods. Sparse sampling, an area of recent interest to the MR community, offers another opportunity to accelerate myocardial perfusion imaging methods. Sparse sampling methods based on the partial separability (PS) model [3] and on compressed sensing (CS) [4] have both been previously proposed. In this work, we sparsely sample $(\mathbf{k}, t)$-space, using both PS and CS to accelerate imaging and experimentally demonstrate first-pass myocardial perfusion imaging in rats at 390 μm in-plane resolution and 15 ms temporal resolution.

METHODS

The signal $s(\mathbf{k}, t)$ measured in a first-pass myocardial perfusion MR experiment can be represented in general as $s(\mathbf{k}, t) = \int_{-\infty}^{\infty} \rho(\mathbf{r}, t) e^{-i2\pi \mathbf{k}\cdot\mathbf{r}} d\mathbf{r}$, where $\rho(\mathbf{r}, t)$ is the desired spatiotemporal function. We can sparsely sample $(\mathbf{k}, t)$-space using a scheme such as the scheme illustrated in Fig. 1. In this data acquisition scheme, two data sets are obtained, one dense subset with high temporal resolution and one sparse subset with high spatial resolution. In image reconstruction, both spatial-spectral sparsity and partial separability constraints are enforced. Mathematically, this can be formulated as

$$\hat{\boldsymbol{\rho}} = \underset{\rho(\mathbf{r},t)\in\{\sum_{\ell=1}^{L}\psi_\ell(\mathbf{r})\varphi_\ell(t)\}}{\arg\min} \|\mathbf{d} - \mathbf{E}\boldsymbol{\rho}\|_2^2 + \lambda\|\mathcal{F}_t\boldsymbol{\rho}\|_1,$$

where $\hat{\boldsymbol{\rho}}$ is the reconstructed image vector, $\mathbf{d}$ is the measured data, $\mathbf{E}$ is the imaging operator, and $\mathcal{F}_t$ represents the Fourier transform over the temporal dimension [5]. The temporal basis functions $\{\varphi_\ell(t)\}$ can be directly obtained from the dense subset of the measured data to simplify reconstruction. The above optimization problem can be solved using numerous algorithms; we choose half-quadratic optimization with a continuation procedure [5].

The proposed scheme has been implemented on a Bruker Avance AV1 4.7 T / 40 cm scanner and demonstrated experimentally in healthy Brown Norway rats. The experiments used a FLASH pulse sequence with the following imaging parameters: T_R = 7.5 ms, T_E = 2.4 ms, FOV = 40 mm × 50 mm, in-plane spatial resolution = 390 μm × 390 μm, and slice thickness = 1.5 mm. A 0.05 mmol/kg bolus of gadolinium contrast agent was injected into the subject after the start of data acquisition. Data were collected continuously with neither ECG gating nor breath holding over 5 minutes.

RESULTS AND DISCUSSION

A typical set of experimental results are shown in Figs. 2 and 3. As can be seen, the reconstruction suffers no visible aliasing artifacts from sparse sampling, even though we sampled $(\mathbf{k}, t)$-space at an effective acceleration factor of 51. Both spatial and temporal (e.g., perfusion) features are clearly represented.

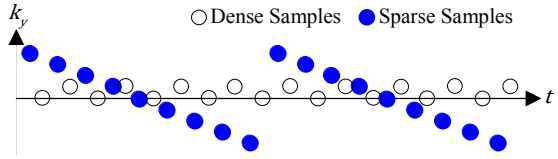

Figure 1. Illustrated example of $(\mathbf{k}, t)$-space sampling with interleaved acquisition of sparse and dense subsets.

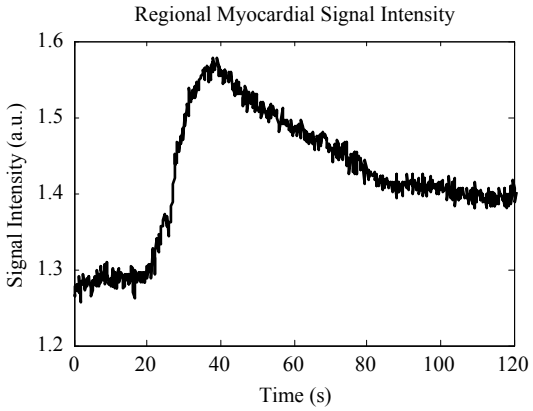

Figure 2. Temporally filtered signal intensity of a representative myocardial region, using data points extracted from end-diastolic cardiac phases.

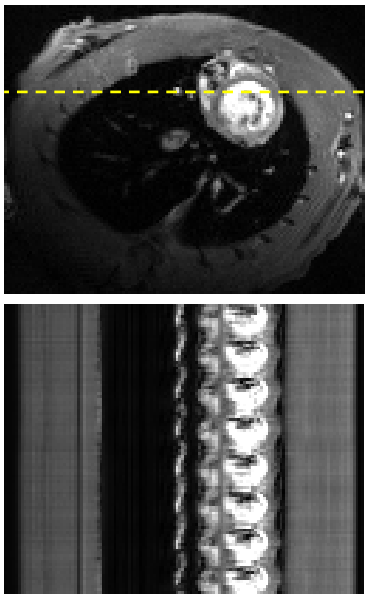

Figure 3. *Top*: A single frame from the reconstructed image sequence. *Bottom*: Temporal changes (along the vertical axis) over the spatial region represented by the dashed line in the static frame above.

CONCLUSION

We have performed first-pass myocardial perfusion imaging in high spatiotemporal resolution using sparse sampling of $(\mathbf{k}, t)$-space. High-quality images have been reconstructed from the very sparsely sampled data using both partial separability and spatial-spectral sparsity. The method should prove useful for various myocardial perfusion imaging experiments.

REFERENCES

[1] Bogaert, J. et al., Eds., *Clinical Cardiac MRI.* 2005. [2] Muehling, O. M. et al., *J Heart Lung Transplant* 24:1122-1123, 2005. [3] Liang, Z.-P. *IEEE-ISBI* 2007. pp. 988-991. [4] Jung, H. et al., *Magn Reson Med* 61:103-116, 2009. [5] Zhao, B. et al. *IEEE-EMBS* 2010. pp. 3390-3393.