High-resolution imaging using partial separability of spatiotemporal signals with a novel data sampling scheme

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Introduction: The Partial Separability (PS) of spatiotemporal signals has been exploited for sparse sampling of (k, t)-space to speed up MRI [1,2]. PS model-based sparse sampling schemes often collect two datasets, one (called image data) with extended k-space coverage to provide the desired spatial resolution and the other (called navigator data) with high temporal resolution to define the temporal subspace. Based on the theory of partially separable functions, the more spatial frequency components in (k-f) space the navigator data covers, the more accurately the PS model will capture spatiotemporal changes. To address this issue, we present a novel sampling method that uses radial sampling trajectories for collecting the navigator data and Cartesian sampling trajectories for collecting image data. Simulation and *in vivo* cardiac imaging results demonstrate that the proposed method could produce much better reconstructions.

Theory: Based on the theory of partially separable functions [3], if a signal $S(\vec{k},t)$ is dependent on both space $\vec{r}$ and time t, it can be decomposed as

$$S(\vec{k},t)=\sum_{l=1}^{L} c_l(\vec{k})\varphi_l(t) \qquad (1)$$

where L is the model order, $\{c_l(\vec{k})\}$ is the spatial basis relevant to the signal, and $\{\varphi_l(t)\}$ is the temporal basis for the signal which is sensitive to object motion. When these parameters are determined accurately, the MR signal at unmeasured (k,t)-space locations can be interpolated through Eq. (1) (Fig. 1). Then dynamic images with high temporal resolution can be reconstructed by applying the inverse Fourier transform to the interpolated data. The spatial and temporal resolutions are decided by the image data and the navigator data, respectively. And the image data and navigator data are both acquired in Cartesian trajectories in conventional PS sampling scheme.

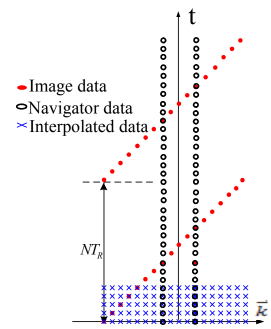

Fig.1. Acquired and interpolated data in k-t space.

Experiment and Results: The proposed method was first evaluated on a dynamic numerical phantom. The phantom movie consisted of 11520 frames. Each frame contains a rectangle and two concentric ellipses (Fig. 2(A)). The rectangle moves from left to right and then from right to left over a period of 13 frames. The large ellipse contracts and dilates over a period of 15 frames while the small one does the same over a period of 11 frames. The purpose of this design is to ensure that the phantom has multiple temporal frequency components. The simulation results showed that the reconstructed images using the proposed data sampling method are noticeably better than the images reconstructed from data acquired using the conventional sampling method (Fig. 2(B) and Fig.2(C)). Based on this simulation results, a pulse sequence was implemented (Fig. 3), in which the image data was acquired in Cartesian trajectory in odd TRs while the navigator data was acquired in radial trajectory in even TRs. Next, *in vivo* cardiac MR imaging for a healthy female volunteer was performed on a 3T SIEMENS Trio MRI scanner. The imaging parameters were: 4.0/1.9ms TR/TE, 1.5mm spatial resolution, 6 mm slice thickness, 15° flip angle, 120 measurements and 5 navigator lines. The experiment results show that the proposed method can provide higher-quality cardiac MR images than the conventional data sampling method for PS model-based imaging.

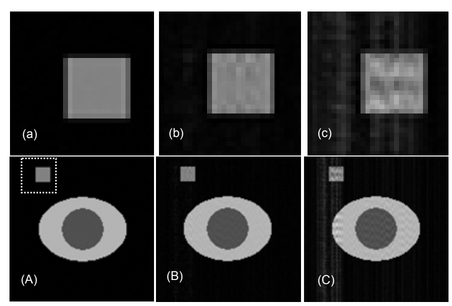

Fig.2. A snapshot of the dynamic numerical phantom and its reconstruction using the PS model. (A) Original numerical phantom; (B) Reconstruction of the PS model with the proposal sampling method; (C) Reconstruction using the PS model with the conventional sampling method. (a)~(c) Enlargements of the rectangle in (A)~(C)

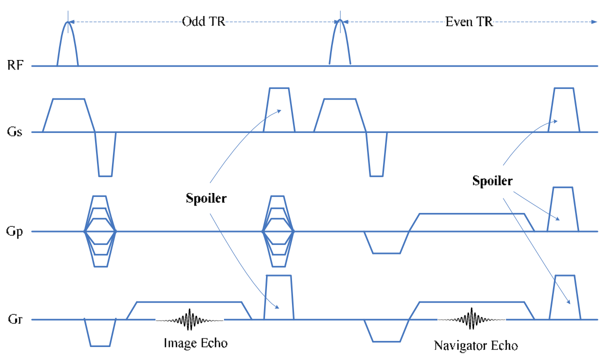

Fig.3. FLASH based sequence for the proposed method

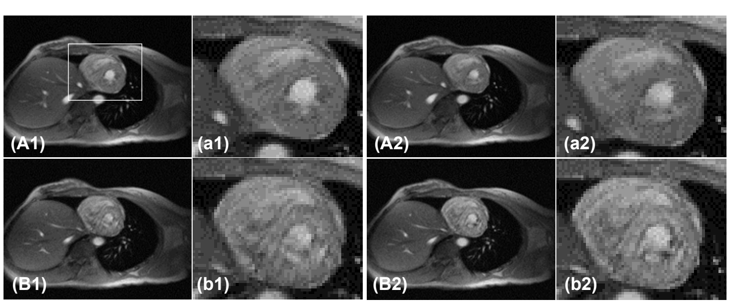

Fig.4. *In vivo* cardiac imaging results for a healthy female volunteer. (A1) and (A2): two snapshots of the reconstruction of the PS model with the proposal sampling method. (B1) and (B2): two snapshots of the reconstruction of the PS model with the conventional sampling method. (a1), (a2), (b1) and (b2) are the enlargements of the heart of (A1), (A2), (B1) and (B2)

Conclusion: This work presents a novel scheme for sparse sampling of (k, t)-space using hybrid Cartesian and radial trajectories. Experimental results from the cardiac imaging studies demonstrate that this scheme provides better data for PS model-based image reconstruction.

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References: [1] Brinegar, C. et al., Magn Reson Med 64: 1162-1170, 2010. [2] A. G. Christodoulou et al., ISMRM 2011. pp.2045. [3] Zhi-Pei Liang, IEEE-ISBI 2007. pp. 988-991.