Single Breath Hold Whole Heart Cine MRI With Iterative Groupwise Cardiac Motion Compensation and Sparse Regularization (kt-WiSE)

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Purpose: Multislice 2D (M2D) CINE MRI is a clinical gold standard for the assessment of ventricular volumes and cardiac function. However, this acquisition currently needs to be performed during several breath-holds, leading to slice-misalignment and long scans duration. In this work we propose a novel undersampled reconstruction approach to perform M2D whole heart CINE MRI in a single breath hold. The proposed method, which we call kt-WiSE, is based on compressed sensing (CS) and a groupwise temporal registration algorithm for the estimation and compensation of the motion of the heart. The proposed approach was tested on healthy volunteers with data acquired on a golden radial trajectory[1], and compared against the gold standard M2D acquisition.

Theory: Compressed sensing has been shown to highly accelerate CINE MRI by exploiting sparsity of the signal in the temporal domain[2]. Motion compensation (MC) has been incorporated into the CS reconstruction to achieve sparser temporal representations by reducing interframe cardiac motion[3,4]. These MC-CS methods enable higher acceleration factors, however present remained artifacts due to motion estimation/compensation errors. To overcome these problems we propose a joint optimization approach[3] for the image $\mathbf{m}$ and motion parameters. This MC-CS approach uses a spatio-temporal regularized groupwise registration algorithm based on a non-rigid B-splines deformation model and can be formulated as iteratively solving the following equations (1) and (2). First:

$$\min_{\mathbf{m}} \|\mathbf{y} - \mathbf{E}\mathbf{m}\|_2^2 + \lambda \|\mathbf{\Psi}\mathcal{T}_{\boldsymbol{\theta}}\mathbf{m}\|_1 \qquad (1)$$

nnnwhere $\mathbf{E}$ stands for the encoding operator (including gridding and coil maps), $\mathbf{\Psi}$ for sparsity transform and $\mathcal{T}_{\boldsymbol{\theta}}$ for the spatial deformation associated to the motion of the heart. $\mathcal{T}_{\boldsymbol{\theta}}$ is parameterized by a regular grid of control points $\boldsymbol{\theta}$. Since no motion is known in the first iteration, an initial CS reconstruction is performed with $\mathcal{T}_{\boldsymbol{\theta}}$ set to the identity and $\mathbf{\Psi}$ to a spatial wavelet transform (Fig1.b). After the first iteration $\mathbf{\Psi}$ is the concatenation of temporal total variation (TV_t) and a spatial wavelet transform (WT_s), so $\mathbf{\Psi}\mathbf{m} = [[TV_t\mathcal{T}_{\boldsymbol{\theta}}\mathbf{m}]^{\mathrm{T}} | [WT_s\mathbf{m}]^{\mathrm{T}}]^{\mathrm{T}}$.
Second, the spatial deformation $\mathcal{T}_{\boldsymbol{\theta}}$ is estimated by solving

$$\min_{\boldsymbol{\theta}} \left\|\mathcal{T}_{\boldsymbol{\theta}}\mathbf{m} - \overline{\mathcal{T}_{\boldsymbol{\theta}}\mathbf{m}}\right\|^2 + C(\mathcal{T}_{\boldsymbol{\theta}}) \qquad (2)$$

where $\overline{\mathcal{T}_{\boldsymbol{\theta}}\mathbf{m}}$ represents the temporal average of the deformed sequence and $C(\mathcal{T}_{\boldsymbol{\theta}})$ is a spatio-temporal regularization cost function[5]. When $\mathcal{T}_{\boldsymbol{\theta}}$ is applied, a quasi-static sequence with high temporal sparsity results, as can be observed in the temporal profiles in Fig1.c.

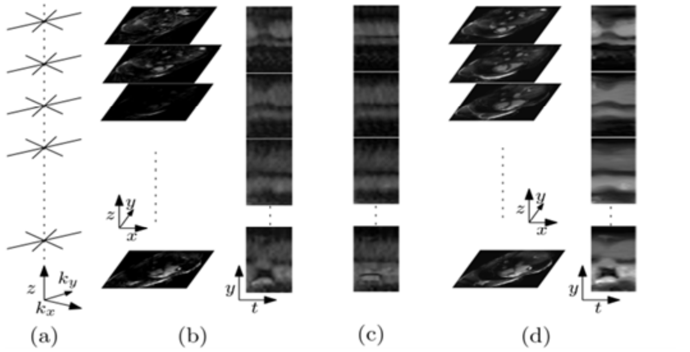

Fig. 1: *Proposed reconstruction algorithm. Left to right: M2D golden radial acquisition, initial CS reconstruction, groupwise registration and MC-CS reconstruction, and iteration over the last two steps.*

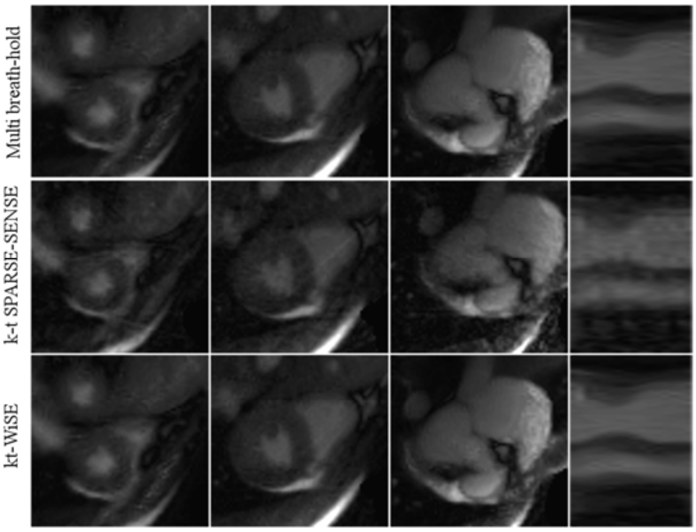

Fig. 2: *(a) Apical, med-ventricular and basal slices at systole for fully-sampled (top), k-t SPARSE-SENSE (middle), and kt-WiSE (bottom) reconstructions. (b) Temporal profiles of a mid-ventrical slice for the three reconstruction methods.*

Methods: A healthy male volunteer was scanned with a 32-element cardiac coil and a golden radial trajectory on a 1.5T Philips scanner. Other relevant scan parameters include: b-SSFP sequence, TR/TE/α = 2.9ms/1.44ms/60º, FOV = 320x320mm^2, spatial resolution = 2x2mm^2, slice thickness = 8mm with no gap between 12 slices. 256 radial profiles were acquired per slice during a single cardiac cycle with ECG triggering. 16 cardiac phases were retrospectively reconstructed (16 profiles per phase), leading to a temporal resolution of 46.4ms. A conventional fully sampled, Cartesian, multi breath-hold scan was performed with similar acquisition parameters for comparison. Total data acquisition time was 11.1 s in the proposed single breath-hold scan and 1 min 42 s in the Cartesian one (without considering resting intervals between breath holds). Sensitivity maps were estimated from a separate scan. For comparison, data was also reconstructed using k-t SPARSE-SENSE[2] with temporal Fourier transform as sparse domain.

Results: Apical, medial and basal slices at end systole obtained from the multi breath-hold Cartesian data and from the single breath hold golden radial data reconstructed with k-t SPARSE-SENSE and kt-WiSE are shown in Fig2.a. Sharper edges and better overall quality can be appreciated in the last case. Fig2.b shows temporal profiles of the medial slice. Better temporal fidelity can be perceived for the kt-WiSE image.

Conclusions: Preliminary results indicate that a standard multislice protocol could be realizable in a single breath-hold, leading to a noteworthy reduction in the scanning time and potentially impact in patient comfort and medical resources allocation. In this preliminary setup, each slice is reconstructed independently. Performing the reconstruction of all the slices jointly could lead to image quality improvement, given the spatial redundancy between consecutive slices.. Further studies will be performed to validate the proposed approach and extended to 3D acquisitions.

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