Sparse Dynamic MRI with an Adaptive Temporal Sparsity Prior for Cardiovascular Imaging

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Introduction: The application of compressed sensing presumes a sampling scheme with incoherent, noise-like aliasing artifacts. In practical cardiovascular MRI this objective is usually not fully met and a spatial variation of aliasing artifacts is induced by varying signal intensity, contrast, motion, and geometry. In particular, the inhomogeneous sensitivity profile of a 32-channel cardiac coil array leads to strong streak artifacts in the proximity of the chest-wall.

Methods: Reconstruction: In this work, the k-t radial SPARSE SENSE (k-t RASPS) [1] image reconstruction method is extended by a new spatiotemporal adaptively regularized reconstruction scheme (k-t STARR). Instead of using a scalar regularization parameter λ, a regularization matrix Λ is used, which adapts the temporal regularization strength to the local magnitude of the aliasing artifacts using the temporal total variation $\Lambda_n = \|x_n\|_{TV}$ for pixel n from the non-iterative gridding solution x. The optimization problem $\mathrm{argmin}_x\{\|Ax-b\|_2^2 + \lambda_t\|\Lambda_t\psi_t x\|_1 + \lambda_s\|\psi_s x\|_1\}$ is solved with ψ_t / ψ_s being the finite difference along the temporal / spatial dimensions, b the data in k-t space, and A the system matrix containing the discrete non-uniform Fourier transform and the coil sensitivities. Temporal regularization λ_t was set to eliminate all coherent aliasing artifacts from the cardio-vascular structures and λ_s was set to a moderate regularization to suppress staircase artifacts induced by the temporal regularization. For fair comparison the matrix Λ was scaled to have a value of $\Lambda_n \approx 1$ for all pixel n in the region of the ventricle.

Acquisition: Short-axis cardiac datasets from 8 healthy volunteers were acquired on a Philips 3T Achieva using a 32 channel coil array under free breathing, a radial golden angle trajectory [3], and a spoiled gradient echo sequence. The parameters were TE/TR = 1.3 / 3.4 ms, flip angle = 15°, pixel bandwidth = 857.8 Hz, FOV = 400 x 400 mm², and spatial resolution = 2 x 2 x 8 mm³. The k-space data was reordered to 13 spokes per time frame, which leads to an undersampling factor of R = 24. The coil sensitivities S were estimated from a separate calibration scan. Additionally, a breath-hold ECG triggered dataset was acquired for each volunteer. Written informed consent was obtained in all cases prior to examination.

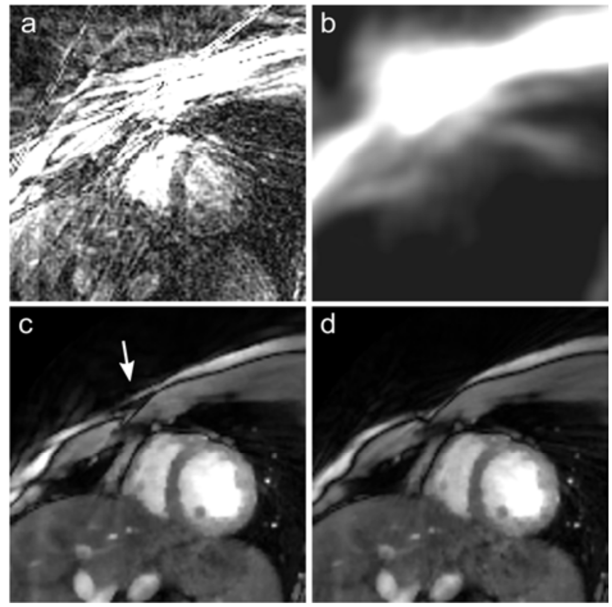

Figure 1: The gridding solution (a), the derived Λ_t matrix (b), the k-t RASPS reconstruction of the end-diastolic time frame (c), and the k-t STARR reconstruction (d).

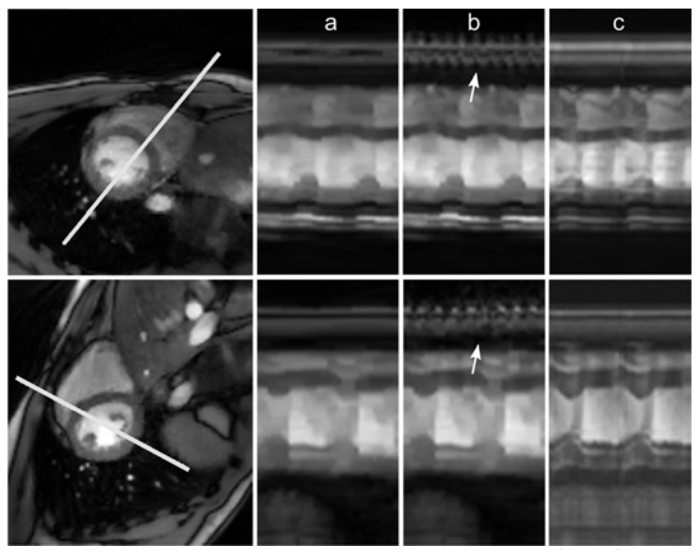

Figure 2: M-mode like plots showing the result of k-t STARR (a), k-t RASPS (b), and the ECG triggered breath-hold reference scan (c).

Results: The gridding solution (Fig. 1a) is clearly dominated by undersampling artifacts. The Λ-map (Fig. 1b) appears to be a good estimation for the distribution of the aliasing artifacts. The k-t RASPS reconstruction exhibits strong aliasing artifacts, especially near the chest-wall ranging into the right ventricle (Fig. 1c), which are clearly reduced in the k-t STARR reconstruction (Fig 1d). M-Mode like plots show that k-t STARR does not affect the temporal fidelity in the cardiovascular structures despite the suppression of the strong oscillating artifacts near the chest-wall (Fig. 2).

Conclusion: The proposed method reduces the residual aliasing artifacts that are typical for dynamic cardiovascular MRI with 32-channel coil arrays without compromising the temporal fidelity of the cardiac region.

References: [1] Feng L, et al. Proc. Intl. Soc. Mag. Reson. Med., 2011. [2] Lustig M, Donoho D, Pauly M, Magn. Reson. Med., vol. 58, no. 6, pp. 1182–95, Dec. 2007. [3] Winkelmann S, et al. IEEE Trans. Med. Imaging, vol. 26, no. 1, pp. 68–76, Jan. 2007.