Golden Angle radial cardiac imaging without ECG gating using nonconvex Compressed Sensing

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Introduction

Tracking the cardiac motion with high spatial and temporal resolution is of great interest since high resolution information about cardiac anatomy, function, and myocardial perfusion can help to improve the diagnosis of heart diseases. Thus, real-time imaging without ECG gating is desirable. Several approaches to achieve this goal have been reported [1-3]. In this work, a Golden Angle radial imaging approach in connection with nonconvex Compressed Sensing (CS) [4] is presented. Radial imaging has been repeatedly demonstrated to be useful in the context of CS because of the intrinsically high sampling density in the central k-space and the incoherent artifact nature in case of undersampling [5-7]. The Golden Angle trajectory allows to retrospectively selecting the temporal resolution by combining a certain number of temporally adjacent projections to a timeframe which introduces a high degree of freedom in the imaging experiment. The data were sparsified by subtracting the individual timeframe data from a temporally averaged composite dataset, leading to spatially sparse dynamic differences which can be accurately reconstructed with CS (Fig. 1). Furthermore, the joint sparsity of the receiver array was exploited by combining the coils prior to the CS reconstruction step. The proposed technique is therefore termed CS on Combined Coils (CS-CC) and allows for cardiac real time imaging with high temporal and high spatial resolution from 24 projections per timeframe (66 ms temporal resolution).

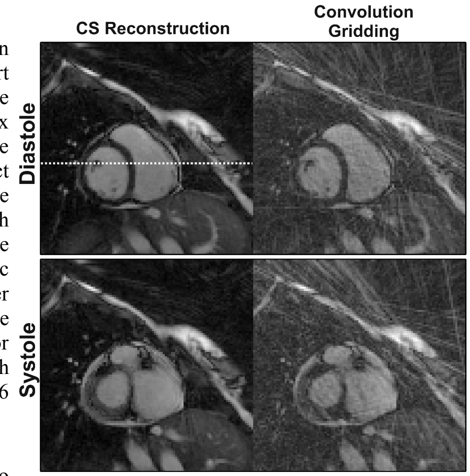

Fig. 2: Example timeframes. The cardiac phase is equivalently represented while the CS reconstructions exhibit less artifacts and higher contrast. The dotted line depicts the profile line which leads to the timecourses displayed in Fig. 3.

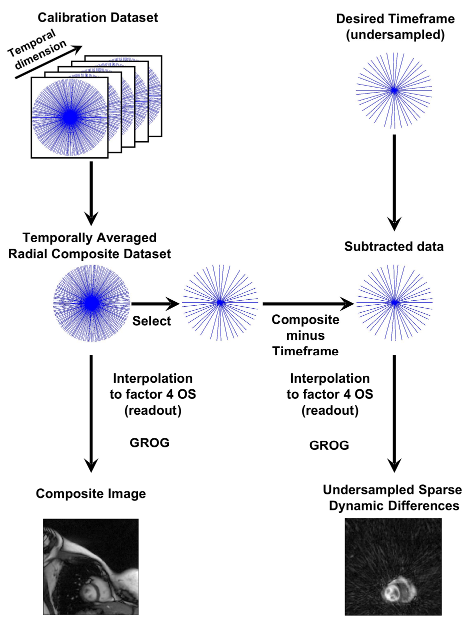

Fig. 1: Sparsification of the dynamic data

Methods

The idea of sparsifying the dynamic cardiac data prior to the CS reconstruction is outlined in Fig. 1. The radially undersampled sparse dynamic differences were gridded using GROG [8]. Thus, all further steps were performed on a Cartesian grid, making the CS-CC algorithm computationally efficient since no further gridding or de-gridding steps were required. The individual channels were adaptively combined [9] prior to each CS step. After each CS step, the data are re-distributed to the individual channels. Then, the originally acquired data were re-inserted at the respective positions in k-space to enforce strict data consistency. Details on the nonconvex CS algorithm without coil combination can be found in [4] and [10]. Finally, the CS reconstructed sparse differences were subtracted from the composite image, thereby obtaining the desired timeframe image. The dataset was acquired in breath-hold on a Siemens Espree 1.5 T clinical scanner (Siemens Healthcare, Erlangen, Germany) from a healthy volunteer exhibiting premature ventricular contractions (PVCs), imaging parameters: Radial SSFP, 15 channels, $\alpha = 70°$, T_E=1.37 ms, T_R=2.74 ms, FOV=300 x 300 mm^2, 256 readout points. 24 temporally adjacent projections of the Golden Angle dataset were grouped to radially undersampled timeframes which were, after sparsification (Fig. 1), reconstructed with CS-CC using a Total Variation penalty with the nonconvex norm p = 0.75.

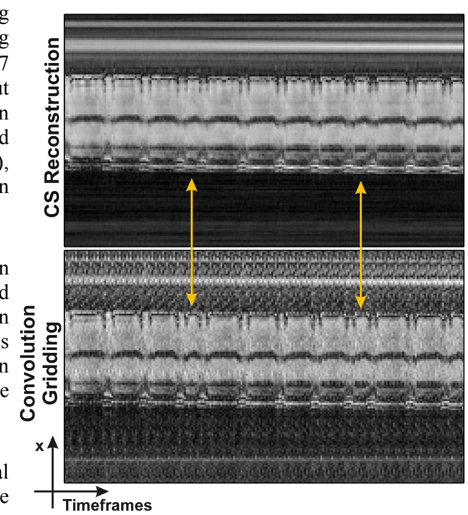

Fig. 3: Timecourses resulting from the profile line depicted in Fig. 2. The temporal fidelity of the CS reconstruction and convolution gridding is equivalent. Again, the CS reconstruction offers less visible artifacts and higher contrast. Furthermore, PVCs can be observed (yellow arrows).

Results

In Fig. 2, exemplary reconstruction results from the dataset are presented. Both CS reconstruction and convolution gridding offer an equivalent depiction of the cardiac phases. However, the CS reconstruction offers improved contrast and no visible streaking artifacts. The temporal fidelity of the CS reconstructed data can be appreciated in Fig. 3 where the profile line depicted in Fig. 1 (dotted line) is displayed for all timeframes. Again, the timecourses are equivalent while the CS reconstructed data exhibit no visible artifacts and higher contrast than the convolution gridded data. Furthermore, in both datasets, arrhythmic cardiac cycles (PVCs, yellow arrows in Fig. 3) can be observed.

Discussion and Conclusion

The main advantage of the Golden Angle radial trajectory is the possibility to retrospectively choose the temporal resolution. In this study, 24 projections corresponding to a temporal resolution of xx ms were used to obtain the presented results. Exploiting the joint sparsity of the receiver array and using a temporally averaged composite image leads to improved images with higher contrast than pure convolution gridding. Furthermore, the CS algorithm efficiently removes the undersampling artifacts. Additionally, this study demonstrated that the CS reconstruction quality is not compromised by PVCs. In conclusion, the proposed method is well-suited to accurately recover radial cardiac real-time data without ECG gating from patients and volunteers with cardiac arrhythmia.

Acknowledgements

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