

Highly-Accelerated Cardiac Cine MR Imaging using kats ARC (Autocalibrating Reconstruction for Cartesian Sampling with k- & Adaptive-t-Space Data Synthesis)

P. Lai¹, A. C. Brau¹, P. J. Beatty¹, and A. Shankaranarayanan¹

¹Applied Science Laboratory, GE Healthcare, Menlo Park, CA, United States

Introduction:

Cardiac cine MRI (CMRI) is a routine exam for studying myocardium functionality. High spatiotemporal-resolution CMRI has been challenging, limited by breathhold capability. Recently, various k-t techniques [1,2] have been developed to achieve acceleration factors (AF) ≥ 3 in dynamic imaging by incorporating temporal correlations. Among these approaches, k-t GRAPPA possesses the advantages of self-calibration but suffers from significant temporal blurring with high AF's. This study was aimed at developing a new ARC (Autocalibrating Reconstruction for Cartesian Sampling [3]) -based technique with k- & adaptive-t-space data synthesis (**kats ARC**) and investigate its effectiveness for fast CMRI.

Theory & Methods:

Conventional k-t GRAPPA performs undersampling in k-t space with linear k-space shifting along time. It exploits temporal correlations by including the nearest two temporal neighbors with the same phase-encoding (PE) to recover a missing k-space line. Such reconstruction uses k-space data faraway in time from the target line for data synthesis and results in interpolation in a large temporal window covering $2AF-1$ frames at all cardiac phases. This greatly reduces its temporal fidelity, which is critical for cardiac motion delineation. For comparison, k-t ARC was implemented in this study by combining the same k-t scheme with ARC.

Generally, cardiac motion induces heart deformation proportional to time distance. Compared to the k-space lines with the same PE, a line with similar PE and a shorter time distance should correlate with the target k-space line with higher temporal fidelity. Furthermore, the degree of temporal correlations is highly cardiac phase-dependent [4]. Based on these rules, our new method utilizes the concept of k-t-space synthesis with modified acquisition and reconstruction. Similar to ARC, data were first converted to hybrid space by Fourier transforming along k_x [5]. As demonstrated in Fig. 1, kats ARC data synthesis was performed using the nearest two neighbors along PE at the same phase (t_n) and the sampled neighbor with the closest PE at each adjacent phase covered by a phase-specific time window (W_n). To optimize temporal correlation and fidelity, data were acquired in a nonlinear time-alternating fashion with minimal overall PE difference for data synthesis between immediately adjacent phases. W_n was determined for each phase based on local motion derived from autocalibration signals (ACS). A low-resolution image could be obtained from fully sampled ACS at each phase, roughly depicting cardiac motion. Deviation (*DEV*) between two ACS images was calculated to estimate the consistency between phases and was equivalently performed by direct k-space subtraction:

$$DEV_{n,m} = \sum_t \sum_{k_x, k_y} \|F_{n,l}(k_x, k_y) - F_{m,l}(k_x, k_y)\|^2$$

where $F(k_x, k_y)$: ACS k-space data; n, m : phase indices; l : coil index. To determine W_n , *DEV* of each pair of ACS images in the entire cardiac cycle with $|n-m| < AF-1$ was calculated and the median *DEV* was regarded as baseline *DEV*. Next, at each t_n , *DEV* of its adjacent phases was calculated. All phases with *DEV* < baseline *DEV* was accepted for W_n (min W_n : $AF/2$; max W_n : AF) (Fig. 1.). Typically, W_n is narrower at systole and wider at diastole, corresponding to variations in local temporal correlations.

5 healthy volunteers were scanned on a GE 1.5T Signa HD scanner (GE Healthcare, Waukesha, WI) in short & long axes with informed consent. Full k-space datasets were collected using a 2D cine FIESTA sequence and an 8-channel GE cardiac coil. Typical imaging parameters were: 320×220 mm² FOV; 1.25×1.31 mm² spatial resolution; 5 mm slice thickness; 60° flip angle; 10 lines/segment; TR/TE: 4.0/2.0 ms; 40 ms temporal resolution. Different fast imaging techniques, namely, ARC, sliding window, k-t & kats ARC, were simulated with various AF's by decimating full k-space offline and compared based on visual assessment and artifact-power (AP) calculations.

Results:

Fig. 2 shows a 4-chamber slice at mid-systole reconstructed using different methods. As AF increases, ARC suffers from rapidly increasing noise and residual artifacts, whereas sliding window generates increasingly severe blurring. k-t ARC provides better overall image quality with the same AF's. However, substantial artifacts and blurring appears with $AF > 4$ (arrows). Contrarily, acceptable delineation is maintained using kats ARC with high AF's. On all subjects, kats ARC generates the lowest AP at all cardiac phases. This improvement is most evident at mid-systole (Fig. 3), the period with the most intensive cardiac motion. Clearly, AP of ARC alone increases steeply with higher AF's. Sliding window generates larger error compared to the two k-t techniques ($p > 0.05$). kats ARC is more accurate than k-t ARC with high AF's and this improvement becomes significant with $AF's > 4$ ($p > 0.05$).

Discussion:

The proposed method inherits the high computation efficiency of ARC. Compared to k-t ARC, kats ARC performs k-t synthesis selectively among cardiac phases with the highest and sufficient correlations and greatly reduces the temporal interpolation window ($AF/2 - AF$ vs. $2AF-1$). Therefore, kats ARC can better preserve reconstruction accuracy and temporal resolution. Moreover, the adaptive t window can be self-determined simply using ACS data for each scan, without requiring additional acquisition. This study demonstrates that kats ARC can improve overall image quality and cardiac motion delineation compared to conventional methods and is promising for highly-accelerated CMRI.

References: [1] Tsao J et al, MRM 2003:1031; [2] Huang F et al, MRM 2005, 54:1172; [3] Beatty P et al, ISMRM 2007:1749; [4] Lai P et al, JMRI 2008:27:659; [5] Brau A et al, MRM 2008:59:382.

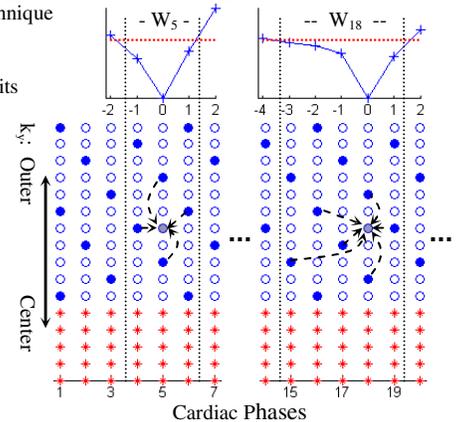


Fig. 1. kats ARC (AF=5). Upper: DEV vs. phase shift at mid-systole (phase 5) and mid-diastole (phase 18). Pluses: DEV; dotted red line: baseline DEV. Lower: data acquisition and synthesis. Stars: ACS; dots: sampled; circles: unsampled.

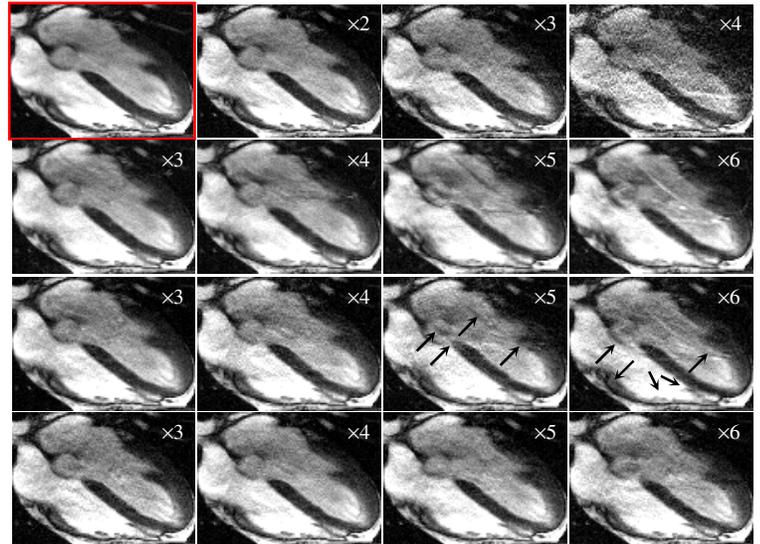


Fig. 2. Images reconstructed using full k-space (red frame), ARC (row 1; 2-4), sliding window (row 2), k-t ARC (row 3) and kats ARC (row 4). Numbers indicate AF's.

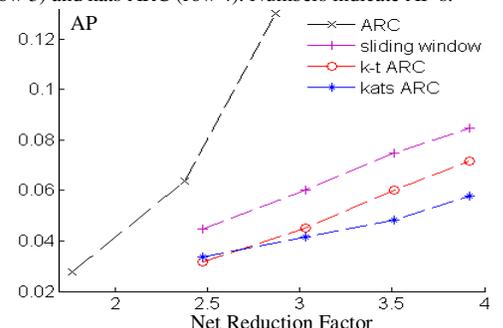


Fig. 3. Mean AP vs. net reduction factor at mid-systole. Left to right: AF 2-4 for ARC and 3-6 for the others.