Improving k-t Auto-Calibrating Parallel Imaging for 3D Cardiac Cine MRI using Prior-Reconstruction Static Tissue Estimation and Elimination

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Introduction:

3D cardiac cine MRI (CMRI) requires highly accelerated data acquisition for cardiac motion resolved imaging of the entire heart within a single breathhold. Recently, use of high-density coils and k-t methods exploiting spatiotemporal correlation [1,2] has demonstrated promising results for 3D CMRI. However, potential aliasing artifacts due to high acceleration may compromise diagnosis. Furthermore, k-t reconstruction on high coil channel number datasets demands highly intensive computation, which is challenging to online reconstruction and clinical use of 3D CMRI. In this work, we extended a static tissue elimination (STE) scheme [3] to address both image quality and computation challenges for 3D CMRI and validated the proposed method using a k-t auto-calibrating parallel imaging (acPI) method [4].

Theory:

acPI reconstruction generally degrades with higher acceleration due to increasing aliasing in original data acquisition and its computation increases in proportion to the size of the acquired data in the synthesis step and approximately to the square of the number of coil channels in both calibration and synthesis. STE could improve k-t acPI from two perspectives as below.

1. Improve Image Quality: With time-shifted acquisition for k-t accelerated 3D CMRI [1,2,4], we generate 3 scouting images using view sharing with trigger delay of 0, 1/3 and 2/3 cardiac cycle duration (Fig. 1a), respectively, based on which pixel-wise signal variation along time is calculated as estimation of cardiac motion (Fig. 1b). Though 3D CMRI images the whole chest, most voxels within the imaging volume are static. On the resorted time variation curve (thin line in Fig. 1c), a threshold (asterisk in Fig. 1c) with maximum curvature is selected to differentiate static and dynamic pixels. A soft-threshholding filter (thick line in Fig. 1c) is generated with smooth transition from 0 to 1 around the threshold and is applied to the time average of the 3 scouting frames (I_{ave}) to calculate an image of static tissues (I_{static}) (Fig .1d). Next, signals of I_{static} are subtracted from the original acquired k-space data. Subsequently, k-t acPI is performed on residual k-space containing signals from dynamic tissues only. STE effectively sparsifies the image content and therefore substantially reduces signal aliasing and improves the condition of subsequent k-t reconstruction.

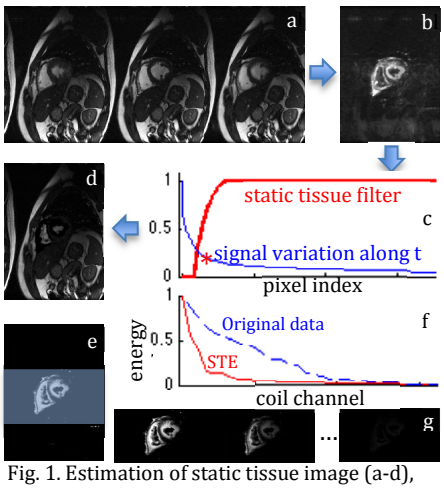

Fig. 1. Estimation of static tissue image (a-d), effective x-location (e) & coil selection (f, g) based on residual dynamic signals.

2. Reduce Computation: $\|I_{ave} - I_{static}\|$ (Fig .1e) provides a landmark of the residual dynamic signals in k-t reconstruction after STE. For CMRI, dynamic signals mostly originate from near heart and aorta in the central arterial chest. As demonstrated in [5, 6], original k-space data could be converted to hybrid x-k_y-k_z space by Fourier transform along k_x and ac-PI performed sequentially along x locations generates equivalent reconstruction with faster computation. With such hybrid space synthesis, k-t ac-PI is effective only at central x locations around the heart (grayed area in Fig. 1e), while is essentially fitting noise at peripheral x locations. Therefore, such peripheral x locations could be eliminated from k-t data synthesis without loss of clinical information. Furthermore, as revealed by Fig. 1.f, STE substantially reduces signals from peripheral coil elements compared to the original data. Especially for a high density coil, many peripheral coil elements do not 'see' the heart due to their limited sensitivity region. Such coil elements contribute mostly noise (Fig. 1g) in k-t acPI on dynamic signals and could be eliminated from reconstruction. Such selective reconstruction (SelRecon) could reduce processing time depending on the ratio of x-location and coil-channel elimination.

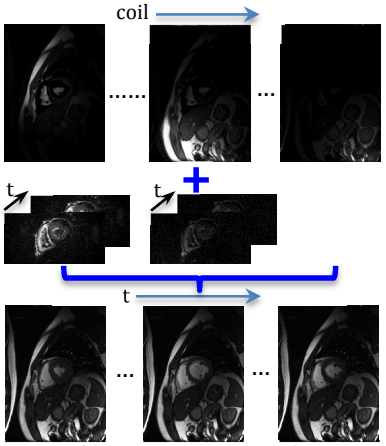

Fig. 2. Adding static tissue signals (1st row) back to selectively reconstructed dynamic signals (2nd row) and combining coil as the final image (3rd row).

Methods and Materials:

A k-t ac-PI method with adaptive time window selection and hybrid space data synthesis (kat ARC, [4, 7]) was implemented in C++ and was used to validate the proposed STE method. As shown in Fig. 2, first, coil-by-coil I_{static} was estimated and subtracted from the original k-space data. Noise-only x locations and coil elements without dynamic signals were eliminated based on $\|I_{ave} - I_{static}\|$. Then, kat ARC was used to recover the dynamic tissue signals at selected x locations and coil channels only. Finally, static and recovered dynamic images are combined as the final reconstruction.

3D CMRI datasets were collected from 5 healthy volunteers on a GE 1.5/3T scanner using 32-ch cardiac/body coils. Imaging parameters were: ~2.2×1.8mm^2 spatial resolution, 20 slices with 5mm thickness, 20 phases/cardiac cycle, 8-10× acceleration, 17-20 sec scan time. 3 images were reconstructed from each dataset using kat ARC on original data, with STE and with both STE and SelRecon, respectively, and compared based on image quality and computation time.

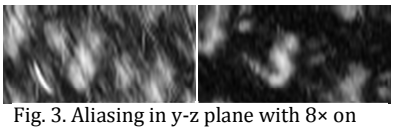

Fig. 3. Aliasing in y-z plane with 8× on original data (a) and after STE (b)

Results:

As shown in Fig. 3.a, high acceleration undersampling induces severe signal aliasing. STE can significantly suppress aliasing before k-t reconstruction (Fig. 3.b). On most 3D CMRI datasets evaluated in this study, kat ARC on original data produces visible flicking effects along time due to time-shifting residual aliasing artifacts. kat ARC with STE completely removes such artifacts and provides higher image quality. Fig. 4 shows a representative example for a 9× kat ARC image at mid-systole (upper row) and a reformatted y-z slice at late-diastole (lower row). STE (c, d) resolves the residual artifacts in conventional kat ARC reconstruction (a, b) without loss of sharpness. SelRecon (e, f) generates visually identical image quality as c & d in the entire volume. The average reconstruction time for kat ARC with and without SelRecon is 14 and 5 min with single-thread computation, respectively.

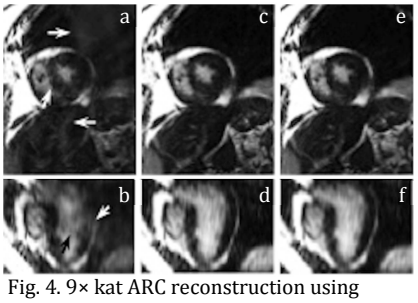

Fig. 4. 9× kat ARC reconstruction using original data (a, b), with STE (c, d) and both STE and selective reconstruction (e, f).

Conclusion:

In this work, we demonstrated a STE method that could improve image quality of k-t acPI with high acceleration without sacrificing temporal blurring. Furthermore, STE enables detection of x locations and coil channels without dynamic signals and thereby selective reconstruction on effective x locations and coil channels only. SelRecon provides ~3× reduction in computation in this work without losing image quality. A multi-thread implementation of the proposed method could further decrease the reconstruction time for online processing in a clinical setting.

References: 1. Tsao, MRM 2003:1031; 2. Huang, MRM 2005:1172; 3. Lai, ISMRM 2012:2280; 4. Lai, ISMRM 2009:766; 5. 5. Beatty, ISMRM 2007:1749; 6. Brau, MRM 2008:382; 7. Lai, ISMRM 2012:4245.