A Static Tissue Removal Scheme for Improving tGRAPPA and ktGRAPPA with High Acceleration

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Introduction: tGRAPPA [1] and ktGRAPPA [2] are two commonly used techniques for accelerated dynamic MRI. To improve reconstruction at high acceleration, the DC term, estimated by time-averaging acquired data, can be removed before tGRAPPA and ktGRAPPA data fitting [2]. As demonstrated by previous studies [2-4], removing DC signals can substantially sparsify the image that parallel imaging needs to unfold and therefore provides improved reconstruction. However, such DC signal estimation based on time averaging of kt-accelerated data is subject to temporal blurring, which is undesirable for dynamic imaging. In this work, we propose a modified scheme for improving the conventional DC removal method based on our analysis of the source of temporal blurring and demonstrate its effectiveness on cardiac cine MRI using tGRAPPA and ktGRAPPA.

Theory: With time-interleaved k-space sampling in tGRAPPA and ktGRAPPA, time average of acquired data generates a full k-space that can be used as an estimation of the DC term for DC removal. Similar to signal nulling problems in ktSENSE [5], this method, TAR: time average removal, generates temporal blurring in tGRAPPA and ktGRAPPA reconstruction. Simply take tGRAPPA with 2× for example. The estimated DC k-space is actually a mixture of 1. $T_{ave,odd}$ (time average of odd-numbered time frames) at odd-numbered phase encodings (PE_{odd}) and 2. $T_{ave,even}$ (time average of even-numbered time frames) at even-numbered phase encodings (PE_{even}). At an odd-numbered time point, TAR removes $T_{ave,odd}$ DC signals at PE_{odd}'s . While tGRAPPA at this time point generates dynamics on top of $T_{ave,odd}$, $T_{ave,even}$ is added back onto PE_{even}'s to recover DC signals in the final reconstruction. This discrepancy between dynamics reconstruction and DC recovery results in temporal blurring at all time points for tGRAPPA and similarly for ktGRAPPA. Furthermore, this temporal blurring deteriorates with higher acceleration as the dynamics/DC discrepancy increases, contradictory to high acceleration that TAR intends to enable. From an alternative perspective in image domain, this temporal blurring is caused by discrepancy between the expected DC image for accurate DC recovery and the estimated DC image and this discrepancy clearly exists only on dynamic tissues. Based on this notion, we propose a slight modification to TAR and the new method removes signals from static tissues only (SSR: static signal removal).

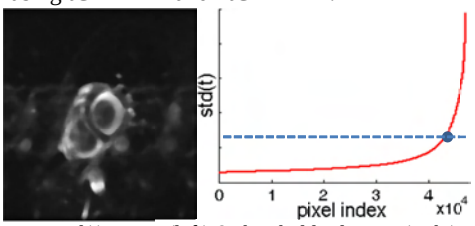

Fig.1 std(t) image (left) & threshold selection (right)

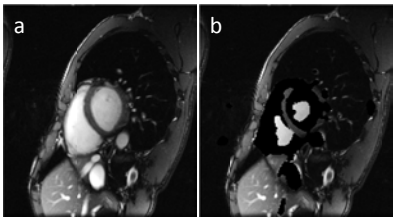

Fig.2 signal removed for TAR (a) & SSR (b)

For SSR, we first obtain an initial reconstruction from acquired k-t data using sliding window, based on which we estimate pixel-wise intensity of temporal dynamics by calculating the standard deviation along time (*std(t)*) at each pixel. As shown in Fig.1.a, *std(t)* is ~zero in air and static tissues (e.g. chest wall, abdomen) and exhibits high intensity only in the heart and aorta, especially at blood-myocardial boundaries that undergo intensive cardiac motion. The re-sorted *std(t)* signal shows an L-shape curve (Fig.1.b) and its turn-point with max curvature is selected as the threshold to differentiate static and dynamic tissues. Next, we construct a static tissue image (Fig.2.b) comprised of pixels in the TAR DC image (Fig.2.a) with *std(t)*<threshold and transform this image to k-space, which is subtracted from acquired k-t data. tGRAPPA and ktGRAPPA are performed on the residual signals of dynamic tissues. Comparing Fig.2.a&b, we can see that SSR removes signals from the majority of the FOV except the highly dynamic tissues (typically <10% of the entire FOV for cardiac MRI), therefore largely reduces aliasing similar to TAR and meanwhile avoids temporal blurring in dynamic tissues. After tGRAPPA\ktGRAPPA, the static tissue image is added back to the recovered dynamic tissue image as the final reconstruction.

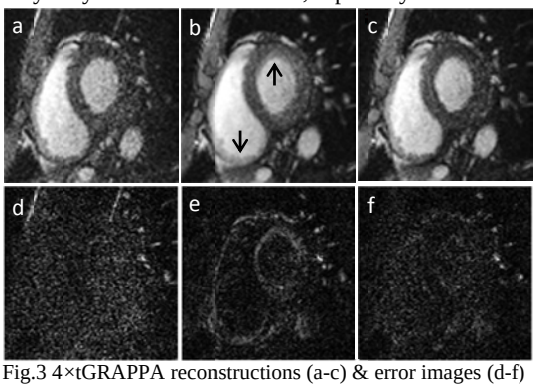

Fig.3 4×tGRAPPA reconstructions (a-c) & error images (d-f)

Methods & Materials: 5 healthy volunteers were scanned on a GE 1.5T HDx scanner. Full k-space cardiac cine datasets were collected using an 8-element cardiac coil with $1.3\times1.3mm^2$ spatial resolution and 40ms temporal resolution. Full k-space was downsampled offline to simulate accelerated data acquisitions for 1. tGRAPPA with 3&4×; 2. ktGRAPPA with 3× center and 6 to 8× outer acceleration. For ktGRAPPA datasets, tGRAPPA was used to complete central k-space with low acceleration first and next outer k-space with high acceleration was recovered using ktGRAPPA. For comparison, 3 images were reconstructed from each dataset on the original k-space and using TAR and SSR.

Results: Fig.3 shows a systolic phase reconstructed using tGRAPPA. With 4×, tGRAPPA on the original k-space (Fig.3.a) produces significant ghosting artifacts and low SNR. TAR (Fig.3.b) cleans up aliasing artifacts and improves SNR but generates considerable temporal blurring (indicated by arrows). In comparison, SSR (Fig.3.c) provides both high overall image quality and sharp delineation of myocardial edges. The improvements can be more clearly observed on the error images (Fig.3.d-f). Similarly, as shown in Fig.4, TAR (Fig.4.b) improves overall image quality of ktGRAPPA at 8× at the expense of significant blurring at motion tissues, while SSR (Fig.4.c) reduces reconstruction errors of ktGRAPPA and meanwhile preserves temporal fidelity.

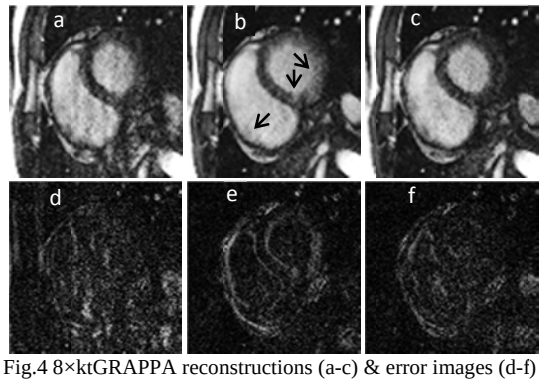

Fig.4 8×ktGRAPPA reconstructions (a-c) & error images (d-f)

Conclusion: This work provides an analysis of temporal blurring problems of TAR and presents a modified image sparsification scheme, SSR, to address this problem with only minor additional processing. Our experiments on cardiac cine MRI show that SSR can suppress aliasing artifacts and improve SNR for tGRAPPA and ktGRAPPA without suffering from temporal blurring of TAR. The proposed method is promising for highly-accelerated dynamic MRI, such as cine, perfusion, dynamic contrast and real-time imaging.

References: 1. Breuer, MRM 2005, 53:981; 2. Huang, MRM 2005, 54:1172; 3. Tsao, MRM 2003:1031; 4. Storey, ISMRM 2010:343; 5. Xu, MRM 2007, 57:918