KLT-GRAPPA: A New Method to Estimate Auto-Calibration Signal in Dynamic Parallel Imaging

Y. Ding[1], M. Jekic[1], Y-C. Chung[2], and O. P. Simonetti[1]
[1]The Ohio State University, Columbus, OH, United States, [2]Siemens Medical Solutions, Columbus, OH, United States

Introduction: Parallel imaging techniques such as SENSE and GRAPPA [1, 2], are frequently used for dynamic imaging of physiological processes requiring high temporal resolution, such as cardiac cine or perfusion imaging. The performance of any parallel imaging technique depends on the accurate estimation of channel sensitivity. TSENSE and TGRAPPA are parallel acquisition methods that can dynamically update the sensitivity map to accommodate variations caused by physiological motion. These methods use temporal low-pass filtering (TLP) [3] or sliding window averaging (SWA) [4] to estimate a dynamically changing sensitivity map. However, in applications where there is heavy breathing (such as at peak exercise stress [5]) significant chest wall motion can result in severe aliasing artifacts due to the mismatch between the image data and channel sensitivity used in image reconstruction. Here, we propose to use the Karhunen-Loeve Transform (KLT) filter to generate a frame-by-frame estimate of the time-varying channel sensitivity. We hypothesize that the KLT filter, which is optimal in the 2-norm or Frobenius norm sense [6], will improve the accuracy of channel sensitivity estimation and hence reduce aliasing artifacts in TSENSE and TGRAPPA.

Theory: The new filter is applied in the following way. 1. Acquire p frames of interleaved k-space lines with parallel imaging reduction factor n; 2. reconstruct p-n+1 full k-space data using a sliding window (width = n frames); 3. apply the KLT filter to the k-space data along the temporal direction; 4. use the KLT filtered k-space data to evaluate the channel sensitivity map for TSENSE reconstruction, or as the reference k-space data in TGRAPPA reconstruction; 5. perform TSENSE or TGRAPPA reconstruction for all the p temporal frames.

Methods: We limit our preliminary study to TGRAPPA, and compare the performance of three different temporal filters in reducing respiratory artifact in real-time post-exercise cine images acquired during heavy breathing. We refer to the TGRAPPA reconstruction with three different auto-calibration signal estimation methods as TLP-GRAPPA, SWA-GRAPPA, and KLT-GRAPPA. We acquired SSFP real-time cine images on a 1.5T MR scanner (MAGNETOM Avanto, Siemens Healthcare, Germany) using TGRAPPA with parallel acceleration rate n = 3, 4, or 5 in vertical and horizontal long-axis and four short-axis views in seven healthy volunteers immediately following peak exercise on an MRI-compatible treadmill (in 5 volunteers, n=3 and 4 were used, and in 2 volunteers, n=4 and 5 were used in randomized order). Imaging parameters were: 160 × 84 matrix, 10mm thick slice, flip angle=68^o, TE/TR = 0.99/2.26 ms, pixel bandwidth=1360 Hz/pixel, FOV = 380 × 300 mm^2. A total of 70 series of cine images were acquired. All images were reconstructed offline on a personal computer (Intel Duo Core Quad 3.0GHz CPU, 8GB memory) using software written in MATLAB 7.8. Three image series were reconstructed from each raw data series using TLP-GRAPPA, SWA-GRAPPA, and KLT-GRAPPA. Aliasing artifact was quantitatively evaluated by examining the autocorrelation coefficient in the phase encoding direction at FOV/n. For each series, the mean of the highest 10% autocorrelation coefficients were defined as the artifact index of the image series [7]. Statistical t-test was applied to study the artifact index differences between the three methods.

Results: Table I shows the artifact indices for the three temporal filtering schemes with different acceleration factors. The artifact index was normalized by the smallest value among the three methods. The KLT-GRAPPA method significantly ($p<0.05$) outperformed the other methods at all acceleration rates. Fig.1 shows an example image in which KLT-GRAPPA demonstrated practically no chest-wall aliasing while TLP-GRAPPA and SWA-GRAPPA reconstructions had severe motion artifacts.

Discussion and Conclusion: We proposed to reduce motion artifacts in dynamic imaging by using the temporal KLT filter to improve the estimation of channel sensitivity for TSENSE and auto-calibration signal for TGRAPPA. *In-vivo* experiments showed that the new KLT-GRAPPA method significantly reduces the artifact level in TGRAPPA reconstruction compared to traditional approaches. In the future we will extend the evaluation to TSENSE reconstruction.

References: [1] Pruessmann, KP et al, Magn Reson Med 42 (1999) 952-962. [2] Griswold MA, et al, Magn Reson Med, 47 (2002), 1202-10. [3] Kellman P, et al, Magn Reson Med, 45 (2001), 846-52. [4] Breuer FA, et al, Magn Reson Med, 53 (2005), 981-85. [5] Jekic M, et al, J Cardiovasc Magn Reson 10 (2008), 3. [6] Ding Y et al, Phys. Med. Biol. 54 (2009) 3909-22. [7] Jekic M, et al, Proc. ISMRM 2009, p4619.

Table I Normalized Artifact Indices

	TLP-GRAPPA	SWA-GRAPPA	KLT-GRAPPA
Rate 3	2.34 ±0.32	1.14 ±0.08	1.0
Rate 4	2.15 ±0.28	1.05±0.08	1.0
Rate 5	1.72 ±0.13	1.04 ±0.05	1.0

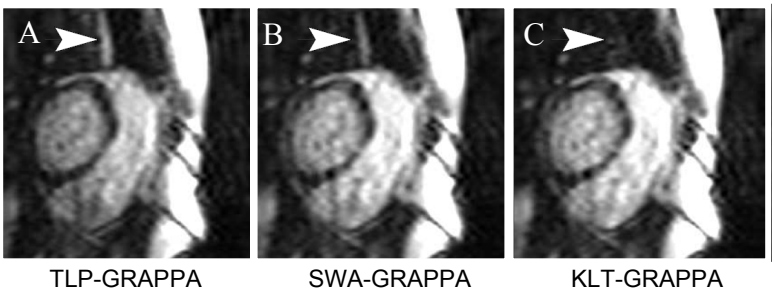

Fig. 1. TGRAPPA images (rate 5) reconstructed from the same data using auto-calibration signal estimated from (A) sliding window average, (B) temporal low-pass filter, and (C) KLT filter. The arrows indicate chest wall aliasing artifacts.