Improved k-t GRAPPA for Phase Contrast Cine MRI by using Modified Artificial Sparsity

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Target audience: Scientists interested in high spatiotemporal flow imaging

Introduction: The previous studies have shown that phase-contrast (PC) cine MRI is a powerful tool for studying flow-related physiology and pathophysiology. However, the additional scans for encoding the flow velocity information increase the total scan time and limit the achievable spatial and temporal resolutions within a clinically acceptable duration. Recently, kinds of k-t reconstruction algorithms exploiting spatiotemporal correlation have been developed and also demonstrated promising results for PC cine MRI [1]. Among these methods, k-t GRAPPA has the advantage of self-calibration, but degrades the temporal resolution when acceleration factor is high [2]. In this work, we propose an artificial sparse scheme using static tissue elimination scheme to improve the temporal resolution preservation of k-t GRAPPA for blood flow measurements of thoracic aorta.

Theory & Methods: Conventional k-t GRAPPA is operated on residual k-t space, which is calculated by the subtraction of an averaged k-space from each k-space frame. However, this kind of residual k-t space could blur the temporal resolution because the average of the dynamic region is used as the static signal. Moreover, the constant average k-space could not result in residual k-space with ideal sparsity because of the potential motion during acquisition. In this study, we propose to use two schemes to attack these two issues: First, instead of one constant averaged k-space, temporarily adaptive averaged k-space is used. The adaptive averaged k-space is averaged among its nearest time frames which should compose at least two completed k-spaces and it is different for each k-space frame. In this way, the impact due to motion is moderated. Second, we segment the static region, and only subtract the corresponding averaged k-t space to avoid the temporal resolution blurring at dynamic region [3]. The segmentation procedure is automatic which involves multiplying the phase-difference image by the magnitude image acquired from view sharing. Then we set a threshold of 20% of the maximum temporal variance of the resulting image to yield the resulting binary mask including the whole thoracic aorta vessel, which can be used to generate an image of static tissues. The processing procedure is shown in Fig. 1 (a). Finally, the interpolated full k-t space and that k-space corresponding to the static tissue are added back together to obtain the fully reconstructed k-t space. The proposed artificial sparsity method is denoted by modified artificial sparsity (mAS). The original scheme by simple signal average is denoted by conventional artificial sparsity (cAS).

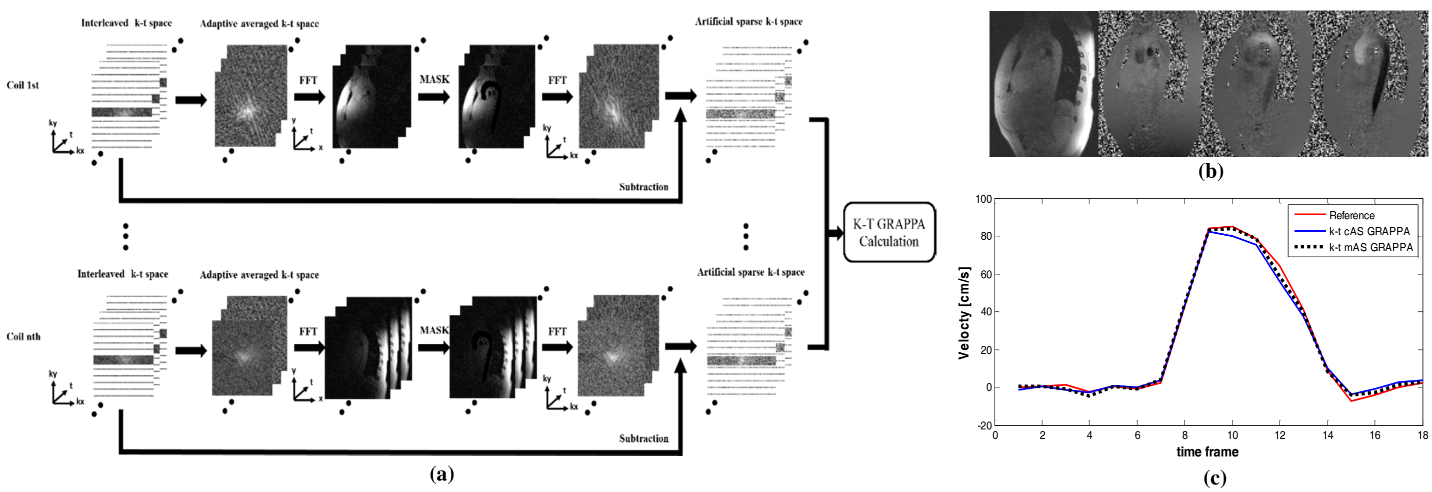

Fig. 1 (a) Procedure by applying artificial sparse and static tissue elimination. (b) Coil-combined magnitude and phase images along three directions (RL-AP-FH) reconstructed by k-t mAS GRAPPA when acceleration factor is eight. (c) Velocity time courses of aortic flow measurements along FH-direction in ascending aorta when acceleration factor is eight.

The full datasets of thoracic aorta were collected from 3 healthy volunteers with no symptoms of cardiovascular disease and informed written consent obtained. All scans were performed on 3.0T whole body scanner (Achieva, Philips Medical System, Best, The Netherlands) with a 32-channel cardiovascular coil. The relevant imaging parameters were: FOV = 270mm×240mm×43mm (FH/AP/RL); spatial resolution = 2.8mm×2.8mm×2.8mm (FH/AP/RL); flip angle = 5°; TR/TE=4.1/2.0ms; temporal resolution = 50ms; k-space segments = 4; VENC = 150 cm/s (RL)/ 150 cm/s (AP)/ 200 cm/s (FH); cardiac synchronization: PPU-trigger. Different artifical sparsity schemes, mAS and cAS, were simulated with various reduction factors by recovering full k-t space offline and compared based on visual assessment and root-mean-square -error (RMSE) calculations.

Table 1 Comparison between k-t cAS GRAPPA and k-t mAS GRAPPA

RMSE	k-t cAS GRAPPA			k-t mAS GRAPPA		
	AP	RL	FH	AP	RL	FH
R=4	5.50%	12.39%	5.48%	5.15%	10.54%	4.92%
R=8	6.16%	17.99%	7.60%	5.51%	16.30%	7.43%
R=12	7.66%	21.00%	8.75%	6.50%	19.80%	8.60%

Results: As shown in Fig. 1 (b), a slice within aortic artery at mid-systole is derived from our proposed method when the acceleration factor is eight. In Fig. 1 (c), the velocity time courses of the aortic flow measurements along FH-direction in ascending aorta show excellent agreement when mAS was used. On the contrary, an underestimation of peak velocities by cAS data can be seen. The mean RMSE of the reconstructed mean velocities in the aortic artery for different undersampling factors and for three flow directions are compared in Table 1. The proposed mAS consistently resulted in lower RMSE than cAS.

Discussion and Conclusions: In this work, we demonstrated the adaptive artificial sparsity scheme could improve image quality and temporal dynamics of aortic artery velocities than conventional average method. Additional experiments will be included in our next work to allow for a statistical analysis of the results and further evaluate the achievable improvement by using our proposed method.

References: [1] Tsao J *et al*. MRM 2003:1031; [2] Huang F *et al*. MRM 2005, 54:1172; [3] P. Lai *et al*. ISMRM. 2013. [4] Henrik Pedersen *et al*. MRM 2009, 62:706 – 716.