The Second Generation (2G) k-t GRAPPA: Faster and More Accurate

F. Huang1, W. Lin1, G. R. Duensing1, and A. Reykowski1
1Invivo Corporation, Gainesville, Florida, United States

Introduction

k-t GRAPPA [1,2,3] has been proposed for dynamic imaging with high reduction factors. In this work, GRAPPA operator [4] and narrow window data sharing are used to significantly improve the accuracy and reconstruction speed of k-t GRAPPA. The enhanced version is called the second generation (2G) k-t GRAPPA. Experiments with cardiac cine data sets show that the 2G k-t GRAPPA can produce images with lower error using shorter reconstruction time than k-t GRAPPA, and a compressed sensing technique in k-t space (k-t FOCUSS) [5].

Theory

GRAPPA operator [4] is a self-calibrated PPI technique for data extrapolation. Given appropriate coil geometry and optimal regularization [6], the extrapolation can be very accurate at a limited extrapolation distance [4, 6]. Therefore, we propose to use GRAPPA operator [4] to reconstruct partial k-space without degrading temporal resolution. Fig. 1b shows one example. In this example, the reduction factor initially is 9 (Fig. 1a). After GRAPPA operator, each PE line is extended to be 3 PE lines, and the reduction factor is reduced to be 3. Blue dots in Fig. 1b show the results of the GRAPPA operator. Data sharing has been widely used in dynamic imaging. To preserve temporal resolution, we propose to only share (copy) high frequency information from immediate adjacent time frames. Fig. 1c shows the trajectory after data sharing, where the red dots show the results. The reduction factor becomes 1.6 at high frequency regions after data sharing. The remaining unreconstructed data are approximated by conventional k-t GRAPPA using acquired data (black dots).

Methods and Results

A fully sampled data set was acquired using a 32-channel cardiac coil (Invivo Corp.) with Vectorcardiography (VCG) gating on a Philips 1.5T Achieva system. One healthy volunteer was scanned using a balanced TFE sequence in a single 23s-long breath-hold. The acquisition parameters were FOV 320×320 mm², matrix size 192×190, phase encodes per segment 5, number of phases 30, TR/TE 3.4/1.72 ms, flip angle 60°, slice thickness 8 mm. The PE direction was anterior-posterior. The fully acquired data was artificially undersampled using the trajectories similar to the one shown in Fig. 1d. The exact center 5 PE lines had reduction factor 1. The center 21 lines, except the very center 5 lines, had reduction factor 3. Reduction factors 5 to 10 were used for the outer k-space regions in 6 individual experiments used as input data for Fig. 2e. The proposed 2G k-t GRAPPA (black line in Fig. 2e), conventional k-t GRAPPA (blue line), and the channel-by-channel k-t FOCUSS [5] (red line) were used for reconstruction. All methods were implemented using the Matlab programming environment. The Matlab codes were processed on a xw4100 HP workstation with two 3.2 GHz CPUs and 2 GB RAM. Figs. 2 show the results with net reduction factor 6. The reconstruction was significantly faster than conventional k-t GRAPPA. The GRAPPA operator reduced the initial reduction factor without penalty in temporal resolution, and with only minimal impact on signal to noise ratio (SNR) [4, 6]. Since the central 24 lines were fully available after GRAPPA operator, data sharing did not influence the center of k-space. Hence data sharing with immediate adjacent time frames preserved the SNR with only minimal penalty in temporal resolution. Furthermore, the full (after GRAPPA operator) center 24 lines provided more calibration signal for the next reconstruction step. The improvement of the 2G can be clearly observed by comparing Figs. 2b, 2f and Figs. 2c, 2g, as well as Fig. 2e. Channel-by-channel k-t FOCUSS did not take fully advantages of parallel imaging. Hence, the root mean square error (RMSE) of k-t FOCUSS was significantly higher than that of k-t GRAPPA and 2G k-t GRAPPA (Fig. 2e), while took much longer reconstruction time. In conclusion, the idea of using a GRAPPA operator and narrow window data sharing for partial reconstruction is valuable for dynamic imaging with high reduction factors since both operators are computationally inexpensive and have minimal side effects. The proposed method can be combined with the optimal kernel and/or trajectories proposed in [2, 3] for further improvement.

Discussions and Conclusion

Because both GRAPPA operator and data sharing are computationally less expensive than k-t GRAPPA, 2G k-t GRAPPA reconstruction was significantly faster than conventional k-t GRAPPA. The GRAPPA operator reduced the initial reduction factor without penalty in temporal resolution, and with only minimal impact on signal to noise ratio (SNR) [4, 6]. Since the central 24 lines were fully available after GRAPPA operator, data sharing did not influence the center of k-space. Hence data sharing with immediate adjacent time frames preserved the SNR with only minimal penalty in temporal resolution. Furthermore, the full (after GRAPPA operator) center 24 lines provided more calibration signal for the next reconstruction step. The improvement of the 2G can be clearly observed by comparing Figs. 2b, 2f and Figs. 2c, 2g, as well as Fig. 2e. Channel-by-channel k-t FOCUSS did not take fully advantages of parallel imaging. Hence, the root mean square error (RMSE) of k-t FOCUSS was significantly higher than that of k-t GRAPPA and 2G k-t GRAPPA (Fig. 2e), while took much longer reconstruction time. In conclusion, the idea of using a GRAPPA operator and narrow window data sharing for partial reconstruction is valuable for dynamic imaging with high reduction factors since both operators are computationally inexpensive and have minimal side effects. The proposed method can be combined with the optimal kernel and/or trajectories proposed in [2, 3] for further improvement.

Fig. 1. k-t space trajectories. a) k-t space trajectory with reduction factor 9; b) trajectory after GRAPPA operator; c) trajectory after data sharing; d) trajectory pattern used in the experiment.

Fig. 2. Comparison of reconstruction algorithms. a) reconstruction with fully acquired data; b)~d) reconstruction at net acceleration factor 6 by 2G k-t GRAPPA (b), conventional k-t GRAPPA (c), and channel-by-channel k-t FOCUSS (d); e) plot of average RMSE at region of interest with respect to different net reduction factors. f)~h) are magnitude of differences between b)~d) to a). f)~h) were brightened 5 times.