TV Regularization for High-Pass GRAPPA with Higher Net Acceleration Factor

X. Ye[1], Y. Chen[1], and F. Huang[2]

[1]Department of Mathematics, University of Florida, Gainesville, Florida, United States, [2]Invivo Corporation, Gainesville, Florida, United States

Introduction - In this work, a novel method using calculated calibration signal is introduced to improve high-pass GRAPPA (hp-GRAPPA) [1] when only limited auto-calibration signal (ACS) lines are acquired. Hp-GRAPPA suppresses the central calibration signal to reduce image support. When the number of ACS lines is limited, this suppression will result in insufficient calibration signal which causes residual aliasing artifact in the reconstruction. To overcome this remaining drawback, a total variation (TV) regularized GRAPPA technique is used to calculate supplemental calibration signal for hp-GRAPPA. The experimental results, with comparisons with conventional GRAPPA [2] and hp-GRAPPA [3], show that the proposed method can generate images with lower noise/artifact level when only 32 ACS lines are used with reduction factor 4. This work enables hp-GRAPPA with limited ACS lines, and hence increases the net acceleration factor while preserving the image quality.

Methods - In hp-GRAPPA, the partially acquired k-space data is processed with a high-pass filter. And then the filtered ACS lines are used to calculate the corresponding convolution kernels for reconstruction [1]. Since ACS lines are only for the calculation of convolution kernels, they are not necessary to be perfect. Hence it is possible to use calculated calibration signal instead of the acquired ACS lines [3]. In this work, TV denoised GRAPPA reconstruction is used as calculated calibration signal. The proposed method consists of two steps. In the first step, full k-space calibration data is calculated using regularized GRAPPA with the limited ACS lines. Minimization of TV is used as the regularization term to reduce the noise level. The TV regularized reconstruction does not have to be optimized. The choice of the regularization parameter is flexible as long as the reconstruction provides supplemental calibration signal. In the second step, the TV regularized reconstruction is used as calibration signal for hp-GRAPPA. To test the performance of the proposed method, a sagittal brain data set was collected on a 3T GE system (Waukesha, USA) using the T1 FLAIR sequence with an 8-channel head coil (Invivo Corp, Gainesville, FL). The matrix size was 512×512×8. Fully acquired k-space data was artificially under-sampled with acceleration factor 4 (along anterior-posterior direction) and 32 ACS lines. The net acceleration factor was 3.4. Images were also reconstructed by conventional GRAPPA and hp-GRAPPA for comparison. The convolution kernel size was 4×7 for all 3 methods. The high pass filter suggested in [1] was used for hp-GRAPPA and the proposed method. Image reconstructed with the full k-space was used as a reference to calculate root mean square error (RMSE).

Results - Fig. 1e is the image from the calculated calibration data (the results of TV regularized GRAPPA). Even though Fig. 1e has reduced spatial resolution, it provides supplemental calibration signal for hp-GRAPPA. The result of the proposed method (Fig. 1d) has clearly lower noise/artifact level than these by GRAPPA (Fig. 1b) and hp-GRAPPA (Fig. 1c). RMSE of these three reconstructions (Figs. 1b~1d) are 19.4%, 15.9% and 11.1%, respectively. The zoomed-in images in Fig. 2 further demonstrate the advantages of the proposed method: lower noise/artifact level than results by conventional GRAPPA and hp-GRAPPA, well-preserved spatial resolution.
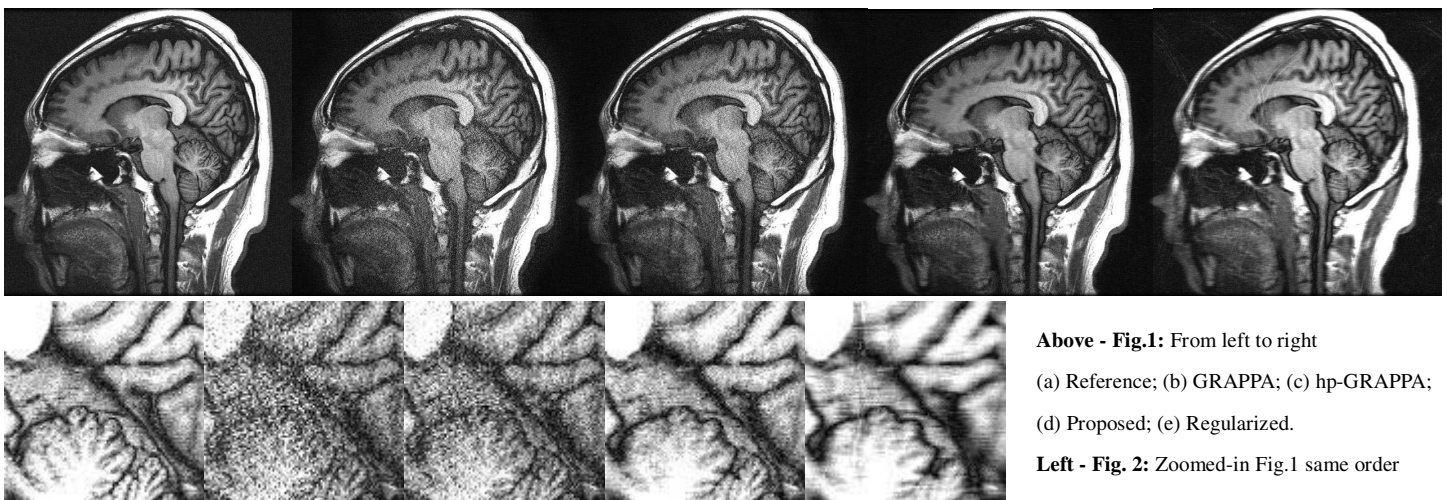
Above - Fig.1: From left to right
(a) Reference; (b) GRAPPA; (c) hp-GRAPPA; (d) Proposed; (e) Regularized.
Left - Fig. 2: Zoomed-in Fig.1 same order

Conclusion - When the number of ACS lines is limited, these conventional methods [1, 2] have non-optimized performance because of the insufficient calibration signals. TV regularized reconstruction technique improves signal to noise ratio, but damages the spatial resolution. The result of the non-optimized regularized reconstruction is not good enough for diagnoses, but provides additional calibration information. This work has proposed and demonstrated a novel application of regularized reconstruction: hp-GRAPPA with higher net acceleration factor.

References - [1] Huang, F. et. al . MRM 2008; 59:642–649. [2] Griswold MA, et. al . MRM 2002;47:1202–1210. [3] Huang, F et.al. MRM 2007;57(6):1075-1085.