TV Regularization for Segmented GRAPPA with Higher Net Acceleration Factor

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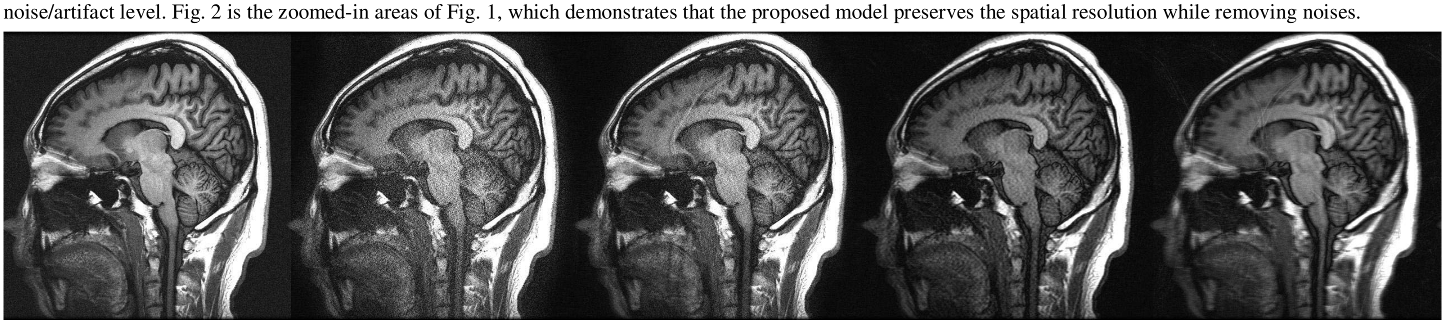
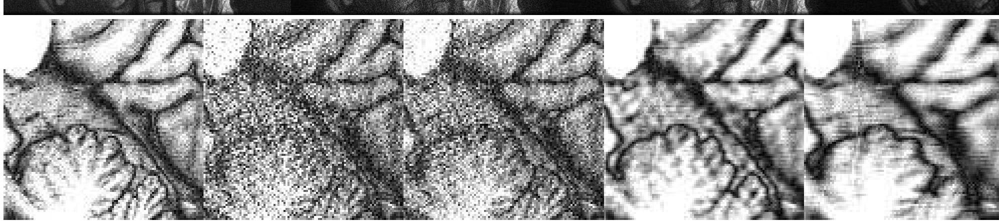
Introduction - In this work, we propose a novel method to apply segmented GRAPPA [1, 2] when only limited auto-calibration signal (ACS) lines are available. As pointed out in [3], segmented GRAPPA is superior to GRAPPA [4] but requires significant amount of ACS lines. To overcome this drawback, a total variation (TV) regularized GRAPPA technique is used to produce a full calibration k-space with limited ACS lines. In the next step, the full calibration k-space data is used as calibration signal for segmented GRAPPA. The experimental results, with comparisons with GRAPPA and high-pass 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 segmented GRAPPA with limited ACS lines, and hence increases the net acceleration factor while preserving the image quality.

Methods - Segmented GRAPPA partitions k-space and processes interpolation in each region individually. It produces reconstruction with lower noise/artifact level at the cost of lower net acceleration factor due to higher requirements on the number of ACS lines. Notice that ACS lines are only for the calculation of convolution kernels and not necessary to be perfect. Hence it is possible to use calculated calibration data instead of the acquired ACS lines [5]. In this work, TV de-noised GRAPPA reconstruction is used as 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 total variation (TV) is used as the regularization term to reduce the noise level. The TV regularized reconstruction is not good enough as the final reconstruction because of the residual aliasing artifact and reduced spatial resolution. However, it provides supplemental calibration signal. In the second step, the TV regularized reconstruction is used as calibration signal for segmented 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 $512\times512\times8$. Fully acquired k-space data was artificially under-sampled with acceleration factor 4 (along anterior-posterior direction) and 32 ACS lines. Net acceleration factor was 3.4. KIPA [2] was used for the implementation of segmented GRAPPA. Images were also reconstructed by GRAPPA and hp-GRAPPA for comparison. The convolution kernel size was 4×5 for all 3 methods. The high pass filter suggested in Ref [4] was used for hp-GRAPPA. 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. Even though Fig. 1e has reduced spatial resolution, it provides supplemental calibration signal for KIPA. 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 19.7%, 15.1% and 12.6%, respectively. RMSE quantitatively shows that the proposed method generated image with the lowest noise/artifact level. Fig. 2 is the zoomed-in areas of Fig. 1, which demonstrates that the proposed model preserves the spatial resolution while removing noises.





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 [1~4] have non-optimized performance because of the insufficient calibration signals. The experiments indicated that the calculated calibration data provides additional calibration information and hence reduce the requirement for the number of acquired ACS lines. The reconstructions by the proposed method have much lower artifacts/noise levels.

References - [1] Park J, et. al. MRM 2005;53:186–193. [2] Guo, J-Y et al. Magn Reson Imag 2006; 24: 903–915. [3] Huang, F et. al . Magn Reson Med 2008; 59:642–649. [4] Griswold MA, et. al . Magn Reson Med 2002;47:1202–1210. [5] Huang, F et.al. Magn Reson Med 2007;57(6):1075-1085.