A regularization with prior information technique for GRAPPA

F. Huang[1], Y. Li[1], and G. R. Duensing[1]
[1]Advanced concept development, Invivo Corporation, Gainesville, FL, United States

Introduction: Regularized partially parallel imaging (PPI) techniques with prior information [1] produce images with higher signal to noise (SNR) and fewer artifacts than un-regularized PPI. In regularized PPI, a regularization parameter is used to balance the regularization term and the data fidelity term. An improper choice of parameter may cause significant error. In this work, a regularized GRAPPA [2] with prior information technique is introduced. The regularization parameters are channel-wise, and are automatically determined by fitting the auto calibration signal (ACS) lines. Experimental results demonstrate that the proposed method can dramatically improve image quality, even if there is significant difference between the prior information and the target image. Moreover, the usage of low frequency prior information will not reduce the spatial resolution of the target image. The reconstruction time of conventional GRAPPA and the proposed regularized GRAPPA are almost idential.

***Theory*:** This regularization technique is implemented in *k*-space. It is assumed that some prior information about the target image in *k*-space is available. This prior information for regularization can be pre-scanned calibration signal, data from other time frame, or reconstruction using other techniques. The data acquisition scheme for the target image is the same as the one for GRAPPA. Eq. 1 shows the scheme for image reconstruction. $\hat{S}_l$ denotes the regularization *k*-space data from channel *l*, $n(j, N_b, l, m)$ is the regularization parameter, The remaining notations in Eqs. 1 and 2 are the same as those defined in Ref [2]. Compared with original GRAPPA equation, one more block is added, which is the prior information of the value at the targeted *k*-space location. The regularization parameters $n(j, N_b, l, m)$, as well as reconstruction weights $n(j,b,l,m)$, are determined by fitting ACS lines as in GRAPPA. Hence there is no extra effort for regularization parameter calculation. Clearly, regularization parameters are different channel by channel. This is reasonable because the sensitivity to the difference between the prior information and target image are different channel by channel.

***Methods*:** As an example, pre-scanned calibration signal at central *k*-space were used as prior information in the following experiments. **Simulated data sets**: Three sets of PPI data were generated using the Shepp-Logan phantom and sensitivity maps of a prototype 4-channel cardiac coil (Invivo Corporation, Gainesville, FL, USA). The matrix size of the simulated data set was 256×256×4. The PE direction was along the vertical direction in the image. Random noise was added during simulation. The first set and the second set used the same phantom (Fig. 1a) but had different noise. The third set used a Shepp-logan phantom with a removed object (Fig. 1b). The central 64×64 *k*-space data of the first data set were used as prior information. The second and third data sets were artificially under-sampled with *A* = 4, and only 5 extra ACS lines were used; hence the net reduction factor was 3.7. **In vivo data set**: Full *k*-space data were collected on a SIEMENS Avanto system using a cine true FISP sequence with a 32-channel cardiac coil (Invivo Corp, Gainesville, FL, USA) for the oblique cardiac cine images. 12 time frames were acquired. 64 central *k*-space lines from time frame 1 were used as prior information. The 8th time frame was artificially under-sampled with *A* = 6 and 6 extra ACS lines. The net acceleration factor was 4.8. **Reconstruction**: GRAPPA was implemented with convolution kernel size 4×5. Convolution kernels were calculated with the prior information. Regularization parameters and scaling of reconstruction weights ($\lambda(j,l,m)$) were calculated by fitting extra (5 or 6 in these experiments) ACS lines using Eq. 2. In Eq. 2, $\hat{n}(j,b,l,m)$ denotes the reconstruction weights calculated with the prior information. Regularized GRAPPA used Eq. 2 for reconstruction. Conventional GRAPPA used Eq.2 without the last term for reconstruction. In all reconstructions, the extra ACS lines were used for final reconstruction.

$$S_j(k_y - m\Delta k_y) = \sum_{l=1}^{N_c}\left(\sum_{b=0}^{N_b-1} n(j,b,l,m)S_l(k_y - bA\Delta k_y) + n(j,N_b,l,m)\hat{S}_l(k_y - m\Delta k_y)\right) \quad [1]$$

$$S_j(k_y - m\Delta k_y) = \sum_{l=1}^{N_c}\left(\lambda(j,l,m)\sum_{b=0}^{N_b-1} \hat{n}(j,b,l,m)S_l(k_y - bA\Delta k_y) + n(j,N_b,l,m)\hat{S}_l(k_y - m\Delta k_y)\right) \quad [2]$$

Results: Fig. 1 shows the results of the second (top row) and third (bottom row) data sets of the simulated data. The first column shows the reference images. The second column shows the results of conventional GRAPPA. The third column shows the results of regularized GRAPPA. Clearly, regularized GRAPPA generated images (Figs. 1e and 1f) with much lower artifact and noise level than these reconstructed by conventional GRAPPA (Figs. 1c and 1e). The usage of low frequency information as prior information (only central 64×64 *k*-space data of the first data set were used for regularization) did not reduce spatial resolution of the target images. When there are significant differences between prior information and the target image (Fig. 1b has one object removed), the regularization did not introduce considerable error in Fig. 1f. Fig. 2 shows the results of in vivo data set. For better visualization, only region of interests (ROI) was shown in Figs. 2a~2d. Fig. 2a is the low-resolution image reconstructed with central *k*-space data which were used as prior information; Fig. 2b is the reference of the target image; Figs. 2c, and 2d are the results from regularized GRAPPA, and conventional GRAPPA. The relative errors are 14.7%, and 21.8% respectively at ROI. Figs. 2e, and 2f show the difference maps between the reference and the results by regularized GRAPPA, and conventional GRAPPA at the whole field of view. The results of in vivo data demonstrate again that regularized GRAPPA dramatically improved image quality (compare Figs. 2c and 2d, Figs. 2e and 2f), even though there is significant difference between prior information (Fig. 2a) and the target image (Fig. 2b). And again, the usage of low frequency information (Fig. 2a) did not reduce the spatial resolution of the target image (compare Figs. 2b and 2c).

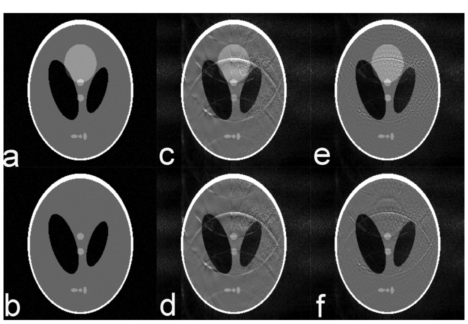

Fig. 1 Phantom data reconstruction at net acceleration factor 3.7 with 4-channel data

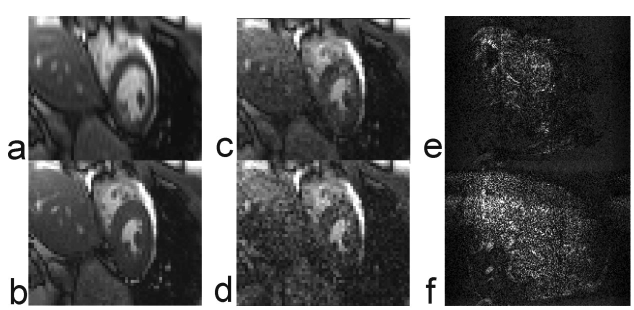

Fig. 2 In-vivo data reconstruction at net acceleration actor 4.8 with 32-channel data

Discussion and Conclusion: A regularized GRAPPA with prior information technique is introduced. This method offers serveral advantages: 1) Regularization parameters are automatically determined ; 2) Spatial resultuion can be preserved even when only low frquency information are availabe as prior information; 3) Significant difference between prior information and the target image does not introduce considerable errors; 4) The artifact/noise level is much lower than conventional GRAPPA. This technique can be used in PPI calibrated with prescan, dynamic imaging with a small number of time frames, and combination of reconstruction results by different algorithms.

References: [1] Lin F-H, *et al*, MRM 2004, 51:559-567; [2] Griswold M *et al*., MRM 2002, 47:p1202-1210