GRAPPA-POCSENSE

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Introduction: GRAPPA [1] is a widely used technique for parallel MRI (P-MRI). The technique usually has sub-optimal SNR and residual aliasing in comparison with SENSE [2] but it does not require an accurate knowledge of coil sensitivities. Each coil image is reconstructed in GRAPPA independently from all the others, resulting in inconsistency between the coil images. This inconsistency is one of the main causes of the GRAPPA sub-optimality. POCSENSE [3,4] is an iterative technique for parallel MRI that enforces consistency between individual coil images and allows incorporation of various constraints to improve resulting image quality. However, POCSENSE requires accurate estimates of coil sensitivities and the algorithm convergence can be slow. Convergence may be achieved faster can be significantly when a good initial guess is available. GRAPPA and POCSENSE can be easily combined to utilize strong points of both techniques for improved P-MRI reconstruction.

Theory and Methods: The GRAPPA-POCSENSE reconstruction method for parallel MRI was implemented as follows. At first, multi-dimensional GRAPPA [5,6] is applied to find an initial estimate of individual coil k-space data. Then, noise amplification factors for reconstructed k-space data are calculated according to

$$m_i = \sum_{j=1}^{N_c} \sum_{l \in \Omega_k} w^2(i,j,l) \,\sigma_j^2 \big/ \sigma_i^2$$

where $w(i,j,l)$ is the GRAPPA reconstruction coefficient, indices i and j count through N_c coils, index l counts through k-space points included in the multi-dimensional GRAPPA kernel. Each reconstructed k-space point is weighted by a factor depending on the noise amplification factor and a distance between the point and the center of k-space. In cases of high reduction factors, the images reconstructed from the data processed by this noise suppression (NS) technique have noticeably improved SNR in comparison with the images reconstructed from the original GRAPPA recovered data. These nose-suppressed data are subsequently used as an initial guess in the POCSENSE iterations. Coil sensitivity estimates required for POCSENSE are calculated using the central region of the k-space data (autocalibrating data and recovered data). GRAPPA gives good estimates for k-space lines adjacent to autocalibrating data. Thus, reliable coil sensitivity estimates can be found from this k-space region. Finally, POCSENSE with a predefined set of constraints is applied. POCSENSE requires at least two constraints: data consistency constraint (k-space data for individual coil images coincide with the acquired k-space data) and coil images consistency constraint (individual coil images should be consistent between themselves and the resulting combined image). Additional constraints such as image support, phase smoothness, image reality, non-negativity can be used to further improve image quality and achieve faster convergence.

To test the proposed technique, imaging studies were performed on a 3T Trio MR system (Siemens Medical Solutions, Erlangen, Germany) using the eight-channel head coil (MRI Devices, Waukesha, WI). Phantom images were acquired using a GRE pulse sequence with the following imaging parameters: FOV=18x18 cm, 384x384 matrix, 3 mm slice thickness, TR/TE=100/6 ms, a=20°. Brain images were acquired using dual contrast TSE pulse sequence with FOV=220x165 mm, matrix=320x245, 3 mm slice thickness, TR/TE1/TE2=4000/12/99 ms, reduction factor, R=4 with 39 reference lines, N_{ref}=39.

Results: Images shown in Fig. 1 and 2 illustrate typical results for GRAPPA, GRAPPA with the noise suppression (NS) technique, and GRAPPA-POCSENSE. GRAPPA reconstructed image (Fig. 1a, 2a) has the worst SNR and the highest RMS error from all the considered reconstruction methods. Application of the NS technique improved image SNR and reduced RMS but resulted in slightly visible aliasing artifacts (Fig. 1b, 2b). POCSENSE suppressed these artifacts and improved image SNR further (Fig. 1c, 2c). Fig. 3 illustrates that additional constraint can noticeably improve the resulting image quality in case of the GRAPPA-POCSENSE reconstruction.

Discussion and Conclusion: GRAPPA is an efficient algorithm to recover missing k-space views in individual coil data. However, the algorithm has serious limitations (significant noise amplification and residual aliasing artifacts) in cases of highly undersampled data. One of the main reasons for this is an inconsistency between individual coil images reconstructed by GRAPPA. The noise suppression technique is a computationally efficient method to improve SNR in the resulting GRAPPA image but it may cause residual aliasing artifacts. POCSENSE can be applied to remove these artifacts and restore consistency between individual coil images resulting in high image quality. GRAPPA and POCSENSE can be easily combined to utilize strong points of both algorithms for efficient and reliable image reconstruction from P-MRI data with high reduction factors.

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References: [1] Griswold MA, et al, MRM 2002;47:1202-10. [2] Pruessmann KP, et al, MRM 1999;42:952-62. [3] Kholmovski EG, et al, ISMRM 2002, p. 194. [4] Samsonov A, et al, MRM 2004;52:1397-406. [5] Wang Z, et al, ISMRM 2005, p. 2449. [6] Kholmovski EG, et al, ISMRM 2005; p 2672.

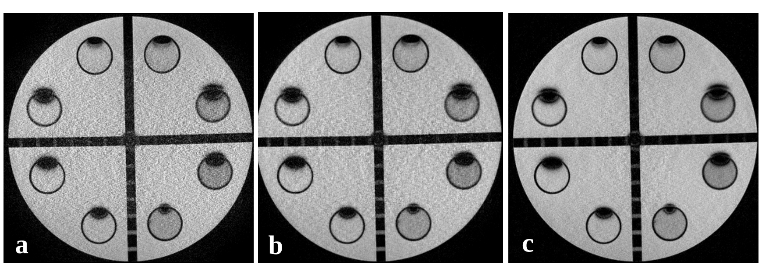

Figure 1. Phantom images reconstructed using (**a**) GRAPPA; (**b**) GRAPPA followed by the noise suppression technique; (**c**) GRAPPA-POCSENSE iterations (5 iterations, data consistence and coil image consistency constraints). R=3, N_{ref}=24, 4x5 GRAPPA reconstruction kernel. RMS error for (a) 0.15; (b) 0.08; (c) 0.05.

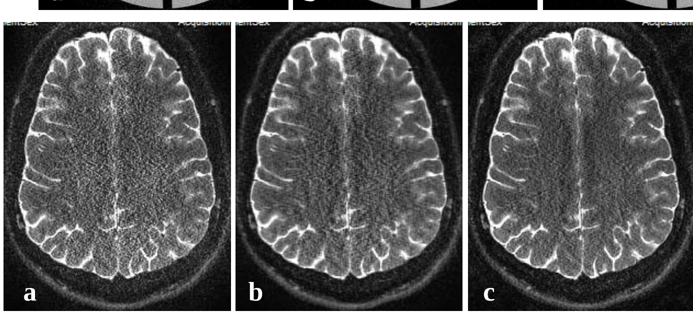

Figure 2. T2-weighted brain images reconstructed using (**a**) GRAPPA; (**b**) GRAPPA with the NS technique; (**c**) GRAPPA-POCSENSE (10 iterations, data consistence and coil image consistency constraints). R=4, N_{ref}=39, 4x5 GRAPPA reconstruction kernel.

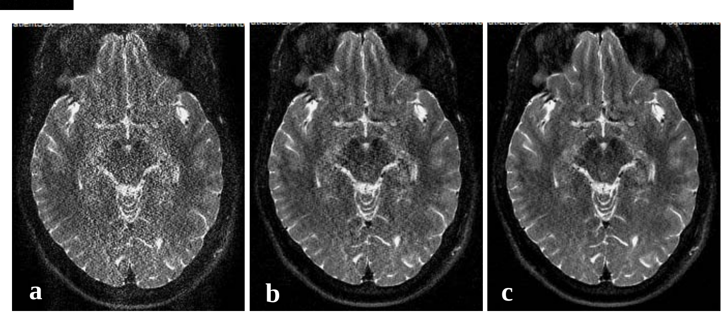

Figure 3. T2-weighted brain images reconstructed using (**a**) GRAPPA; (**b**) GRAPPA-POCSENSE (10 iterations, data consistence and coil image consistency constraints). (**c**) GRAPPA-POCSENSE (10 iterations, data consistence, coil image consistency, and *image reality* constraints). R=4, N_{ref}=39, 4x5 GRAPPA reconstruction kernel.