Optimized Regional Algorithm for GRAPPA Reconstructions

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Introduction With the ability to reduce scan time or improve image quality, Partial Parallel Imaging (PPI) is finding more clinical applications. PPI reconstruction is generally achieved using information contained in the spatially dependent RF coil sensitivities. Two of the early PPI reconstruction strategies; SENSE [1] and GRAPPA [2], have inspired numerous variations in an effort to minimize residual artifact and noise in resulting images [3-5]. MCMLI [4] and SV-GRAPPA [5] are GRAPPA-like implementations that have exploited more data dimensions to improve reconstruction quality, especially with greater outer reduction factors (ORF). In this work, we investigate specific effects and optimization considerations when using additional data dimensions in a 2D Cartesian GRAPPA style technique.

In the GRAPPA algorithm, missing lines in *k*-space are computed as weighted sums of the surrounding acquired lines, facilitated by the inherent spatial variation of the coil profiles in the under-sampled phase encode (PE) or *y*-dimension. However, there is also variation in the frequency encode (FE) or *x*-dimension. In standard GRAPPA, a single set of weighting factors is used to recover lines of *k*-space that represent signal originating from the object over the full field-of-view (FOV). This does not allow flexibility for the weighting factors to reflect any spatial variation in the *x*-direction. MCMLI [4] indirectly accounts for this *x*-variation by providing additional weighting factors from a few neighbouring k_x points, but this allows only a limited representation of the sensitivity variation. In SV-GRAPPA, a GRAPPA kernel targeted on smaller regions along *x* is utilized to provide localized weights that better represent the variation [5]. As a result, SV-GRAPPA achieves higher accuracy in the recovered signal and a better reconstruction. However, how to choose the optimal region size for the localized fitting remains an open question.

We propose a reconstruction strategy that employs the principles of SV-GRAPPA, and further investigate the effects of region size optimization. "Regional-GRAPPA" (r-GRAPPA) is implemented by executing isolated GRAPPA reconstructions on small regions of hybrid (x, k_y) space. Each set of weighting factors will be specifically tuned to recover the data in a region defined by x-RW/2 ≤ x ≤ x+RW/2, where RW denotes the reconstruction region width. The reconstruction window slides along *x* until all missing data has been recovered; overlapping the reconstruction regions provides additional averaging to mitigate noise. To determine the optimal RW, the resulting image quality must be evaluated for each reconstruction. One quantitative measure of image quality is the relative error (RE; calculated as in [3]), but this requires a gold-standard image reconstructed from the full *k*-space data, and cannot be used in a realistic accelerated scan. Alternatively, the gradient energy (Eg; defined in [6], similar to the total variation used in compressed sensing [7,8]), can be used to quantify reconstructed image fidelity and is particularly useful when dealing with aliasing artifacts. Similar to RE, the gradient energy can determine the optimal RW, but can be calculated without the need of a full reference scan.

Methods Preliminary tests have been conducted on *in vivo* axial abdominal images acquired on a 1.5T GE scanner with an SPGR sequence using a 4-element coil array, 5mm slice thickness, TR/TE = 120/2.12ms and a 256x256 matrix size. For each coil, a partial dataset was sampled from full *k*-space to simulate an accelerated acquisition, and an inverse Fourier Transform was performed along k_x to obtain an intermediate hybrid image. Hybrid (x, k_y) datasets were reconstructed using RW's from 1 to 256 pixels, and the RE and Eg were computed for each reconstruction. The GRAPPA reconstruction kernel used 4 blocks and 16 auto-calibration-signal (ACS) lines (as in [2]). Distribution of error is represented in a difference map between accelerated and full *k*-space root sum-of-squares (rSoS) images. The performance of standard GRAPPA and r-GRAPPA was assessed using RE and Eg as well as visual inspection of resultant images and difference maps. The effect of noise on the optimal RW was tested by adding increasing levels of artificial noise (uniform Gaussian) to the raw data.

Results Fig. 1 shows results for standard GRAPPA and r-GRAPPA reconstructions with ORF=3. The minima of the RE and Eg curves consistently predicted the same optimal RW for reconstruction (Fig. 1d). The optimal RW is 6 pixels for r-GRAPPA, while a standard GRAPPA reconstruction with a much higher reconstruction error corresponds to RW=256. This indicates that the variation of the weighting factors occurs on a scale much smaller than the full FOV and cannot be represented by a few neighbouring k_x points as in MCMLI. The optimal r-GRAPPA result shows a ~40% improvement in RE over standard GRAPPA (Fig. 1d). Reduction of aliasing artifact can be seen by comparing GRAPPA and r-GRAPPA reconstructed images (Fig. 1b&c) and corresponding difference maps (Fig. 1e&f). The increase in RE and Eg at very low RW is the result of noise contaminating the fitted weights. When this was further tested by adding artificial noise to the data, optimal RW increased at higher noise levels suggesting a need to balance coil configuration and noise to optimize reconstruction for a given PPI experiment.

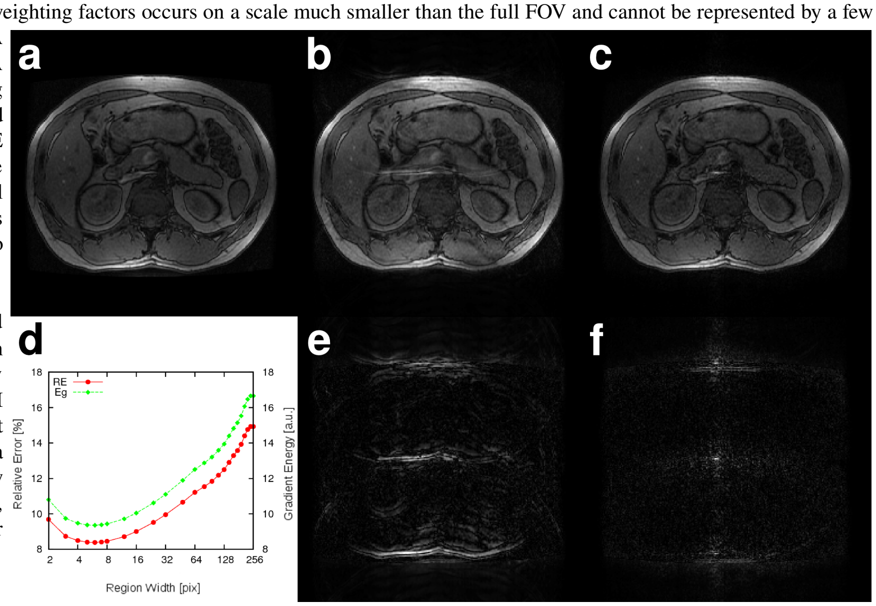

Figure 1 (**a**) Full k-space reference image. (**b**) GRAPPA reconstruction and (**e**) difference map; (**c**) r-GRAPPA reconstruction with RW=6 pixels and (**f**) difference map; (**d**) RE and Eg for r-GRAPPA reconstructions with various RW's (RW=256 corresponds to standard GRAPPA).

Discussion r-GRAPPA represents a balance between SENSE and GRAPPA; the autocalibrated *k*-space processing is optimized in the *x*-direction. We have shown that the gradient energy has very good agreement with the relative error in quantifying PPI reconstruction errors. Since Eg does not require a reference scan it is a viable optimization parameter. In addition to providing a technique for improved image fidelity, r-GRAPPA may allow further insight into the mechanisms of PPI reconstruction error, and balancing artifact, noise and coil profile variation for reconstruction optimization.

References

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