Rapid partially parallel reconstruction using a single synthetic target coil

W. Chen[1], P. Hu[1], and C. H. Meyer[1]
[1]Biomedical Engineering, University of Virginia, Charlottesville, VA, United States

Introduction: GRAPPA [1] is a successful parallel imaging method. In GRAPPA, convolution operations are performed on reduced FOV k-space data from each coil and then summed to obtain a full FOV k-space data set for an individual coil. The process is repeated for each coil and the images are then combined. The convolution kernels in GRAPPA can be derived by performing a least-square fit of same convolution operations using acquired auto-calibration signal (ACS) lines. BOSCO [2] is also based on a convolution process for unaliasing but with different un-constrained convolution kernels, and it has been successfully applied to non-Cartesian parallel imaging. In this abstract, we propose a novel parallel imaging method that formulates the convolution process in the image domain but with dramatically reduced computational cost, particularly when a large number of coils are used. The idea of the method is to remove the outer loop over coils by effectively generating one unaliased data set corresponding to a synthetic "coil". The method is demonstrated using spiral acquisitions but is applicable to more general k-space sampling methods.

Theory: GRAPPA is an extension of AUTO-SMASH [3] and VD-AUTO-SMASH [4]. In AUTO-SMASH and VD-AUTO-SMASH, the training targets are the ACS lines in a composite image. We refer here to training as the process of estimating the convolution kernels and to training targets as the targets fitted during training. The choice of training targets will be reflected in the final unaliased image. Using a simple sum of the ACS lines acquired from each coil as a training target can suffer from severe phase cancellation in certain applications. To avoid this problem, GRAPPA uses the ACS line from a single coil as a training target. The training process is performed for each coil and the final image is formed using existing array combination methods. The same reconstruction strategy is also employed in BOSCO.

In the image domain, GRAPPA and BOSCO can each be viewed as a weighted point-by-point sum of aliased images from each coil. These spatially varying weights cancel out the aliasing energy from each coil and result in an unaliased image for an individual coil. It is straightforward to use phased array combination methods to reconstruct a composite image from acquired low resolution full FOV data without phase cancellation problems. This composite image can then be used as the training target and spatially varying weights can be derived by performing a least-squares fit of low resolution aliased images from each coil to it. The final unaliased image can be reconstructed as the sum of the products of these weights and the high resolution aliased images from each coil . In this way, we only need to perform the training and unaliasing process once to obtain the final image rather than repeatedly for each coil, as in GRAPPA and BOSCO, which significantly reduces the computational cost. Mathematically, the unaliasing process can be expressed as:

$$M(\mathbf{r}) = \sum_{l=1}^{N} h_l(\mathbf{r}) \cdot P_l(\mathbf{r}) \qquad [1]$$

where $N, P_i(\mathbf{r}), M(\mathbf{r})$ are the number of coils, aliased images from each coil, and final reconstructed image, respectively. $h_i(\mathbf{r})$ are the weights for the i^{th} coil, which has a low spatial frequency spectrum. Various image-space bases can be used to represent these spatial masks with only a few unknown coefficients to be determined [5]. Fourier bases were used in this abstract. The unknown coefficients can be determined quickly by minimizing the following norm using the acquired full FOV low frequency k-space data:

$$\left\| m(\mathbf{r}) - \sum_{l=1}^{N} h_l(\mathbf{r}) \cdot p_l(\mathbf{r}) \right\| \qquad [2]$$

where $m(\mathbf{r})$ is the composite image reconstructed as the training target, and $p_l(\mathbf{r})$ are aliased low resolution image. Since both $m(\mathbf{r})$ and $p_l(\mathbf{r})$ are low resolution images, we can use a much smaller matrix size to reconstruct these images to reduce computational cost.

Methods and Results: The proposed method was applied successfully to both phantom and in vivo data sets acquired from a Siemens 1.5T Avanto scanner. Figure 1 show an in vivo head scan acquired from a healthy volunteer. The data sets were acquired using a variable density spiral sequence with 2x acceleration. A head coil with 12 elements was used. BOSCO reconstruction shows similar results for this data set. Zeroth order Tikhonov Regularization was applied to the training in both BOSCO and the proposed algorithm when processing this data set.

Discussion and Conclusion: In the proposed algorithm, the image combination is performed prior to the training and low spatial frequency weighting functions are estimated to form an unaliased image with uniform sensitivity. In contrast, in GRAPPA and BOSCO, spatial weighting functions are estimated to form an unaliased image with a sensitivity map from an individual coil imposed and image combination is performed after unaliasing. Significant computation gain can be achieved in the proposed algorithm because the image combination is performed on much smaller matrix size and the training and unaliasing based on convolution only need to be performed once instead of for each coil. This can be particularly advantageous when a large number of coils are used. A comparison of SNR performance and aliasing artifacts reduction between different strategies is currently under investigation.

A key challenge of the proposed algorithm is how to reconstruct a composite image as the training target with optimized SNR and unaliasing. Currently, we take the square root of sum of square of images from each coil and the phase of the complex sum of images from each coil as the magnitude and phase of the composite image, respectively. There are several established image combination methods for phased array acquisition. Roemer's method [6] and adaptive array combination [7] may be better choices for the proposed algorithm. Both methods are currently under investigation.

Reference: 1. Griswold et al, MRM 47: 1202 (2002) 2. Hu et al, Proceedings 14th ISMRM, 10 (2006) 3. Jakob et al, MAGMA 7: 4254 (1998) 4. Heidemann et al, MRM 45: 1066 (2001) 5. Li et al, Proceedings 15th ISMRM, 146 (2007) 6. Roemer et al, MRM 16: 192 (1990) 7. Walsh et al MRM 43: 682 (2000)

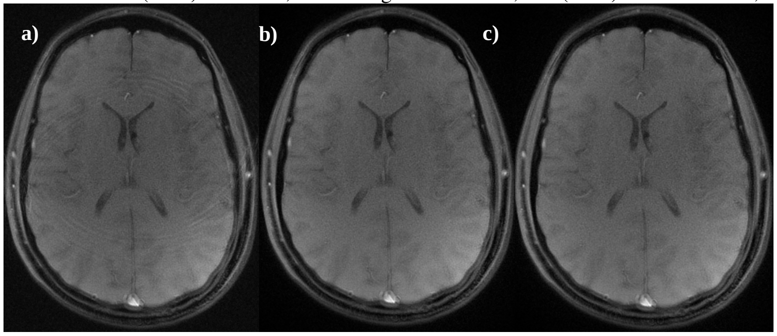

Figure 1: In vivo head scan using 2X under sampled variable density spiral acquisition. a) Aliased image reconstructed using gridding. b) Image reconstructed using BOSCO. c) Image reconstructed using the proposed method.