Synthetic Target combined with PILS (ST-PILS) for improving SNR in parallel imaging

M. Wang[1], W. Chen[2], M. Salerno[1], P. Hu[3], C. M. Kramer[1], and C. Meyer[1]
[1]Biomedical Engineering, University of Virginia, Charlottesville, VA, United States, [2]GE, [3]Beth Israel Deaconess Medical Center

Introduction: GRAPPA [1] is an effective self-calibrated algorithm for parallel imaging reconstruction. However, GRAPPA can be time-consuming when using a large number of coils because of its coil-by-coil reconstruction nature. PILS [2] (Parallel Imaging with Localized Sensitivities) is another popular reconstruction technique with fast reconstruction speed and high SNR. But it suffers from severe aliasing when the acceleration factor is high or the coil sensitivities are not constrained to small areas. In this study, we will introduce a novel rapid method called Synthetic Target-PILS (ST-PILS) that improves computation speed while maintaining high SNR. In the original synthetic target algorithm [3], the key idea was to combine the unaliased low-resolution images into a single synthetic target coil prior to the unaliasing step, rather than combining high-resolution images after unaliasing. In theory, this reduces the computation by roughly the number of coils. This original method worked well for many images, but suffered from signal loss in some regions and some SNR loss. We will show that the improved synthetic target method will largely eliminate these problems. We will also study the computation time of the method relative to a coil-by-coil reconstruction method.

Method: The algorithm works as follows: First, use the spiral PILS algorithm to automatically generate Fermi window masks [4]. These masks work as localized coil sensitivity profiles. Next, apply these masks to the aliased coil images to suppress aliasing energy. Finally, use the synthetic target method with these modified aliased images to obtain the final image. This revised synthetic target reconstruction can be expressed as:

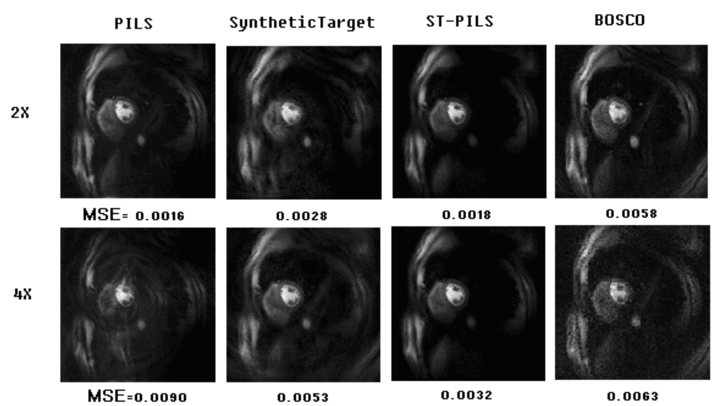
$$m_0(r) = \sum_{1}^{N_c} u_j(r)\,\tilde{m}_j(r)\,w_j(r) \qquad [1]$$

where $m_0(r)$ is the desired final image, $u_j(r)$ are the smooth spatial weighting coefficients, $\tilde{m}_j(r)$ is the aliased coil image and $w_j(r)$ is the Fermi window mask. The subscript j stands for the j^{th} coil. The spatial weighting matrix can be obtained by using the fully sampled k-space center based on the minimization of a least square norm, as in GRAPPA and BOSCO [5], which can be expressed as

$$\left\| m_{0,t}(r) - \sum_{1}^{N_c} \tilde{m}_{j,t}(r)\,u_{j,t}(r)\,w_{j,t}(r) \right\|_2 + \lambda \sum_{1}^{N_c} \left\| \nabla u_{j,t}(r) \right\|_2 \qquad [2]$$

where $u_{j,t}(r)$ is the low resolution, full FOV spatial weighting matrix. $\tilde{m}_{j,t}(r)$ is low resolution, full FOV coil image obtained by ACS lines. $m_{0,t}(r)$ is a composite full FOV low resolution image used as a target image. $w_{j,t}(r)$ is a low resolution, full FOV Fermi window mask, obtained by under sampling $w_j(r)$. $\nabla u_{j,t}(r)$ is the gradient of the weighting mask. According to [3], these spatial weighting masks should be slowly varying in image domain. The second term is used as a constraint to meet this requirement. The empirical value for λ is 10^{-7}.

The target image $m_{0,t}(r)$ was originally obtained by combining the coil images using the root sum-of-squares for the magnitude and the phase of a complex sum for the phase of the synthetic target. We also explored using Roemer's method and adaptive array combination to generate the synthetic target. Somewhat surprisingly, in this study we determined that a simple root sum-of-squares for the magnitude with a real target image yields the best results.



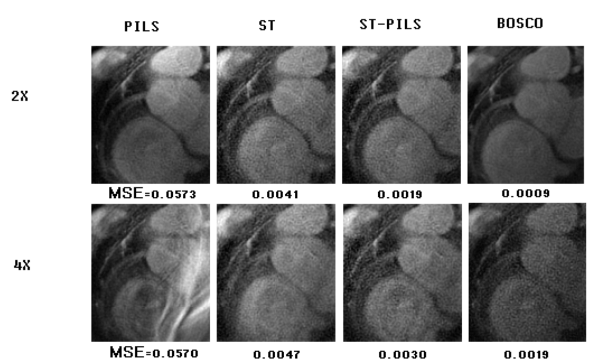


Figure 1: Reconstruction for two 32-channel spiral datasets using PILS , synthetic target, ST-PILS and BOSCO. The top row for each dataset shows results with an acceleration factor of 2 and the bottom row with an acceleration factor of 4.

Results: For data set 1, the coils have a relatively smaller sensitivity profiles than the first side lobe of the PSF. Thus PILS gives highest SNR with an acceleration factor of 2. When the acceleration factor equals 4, PILS has severe aliasing. ST-PILS successfully removed those artifacts, and gives best results among the four. For data set 2, the coils have larger sensitivity profiles, and as a result, the PILS images have severe aliasing or signal drop off.

For an acceleration factor of 2, synthetic target-PILS gives comparable SNR results with BOSCO (which supposed to give highest SNR). For an acceleration factor of 4, the synthetic target image is somewhat blurred while the synthetic target-PILS image has a better view of detail.

For the reconstruction speed study, we used a 6-node cluster; each node has two 2.8GHz Intel Xeon CPU and 2GB memory, it takes ST-PILS about 56s to reconstruct a 512×512 image with 32 coils, while for a coil-by-coil reconstruction method like BOSCO, it takes approximately 1500s. It achieves a 30-fold speed increase when using 32 coils. The reconstruction was performed in Matlab.

Conclusion & Discussion: The ST-PILS method is much faster than BOSCO, because the unaliasing process is only performed for a single target coil and because the image combination is performed on low-resolution images. It can improve image quality as compared to either pure synthetic target or pure PILS. The remaining problem is a loss of SNR when the smoothness of the spatial weighting coefficients cannot be guaranteed. Using a purely real synthetic target image is equivalent to putting a phase constraint to the inverse-matrix problem in training process. Thus it helps maintain the smoothness of weighting matrix. A coil sensitivity constraint is also applied to further improve SNR. Adding a correction phase may contribute to a better result. P Beatty [6] has published a related reconstruction algorithm called Direct Virtual Coil (DVC), in which a phase correction based on coil image phases is used in the target image. Further study may focus on this aspect. These reconstructions were performed in the image domain, but the reconstruction time for this method would be further reduced in the k-space domain, because only one FFT is then necessary. The non-Cartesian parallel reconstruction time could then be even shorter than a non-parallel multi-coil reconstruction.

Reference: [1] Griswold et al, MRM 44:602-609 [2] Griswold et al, MRM 44:602-609 [3] Weitian Chen et al, ISMRM, Toronto, 2008, p1296[4] Hu et al, ISMRM, Seattle, 2006, p371[5]Hu et al, ISMRM, Seattle, 2006, p10 [6] P Beatty, ISMRM, Toronto, 2008, p8