

Phase-Constrained Synthetic Target Algorithm for Non-Cartesian Parallel Image Reconstruction

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Introduction: The Synthetic Target (ST) algorithm is a rapid method for parallel image reconstruction [1]. It reduces computation time while maintaining comparable SNR with other self-calibrated method such as GRAPPA [2]. Instead of combining high-resolution images after unaliasing, the idea of the ST method is to combine the unaliased low-resolution images into a single synthetic target coil prior to the unaliasing step. The reconstruction can be performed in either the k-space domain or the image domain. In theory, this algorithm is capable of dealing with various types of trajectories. Based on our previous work, ST works well for Cartesian and spiral trajectories [3], but can suffer from aliasing artifacts with radial trajectories. In this study, we will show that adding a phase constraint substantially reduces aliasing artifacts for radial data. We will also compare our method with another iterative parallel reconstruction algorithm in terms of image quality and computation time.

Method: The general idea of the ST algorithm is to modulate each acquired coil image $\tilde{m}_j(r)$ with a spatially variant mask $u_j(r)$, and combine them together to get the final unaliased image $m_0(r)$. A series of Fermi windows $w_j(r)$ generated by PILS [4] are also applied to further remove aliasing. The reconstruction can be expressed as follows, with the subscript j corresponding to the j^{th} coil.

$$m_0(r) = \sum_1^{N_c} u_j(r) \tilde{m}_j(r) w_j(r) \quad [1]$$

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 [4]. This can be expressed as

$$\left\| m_{0,t}(r) - P_{0,t}(r) \sum_1^{N_c} \tilde{m}_{j,t}(r) u_{j,t}(r) w_{j,t}(r) \right\|_2 + \lambda \text{Im} \left\| \sum_1^{N_c} \tilde{m}_{j,t}(r) u_{j,t}(r) w_{j,t}(r) \right\|_2 \quad [2]$$

where $u_{j,t}(r)$ is the low resolution, full FOV spatial weighting matrix, $\tilde{m}_{j,t}(r)$ is a low resolution, full FOV coil image obtained from calibration data, $m_{0,t}(r)$ is a composite full FOV low resolution image used as a target image, and $w_{j,t}(r)$ is a low resolution, full FOV Fermi window mask, obtained by under sampling $w_j(r)$. $P_{0,t}(r)$ is our estimated arbitrary phase for the target image. The second term is used as a phase constraint that forces the combination of low resolution images to be real. The empirical value for λ is 10^2 .

The target image $m_{0,t}(r)$ was originally obtained by combining the coil images using the root sum-of-squares for the magnitude. There are various ways to obtain phase maps. In this study we are assuming the target image to be real. Thus the phase map is set to zero. We have also tried to use the phase from one coil image and a summation of phases from all coils. The zero phase map yields to best results. Further study may focus on obtaining a more precise phase map, either from a reference scan or from a more complicated estimation.

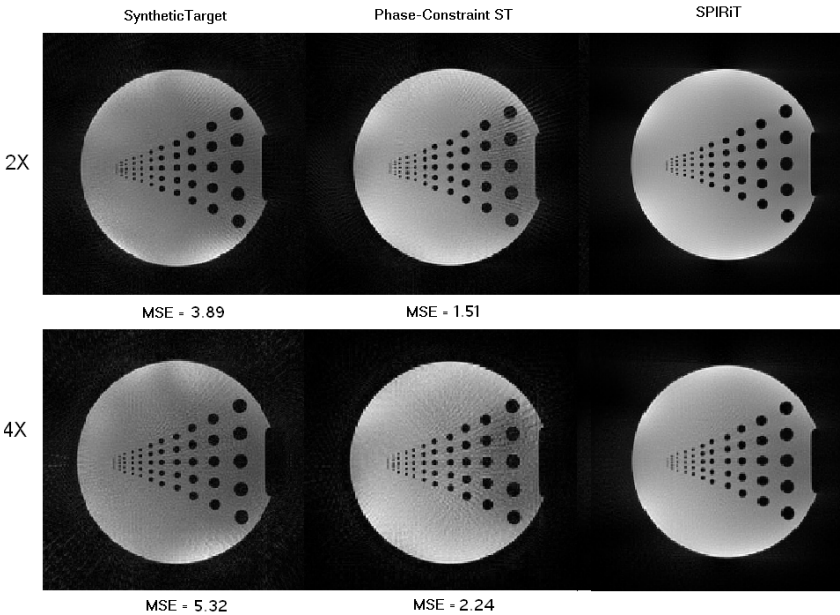


Fig1: Reconstruction of 12-channel dataset using ST, Phase Constrain-ST and SPIRiT

Results: The data is acquired using a 12-channel coil with a radial trajectory. For both the 2X and 4X cases, the original ST images have severe aliasing in the object region, and the noise level in the background is high. With phase constrained method, most of the noise and the aliasing have been removed and the resultant images have higher SNR. The image on the right is presented as reference image, which is obtained using a recently published iterative parallel image reconstruction method called SPIRiT[5]. The SNR in the images reconstructed using SPIRiT can be improved with more iterations. The tradeoff is a small loss of resolution in some cases. In this study we choose the iteration number to be 50.

For the reconstruction speed study, we used a dual-processor computer with 2.8GHz Intel Xeon CPUs and 2GB memory. The reconstruction was performed in Matlab.

It takes ST about 11s to reconstruct a 256×256 image, while for SPIRiT the reconstruction time is approximately 30s for 50 iterations. With array compression [6], the computational time of ST can be further shortened to 7s.

Conclusion & Discussion: Adding a phase constraint to the original Synthetic Target method can improve the SNR in the image, because one of the key ideas in this algorithm is to choose an appropriate phase estimate for target image. By setting the phase map to be zero, we are assuming that both the target image and the final image should be real images. A more precise phase map will be studied in the future.

This study shows that the ST algorithm works reasonably well for radial trajectories, although the results have more residual artifacts than those for Cartesian and spiral trajectories. One possible reason is that the PSF for a radial trajectory is more complex and the aliased energy is harder to remove using a non-iterative reconstruction with a k-space invariant kernel. The underlying reason will be studied more in the future.

Reference: [1] Chen W et al, ISMRM, Toronto, 2008, 1296. [2] Griswold M et al, MRM 44:602-609.; [3] Wang M et al, ISMRM, Stockholm, 2010, 1336. [4] Hu P. et al, ISMRM, Seattle, 2006, 371. [5] Lustig M. et al, MRM 64:457-471,2010. [6] Buehrer M. et al ,MRM 57:1131-1139, 2007. Acknowledgements: NIH R01HL079110 and Siemens Medical Solutions