Generalized Direct Virtual Coil (DVC) with SPIRiT kernel for arbitrary sampling pattern

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Introduction: Direct virtual coil (DVC) is an extension of GRAPPA, in which data synthesis is performed onto one virtual coil instead of individual coils [1, 2, 3]. It merges the GRAPPA kernel and the coil combination kernel together into a DVC kernel to reduce the reconstruction time. However, using GRAPPA to reconstruct images from arbitrary sampling patterns requires many different kernels which is time consuming. In this work, a SPIRiT kernel is calculated from calibration data then merged with the coil combination kernel [4]. Sensitivity maps are also estimated from the coil combination kernel, so images of all coils can be generated from the virtual coil image. The generalized DVC algorithm using the SPIRiT kernel can be applied to arbitrary k-space sampling patterns.

Methods: The conventional DVC algorithm assumes a target virtual coil. The low resolution image of this coil is synthesized from the acquired calibration data. With this calibration data of the virtual coil, a coil combination kernel can be calculated and then merged with the GRAPPA kernel. The virtual coil data can be directly synthesized from the acquired data using the merged kernel as shown in Figure 1.

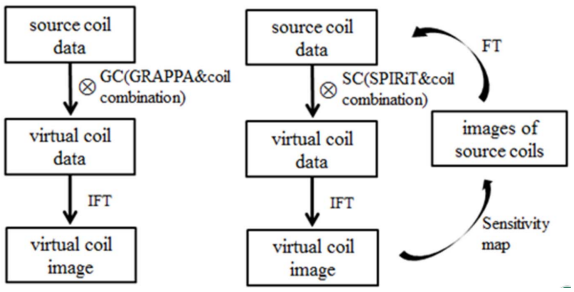

Fig.1 Flowchart of DVC (left) and generalized DVC (right). Data of virtual coil are synthesized from source coil data with the combined kernel. Images of source coils are generated from virtual coil image.

The generalized DVC uses the SPIRiT kernel instead of the GRAPPA kernel. The magnitude and phase information of the virtual coil image is synthesized from the sum of square (SoS) and sum of phase (SoP) of the low resolution images of all sources coils. The sensitivity map can be also generated from the coil combination kernel. Figure 1 illustrates how the final virtual coil image can be iteratively reconstructed from the undersampled k-space data with the merged kernel and sensitivity map. It contains two steps: (1) Convolving the merged kernel with the under sampled k-space data from all source coils; (2) Computing images of all source coils from the virtual coil image using sensitivity map.

Results: Imaging was performed on a 3T MR750 scanner (GE Healthcare. Waukesha, WI) with a commercially available 32-channel torso coil. Retrospective under-sampling is performed in ky and kz direction using 24*24 ACS lines. Results in Fig. 2 used uniform sampling patterns with an outer reduction factor of 4. Figure 3 shows the results of arbitrary sampling patterns and the reduction factor of 5. The SPIRiT images were combined using SoS.

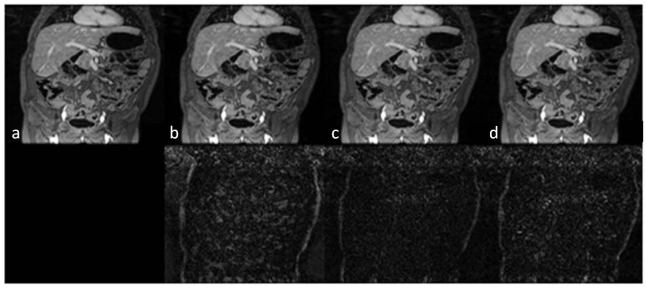

Fig.2 Comparison of reconstruction results of fully-sampled images(a), DVC (b), SPIRiT (c) and generalized DVC (d) of uniform sampling pattern at a reduction factor of 4 and. 5x error maps were shown in second row.

Discussion: 5x error maps in Fig. 3 indicate that generalized DVC can achieve similar image quality to SPIRiT. The results of the generalized DVC algorithm are improved compared with DVC. However, iteration is necessary for SPIRiT, ESPIRiT and generalized DVC [5]. In each iteration, Nc*Nc (Nc is the coil number) multiplications should be implemented in the image domain for SPIRiT while generalized DVC and ESPIRiT need Nc mutiplications. Figure 4 demonstrates that generalized DVC algorithm can be used on arbitrary sampling patterns, with similar the accuracy compared to SPIRiT and ESPIRiT. Table 1 shows the root-mean-square-error (RMSE) of different methods using different sampling patterns and different reduction factors.

Table 1 RMSE of DVC, SPIRiT, Generalized DVC and ESPIRiT under different conditions

	Reduction Factor	DVC	SPIRiT	Generalized DVC	ESPIRiT
Uniform Sampling	4	1.31%	1.00%	1.06%	1.02%
	6	1.88%	1.53%	1.62%	1.46%
Arbitrary Sampling	3	--	0.65%	0.86%	0.80%
	5	--	1.31%	1.27%	1.33%

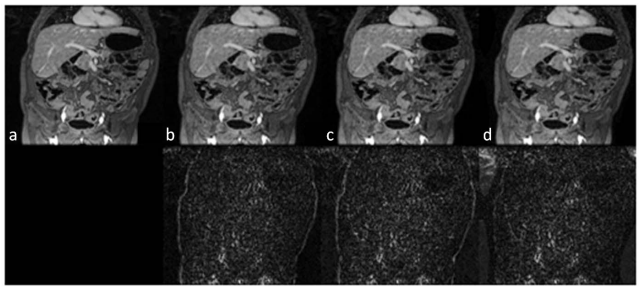

Fig.3 Comparison of reconstruction results of fully-sampled images(a), SPIRiT (b), Generalized DVC (c) and ESPIRiT (d) of arbitrary sampling pattern at a reduction factor of 5. 5x error maps were shown in second row.

Conclusion: This work demonstrates the feasibility of DVC reconstruction using SPIRiT kernel and generation of sensitivity maps from the coil combination kernel. The results of the generalized DVC are nearly the same as SPIRiT and ESPIRiT and are better than those of DVC.

References: [1] Wang K et al. MRM, 2014. [2] Beatty P J al. ISMRM, 2008. [3] Griswold M A et al. MRM, 2002. [4] Lustig M et al. MRM, 2010. [5] Uecker M et al. MRM, 2013.