Feasibility of Direct Virtual Coil (DVC) Reconstruction for 3-D Imaging

P. J. Beatty[1], J. Y. Cheng[2], A. Shankaranarayanan[1], A. Madhuranthakam[3], H. Yu[1], E. Bayram[4], S. Chang[4], and J. H. Brittain[5]

[1]Applied Science Laboratory, GE Healthcare, Menlo Park, CA, United States, [2]Electrical Engineering, Stanford University, Stanford, CA, United States, [3]Applied Science Laboratory, GE Healthcare, Boston, MA, United States, [4]GE Healthcare, Waukesha, WI, United States, [5]Applied Science Laboratory, GE Healthcare, Madison, WI, United States

Coil arrays with 32 to 128 elements have been shown to improve SNR and allow for higher acceleration factors in many imaging situations (1-3). However, image reconstruction techniques that work well for fewer coil elements can run into problems with the computer memory and computation requirements of a larger number of coil elements (4-6). The direct virtual coil (DVC) approach has been proposed as a way to greatly reduce both the computation and memory requirements for data-driven parallel imaging methods (4). The DVC approach uses the accelerated data from multiple coil elements to synthesize the dataset of a single 'virtual coil'. This greatly reduces the amount of computation compared to the 'coil-by-coil' approach used in GRAPPA (7). Previous results have shown that the DVC approach can achieve similar image quality to the coil-by-coil approach in certain 2D imaging applications (4). This work studies the feasibility of the DVC approach for 3D imaging with 2D acceleration. Phantom and *in vivo* datasets demonstrate that the DVC approach is able to achieve image quality comparable to the 'coil-by-coil' approach while reducing memory and compute requirements, especially for coil arrays with a large number of elements.

Theory Coil-by-coil data synthesis (unaliasing) is typically performed in k-space or a hybrid (x, ky, kz) space (8) whereas coil combination is typically performed in image space. In the DVC approach, the coil combination step is moved to hybrid space, where it is merged with the unaliasing operation, greatly reducing the required computation. As shown in Fig. 1, merging the unaliasing kernel and coil combination kernel leads to a kernel of larger diameter; the increased cost of a larger diameter kernel is more than outweighed by the computational savings of only having to synthesize data for a single coil. The computational savings grows with the number of elements in the coil array.

Methods C++ code was written to combine the DVC approach with ARC parallel imaging (9), creating a 'host reconstruction' program that produces two reconstructions for each acquired data set: 1) a coil-by-coil based reconstruction and 2) a DVC based reconstruction. Accelerated phantom and *in vivo* data sets were acquired on 1.5T and 3T scanners (Signa HDx, GE Healthcare, Waukesha, WI) using 8 and 32-channel body arrays. Volunteers were scanned after obtaining informed consent. Coil-by-coil images were combined using sum-of-squares (SoS) combination. Image reconstruction results were compared using difference images.

Results Shown in Fig. 2, the proposed DVC method achieves similar image quality to coil-by-coil reconstructions with sum-of-squares coil combination. The largest differences seen in image quality are 1) the reduced DC offset of the noise in regions of little or no signal, seen in Fig. 2a,c and 2) reduced aliasing artifacts seen in Fig. 2b. While these differences can be seen as further advantages of the DVC approach over sum-of-squares coil combination, it is recognized that similar behavior can be obtained using image combination techniques that are more sophisticated than the coil-by-coil approach (10). As seen in Fig. 2(c), the DVC approach reconstructs a complex image, making it straightforward to combine with later phase-sensitive reconstruction steps such as Dixon-based fat/water separation.

Discussion The results of this study indicate that the proposed DVC approach achieves similar image quality to coil-by-coil parallel imaging reconstruction methods for both 2-D and 3-D data sets. The DVC approach synthesizes one virtual coil dataset instead of a dataset for each input coil; because of this, the computational cost required to synthesize unacquired data for the DVC approach grows linearly with the number of coils, instead of, as is the case for the coil-by-coil approach, as the square of the number of coils. Furthermore, the amount of memory required to store the synthesized data grows linearly with the number of coils for the coil-by-coil approach while it does not grow with the number of coils for the DVC approach. These computational and memory savings are especially important in the context of 3-D imaging where compute resource concerns can limit clinical protocol parameters.

References (1) Zhu et al. MRM 2004; 52:869-77. (2) Hardy et al., ISMRM 2007, p244. (3) Wiggins et al., ISMRM 2008, p1072. (4) Beatty et al., ISMRM 2008, p8. (5) Doneva and Bornert, ISMRM 2008, p1260. (6) Stemmer et al., ISMRM 2008, p1274. (7) Griswold et al., MRM 2002 47:1202-10. (8) Skare et al. ISMRM 2005, p2422. (9) Beatty et al. ISMRM 2007, p1749. (10) Bydder et al. MRM 2002; 47:539-48.

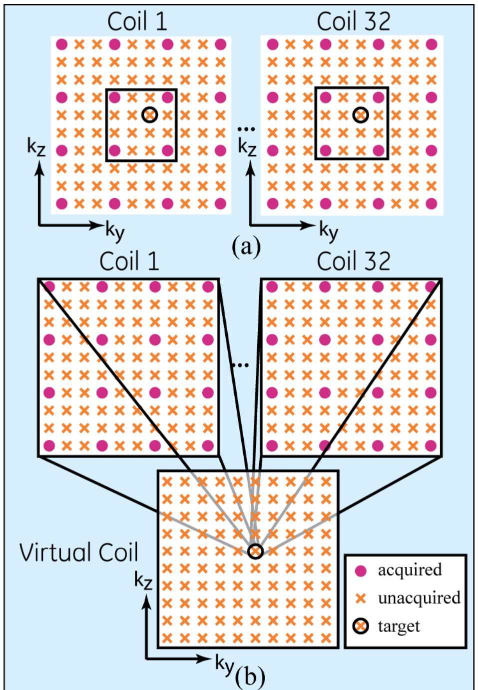

Figure 1: Kernel size & computation, coil-by-coil versus direct virtual coil. (a) For the coil-by-coil approach, the kernel only performs the unaliasing operation. For the example shown, the kernel encompasses 4 acquired phase encode lines per coil. Filling in the example location, across all 32 coils, requires 4 x 32 x 32 = 4096 complex multiply & add operations. (b) For the proposed direct virtual coil (DVC) approach, the kernel performs both the unaliasing and coil combination operations. Combining unaliasing and coil combination kernels results in a kernel of larger diameter–for the example shown, the kernel encompasses 16 acquired phase encode lines per coil. Filling in the example location requires 16 x 32 = 512 complex multiply & add operations. Even with the larger kernel size, the DVC approach is 8X more computationally efficient in this case, since only data on the virtual coil is synthesized.

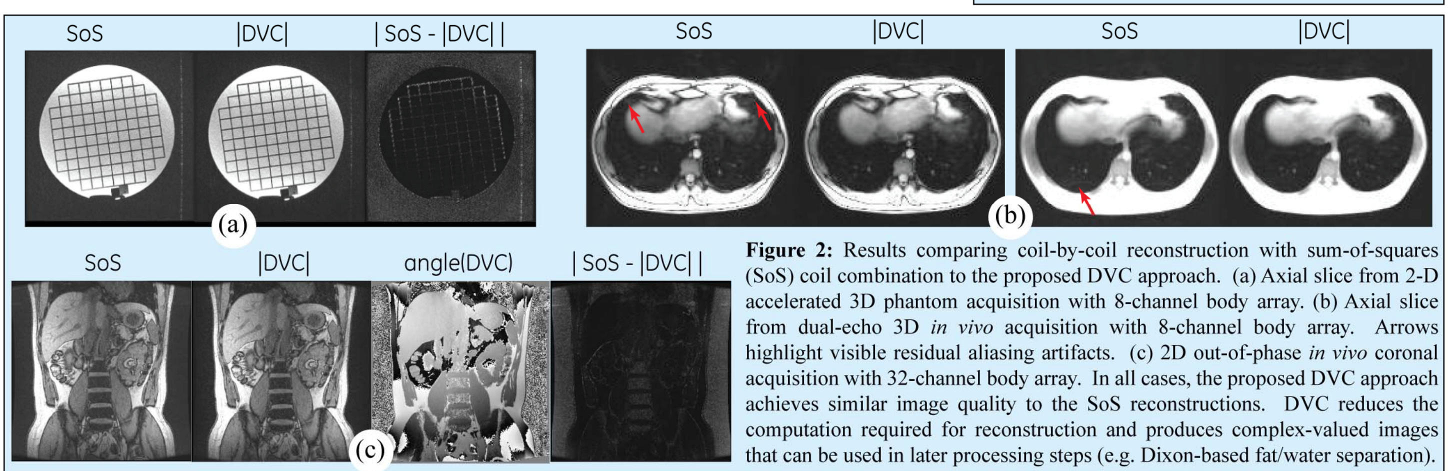

Figure 2: Results comparing coil-by-coil reconstruction with sum-of-squares (SoS) coil combination to the proposed DVC approach. (a) Axial slice from 2-D accelerated 3D phantom acquisition with 8-channel body array. (b) Axial slice from dual-echo 3D *in vivo* acquisition with 8-channel body array. Arrows highlight visible residual aliasing artifacts. (c) 2D out-of-phase *in vivo* coronal acquisition with 32-channel body array. In all cases, the proposed DVC approach achieves similar image quality to the SoS reconstructions. DVC reduces the computation required for reconstruction and produces complex-valued images that can be used in later processing steps (e.g. Dixon-based fat/water separation).