Direct Virtual Coil (DVC) Reconstruction for Data-Driven Parallel Imaging

P. J. Beatty[1], W. Sun[2], and A. C. Brau[1]

[1]MR Applied Science Lab, GE Healthcare, Menlo Park, CA, United States, [2]GE Healthcare, Waukesha, WI, United States

The 'coil-by-coil' approach of GRAPPA (1) (generating unaliased images for each source coil) solves the SNR and phase cancellation problems that affect previous data-driven parallel imaging methods (2,3). However, reconstructing each coil separately causes the reconstruction time to grow as the square of the number of coils and greatly increases the computational burden, especially with high channel counts. The recently proposed Uniform Virtual Coil (UVC) method (4) solves the SNR and phase cancellation problems, without the computational cost of separate coil reconstruction. However, the UVC method requires the additional collection of calibration data from a uniformly sensitive coil. In this work, we propose a method that directly combines the accelerated data from multiple coils into a single 'virtual coil' dataset and does not require collection of any additional data from a uniformly sensitive coil. Phantom and *in vivo* data sets are used to demonstrate the feasibility of the proposed method. Compared to the coil-by-coil approach, the proposed direct virtual coil (DVC) approach can reduce the data synthesis computation by a factor of over 20X for a 32-channel data set and 100X for a 128-channel data set.

Theory Coil-by-coil data synthesis (unaliasing) is typically performed in k-space or a hybrid (x, ky, kz) space (5) whereas coil combination is typically performed in image space. The approach in this study is to move the coil combination to hybrid space, where it can be merged with the unaliasing operation, greatly reducing the required computation. To accomplish this, first virtual coil calibration data is synthesized (Fig. 1) for a virtual coil that has coil sensitivity similar to the shading found in a sum-of-squares image. Next, coil combination coefficients are generated by relating the calibration data from the source coils to the virtual coil calibration data (Fig. 2). Figure 3 illustrates how the coil combination coefficients are then merged with the unaliasing coefficients (generated using the ARC method (6)) to form a single set of "merged" coefficients. The merged coefficients are then applied to the accelerated data to directly synthesize a complete virtual coil data set. The data set is Fourier transformed to bring it into image space, and the combination coefficients are used to correct the overall shading envelope.

Methods Accelerated 2-D Phantom and *in vivo* data sets were acquired on a 1.5T scanner (Signa® HDx, GE Healthcare, Waukesha, WI) using an 8-channel body array. An outer acceleration factor of two was used with 12 additional calibration (ACS) phase encode lines. Coil-by-coil images were reconstructed using ARC and combined by 1) complex addition and 2) sum-of-squares combination. The accelerated data sets were also reconstructed using the proposed direct virtual coil (DVC) method; image reconstruction results were compared between the three reconstruction methods.

Results Shown in Fig. 4, the proposed DVC method achieves similar image quality to coil-by-coil reconstructions with sum-of-squares coil combination, improving SNR and removing phase cancellation artifacts that occur when coil data is combined without correcting for the phase of the coil sensitivities. The cross sectional plots (Fig. 4g,h) show that the DVC results are very similar to the coil-by-coil reconstruction with sum-of-squares combination results: the signal intensity of both methods overlaps almost exactly.

Discussion Coil-by-coil parallel imaging reconstruction methods are recognized for their good image quality and robustness in difficult imaging situations. However, as high channel counts and large 3-D image matrices become more common, coil-by-coil methods do not scale well computationally. This study demonstrates that the proposed method can achieve similar image quality to coil-by-coil methods with sum-of-squares coil combination, while being far more computationally efficient since data for only one virtual coil needs to be synthesized, instead of data for each source coil. The method does not require any additional information beyond that required by coil-by-coil methods with sum-of-squares coil combination, making it straightforward to interchange methods.

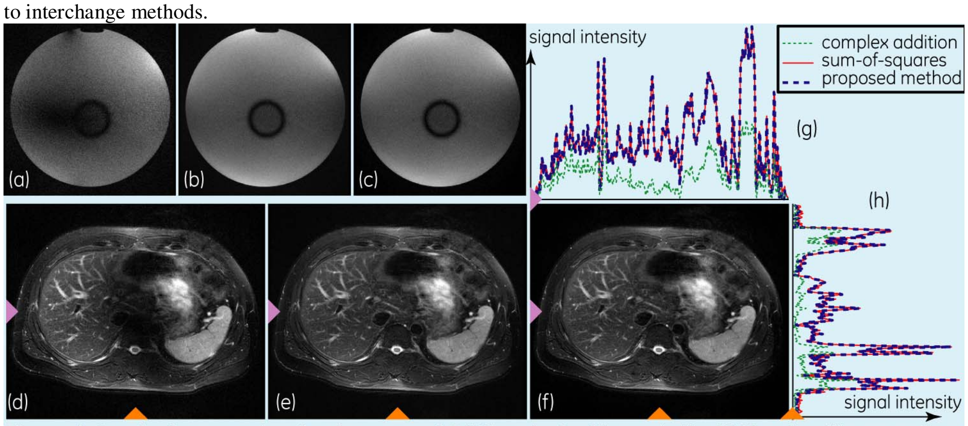

Figure 4: Results demonstrating that the proposed DVC method achieves similar SNR and resiliency to phase cancellation as coil-by-coil reconstructions with sum-of-squares coil combination. (a),(d) show the phase cancellation artifacts that result from coil combination via complex addition without phase correction. (b),(e) sum-of-squares coil combination: note the improved SNR and lack of phase cancelation. (c),(f) reconstruction of the same data sets using the proposed DVC method: note the SNR is similar to the sum-of-squares results and there is no phase cancelation. The similarity in image quality between the proposed DVC method and the sum-of-squares results is studied further using cross sectional plots of the signal intensity magnitude: (g) L/R at ▶; (h) A/P at ▲. The signal intensity of the proposed DVC method overlaps the sum-of-squares signal intensity.

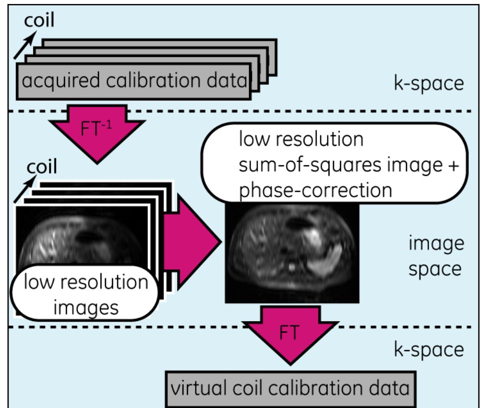

Figure 1: Generating virtual coil calibration data. Acquired calibration data from the source coils are inverse Fourier transformed to create low resolution coil-by-coil images. These images are combined to form a sum-of-squares image, with an added spatially varying phase based on the low resolution coil-by-coil images. Fourier transforming this image generates the virtual coil calibration data.

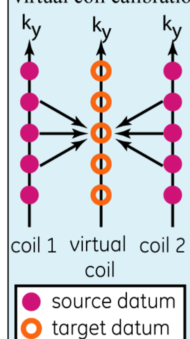

Figure 2: Generating combination coefficients. A data-driven procedure is executed to generate coefficients that fit unaccelerated calibration data from the source coils to virtual coil calibration data (target data). To simplify the illustration, a 1-D kernel is shown; in practice, the kernel spans all spatial frequency directions.

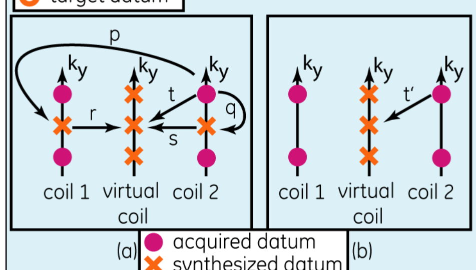

Figure 3: Merging unaliasing coefficients (p,q) and combination coefficients (r, s, t). (a) Unaliasing and combination coefficient paths. A datum from coil 2 contributes to a virtual coil datum via multiple paths (pr, qs, t). (b) The multiple paths in (a) can be combined into a single path using a single "merged" coefficient, t'=pr+qs+t. Reconstruction time is greatly reduced by directly synthesizing the virtual coil data from the acquired data using the merged coefficients.

References

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