Virtual Coil Phase Determination using Region Growing: Description and Application to Direct Virtual Coil Parallel Imaging Reconstruction

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Introduction Direct Virtual Coil (DVC) parallel imaging [1,2] synthesizes unaccelerated data for a virtual coil from accelerated data from multiple source coils. It has been shown that the DVC approach is able to achieve image quality similar to coil-by-coil methods [3,4], while dramatically reducing the computation time and memory requirements for high channel count arrays. One critical and challenging step in the DVC method is setting the phase of the virtual coil. Rapid phase changes in the magnetization (e.g. fat/water interface in an out-of-phase image) will cause rapid phase changes in the source coil images. If these phase changes do not appear in the phase of the virtual coil as well, areas of signal drop out can occur in the reconstructed image. We have found that existing methods for phase-preserving channel combination [5,6] can introduce additional unwanted phase into the virtual coil, causing phase cancellation artifacts when used with DVC. In this work we describe an approach to DVC phase estimation that allows preservation of rapidly varying phase in the magnetization without introducing unwanted phase that could degrade the performance of the DVC approach. 8, 20 and 32-channel *in vivo* results are shown and compared to coil-by-coil results.

Methods Adaptive Reconstruction [5] is able to combine channels while preserving phase. This technique can use a block-by-block approach, where image space is divided into multiple blocks and linear combinations of the source channels are used to create a high SNR result for each block. In the context of DVC, if only one block is used covering the entire field-of-view, the result can still have regions of poor phase estimation. Conversely if multiple blocks are used, phase discontinuities can be introduced along the borders of the blocks. The proposed approach builds on the multiple block approach with a solution to the problem of phase discontinuities along the block borders. The approach uses blocks that *overlap* in image space together with an affine phase matching step that allows us to grow a region of known phase from multiple overlapping blocks (Fig. 1). We start by assigning one block as a region of known phase (ROKP); the ROKP is then grown by affine phase matching an overlapping block and then adding the overlapping block to the ROKP. Affine matching involves adding phase to the partially overlapping block:

$$\widehat{b}(x,y) = b(x,y)e^{i2\pi(\delta+\Delta k_x x+\Delta k_y y)}$$

, where δ, Δkx, Δky are determined to enable b-hat to match the phase of the ROKP in the overlapping region. This can be accomplished by finding the k-space maximum of conj(ROKP)b. Affine matching allows us to accommodate differences in linear phase that can exist between coil sensitivities.

Healthy normal subjects were imaged on 1.5T and 3.0T scanners (HDx and MR750, GE Healthcare, Waukesha, WI), using 8, 20 and 32-channel torso arrays. Both in and out-of-phase datasets were acquired with both 2-D and 3-D acquisitions. All acquisitions were internally calibrated and virtual coil data (magnitude and phase) were generated from the low resolution internal calibration data. ARC [7] was used to perform both coil-by-coil and DVC reconstructions on all datasets.

Results Imaging results, shown in Fig. 2, confirm that the proposed approach results in a sensible solution to the virtual coil phase for both 2-D and 3-D imaging, with both in and out-of-phase magnetization. This enables DVC reconstructions that are consistently nearly identical to coil-by-coil reconstructions (see difference images). For the 32-channel data sets, the coil-by-coil reconstructions synthesized a complete datasets for each of the 32 channels; in contrast, the DVC reconstructions only synthesize data for the one virtual coil, significantly reducing the required computation time and memory.

Discussion Setting the phase of the virtual coil is a critical step in reconstructions that directly synthesize data on a virtual coil (DVC). This work proposes to grow a region of known phase by affine phase matching of multiple overlapping smaller regions. Our results show that the proposed approach can work well for both 2-D and 3-D imaging with high channel count arrays and in difficult situations, such as out-of-phase acquisitions. We continue to test the approach over a wider variety of coil geometries and imaging situations - motivated by the potential of DVC to drastically reduce the computation needed for high channel count reconstructions.

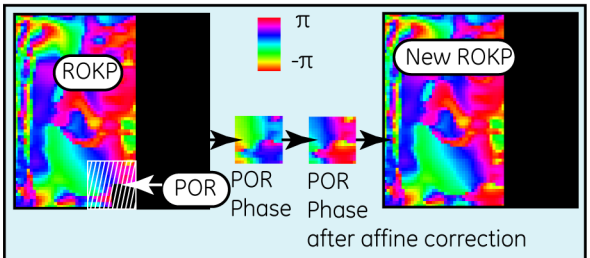

Figure 1 The proposed region growing method expands the size of the region of known phase (ROKP) by choosing a partially overlapping region (POR). A linear combination of the source channels with high SNR is found in the POR. The phase of the linear combination then undergoes an affine correction to match the phase of the ROKP in the overlapping region - and is then added to the ROKP.

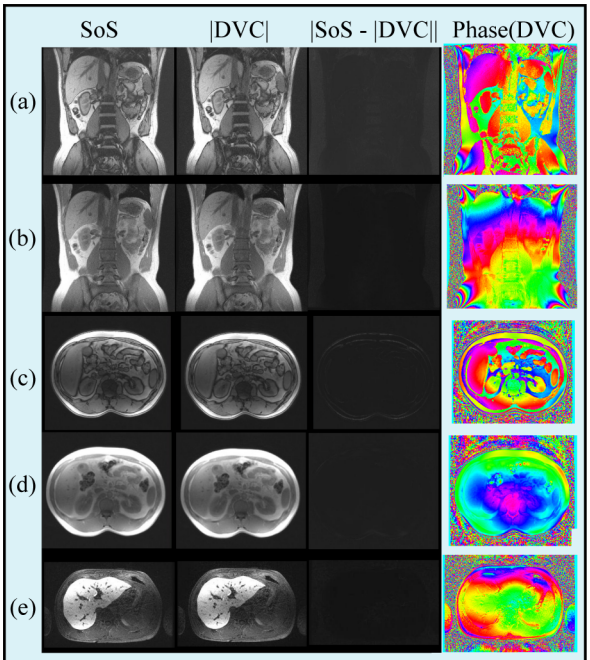

Figure 2 Reconstruction results comparing coil-by-coil reconstruction with sum-of-squares channel combination (SoS) to the DVC method that directly synthesizes data for a virtual coil. 2-D 32-channel results are shown in (a) (out-of-phase) and (b) (in-phase). 3-D 8-channel results are shown in (c) (out-of-phase) and (d) (in-phase) and 3-D 20-channel results in (e). In all cases observed, the proposed region growing approach, used in the DVC reconstructions, was able to set the phase of the virtual coil adequately to avoid phase cancellation artifacts in the reconstructed images.

References [1] Beatty et al., ISMRM 2008, p8. [2] Beatty et al., ISMRM 2009, p2727. [3] McKenzie et al., 2001, MRM 46:619-23. [4] Griswold et al. 2002, MRM 47:1202-10. [5] Walsh et al., 2000, MRM 43:682-90. [6] Buehrer et al, 2007, MRM 57:1131-9. [7] Beatty et al. ISMRM 2007, p1749.