Fully Autocalibrated Parallel Imaging for Arbitrary Trajectories Using a Combination of GRAPPA-Operator Gridding and Conjugate-Gradient Optimization

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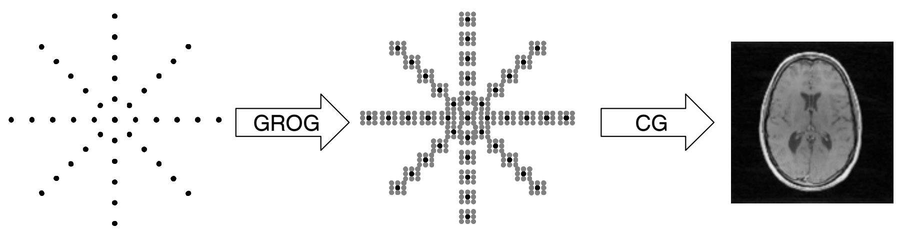
Introduction: Several groups have recently demonstrated autocalibrated k-space based parallel imaging techniques for non-Cartesian trajectories. All of these methods are based on exploiting specific symmetries in the imaging trajectories, such as radial or spiral imaging. However, these methods are not applicable to arbitrary trajectories; to date only the conjugate gradient (CG) SENSE method from Pruessmann et al [1] is able to handle arbitrary trajectories. In this abstract, we propose a completely autocalibrated method for arbitrary trajectories based on the generalized sampling theory of Papoulis [2] and previous work using blipped trajectories. Moriguchi et al. [3] showed that a blipped PR read out with a conjugate gradient (CG) algorithm allows one to reconstruct near perfect radial images with a fewer number of projections than Nyquist would dictate. This method exploits the generalized sampling theory of Papoulis [2], which states that unaliased images can be reconstructed even when the Nyquist criterion is violated in portions of k-space, as long as the average sampling rate is equal to the Nyquist rate (ie bunched sampling). In this work, we replicate bunched sampling using the GRAPPA Operator Gridding (GROG) method [4] to replicate the function of these blipped gradients. These new bunched datapoints can then be used with the CG optimization to reconstruct accelerated images. Because the GROG weights can be calculated from the undersampled non-Cartesian datapoints themselves, this method provides a completely self-calibrating reconstruction of undersampled non-Cartesian data with arbitrary trajectories. Here we show examples of accelerated radial, spiral and rosette trajectories.

Figure 1:
A schematic of the reconstruction. The non-Cartesian trajectory is first "blipped" using GROG, creating the gray points using the acquired black points. The blipped trajectory is then run through a conjugate gradient algorithm, resulting in the unaliased image.



Methods: Standard in vivo radial and spiral data were acquired using a 1.5T MR Siemens Avanto scanner (Siemens Medical Solutions, Erlangen, Germany) and 12 and 32 channel head array coils, respectively; rosette data were also simulated using Matlab and an eight channel head array. The data matrices were as follows: Radial 12x256x512, base matrix = 256x256; Spiral 32x4x14336, base matrix = 256x256; Rosette 8x64x512; base matrix 128x128. The data were undersampled to R=4 for radial, R=2 for spiral, and R=5 for rosette retrospectively. In a first step, GROG weights calculating using the non-Cartesian data were applied to the acquired points to shift them by a maximum of 0.3Δk (Figure 1). Once the additional "blipped" points have been created with GROG, the CG-INNG optimization algorithm was applied to reconstruct the image. For the images shown here, 15 iterations were used. It is important to note that this second step does not use parallel imaging, i.e. no coil information is taken into account for the CG algorithm.

Results: Figure 2 top row shows the radial reference image, the R=4 undersampled image, and the R=4 reconstruction with bunched sampling points created by GROG with CG optimization. As can be seen by comparing the reconstruction with the undersampled image, the addition of blipped points clearly improves the image quality. Figure 2 center row shows the reference spiral image, the R=2 undersampled image, and the R=2 reconstruction with blipped points and CG optimization, and Figure 2 bottom row shows analogous results for the R=5 simulated rosette image. The aliasing artifacts present in the undersampled images are removed after the GROG-CG reconstruction with blipped points.

Discussion: The use of GROG to create blipped non-Cartesian trajectories has several advantages. The first is that unaliased images can be reconstructed from undersampled data without the need for calibration data, either in the form of a sensitivity map or a low-resolution dataset. Secondly, no additional gradient performance or special pulse sequences must be designed, as the points can be "blipped" after the acquisition using GROG. This method can be used with any trajectory; radial, spiral, and rosette have been demonstrated here. The only requirement for the GROG-blipped CG optimization method is a coil array which provides sufficient sensitivity variations to calculate base GROG weights. However, common clinically available coils allow k-space shifts of up to 0.5Δk, which is sufficient for reconstructing the bunched GROG points. Thus, the GROG-blipped CG optimization procedure shows great promise for the reconstruction of undersampled non-Cartesian datasets.

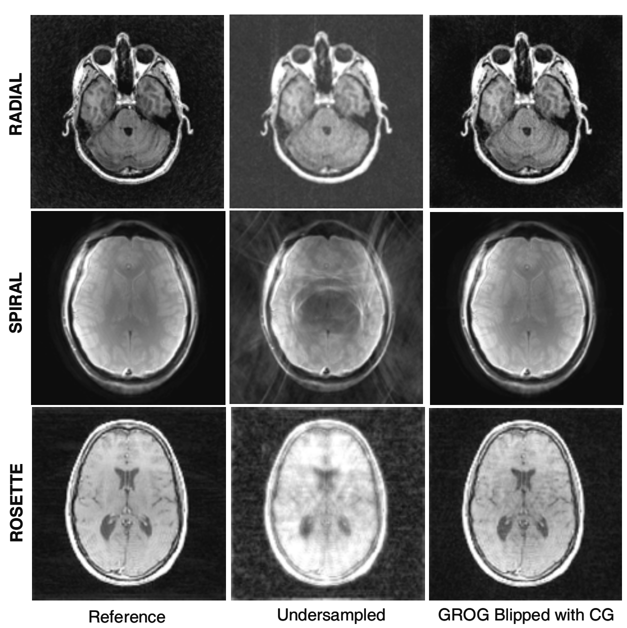


Figure 2
Top: The radial reference (left), R=4 (center), and the GROG blipped, CG optimized R=4 image (right).

Middle: The spiral reference (left), R=2 (center), and GROG blipped, CG optimized R=2 image (right).

Bottom: The rosette reference (left), R=5 (center), and GROG blipped, CG optimized R=5 image (right).

References:
1 Pruessmann, et al MRM 46 :638-651 (2001)
2 Papoulis A. IEEE Trans Circ Syst 1977; CAS-24:652-654
3 Moriguchi H, et al. Proc. ISMRM, pg. 694 (2006)
4 Seiberlich N, et al. Proc. ESMRMB, pg 300 (2006)

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