Reconstructing Undersampled Non-Cartesian Data with Calibrationless Parallel Imaging

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Introduction: Non-Cartesian trajectories in MRI have several advantages over standard Cartesian k-space coverage, including faster acquisition times and fewer undersampling artifacts. Unfortunately, further reduction of measurement time by means of standard parallel imaging techniques such as GRAPPA[1] proves difficult for non-regular sampling patterns. A novel way to use parallel imaging in combination with arbitrary trajectories may be Calibrationless Parallel Imaging (CPI), which was introduced in [2] for random Cartesian sampling patterns. CPI uses a low-rank approximation of the GRAPPA source matrix to calculate missing points. The advantage of CPI in comparison to GRAPPA is that CPI does not require a regular sampling pattern. In this work we show reconstructions of undersampled data acquired along a variable density spiral trajectory.
Because CPI works with Cartesian grid points, one must first grid the undersampled non-Cartesian data before this method can be employed. In this abstract, GRAPPA operator gridding (GROG, [3]), which uses parallel imaging to shift the acquired non-Cartesian points to nearby Cartesian locations, is employed to grid the undersampled data. While the GROG weights needed for gridding can be calculated for radial and some spiral sampling patterns [4], for more complicated trajectories a low-resolution Cartesian prescan is needed. In this work, we present an iterative method both to calculate the GROG weights needed for gridding and to reconstruct unaliased images for arbitrary undersampled trajectories using solely Calibrationless Parallel Imaging.

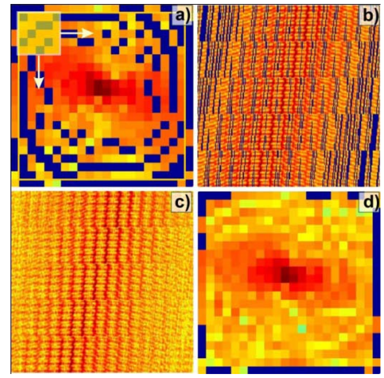

Fig 1: CPI: First, a GRAPPA kernel is used to assemble the undersampled data (a) of all coils into a source matrix (b). A low-rank approximation yields an updated source matrix (c). Finally, the points are reassembled into k-space and data-consistency is invoked by replacing measured data points.

Methods: The concept of Calibrationless Parallel Imaging is depicted in Fig. 1. First, a GRAPPA kernel is used to assemble all points of the undersampled region to be reconstruted (a) into a large source matrix (b). This GRAPPA source matrix should be low-rank, as individual points appear multiple times (depending on the kernel size). In the undersampled data this is not the case due to the irregularly distributed missing points. The SVD of the matrix is calculated, the lowest singular values truncated, and an estimate of the source matrix is formed using these truncated SVDs to enforce the low rank (c). Finally, the reconstructed k-space points are remapped into the original grid and data consistency is invoked by replacing measured points (d). This process is iterated until the reconstructed area converges.
Reconstruction with iterative GROG using CPI is implemented in the following way (Fig. 2). First, the undersampled data are gridded by just moving them to the nearest point on a Cartesian grid (a). Then the middle of k-space is reconstructed using Calibrationless Parallel Imaging (b). After the reconstruction, a first estimate of the GROG weights are calculated from the reconstructed center of k-space and the non-Cartesian data are are again gridded, this time using GROG with the first approximation of the weights (c). Next, the middle of k-space is reconstructed again and all steps are repeated until the GROG weights converge. The weights can then be used to grid the undersampled dataset. After gridding, the full k-space is reconstructed using CPI. For all steps, the CPI reconstruction was performed with a kernel size of 5x5 and the 30 largest singular values of the GRAPPA source matrix were employed.

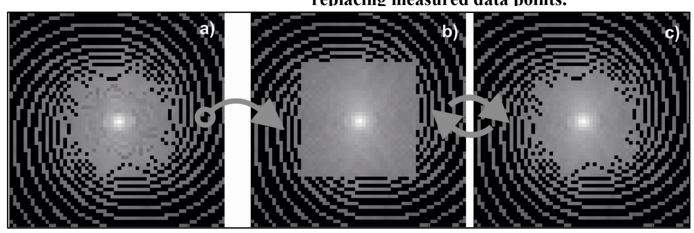

Fig 2: Gridding with iterative GROG. First, the data are moved to Cartesian points (a). Next, k-space is reconstructed (b) using Calibrationless Parallel Imaging. After aquiring the weights using the reconstructed part of k-space, the data are gridded using GROG (c). Steps (b) and (c) are repeated until the GROG weights converge.

An example reconstruction is shown for in-vivo data of a healthy human volunteer acquired along a spiral trajectory (48 projections, 700 readout points) on a standard 1.5T clinical whole-body scanner using a 32 channel head coil (Siemens Medical Solutions). A spiral TrueFISP sequence with the following parameters was employed: TR= 4.96ms, TE=2.48ms, FOV=250mm^2, slice thickness=5mm. The spiral k-space data were undersampled to a factor of R=4 or R=6 retrospectively by employing only 12 or 8 arms for the reconstruction.

Results and Discussion: The in-vivo results using different undersampling factors are shown in Fig. 3. The fully sampled image gridded with iterative GROG is shown in (a). The spiral data were undersampled by a factor of 4, gridded using iterative GROG (b) and reconstructed using CPI (c). The corresponding undersampled and reconstructed k-spaces are shown in (d). Furthermore, the data were undersampled by a factor of 6 and reconstructed in the same manner (e). While image (d) demonstrates few artifacts from undersampling, higher acceleration can lead to artifacts as can be seen in (e).

Conclusions: In this work we have introduced Calibrationless Parallel Imaging with iterative GROG for the reconstruction of images from arbitrary non-Cartesian sampling patterns. The central portion of k-space is first reconstructed to calculate accurate GROG weights for the gridding of the entire undersampled k-space, which can then be reconstructed using CPI. This method is valuable because it requires no additional calibration data for either the computation of the GROG weights or for the consequent parallel imaging reconstruction. The applicability of the method is shown for simulated and in-vivo data sampled along a variable density spiral trajectory with different acceleration factors.

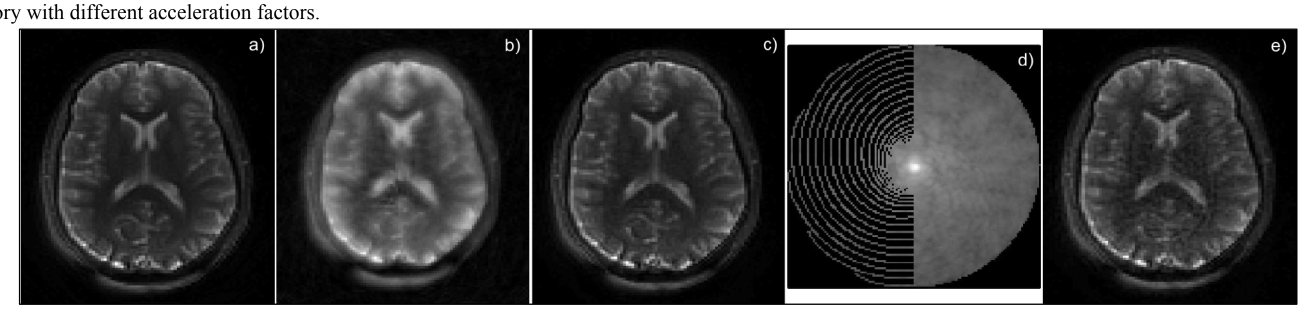

Fig 3: Reconstruction of in-vivo data acquired along a spiral trajectory. The fully sampled image gridded with iterative GROG is shown in (a) Undersampled data were generated with an acceleration factor of 4; the resulting images are shown before (b) and after reconstruction (c) with CPI. The corresponding k-spaces are shown in (d). Finally, the data were undersampled by R=6 and reconstructed (e).

References:
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