Pseudo-Cartesian GRAPPA Reconstruction of Undersampled Non-Cartesian Data

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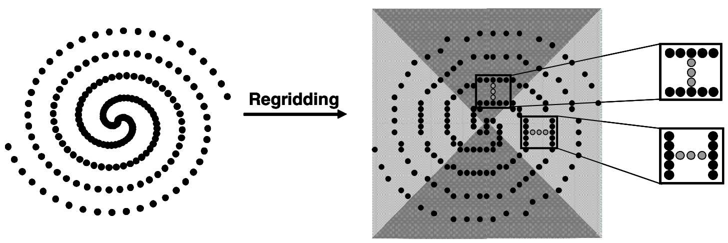
Introduction: The application of the basic Cartesian GRAPPA [1] reconstruction algorithm requires regular, symmetric undersampled data. Non-Cartesian sampling schemes, such as radial or spiral trajectories, do not fulfill this requirement. Therefore, special reconstruction and/or data reordering procedures are necessary. In all previous methods, the GRAPPA reconstruction is performed first on the reordered data, followed by regridding of the reconstructed data onto a Cartesian grid [2-5]. However, if the undersampled non-Cartesian data are first regridded, the inherent symmetry of the acquisition scheme can be used to define several Cartesian patterns in the regridded data which can be used for reconstruction. Examining specifically the spiral case, the regridded undersampled k-space can be divided into several "sectors," where each sector can be reconstructed with a specific Cartesian pattern. The reconstruction for each sector is then identical to a Cartesian GRAPPA reconstruction; the weights for each sector's pattern are determined from low-resolution, fully-sampled data (ACS), and applied to the undersampled data to arrive at the full k-space.



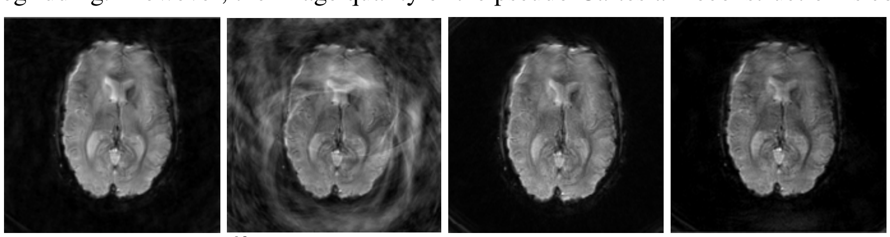
1a 1b

Figure 1a: A typical undersampled spiral sampling scheme. It is clear that the acquired points do not fall on a Cartesian grid, and must be regridded at some point in the reconstruction.

Figure 1b: After the acquired points have been regridded, clear Cartesian patterns are visible. For the case of two sectors, shown here, two distinct patterns are employed to reconstruct the data, shown at right. The black points appear in both the ACS and undersampled data, and are used to reconstruct the gray points. To prevent artifacts, points are only reconstructed if a certain percentage of pattern points are non-zero.

Methods: In vivo data were acquired using a 3T MR scanner (Magnetom Trio, Siemens Medical Solutions, Erlangen, Germany) equipped with an eight channel head array coil (MRI Devices Corporation, Waukesha, WI). Four constant-linear-velocity spiral interleaves were acquired from the center out using a gradient echo sequence. Two of the interleaves were subsequently removed to arrive at the R=2 undersampled dataset used for reconstruction purposes. The ACS for each image was taken as the central 1/25th part of the fully-sampled dataset. The undersampled data were rounded onto the Cartesian grid using the appropriate density compensation function, and the fully-sampled data regridded using the INNG method [6]. Four reconstruction sectors were defined in the undersampled data, analogous to those shown in Figure 1b.

Results: The reference, R=2 undersampled, standard segmented GRAPPA reconstruction [5], and the corresponding four-angle pseudo-Cartesian reconstruction images are shown in Figure 2. The main aliasing artifacts visible in Figure 2b are clearly removed when using either the standard spiral procedure or the pseudo-Cartesian method proposed here. The pseudo-Cartesian image suffers slightly from remaining artifacts as compared with the image reconstructed with the standard method due to inherently improper regridding. However, the image quality of the pseudo-Cartesian reconstruction is comparable to that of the standard reconstruction.



2a 2b 2c 2d

Figure 2a: The reference in vivo brain image.
Figure 2b: The R=2 undersampled image.
Figure 2c: The standard spiral GRAPPA reconstruction
Figure 2d: The proposed four-sector pseudo Cartesian reconstruction.

Discussion: The major advantage of the pseudo-Cartesian GRAPPA reconstruction method proposed here is that it can theoretically be applied to any non-Cartesian sampling scheme with an underlying symmetry. There is no need for separate algorithms for constant-angular velocity spirals, constant-linear velocity spirals, etc; all can be reconstructed given the presence of a small number of applicable Cartesian patterns. In addition, simulations have shown that by using a variable density spiral acquision scheme [7] to acquire the ACS, the image quality can be further improved. However, the inexactness of the regridded undersampled data leads to minor artifacts, which are expected to worsen with increasing acceleration factor. Thus, although the algorithm proposed here is not as exact as previously demonstrated non-Cartesian GRAPPA reconstruction schemes, it is far more general and can be used in a variety of non-symmetric, non-Cartesian applications.

References
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