Direct Parallel Imaging Reconstruction of Radially Sampled Data Using GRAPPA with Relative Shifts

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Synopsis:
The application of parallel imaging to non-Cartesian trajectories is non-trivial, requiring, in general, the solution of large systems of linear equations. In this abstract we demonstrate that in many cases this process can be greatly simplified using a k-space reconstruction with relative shift operations. As a particular example, it is shown that missing projections from a projection reconstruction trajectory can directly be reconstructed with a GRAPPA reconstruction when different weights are used along the read-out direction.

Introduction:
In many cases, non-Cartesian sampling trajectories offer distinct advantages for MRI compared to the normal Cartesian sampling pattern. While these methods can potentially gain from the use of parallel imaging methods, the application of parallel imaging to non-Cartesian trajectories is non-trivial, requiring, in general, the solution of large systems of linear equations [1-4] requiring long reconstruction times. To date, this has been a major hindrance to the implementation of these methods on most clinical scanners. In this abstract, we demonstrate that in many cases this process can be greatly simplified using the GRAPPA reconstruction [5] with relative shift operations. In particular, it is shown that missing projections from a projection reconstruction (PR) trajectory can directly be reconstructed with a normal GRAPPA reconstruction when different weights are used along the read-out direction.

Theory:
The GRAPPA method reconstructs missing lines in each coil element by forming linear combinations of neighboring lines to reconstruct missing data. The weights for these linear combinations are derived by forming a least squares fit between additionally acquired lines using a pseudoinverse operation. However, this least squares fit is simply blindly providing the best solution to the problem that is given to it. In the case of normal GRAPPA, the weights are optimized for shifting data in k-space by a specific amount in a specific direction, since the lines used in the fitting process are all shifted by the same specific amount in the same direction.

However, it is also possible to derive weights which shift data by a specific amount, but in a direction relative to the normally acquired lines. All that one has to do is to provide the least squares fit with the appropriate data to fit. If we examine the case of PR sampling, it can be seen that all points at a particular radius have the same relative displacement with respect to neighboring lines, although the absolute shift is rotated with respect to the origin. A relative shift operator can be derived by rearranging all of the projections from a reference data set as shown in Figure 1 followed by a normal GRAPPA reconstruction for several stripes along the read-out direction. The similarity of this approach to normal Cartesian sampling should be obvious. However, in this case, the least squares fit provides a shift operator which is a relative shift operator in Cartesian k-space. Using these weights, all missing projections can be reconstructed in a time comparable to several small GRAPPA reconstructions, each of which can be done in much less than 1 sec using optimized code. Once the missing projections are reconstructed, the final image can be formed by standard back-projection or regridding.

Results:
Simulated PR reconstructions of the Shepp-Logan phantom with an 8 channel head array are shown in Figure 2. On the left are undersampled PR data with 90 projections x 128 read-out points (top) and 45 projections x 128 read-out points (bottom). Aliasing artifacts are clearly visible in both images. The right side shows GRAPPA acceleration factor 2 (top) and 4 (bottom) reconstructions using the relative shift method above. As can be seen, the aliasing artifacts are largely removed, although not completely in the 4x image. In vivo data shows a similar reduction in aliasing artifacts, but these artifacts are essentially impossible to see in “abstract-sized” images, since the level of artifact in undersampled PR imaging is already low.

Conclusions:
It has been shown that it is possible to derive GRAPPA reconstruction weights which allow reconstruction of data that are shifted relative to the acquired data, as opposed to the normal GRAPPA reconstruction which reconstructs data with an absolute shift. The ability to generate these relative shift operators is not guaranteed, especially in PR acquisitions near the outer parts of k-space, since the required shift can be larger than the coils can provide. Additionally, no parallel imaging is needed in the center of k-space, since this is already fully sampled. Therefore, the use of this method should probably be restricted to a ring of intermediate radii where the contribution is most significant. A partial implementation such as this will also further decrease reconstruction time. While the results of this method are promising, the direct application to PR imaging will need to be investigated further, since undersampled PR imaging already has such a low artifact level [e.g. 6]. However, the application of this method to other symmetric trajectories such as interleaved spiral acquisitions should also be possible and should result in more dramatic improvements.

References:

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