3D Cylindrical GRAPPA

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Introduction:

The advantages of both radial k-space sampling and parallel acquisition techniques for reducing motion artifacts, decreasing imaging time, and providing greater spatial resolution are well-known. This abstract proposes a novel method of applying a cylindrical GRAPPA reconstruction method to undersampled cylindrical k-space trajectories. Whereas previous authors have suggested using GRAPPA to reconstruct cylindrical k-space with undersampling purely in the z-direction (kz) [1], we show that undersampling in both kz and in the angular (θ) direction provides a more efficient usage of the coil sensitivities. As has been shown for 2D SENSE [2], this spreading of undersampling accommodates the usage of higher acceleration factors. We also demonstrate that a CAIPIRINHA [3] undersampling performed by rotation of the disks with respect to each other can further improve image quality.

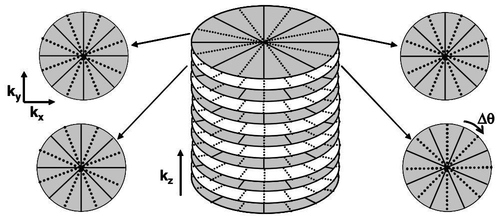


Figure 1 Center: A typical R=4 cylindrical k-space dataset, with R_θ=2 and R_z=2 (white disks not acquired) shown in kx-ky-kz space. Left: A detailed look at two acquired disks. The dotted lines represent projections that were not acquired and must be reconstructed. Right: Two acquired disks, where one disk has been rotated by one Δθ for the application of CAIPIRINHA.

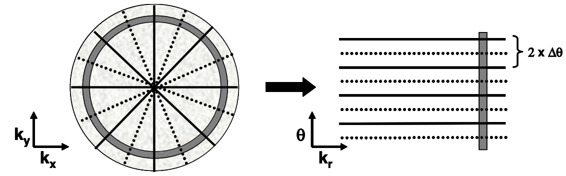
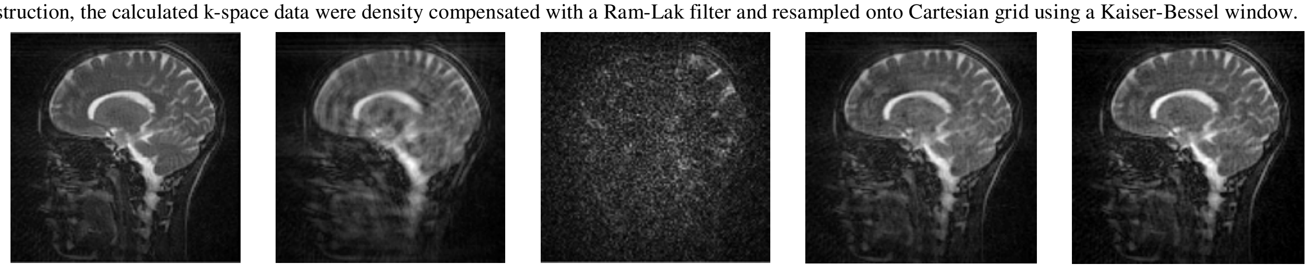


Figure 2 Left: Radial k-space in the ky-kx plane. An angular segment is highlighted in gray. Right: The same k-space reordered onto the θ-kr plane, where the angular segmentation is also shown. A further segmentation in the read direction can also be performed to enhance the reconstruction performance

Methods:

A representative undersampled 3D cylindrical k-space is shown in Figure 1; while the total acceleration factor is R=4, the undersampling can be distributed in both phase encoding directions, i.e. R_z=2, R_θ=2. As in the radial GRAPPA reconstruction method [4], the radial data must first be reordered and divided into read-direction and angular segments which have approximately the same undersampling factor, as depicted in Figure 2. Multiple 3D GRAPPA weight-sets are determined and applied in the kr-θ-kz segmented space (as opposed to the kx-ky-kz space), yielding the fully reconstructed k-space.

Images from healthy volunteers were acquired on a 1.5 T Avanto whole body scanner (Siemens Medical Solutions, Erlangen, Germany) using a radial SSFP sequence and a 12 channel head coil. The 3D data were comprised of 90 slices, with 96 projections per slice, and 256 read points, resulting in a 128x128x90 data matrix with a FOV of 240x 240x225 mm^3 (TR/TE=3.6/1.8 ms, with a total acquisition time of approximately 1.5 minutes). The cylindrical GRAPPA algorithm proposed here was applied with 16 read segments and 8 angular segments after accelerating the data by a factor of R=8. The central 20 slices were used as the auto-calibration signal (ACS). Additionally, reconstruction after rotation of the undersampled disks with respect to each other, similar to CAIPIRINHA, was also performed. Following the reconstruction, the calculated k-space data were density compensated with a Ram-Lak filter and resampled onto Cartesian grid using a Kaiser-Bessel window.



A: Reference B: R_θ=8 C: R_z=8 D: R_θ=2, R_z=4, Δθ=0 E: R_θ=2, R_z=4, Δθ=2

Figure 3 Reference and R=8 reconstructed images. The purely radially undersampled image (B) reconstructed with radial GRAPPA shows strong blurring, and an image could not be reconstructed using the 2D GRAPPA from the z undersampled image (C). In contrast, the 3D cylindrical GRAPPA algorithm offers significantly better image quality (D). The use of a CAIPIRINHA-like rotation of the disks in conjunction with method proposed here yields the best reconstruction (E).

Results:

Representative reference and reconstructed images are shown in Figure 3. As can be seen in Figure 3A, the use of 96 projections for a 128x128 matrix leads to slight streaking artifacts in the reference image, as the Nyquist criterion is not fulfilled at the outer portions of k-space. Despite this data undersampling, highly accelerated images can be reconstructed. The figures clearly demonstrates that cylindrical GRAPPA (D) performs better than either slice-by-slice radial GRAPPA (B) or Cartesian GRAPPA in the z-direction (C) for the same acceleration factor, in this case R=8. The performance of cylindrical GRAPPA is further enhanced using acquired disks that have been rotated with respect to each other, as in CAIPIRINHA (E).

Discussion:

We have shown that the use of cylindrical GRAPPA allows for the reconstruction of images using higher acceleration factors than conventional z-direction or 2D radial GRAPPA on a cylindrical k-space. While the image quality remains comparable to that of the reference image, for very high acceleration factors, blurring due to extreme radial undersampling in the outer parts of k-space and regridding can cause a loss in resolution. This effect can be countered by applying additional corrections to the density compensation function. The higher acceleration factors achieved by this method can be used to further improve resolution and speed in time-critical imaging, such as time-resolved contrast-enhanced angiography or cardiac functional imaging.

References:

1 Cashen, TA, et al. Proc. ISMRM pg. 288 (2005).
2 Weiger, M, et al. MAGMA. 2002 Mar;14(1):10-9.
3 Breuer, FA, et al. Proc. ISMRM, pg. 326 (2004).
4 Griswold MA, et al. Proc. ISMRM, pg. 2349 (2003).

Acknowledgements: The authors would like to thank Siemens AG Medical Solutions, especially Dr. Sonia Nielles-Vallespin, for cylindrical data. This work was funded by the Deutsche Forschungsgemeinschaft project JA 827/4-4.