GRAPPA Operator for Wider RadiaL Band (GROWL)

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Introduction

In recent years, there has been an increased interest in radial MRI due to its potential for highly-accelerated dynamic imaging [1], advantages in motion artifacts reduction [2] and ability to achieve ultra-short echo times [3]. In many applications, radial images are acquired using a phased-array coil, providing the opportunity for further acceleration using partial parallel imaging (PPI) techniques. K-space based PPI techniques for non-Cartesian datasets are challenging due to requirements for complex k-space division schemes, kernel patterns and additional calibration data [4-5]. In this work, we propose a novel self-calibrated PPI technique, GRAPPA operator for wider radial band (GROWL), for azimuthally undersampled radial datasets. This technique is based on expanding each radial readout line into a wider band using GRAPPA operators.

Methods

In an azimuthally undersampled radial dataset, the Nyquist criterion is only satisfied within a central k-space circle, which in this study is denoted as "Nyquist circle". The initial Nyquist circle has a radius of $r_0 = N / (\pi FOV)$, where N is the number of radial readout lines (**Fig. 1a**). In the proposed GROWL method, GRAPPA extrapolation operator is used to expand each radial line into a k-space segment consisting of *m* parallel k-space lines (**Fig. 1b**). As a result, the radius of the Nyquist circle approximately increases to $r = mr_0$, therefore reducing the streaking artifacts caused by azimuthal undersampling. As the data within the initial Nyquist circle is fully sampled, it can be used for self-calibration. Data within this region is regrided onto a rotated Cartesian grid separately for each readout line, prior to the computation of the GRAPPA weights (**Fig. 1c**).

A healthy volunteer was scanned on a 3.0T Achieva scanner (Philips, Best, Netherlands), using an eight-channel head coil (Invivo, Gainesville, FL) and a multi-slice 2D radial gradient echo sequence. Scan parameters: FOV 230x230 mm^2, slice thickness 5mm, matrix size 256 (readout) x 256 (view no.), TR/TE=100/3 ms, flip angle = 80^0. Undersampled 64 and 32-view data sets were subsequently generated by extracting every 4^{th} or 8^{th} radial k-space line from the full dataset. Each GRAPPA operator uses 5 neighboring points in the read-out direction to extrapolate one radial view into a band of three or five k-space lines (**Fig. 1c**). Both conventional regridding and GROWL reconstruction were performed using a Kaiser-Bessel kernel, and normalized root mean square errors (RMSE) were computed using the full dataset as the reference. To further reduce residual noise, a regularization method minimizing Total Variation (TV) [6] was also applied to the GROWL images.

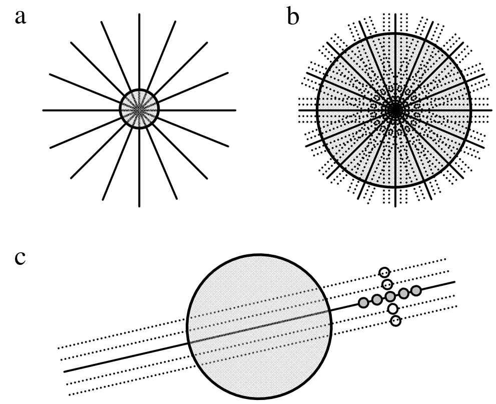

Fig. 1 (a) The original undersampled dataset with a small Nyquist circle. (b) After each radial view is widened into a band, Nyquist circle is enlarged. (c) For each radial line, calibration is first performed in the initial Nyquist circle, followed by GRAPPA extrapolation from source (gray) points to target (white) points.

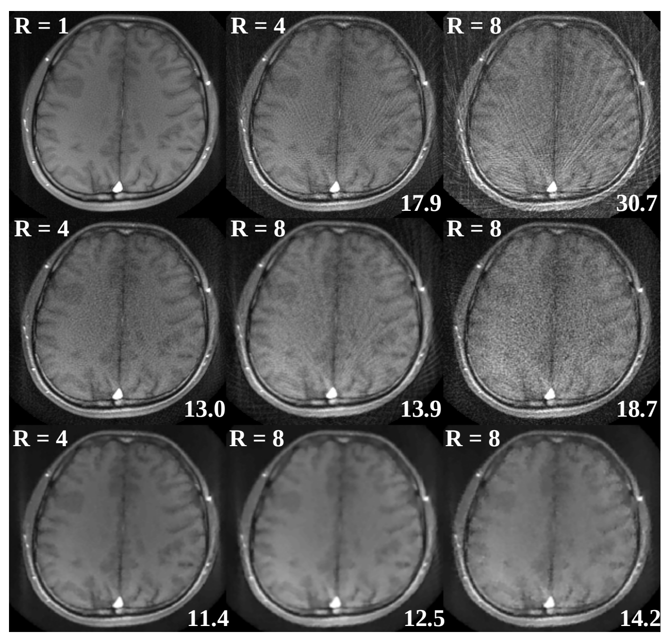

Fig. 2 Comparison of *in vivo* gradient echo images using conventional regridding (top), GROWL reconstruction without (middle) and with (bottom) regularization. Reduction factor R is shown at the top-left corner of each panel, while numbers at the bottom-right corners are normalized error percentage from the gold-standard (R=1, 256 view) image. For GROWL, the number of parallel k-space lines within each segments are 3, 3, 5 (left to right), respectively.

Results and Discussions

Figure 2 compares GROWL reconstruction with conventional regridding for data reduction factors of R = 4 and 8. In both cases, direct regridding of the undersampled datasets generated significant streaking artifacts (Fig. 2, row 1). In comparison, GROWL reconstruction dramatically suppressed the streaking artifacts, and generated images with much lower reconstruction errors (Fig. 2, row 2). In addition, the use of regularization (Fig. 2, row 3) further suppressed noise and reduced reconstruction errors, at a cost of some image blurring. Reconstruction time for GROWL is about 10 seconds for the 32-view dataset on a 2.2GHz PC.

An interesting observation is that at the reduction factor of R = 8, much lower errors (13.9% vs. 18.7%) were generated when each radial line is extrapolated to three lines (m=3) instead of five lines (m=5). Visual assessment of image quality shows that while the m = 3 image contains some residual streaking, the m = 5 image appears more noisy. This implies that there is a tradeoff between the noise amplification caused by extrapolation at data points farther away from the original readout lines and the residual streaking artifacts.

In conclusion, a novel self-calibrated PPI reconstruction method has been introduced for undersampled radial imaging. *In vivo* results demonstrate significant suppression of streaking artifacts at reduction factors R = 4 and 8 with an eight-element coil array.

References

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