Highly Accelerated 2D GRAPPA by Randomized K-Space Sampling

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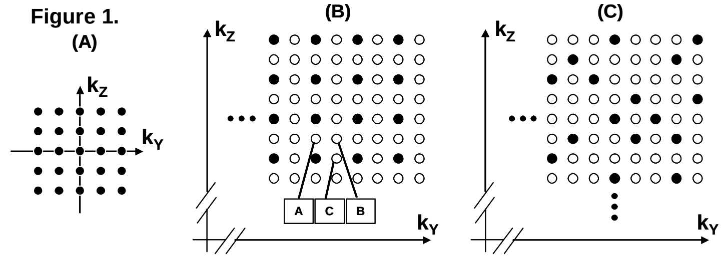
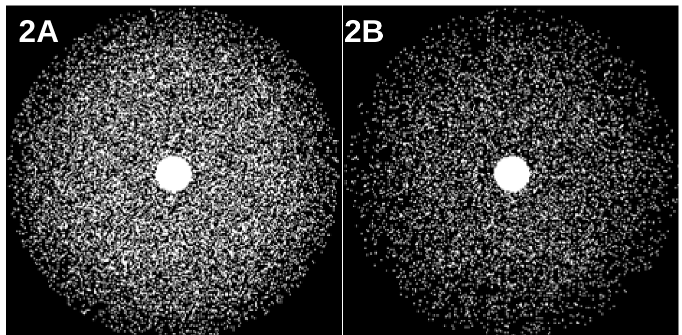
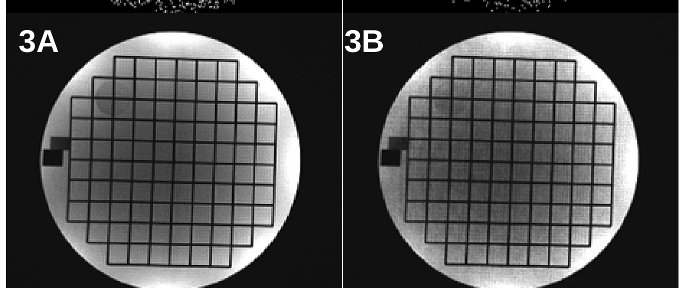
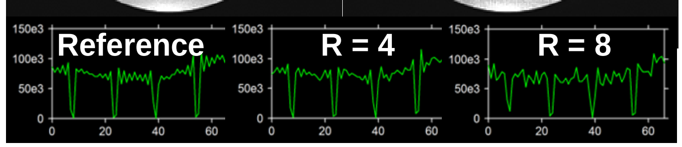
INTRODUCTION: With typical Cartesian acquisition the maximum acceleration along a single direction is more often limited by the inability to unalias the image than by the noise amplification. In SENSE this is a result of imperfect estimates of sensitivity profiles. In autocalibrated acquisitions the cause is similar and results from the use of the same imperfect weighting kernel to reconstruct spatial frequencies in rasterized fashion, thereby modulating the k-space reconstruction with the same error. As 1D accelerated GRAPPA reaches 3- to 4-fold acceleration this artifact begins to become very pronounced as shown by, e.g. [1]. Simple modification of the undersampling pattern can improve the performance by shifting the aliasing to the periphery of image space, but all the aliased energy is still localized and thus objectionable [2,3]. The general goal of this work is to address the limitations occurring in k-space-based acceleration methods such as GRAPPA which are due to deterministic inaccuracy in the sampling kernel. When such a kernel is applied across k-space to estimate the non-sampled points, the inaccuracy can propagate coherently into the resultant image. The approach taken in this work is to attempt to randomize or decorrelate the effects of this inaccuracy. Once the kernel is determined, rather than performing the undersampling in a regular manner, such as by not sampling every second or third k-space point, the undersampling is done quasi-randomly while still providing some net acceleration. Because acceleration techniques are generally more robust when performed along two vs. one direction, the initial implementation studied here is 2D acceleration. Further, a Gaussian distribution is applied to differentially weight the sampling of the lower spatial frequencies to improve image quality. We show experimental studies done in phantoms using eight coils with net acceleration factors, including the autocalibration region, of 4 and 8.

Figure 1.









METHODS: Description of Approach: A schematic description of the method is shown in Figure 1. Figure 1A shows a hypothetical 2D GRAPPA kernel as estimated from a calibration procedure. The kernel size is 5 x 5 pixels. Figure 1B shows how this is applied to data which is conventionally undersampled from knowledge of the kernel size. In this example there is assumed two-fold undersampling along both phase encode directions. Placement of the kernel in (A) at successive positions in (B) and performance of the appropriate interpolation provides estimates for the missing data. Given the regular sampling there are only three possible positions of the kernel A, B, C. Figure 1C shows randomized undersampling as developed in this work.

Data was acquired using an axial GE 1.5T (V14.0) fast GRE acquisition with a standard 8 channel head coil of a high contrast resolution phantom. Sampling patterns were generated using pseudo-random bit stream modified by a Gaussian weighting to generate a 2D variable density binary sampling pattern with a fully sampling central region consisting of 600 hundred points used for autocalibration and Gaussian falloff with asymmetrically sampling to the periphery of k-space. The size of the central region was chosen as it allows estimates of all GRAPPA kernels used in the reconstruction and is large enough to allow for 400 kernel averages to better condition the inversion. A standard 2D GRAPPA reconstruction [4] was modified to perform the reconstruction by calculating the inversion weighting matrix for each kernel. Sum square root images were compared to the fully sampled phantom to demonstrate coherence of artifact while line profiles were taken from a central region to show the effect of high net acceleration vs. spatial resolution.

RESULTS: The 4x and 8x undersampling patterns are shown in Figure 2A-B respectively. Corresponding GRAPPA reconstructions are shown in Figure 3 A-B. No coherent artifact is visible and reconstruction error is dominated by noise amplification. Figure 4 demonstrates line profiles through the central region of the phantoms showing noise amplification degraded the image quality but no loss of spatial resolution.

CONCLUSION: We have given the plausibility of random sampling with GRAPPA like reconstruction as a means to reduce coherent undersampling artifact in parallel imaging reconstruction. Acceleration factors as high as 8 were shown to retain high SNR and good spatial resolution.

[1] Gauvrit JY, et al. AJNR, 2007. [2] Breuer F, et al. MRM, 2005. [3] Wang Z, et al. MRM, 2006. [4] Blaimer M, et al. MRM, 2006.