Cross Sampled Nonlinear GRAPPA for Parallel MRI

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INTRODUCTION

GRAPPA [1] allows parallel imaging reconstruction without knowledge of coil sensitivities. However, a significant number of auto-calibration signal (ACS) lines need to be acquired which prolongs the imaging time. Reduction in ACS lines can cause aliasing artifacts, and an increase in outer reduction factor usually results in poor SNR in GRAPPA [2]. We have proposed a cross-sampling approach (Cross-GRAPPA) to reduce ACS acquisition [3] and a nonlinear reconstruction algorithm (NLGRAPPA) to improve SNR for GRAPPA [4]. In this abstract, the novel data acquisition and image reconstruction methods are integrated to improve the image quality of GRAPPA at high accelerations. The integrated method brings the benefits of Cross-GRAPPA and NLGRAPPA such that both ACS and outer k-space sampling are reduced without compromising SNR or artifacts suppression. Results from in vivo experiments demonstrate the proposed integrated method is superior to GRAPPA when the same reduction factor is used.

METHOD

The objective of the proposed method is to reduce both aliasing artifacts and noise in GRAPPA reconstruction when a high acceleration factor is used. The proposed method, named cross-sampled nonlinear GRAPPA (Cross-NLGRAPPA), integrates cross-sampled GRAPPA [3] and nonlinear GRAPPA [4] to achieve this objective. Figure 1 illustrates the procedures of the proposed method. In data acquisition, the ACS lines are acquired along the direction orthogonal to that of the undersampled lines (Fig. 1 step 1). By this means, much more ACS data are available along the undersampled direction to improve the calibration accuracy. An iterative co-registration method is then used to correct any inconsistency between the data acquired in two orthogonal directions (Fig. 1 step 2). In reconstruction, a nonlinear model is used to represent the relationship between the missing data and the acquired undersampled data (Fig. 1 step 3). Specifically, we have

\[ S_j(k_j + r\Delta k_j, k_j + h\Delta k_j) = w_{j,0} \times 1 + \sum_{i=1}^{L} \sum_{b=1}^{B_j} \sum_{h=1}^{H_j} w_{j,i}(l, b, h) \times S_j(k_j + bR\Delta k_j, k_j + h\Delta k_j) + \sum_{i=1}^{L} \sum_{b=1}^{B_j} \sum_{h=1}^{H_j} w_{j,i}(l, b, h) \times S_j(k_j + bR\Delta k_j, k_j + h\Delta k_j) \]

where \( S_j(k_j + r\Delta k_j, k_j) \) denotes the unacquired k-space signal at the target coil, \( S_j(k_j + r\Delta k_j, k_j + h\Delta k_j) \) denotes the acquired undersampled signal, and \( w_{j,i}(l, b, h) \) are the coefficients obtained through calibration. The orthogonal ACS lines are used to estimate the coefficients of the nonlinear model. The interpolation is then repeated for each missing point at each coil. These images are then combined by a root sum-of-squares (SoS) method [7] to obtain the final image.

RESULTS AND DISCUSSION

The proposed method was evaluated in two in vivo experiments on a 3T commercial scanner (GE Healthcare, Waukesha, WI) with an 8-channel head coils (Invivo, Gainesville, FL). Figure 2 presents the reconstruction results. Here REF represents the reference image obtained from fully sampled data; Cross represents cross-sampled GRAPPA [3]; Cross-NL represents the proposed cross-sampled nonlinear GRAPPA method. The in vivo dataset in Fig. 2(a) was acquired using a spin echo sequence (TE/TR = 10/500 ms, 31.25 kHz bandwidth, matrix size = 256×256, FOV = 220 mm²). The reconstructions were obtained at an outer reduction of 4 and 10 ACS lines (represented as 4-10 in figures). For nonlinear reconstruction, a size of 4 blocks and 5 columns was used. The other in vivo dataset in Fig. 2(b) was acquired using a spin echo sequence (TE/TR = 14/500 ms, 62.5 kHz bandwidth, matrix size = 256×256, FOV = 240 mm²). An outer reduction factor of 4 and 12 ACS lines (4-12) were used for acquisition, and a coefficient size of 4 blocks and 3 columns was used for reconstruction. In both experiments, Cross and Cross-NL are able to reduce the aliasing artifacts (white arrows) in GRAPPA when only a few ACS lines are acquired. In addition, Cross-NL can further reduce the noise in Cross-GRAPPA.

CONCLUSION

The proposed cross-sampled nonlinear GRAPPA method is able to suppress the residual aliasing artifacts in conventional GRAPPA without compromising SNR.

REFERENCES