CS-GRAPPA: Improving GRAPPA Using Cross Sampling

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INTRODUCTION

As one of the widely-used parallel-imaging methods, GRAPPA technique (1) reconstructs the missing *k*-space data by a linear combination of the acquired data using a set of weights. The combination coefficients are usually derived from auto-calibration signal (ACS) lines that are acquired in parallel to the reduced lines. Several methods (e.g. (2-4)) have been proposed to reduce aliasing artifacts and image noise for GRAPPA, but only a few methods (5) modify the data acquisition procedure. In this abstract, a cross sampling method is proposed to acquire the ACS lines orthogonal to the reduced lines. This cross sampling method increases the amount of calibration data along the direction that the *k*-space is undersampled and thus improves the calibration accuracy, especially when a small number of ACS lines are acquired. We name the method cross-sampled GRAPPA (CS-GRAPPA). The experimental results demonstrate that the proposed method named as cross-sampled GRAPPA (CS-GRAPPA) can significantly reduce the artifacts compared to GRAPPA with the same quantities of ACS lines and reduction factors.

METHOD

It is known that more ACS lines in conventional GRAPPA reduce the aliasing artifacts in reconstruction. To increase the number of ACS data along the direction of undersampling with approximately the same acquisition time, we propose a cross-sampling method (CS-GRAPPA) for data acquisition. Specifically, the ACS lines are acquired orthogonal to the undersampled lines, as illustrated in Fig. 1. The proposed method can be realized by dynamically swapping the phase encoding and frequency encoding gradients such that the phase encoding direction is changed from the Anterior/Posterior (A/P) direction for ACS acquisition to Right/Left (R/L) direction for reduced acquisition as in (6,7). Under ideal conditions, the cross-sampled *k*-space data can be directly used in GRAPPA reconstruction. However, practical conditions such as eddy current and chemical shift can result in misalignment in the *k*-space data acquired in different phase encoding directions (8,9). These data need to be corrected before being used for image reconstruction. To co-register the two datasets that are acquired in orthogonal directions, we propose to use a model similar to (9) to account for the difference due to eddy current. More complicated model accounting for other effects such as chemical shift will be studied in future work. The model assumes the *k*-space data with R/L and A/P readout directions are related by $S_{R/L}(k_x,k_y)=\sigma\cdot S_{A/P}(k_x-\delta_x,k_y-\delta_y)$ [1] which means the *k*-space locations can be misaligned (shifted by δ_x along *x* and δ_y along *y* as shown in Figure 1) and the *k*-space values can be off by a complex scaling factor σ. The model in Eq. [1] can also be represented in the image domain as $s_{R/L}(x,y)=\sigma\cdot s_{A/P}(x,y)\cdot e^{-i2\pi(\delta_x\cdot x+\delta_y\cdot y)}$ [2]. Because the ACS lines with R/L readout and the reduced lines with A/P readout intersect at some *k*-space locations, data at these locations can be used to estimate the shifting and scaling parameters in Eq. [1] and thereby used to co-register the *k*-space data at other locations. The intersecting locations are illustrated in Figure 1. To estimate the unknown parameters, the L_1 norm of the difference between the reduced lines $S_{\text{reduced}}(k_x,k_y)$ and ACS lines $S_{\text{ACS}}(k_x,k_y)$ at the intersecting *k*-space locations is minimized after registration. We have $\min_{\delta_x,\delta_y,\sigma}\sum|S_{\text{reduced}}(k_x+\delta_x,k_y)-\sigma S_{\text{ACS}}(k_x,k_y-\delta_y)|$ [3]. The above minimization problem is solved using the *Nelder–Mead* algorithm as in (10). After both data sets are co-registered, the image reconstruction procedure is the same as that of the conventional GRAPPA, except that there are much more ACS data for calibration along the undersampled direction.

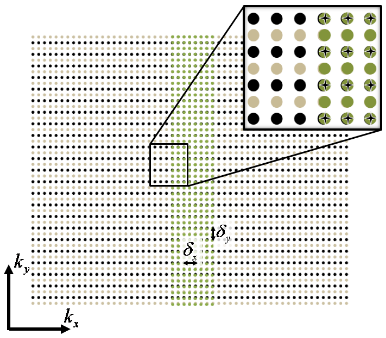

Fig.1. Green lines denote cross-sampled ACS, black and tan lines are acquired and missing data. Green points with a cross inside are intersecting locations for registration.

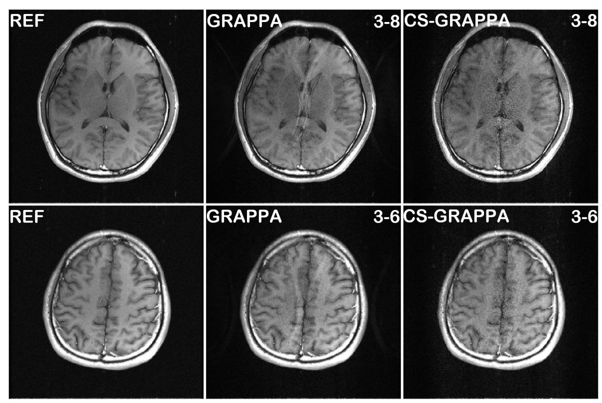

Fig.2 Reference, GRAPPA and CS-GRAPPA reconstructions. ORF-ACS are shown on the top right corners.

RESULTS

Two *in vivo* human brain data sets were used to compare the performances of GRAPPA and CS-GRAPPA, acquired by a spin echo pulse sequence (TE/TR = 10/550 ms, 31.25 kHz bandwidth, 256×256 pixels, FOV = 220 mm^2) on a 3T scanner (GE Healthcare, Waukesha, WI, USA) with an 8-channel head coil (Invivo Corporation, Gainesville, FL, USA). The reconstructed images (outer reduction factor (ORF) and ACS on the top-right corner) are shown in Fig. 2. They demonstrate that CS-GRAPPA can suppress the artifacts in GRAPPA with the same outer reduction factors and ACS lines.

CONCLUSION

CS-GRAPPA has shown to be able to suppress the residual aliasing artifacts in conventional GRAPPA reconstructions when very few ACS line are acquired. The method also can be easily applied to the other derivatives of GRAPPA. Future work will further improve the model for data co-registration between datasets acquired along orthogonal directions.

REFERENCES

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