## Highly Accelerated 3D Parallel Imaging with Transitional Auto-calibration (3D-PITA)

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**Introduction:**

Autocalibrated parallel imaging techniques such as GRAPPA [1] and Nonlinear GRAPPA [2] require estimation of the weight coefficients during the calibration process to reconstruct the missing k-space data using a linear or nonlinear combination of the acquired data. In 2D imaging, the k-space is uniformly undersampled in the phase encoding direction with full acquisition in the central k-space (ACS) for autocalibration. In 3D volumetric parallel imaging, there is much more flexibility in the sampling pattern because both the phase and slice encoding directions can be reduced. A straight-forward extension from 2D to 3D is the separable sampling pattern. However, when the reduction factor is high, there is a large unacquired region in k-space, which greatly degrades the accuracy of the reconstructed missing data using the acquired data. To address this issue, we propose a novel method named 3D Parallel Imaging with Transitional Auto-calibration (3D-PITA). The method introduces a transition region between the ACS region and the highly reduced outer region [3], where the sampling pattern is specially designed to have a lower reduction factor than the outer region. We then perform a two-step calibration/reconstruction, one step with nonlinear GRAPPA and the other with GRAPPA, to obtain the final full k-space data. Experimental results demonstrate the proposed method is able to achieve high reconstruction quality at reduction factors higher than 5 and is superior to the conventional 3D GRAPPA.

**Theory and Method:**

For conventional 3D GRAPPA, k-space data is under-sampled along $k_y$ and $k_z$ for each coil. The ACS region is fully sampled and the rest is uniformly under-sampled with a separable sampling pattern (e.g., 2×2). The proposed method introduces a new transition region in between, as shown in Fig. 1(a) (marked in orange). The sampling pattern in the transition region, shown in Fig. 2(a), is designed to add some diamond-shaped samples in the uniformly under-sampled region, which lowers the reduction factor. Using such a sampling pattern, the calibration and reconstruction are performed twice as shown in Fig. 1. First, we use the data in both ACS and transition regions for calibration to reconstruct the highly undersampled region using nonlinear GRAPPA, such that the entire region other than ACS has the same "diamond" pattern as that in the transition region shown in Fig. 1 (b). Fig. 2 (b) illustrates how the source data and target data are designated for calibration and reconstruction. In the second step, we then perform the conventional GRAPPA but with a specially designed sampling pattern. Fig. 2 (c) illustrates locations of the source and target data. The central point of each window is regarded as target data and every sampled point in the window as source data. After the second step, the full k-space data are estimated as shown in Fig. 1 (c). For the first Calibration, we use a 5 × 5 window without overlap. For the second calibration, a 7 by 7 window with maximum overlap is used so that many different patterns are possible. Nonlinear GRAPPA is used for better calibration accuracy in first step because only 4 k-space data points are used to estimate the central 4 unknown data points. In contrast, nonlinear GRAPPA is not used in the second step because of the availability of much more known data points and the significantly increased computation time. Moreover, random projection [4] is used with both GRAPPA and nonlinear GRAPPA to speed up reconstruction.

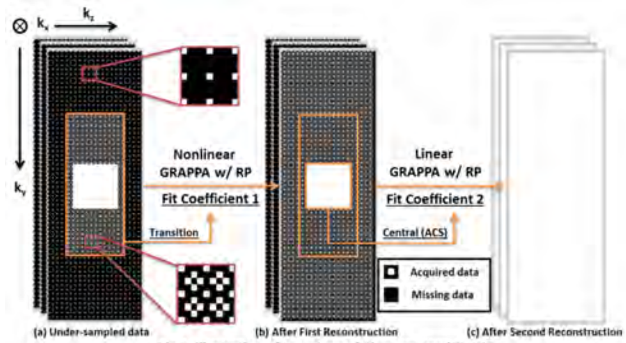

Fig.1 Illustration of two steps of the proposed 3D-PITA

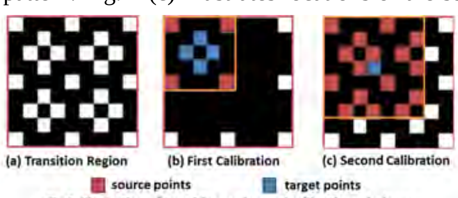

Fig.2 Illustration of transition region and calibration windows

**Results and Discussion:**

To evaluate the performance, the proposed method was tested on a set of 3D *in vivo* brain dataset which was acquired on a Philips Ingenia 3T scanner (Philips Healthcare, Best, Netherlands) with a 12-channel head coil using a 3D fast Field Echo sequence (TE/TR=4.6/25 ms; matrix size = FE 239 × PE 239 × SE 88; FOV = 240×240×130mm$^3$). The k-space data was fully acquired and manually under-sampled retrospectively to simulate the accelerated acquisition for 239 × 88. In Fig. 3, the reconstructed images by the proposed method are compared with the reconstructions using the conventional GRAPPA. The net reduction factors (NRF) were adjusted by changing the size of the transition region for the proposed method. All results used a fixed central ACS region (40 × 40). It is seen that the noise in 3D GRAPPA reconstructions is significantly suppressed by the proposed 3D-PITA at high NRFs. The CPU time of 3D-PITA with random projection is about the same as that of conventional 3D GRAPPA.

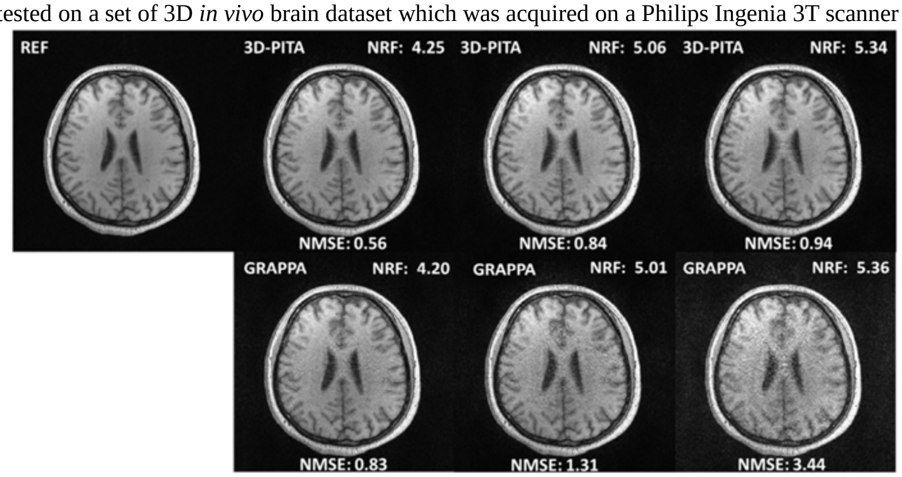

Fig.3 A Slice of 3D image reconstructed using 3D-PITA (top) and 3D-GRAPPA (bottom) for different NRFs

**Conclusion:**

A novel 3D-PITA method is proposed for volumetric auto-calibrated parallel imaging. The experimental results show that the proposed method is able to significantly improve the reconstruction quality compared to the conventional 3D GRAPPA at high reduction factors.

**References:** [1] Griswold MA, et al., MRM, 47, 2012: 1202-1210 [2] Chang Y, et al., MRM, 68, 2012: 730-730 [3] Zhong X, et al., ISMRM, 4391, 2014 [4] Lyu J, et al., MRM, DOI: 10.1002/mrm.25373, 2014