Robust ARC Parallel Imaging with 3D Prospective Motion Correction

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Introduction: Three dimensional (3D) scans are susceptible to motion artifacts because scan times are often long even after acceleration with parallel imaging and because any motion affects the entire volume measurement. Prospective motion correction techniques that directly estimate rigid body motion parameters with the help of navigators and adjust scan coordinates to realign with the subject in the event of motion have been shown to successfully reduce these artifacts in volumetric acquisitions [1-3]. Use of parallel imaging is still desirable in these scans for reduction of scan time. When parallel imaging is employed in sequences that have retrospective motion correction, the parallel imaging reconstruction is performed first, followed by motion correction [4-5]. The situation is different with prospective motion correction; since the transformations of scan coordinates effectively results in a stationary object and moving coil condition (assuming a rigid coil, as is usually the case with brain imaging) during the measurement. Such data can be reconstructed using the expanded SENSE formalism proposed by Bammer et al [6]. But because of the caveats of sensitivity estimation, this work explores a data driven parallel imaging solution to this problem. Using the ARC algorithm [7], it proposes an adapted calibration+ reconstruction strategy that robustly accounts for the scan coordinate transformations affected by prospective motion correction.

Theory and Method: Since the scan coordinate reorientation changes the sensitivity weighting in the measured data, k-space data that are measured in different scan coordinate orientation should be reconstructed separately. This is feasible, since ARC is capable of reconstructing data in an arbitrary k-space segment. Data assignment to separate reconstructions can be made by examining the navigator outputs. Data from all the reconstructions can then be collated to obtain full k-space data. Calibration data for each such reconstruction can be acquired after each realignment .(*Recon_multiacqcal*). But multiple reacquisition of calibration data is time-intensive. Since the coil sensitivity of the different receiver elements are not changing with respect to each other, the calibration data can also be extracted from a single oversampled calibration dataset, to which the same motion transformation as the realignment has been applied (*Recon_regridcal*) [5]. Conventional self-calibrated ARC reconstruction, which doesn't account for the realignments, will form our baseline (*Recon_baseline*).

Simulations: Using a 3D phantom and simulated coil sensitivity profile of an eight channel array we performed simulations of prospective motion correction experiments in MATLAB for two different 3D viewordering schemes: a) sequential b) ky modulated viewordering that is employed in the eXtended Echo Train Acquisition [8] for a (2x2) 2D acceleration in ky-kz. For the first viewordering, we assumed motion between the ky phase-encodes and for the second, between the echo trains. After every simulated motion, the imaging volume was resampled to align the scan coordinates with the object.

MR Experiments: After informed consent, we acquired in vivo data from a volunteer using a T2 weighted 3D PROMO sequence that is incorporated in 3D FSE XETA [3] on a 1.5 T scanner (GE Healthcare, Waukesha) and eight channel head array (matrix: 192x192x120, field of view: 24 cm, slice thickness: 1.8mm). The k-space sampling scheme consisted of 2x2 acceleration in ky-kz with an elliptical calibration region. For simplicity, the subject was asked to move the head once during the scan. A low resolution 3D gradient echo calibration scan oversampled 2x in image space was also acquired. The data was reconstructed offline using the reconstruction strategies described above.

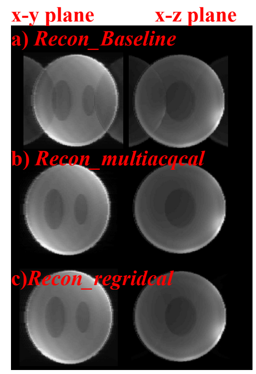

Figure 1: Simulation results are shown for the sequential viewordering. *Recon_baseline* shows aliasing artifacts, but *Recon_multiacqcal* and *Recon_regridcal* have good image quality.

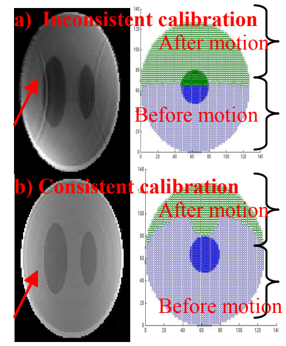

Figure 2: Simulation results for XETA viewordering. Images obtained with *Recon_baseline* and ky-kz datapoints that were sampled before (blue) and after motion (green) are shown. Fig 2b) which has a consistent calibration data, shows less image artifacts than Fig 2a).

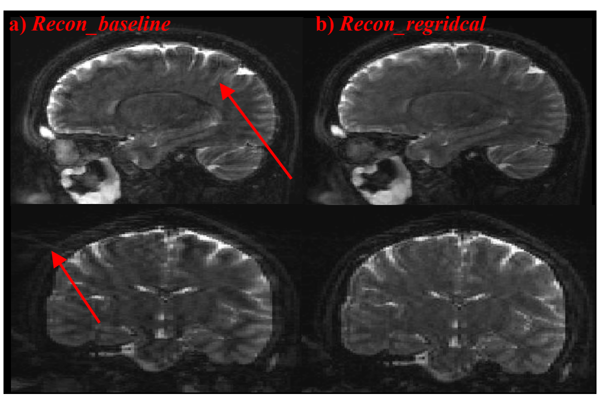

Figure 3: Invivo sagittal and reformatted coronal images acquired with 3D PROMO and 2D acceleration. Images reconstructed with *Recon regridcal* have fewer artifacts than *Recon baseline*.

Results: As expected, *Recon_baseline* yielded aliased reconstructed images in simulated prospective motion correction experiments. **Fig 1** shows representative images from simulated sequentially view-ordered acquisition for a)*Recon_baseline* b) *Recon_multiacqcal* c) *Recon_regridcal*. Image quality is comparable between b) and c) which implies that we can recompute our calibration weights from only a single oversampled calibration dataset. *Recon_baseline* artifacts were less severe with XETA viewordering. The image quality was also sensitive to the time of motion occurrence. Images obtained with *Recon_baseline* in XETA simulation experiment and the datapoints in ky-kz plane that were sampled before and after the motion are shown in **Fig 2**. In **2a)** some of the calibration data was acquired before motion and some after. In **Fig 2b**, all of the calibration datapoints were sampled before occurrence of motion, which provided a consistent calibration data. As a result, aliasing artifacts are subtler in the reconstructed image in **Fig 2b)**. Here all simulation images have been shown for a single motion comprising of a 45º rotation about the z axis and 2.4 cm translation in the z direction.

Fig 3 shows invivo sagittal and reformatted coronal images of the brain acquired with the 3D PROMO sequence. In this invivo scan, motion occurred before acquisition of any self-calibration data points-so the calibration datasamples are consistent with each other. In conformance with simulation results, the aliasing artifacts were thus very subtle in the images obtained with *Recon_baseline* **(Fig 3a).** However, aliasing artifacts were further reduced and image quality further improved with *Recon_regridcal* (**Fig 3b**).

Discussion: This work proposed a robust ARC reconstruction strategy that is compatible with prospective motion correction. Even though we presented results for the case of a single motion occurrence within a scan, this technique can be applied for multiple motion occurrences in a scan measurement. This work also showed the feasibility of recomputing calibration weights from a single external calibration dataset, instead of reacquiring calibration data after every scan coordinate transformation. Oversampling of the calibration data ensures robust interpolation for any scan coordinate transformation.

Reference: **1** White N et al. ISMRM 2007, p 1829
2 Shankaranarayanan A et al. ISMRM 2007, p 2117
3 Shankaranarayanan A et al. ISMRM 2008, p1475 **4**. Skare S et al MRM (57) 881-890, 2007 **5**. Beatty PJ et al, ISMRM 2008, p1464
6. Bammer R et al, MRM (57) 90-102, 2007 **7.** Beatty PJ et al. ISMRM 2007, p1749 **8** Busse et al. MRM (60) 640-649, 2008