Motion Correction for 3D Phase Contrast Flow Imaging with Cranial PCVIPR

Ashley Gould Anderson III[1], Julia Velikina[1], Oliver Wieben[1,2], and Alexey Samsonov[2]
[1]*Medical Physics, University of Wisconsin, Madison, Wisconsin, United States,* [2]*Radiology, University of Wisconsin, Madison, Wisconsin, United States*

Introduction: Despite advances in accelerated imaging techniques, patient motion remains a problem in many MR acquisitions due to long acquisition times. Blurring, ghosting, and other motion related artifacts force repeat scans. Quantitative phase contrast (PC) imaging requires reference data for background phase subtraction, imposing a four-fold increase in sampling requirements to measure the 3D velocity vector in each voxel. PC MR images typically have to be cardiac-gated in order to provide information on flow throughout the cardiac cycle, further extending scan time. These increased sampling requirements result in additional challenges for otherwise effective motion compensation techniques such as PROPELLER [1]. We adapted our previously proposed 3D rigid body motion correction scheme [2] for use in 3D cranial PC flow MRI.

Methods: Our method assumes discontinuous motion (such as twitching or adjusting for comfort) throughout the scan delimiting several motion-free periods. Object center of mass (COM) is estimated separately for each coil channel using properties of radial Fourier and Radon transforms on successive subsets or interleaves of projections. The number of projections used for COM estimations sets the timescale for motion detection. Instances of motion are identified where discontinuities in the COM vector plots are detected using a multi-level 1D edge detection technique. Identified motion-free subsets of k-space data are reconstructed and co-registered to determine motion parameters. Corresponding k-space data are corrected for bulk translation and rotation before being combined and reconstructed using gridding. This process decouples the motion detection and motion estimation processes, enabling more accurate motion estimation and a shorter timescale for motion detection. No additional navigators or external motion monitoring are required for this scheme.

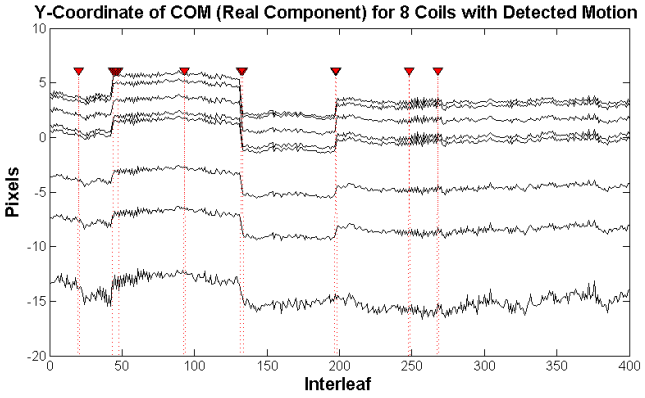

Figure 1 – COM x-coordinate estimations for eight separate coil channels used to for motion detection. Seven instances of motion (red arrows) were detected during this volunteer exam.

The described approach was adapted for a 3D radial flow acquisition (PC VIPR [3]) with pseudo-random projection ordering. Five separate echoes were acquired for each projection angle with balanced 5-point flow encoding sensitivity [4]. The separate flow encoding projections were averaged in sinogram space before COM estimation. This provided an increase in SNR, allowing the use of fewer projection angles in COM estimation, thereby mitigating the increase in motion detection timescale. Motion estimation was performed using FLIRT (FBRIB Software Library linear image registration tool) [5]. Complex difference images were used for registration due to their high contrast and sparsity, which makes them more suitable for high levels of angular undersampling. Subsets too small for accurate registration were discarded.

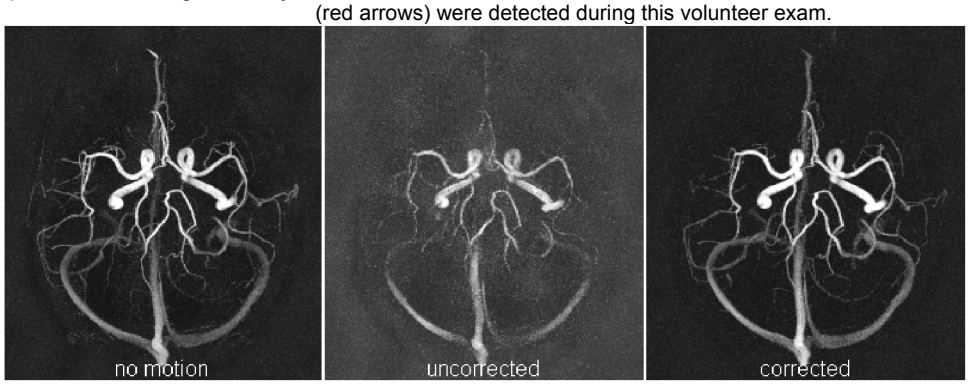

Figure 2 – Time-averaged complex difference axial MIPs for a volunteer exam with five instances of detected motion (six consistent subsets of data).

Images of a healthy volunteer were acquired in accordance with IRB protocol on a clinical 3T scanner (Discovery MR^{TM} MR750, GE Healthcare, Waukesha, WI). The volunteer was asked to move "several times" during one scan, and asked to remain still for a subsequent scan to provide a motion-free comparison. Scan parameters included: TE/TR = 3.9/7.7 ms, BW = 166 kHz, flip angle = 7°, voxel size = 0.75 mm isotropic, FOV = 240x240x240 mm^3, 8 channel phase array head coil, 5-pt flow encoding, V_{enc} = 80 cm/s, 10,000 projection angles, scan time = 6 m 30 s. A pulse-oximeter was used to measure triggers for retrospective cardiac gating. Gradient delays were compensated during acquisition with modified prewinder areas [6].

Results: Figure 1 shows a plot of the real component of the y-coordinate of the object COM as estimated by each coil. Red arrows and dotted lines indicate detected instances of motion. Center of mass was calculated for every 25 projection angles (5 flow-encoding echoes per angle), setting the timescale for motion detection to 925 ms. Standard deviations for the x, y and z COM coordinates for the corresponding motion-free exam were 1.2, 1.2, and 0.9 mm, respectively. These values determine the motion detection sensitivity. Figure 2 compares time-averaged complex difference axial MIPs from the motion-free, uncorrected motion-corrupted exams, and reconstructed with the proposed motion correction process for a volunteer scan with six detected instances of motion. Corrected images were reconstructed with 9225 uncorrupted projection angles remaining after elimination of the detected corrupted data.

Discussion and Conclusions: We successfully adapted our 3D motion correction scheme for the unique challenges of cardiac-gated 3D PC flow imaging. Parameters of the technique were optimized to take advantage of redundant projections and velocity information, mitigating the increased sampling requirements of a cardiac-gated phase contrast acquisition. Image quality is almost entirely restored, although some small (<1 mm diameter) vessels were lost in the corrected images. This is likely due to either small registration errors, or uncorrected continuous motion in the corrupted exam. Final image quality would improve further with a motion-optimized parallel imaging reconstruction, such as that proposed by Bammer, *et al* [7].

Acknowledgements: We would like to thank NIH grants R01NS065034 and 5R01HL072260 for funding and GE Healthcare for research support.

References: [1] Pipe, JG, MRM, 42(5):963, 1999
[2] Anderson, AG, *et al*, Proc IEEE ISBI 8:1528, 2011
[3] Gu T, *et al*, AJNR 26:743, 2005
[4] Johnson, KM, Markl, M, MRM 63(2):349, 2010
[5] Jenkinson, M, *et al*, Medical Image Analysis, 5(2):143, 2001
[6] Khansa I, *et al*, ISMRM 25, Berlin, 3422, 2007
[7] Bammer, R, *et al*, MRM, 57(1):90, 2007