Title: Automating Background Phase Correction in Cranial 4D Flow MRI

Grant S. Roberts[1], Kevin Johnson[1,2], Carson A. Hoffman[1], Laura Eisenmenger[2], Oliver Wieben[1,2]
[1]Department of Medical Physics, University of Wisconsin-Madison, WI, [2]Department of Radiology, University of Wisconsin-Madison, WI

Purpose: Phase contrast (PC) MRI is based on the principle of motion encoding using bipolar magnetic field gradients. In standard PC MRI, velocity along the gradient direction is directly proportional to a phase accrual in image space. However, many other factors contribute to phase changes unrelated to velocity, thus necessitating additional steps to generate quantitative velocity maps including: (1) the acquisition of 2 images to calculate a phase difference image rather than an absolute phase image with confounding factors; corrections for phase distortions from (2) non-linear gradients and (3) concomitant gradients[1]. Yet, there are still remaining phase errors from sources that are difficult to model deterministically, predominantly from (4) eddy currents. These can be removed by a subsequent scan with a stationary phantom and identical acquisition parameters[2] or, more frequently, through modeling of slowly-varying background phase corrections (BPC) based on static tissue. However, it requires user interaction for the identification of static tissue[3] and remains a source of error[4]. Also, it can be particularly time-consuming in 4D flow acquisitions because of its large volumetric coverage. The purpose of this study is to evaluate the performance of a fully automated 3D BPC algorithm embedded into the reconstruction with and without additional interactive BPC processing.

Methods: Ten healthy 4D flow brain scans were acquired to evaluate the degree of BP errors after: **1**) no BPC **2**) manual BPC **3**) automatic BPC **4**) both automatic and manual BPC, which is used in our current pipeline. Imaging was performed on a clinical 3T scanner (MR750, GE Healthcare) using a radially-undersampled 5-point PC-VIPR[5] acquisition with the following parameters: volume = 22x22x22 cm^3, isotropic spatial res. = 0.69 mm; VENC = 80 cm/s; scan time = 7 min., and retrospective cardiac gating (20 cardiac frames). Manual BPC was performed in a custom MATLAB GUI (Figure 1), where the user separates background tissue by adjusting thresholds for low magnitude (noise threshold) or high velocity (complex difference [CD] threshold). Similarly, the automated and integrated BPC algorithm identifies these 2 threshold values to perform the same procedure. Both methods use a 3rd degree volumetric polynomial fit to estimate phase variations in the background tissue for each velocity direction (x,y,z) (Figure 2). The effectiveness of the 4 BPC methods was evaluated using the mean absolute error (MAE) averaged over each velocity dimension: $\overline{MAE} = \frac{1}{3}\left(\sum_{d=1}^{3}\sum_{n=1}^{N}\frac{|\bar{v}_{d,n}-fit_{d,n}|}{N}\right)$ where $|\bar{v}_{d,n} - fit_{d,n}|$ is the absolute difference between the time-averaged velocity and polynomial fit in dimension *dim* at voxel *n* in the 3D image. Additionally, the noise and CD thresholds obtained by the manual BPC were compared to the thresholds in the automatic reconstruction BPC.

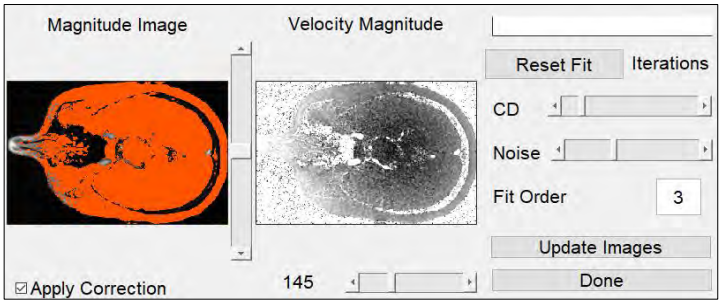

Figure 1: Manual BPC processing in our customized MATLAB GUI. The orange mask (left) overlaid on the magnitude image represents voxels identified as static background based on CD and noise thresholds (right).

Results: All 4 BPC methods were successfully evaluated on all 10 subjects. Average $\overline{MAE}$ across subjects was: **1**) 2.35±0.97 cm/s (no BPC) **2**) 0.89±0.29 cm/s (manual); **3**) 0.80±0.24 cm/s (automatic); **4**) 0.80±0.24 cm/s (automatic+manual). The automatic BPC outperformed the manual BPC and no BPC methods. Using both automatic and manual BPC resulted in negligible changes in phase correction. After manual BPC, the average CD threshold was 11.2±4.0% (of the lowest velocity values) and the noise threshold was 25.5±4.0% (of the highest magnitude values). The reconstruction used a fixed CD threshold of 8% and noise threshold of 30%.

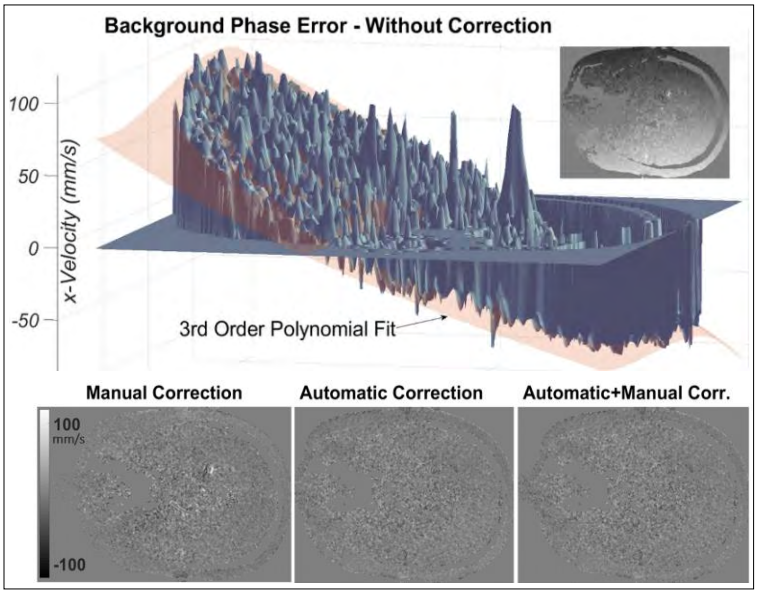

Figure 2: Surface plot of velocity (x-direction) before BPC depicting phase errors in static tissue for a single slice. The polynomial fit is shown in light red. 2D images of before and after BPC for each method is shown.

Discussion: It is concluded that automatic reconstruction BPC is sufficient (in fact, more accurate [p=0.005] than user-based threshold choices) in correcting BP errors in 4D flow brain scans. The fixed thresholds used in the reconstruction were more conservative in estimating static tissue compared to the manually-generated threshold values. Automatic BPC will result in greater reproducibility and will allow for a completely automated reconstruction post-processing pipeline. Without user interaction, the post-processing time of our 4D flow cranial analysis is estimated to reduce by ~90% (300s to 25s). These results might not apply to other body regions that can more prone to motion artefacts, e.g. from breathing.

References: [1] Nayak, K. et al JCMR 2015;17:71. [2] Chernobelsky, A. et al, JCMR 2007, 9:681-5. [3] Walker, P.G. JMRI 1993,3:251-30. [4] Gatehouse JCMR 2010 12:5. [5] Johnson, K. M. et al MRM. 2008; 60(6), 1329-1336.