Analysis and correction of background velocity offsets in cine phase-contrast imaging using magnetic field monitoring

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Introduction: The value of phase-contrast MRI for velocity assessment in larger vessels has been well studied. However, concerns have been raised about the accuracy of the technique with a recent multi-center study confirming significant background velocity offsets across sites and scanner types for typical flow quantification protocols [1].
Image-based approaches have been proposed to correct for velocity background errors by fitting low-order polynomials to the image phase of static voxels [2]. While these approaches work well if the vessels of interests are embedded in static tissue, inaccurate correction can result when imaging areas with large air cavities or moving structures.
The development of magnetic field monitoring [3] and its application to background velocity correction [4] has shown the potential to provide accurate velocity data from phase-contrast measurements.
The objective of this work was to characterize background velocity offsets with respect to spatial order and temporal evolution for a standard cardiac triggered cine phase-contrast protocol using a 16-channel field camera [5]. Gridding Fourier reconstruction using measured k-space trajectories was employed to demonstrate velocity background correction in phantoms.

Methods: A higher-order magnetic field camera with 16 probes mounted on a 20 cm diameter sphere was placed in the isocenter of a 3.0T Philips Achieva system (Philips Healthcare, Best, The Netherlands). The probe positions and reference *Larmor* frequencies were determined using FIDs collected during a preparation scan [3].
A standard gradient-echo, cardiac-triggered phase-contrast protocol with balanced velocity encoding gradients (TE/TR:2.5/3.6ms, venc: 50, 100, 200 cm/s) was monitored and the phase evolution from each of the 16 probes recorded. Dynamic phase coefficients, fitted to spatial spherical harmonics up to the 2nd order were then calculated, permitting reconstruction of spatiotemporal phase maps. For image reconstruction, a standard gridding procedure was employed utilizing the measured k-space trajectories of 0th and 1st order.

Results: Figure 1 shows measured 0th order offsets (spatially global phase offset φ_0) and k-space trajectories during several entire TRs for two different flow sensitive directions (top and bottom row). Eddy-current effects of the bipolar gradients are well seen in the φ_0 graphs, resulting in a non-zero global phase offset at *TE*. The deviation of the actual k-space trajectory from the nominal trajectory during data sampling is shown for the phase encoding step of the central k-space line (top right).
In Figure 2 phase images obtained with the cine sequence in a static water-filled bottle are given. The reference image shows a 0th and 1st order phase in velocity encoding direction with maximum phase errors up to 0.3 radian. With gridding reconstruction based on measured k-space trajectories the large background phase is corrected with residual background phase errors of less than 0.1 radian. Figure 3 contains phase maps of first (linear) and second (quadratic) spatial orders. A strong linear spatial component along the PC direction is predominant. There exist, however, 2nd order phase offsets on the order of 0.2 radian at the edges of the field-of-view confirming the need for higher order correction in space.
In Figure 4 deviation of the measured k-space trajectory and 0th order phase as a function of time frames is plotted. Eddy-current related distortions are considerable during the first frames after the trigger and decay over a period of 40-50 ms. This observation confirms the need to correct for gradient imperfections on a frame-by-frame basis in multi-phase sequences with high temporal resolution.

Discussion: The presented results demonstrate the potential of using a field camera to correct for background phase offsets in phase-contrast MRI. It has been shown that phase offsets are primarily linear in space but vary over time frames recorded with triggered cine pulse sequences. Higher spatial orders are present and need to be taken into account when imaging large field-of-views.

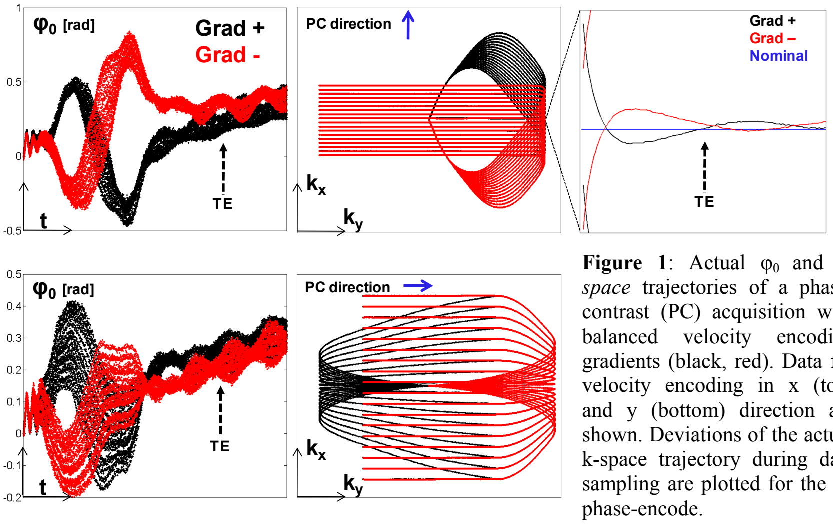

Figure 1: Actual φ_0 and *k-space* trajectories of a phase-contrast (PC) acquisition with balanced velocity encoding gradients (black, red). Data for velocity encoding in x (top) and y (bottom) direction are shown. Deviations of the actual k-space trajectory during data sampling are plotted for the 0th phase-encode.

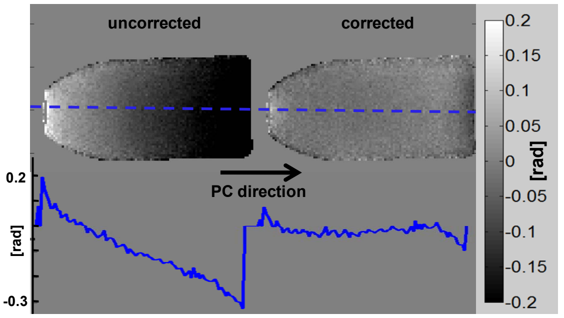

Figure 2: Comparison of phase images from uncorrected and corrected data acquired with velocity encoding along the horizontal axis. Using the nominal k-space trajectory a strong linear phase results (bottom, left). Incorporating the actual k-space trajectory into image reconstruction eliminates the background phase offset (bottom, right) and only a small residual error remains.

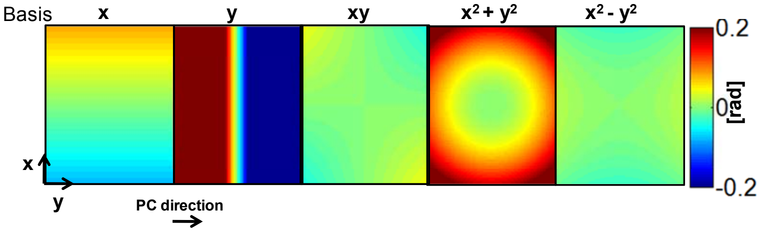

Figure 3: Higher order phase offsets generated by phase-contrast encoding. The linear fields are dominant but higher order fields can become significant if larger field-of-view are imaged.

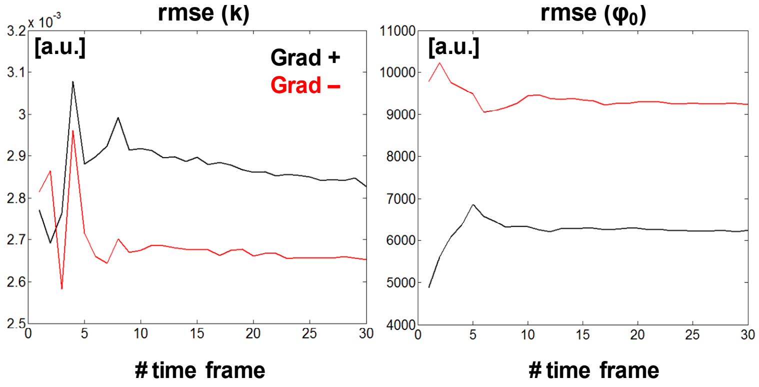

Figure 4: Temporal evolution of k-space and φ_0 offsets recorded with a triggered cine phase-contrast sequence.

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