INTRA-FRAME MOTION CORRECTION IN DYNAMIC RADIAL MRI USING THE PHASE CORRELATION METHOD

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Introduction: Motion occurring during MR data acquisition is a well-known factor of image quality degradation. In dynamic MRI, a segmented acquisition is usually performed to cover the complete k-space in several complementary portions, called segments, to reduce the effect of motion. Image-based registration can then be used for estimating motion from images reconstructed from these individual segments. However, its performance might be degraded because of undersampling artefacts as the segmentation gets higher. Recently, the phase correlation method (PCM) was proposed to detect rigid body motion directly from segmented Cartesian data and to compensate for translation [1]. However, this method remained highly sensitive to rotation and required to drop or re-acquire the corrupted samples. It has been shown that a segmented radial acquisition can minimize motion effects using a sliding window reconstruction [2] but does not correct for them. We propose the combination of a segmented radial acquisition with the PCM for measurement of rigid motion and its correction. The proposed method has been tested in simulation to compare its performance to state-of-the-art image-based registration. It has been applied to the reconstruction of motion-corrupted dynamic scans of the brain for 6 volunteers.

Methods: The PCM allows spatial shift measurement in k-space by computing the normalized cross-power spectrum and locating the maximum of its inverse Fourier transform [3]. The PCM can be extended for rotational motion estimation since a rotation in image space translates as the same rotation in k-space. Thus, the PCM can also determine the angular shift in the polar coordinate system, independently of the phase shift induced by translational motion [4]. *Figure 1* shows a schematic of the proposed PCM-based reconstruction framework for radially acquired dynamic data. A reconstruction window composed of a reference and its subsequent segments is defined. First, the rotation parameters are obtained by applying the PCM on the magnitude of the radially acquired k-spaces. Correction for rotation is performed by updating each segmented trajectory accordingly. From this, a rotation-free image is reconstructed for each segment using gridding. The PCM is then applied one more time on these images in order to estimate the remaining translation parameters. Correction for translation is eventually performed directly on the phase of the k-space data prior to a final gridding step, which combines the phase corrected k-space data and corrected trajectories to produces motion-artefact-free image corresponding to the reconstruction window.

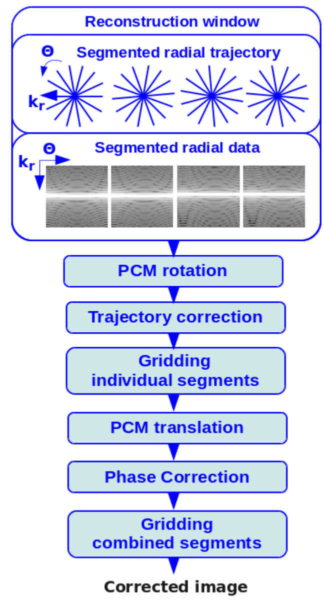

Figure 1: The proposed PCM-based rigid-motion corrected reconstruction for radially-acquired dynamic MR data

Experiments: 2D scans were performed on a Philips Achieva 1.5T with a radial SSFP acquisition, FOV 256 mm, resolution 1x1x6 mm, TR/TE=5.1/2.2ms, FA=30. Two sets of experiments were carried out, one for assessing PCM registration accuracy on simulated motion and the other for validating PCM for continuous voluntary motion. *Simulated motion*: fully sampled radial acquisitions of the brain were acquired. Defined motion was induced by rotating and translating the scan plane prior to each acquisition, providing datasets completely free from intra-frame motion. They were retrospectively segmented and combined to simulate dynamic scan acquisitions. Rigid motion parameters were estimated using the PCM-based registration method (PCMR) described above. Its accuracy was compared with image-based registration (IBR) [5] applied on the reconstructed frames for each segment, with and without user-defined region-of-interest. This comparison was done for segmenting factors of 4, 8 and 16 (segments of 64, 32 and 16 radial profiles respectively). *Dynamic scan experiment*: continuous dynamic scans of the brain for different under-sampling factors have been acquired on 6 volunteers. They were asked to rotate their head from left to right during the scan. The same protocol was repeated for different moving pace to generate varying amount of intra-frame motion. We compared the quality of the reconstructed data from our method versus a conventional sliding window reconstruction.

Results: *Figure 2* shows the improvement of image quality obtained with the proposed method over the conventional sliding window reconstruction for a retrospectively segmented brain dataset. This reconstruction window was composed of 16 segments with 16 radial profiles each. We then compared PCMR and IBR using the scan plane parameters as the gold truth. *Table 1* shows this comparison for rotation measurement between a reference and its 4 successive segments. Although only rotation is shown, the following observations were also found for the translation results. Without manually specifying a region-of-interest (ROI), IBR accuracy decreased as the segmentation gets higher, as in *Figure 2*. We believe that at some breaking points, IBR started to track on the streaking artefacts rather than the moving object. Results were improved using the ROI shown in red. On the other hand PCMR successfully registered each frame, often within less than 10% error, for segmentation factors of 4, 8, 16 and eventually failed for 32 (8 radial profiles). *Figure 3* displays PCMR reconstruction results on a continuous dynamic scan acquisition. Compared to the conventional sliding window, PCMR achieved little improvement on regions of moderate motion (2nd col.) to significant artefactual power reduction on regions of higher movement amplitude (1st and 3rd col.).

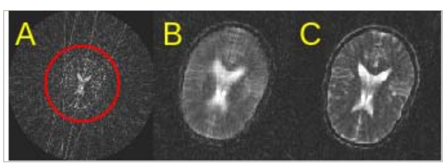

Figure 2: Sliding window reconstruction of a retrospectively segmented frame (16 profiles) from a moving brain dataset. A: reference, B: no motion correction, C: with motion correction. In red: ROI used for image-based registration

Ref.	IBR	IBR with ROI	PCMR
segmentation by 4 (64 radial profiles)			
5°	5	5.125	**4.92**
10°	9.875	9.875	**9.96**
15°	16.125	15.125	**14.58**
20°	19.75	19.75	**20.23**
segmentation by 8 (32 radial profiles)			
5°	6.375	6.125	**5.24**
10°	12.625	10.125	**9.84**
15°	13.375	14.125	**14.69**
20°	19.625	19.75	**19.83**
segmentation by 16 (16 radial profiles)			
5°	0.75	5.25	**4.12**
10°	1.375	12.375	**9.61**
15°	2.125	13.5	**15.31**
20°	2.875	20	**19.69**

Table 1: Comparison between image-based registration and PCM for rotation estimation. Highlighted in yellow, case where image-based registration failed to track the object.

Discussion: The effects of the remaining intra-frame motion in each segment remain to be studied. In theory, PCMR should be trajectory independent and we plan to extend it to a golden-radial sampling scheme [6]. Overall, PCMR is an automatic and accurate Fourier-based registration method that is complementary to the sliding window reconstruction and particularly suitable for highly-accelerated dynamic MR.

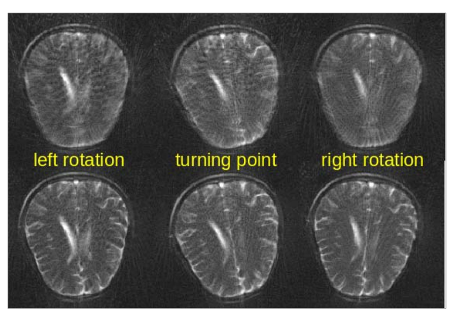

Figure 3: Dynamic scan reconstruction results obtained with a conventional sliding window (1st row) and the proposed method (2nd row), for different positions in a volunteer scan.

References: [1] Mendes et al. 2009 MRM, [2] Rasche et al 1995 MRM, [3] Kuglin and Haines 1975 Proc. IEEE, [4] Reddy and Chaterji 1996 IEEE TIP, [5] Rueckert et al. 1999 IEEE TMI, [6] Winkelmann et al. 2007 IEEE TMI