IMAGE BASED CORRECTION OF PHASEWRAPS IN 4D PC-MRI DATA USING FAST REFERENCE SCANS

D. Stucht[1], M. Markl[2], R. Gasteiger[3], and O. Speck[1]

[1]Biomedical Magnetic Resonance, Otto-von-Guericke University, Magdeburg, Germany, [2]Dept. of Diagnostic Radiology, Medical Physics, University Hospital, Freiburg, Germany, [3]Institute of Simulation and Graphics, Otto-von-Guericke University, Magdeburg, Germany

INTRODUCTION: Recent studies have shown the feasibility of 4D PC-MRI to measure four dimensional (3D-spatial plus temporal domain) blood flow and to give a qualitative and quantitative analysis of the hemodynamics e.g. in the aorta or the carotids. This technique requires the conversion of the measured phase angle ($-\pi$ to $+\pi$) to velocity vectors by the usage of a parameter that specifies the velocity sensitivity (venc, velocity encoding) [1] [2]. If the actual flow velocities exceed this parameter, velocity phase wraps will occur, which lead to errors in the flow data. Using a lower velocity sensitivity (a higher venc) leads to a lower velocity to noise ratio (VNR), which is also undesirable. Manual correction of the phase wraps is possible but unpractical considering the large quantity of the data. Automatic image based post processing techniques that focus on finding and correcting large jumps between neighboring voxels in the phase data have been developed and extended to 4D. [3] [4]. An alternative approach to solve this problem is to acquire the data using more complex velocity encoding schemes [5]. A simple method is to acquire the data twice. Once with the lower venc and the higher VNR. Then with a higher venc to correct the phase wraps in the first low venc dataset [6]. This requires additional scanning time for the reference dataset. The aim of this study is, to systematically analyze in phantom scans to what extent a reduction of the additional scan time can be achieved by reducing the spatial and temporal resolution of the high venc reference scan.

MATERIALS AND METHODS: ***MRI Measurements*** were performed on a 7T whole body MRI (Siemens Medical Solutions, Germany) using a 24-channel coil (Nova Medical, Wilmington MA, USA). Flow data were acquired using 4D PC-MRI which is based on a triggered and RF-spoiled GRE sequence (coronal slice orientation, image matrix = 72 × 128 × 60, Field of View (FoV) = 72 × 128 × 60mm, 1.0 x 1.0 x 1.0mm voxelsize, TR / TE=92.8ms / 2.771ms, parallel imaging (GRAPPA) factor 2, FA = 15°, bandwidth = 360Hz/Px). The measurement was repeated twice with two different venc-parameters (venc1 = 0.75m/s and venc2 = 3.0m/s) where the scan with the higher venc is the reference dataset. The sequence was triggered by a signal delivered by the pump. 20 time frames were acquired with a temporal resolution of 89.6 ms.

Masking and unwrapping: A static mask was created by summing up the magnitude data of all 20 phases and thresholding the result by 8% of its maximum value. The phase data was converted to flow information using the specified venc parameters. Phase wraps were identified by calculating the difference of the two flow datasets and separating the result in intervals of 2n • venc1 ± venc1. The unwrapping was done by removing the extra phases respectively adding the missing phases. E.g. a voxel with a flow difference between 0.75m/s and 2.25m/s (1.5m/s ± 0.75m/s) was considered being affected by a phase wrap and was corrected by adding or subtracting 1.5m/s.

A ***comparison dataset*** was calculated using the method described above. Here a 3 × 3 median filter was additionally applied to the reference dataset before the difference calculation to avoid incorrect phase wrap identification at the edges of the vessels caused by the strong noise in the background outside the vessels. In this dataset all phase wraps were removed, only very few voxels at the edges of the vessel were still influenced by the background noise.

Reduction of special and temporal resolution: To reduce the resolution of the reference dataset in the spatial domain, the original data were transformed to k-space and zerofilled before retransforming them to image space. The phase unwrapping was performed with reference datasets between 100% and 3% of the original size (100% to 3% of the original k-space data were retained and the remaining lines were zero filled). The reduction of the temporal resolution was performed by simply averaging two consecutive phases. The resulting average was assigned to both phases.

RESULTS: The results of the incremental reduction of the spatial resolution and the following comparison to the comparison dataset are shown in figure 1. The calculations were performed with (max. correlation at 46% spatial resolution) and without (max. correlation at 43% spatial resolution) changes in the temporal resolution. In the second case, the averaged phases were always the basis for the correction. Figure 2 shows the partial results of individual processing steps.

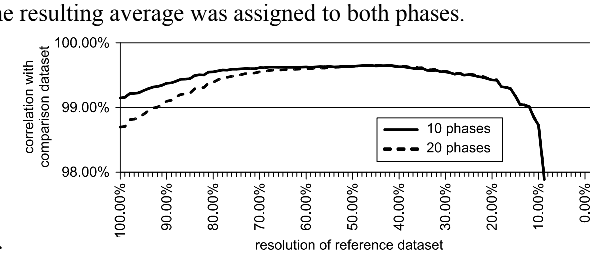
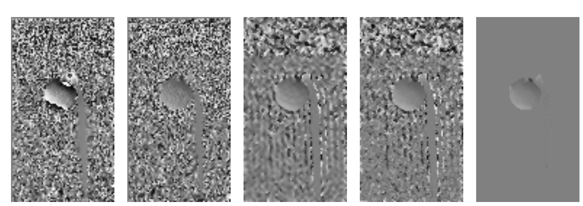


Figure 1: correlation of comparison dataset and result data in the non-masked area with decreasing spatial resolution of the reference dataset at full 20 time periods and at reduced 10 phases (percentage of unequal voxels).



(a) (b) (c) (d) (e)

Figure 2: Steps of the phase wrap correction: (a) $venc_1$ = 0.75 m/s Phase wraps are visible, higher VNR (b) $venc_2$ = 3.00 m/s, no phase wraps, lower VNR (c) corresponds to (b) with reduced spatial (50%) and temporal resolution, (d) corrected data from (a), (e) corresponds to (d) with masked background.

DISCUSSION: The proposed method provides good results even at 50% of the original resolution (factor 8 reduction in k-space data), while preserving the high VNR of the measurement with the low venc. Presumably, the higher error rates at higher resolutions are caused by the noise at the edges of the vessels where faulty voxels are almost exclusively found. These errors are mainly caused by the imperfect masking. A better segmentation would be beneficial. The increasing correlation at higher reduction rates is probably due to the noise reduction effects of the reduction of the spatial and temporal resolution. Errors in the phase wrap correction start to occur at a reduction to 45% of the original spatial resolution. It has to be shown, weather this is an absolute value or a value relative to the original size. In this study a theoretical reduction to 15-20 % of the additional scan time could be achieved, which could be even more reduced by a higher GRAPPA factor and further reduction of the temporal phases. It is necessary to examine to what extent the results of these phantom tests can be transferred to in vivo experiments. The larger sample volumes and the less pronounced background noise suggest good results.

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