ON COMPRESSED SENSING FOR PHASE-CONTRAST VELOCITY MAPPING

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Introduction: Cine phase contrast (PC) velocity mapping is associated with relatively long scan times. Among the various scan acceleration techniques available to PC-MRI, Compressed Sensing (CS) [1] has recently been demonstrated [2-4]. Given the incoherent sampling requirement in CS it may seem surprising that the object phase and hence velocities can be well recovered from randomly undersampled PC-MRI data. In this work, the performance of CS to reconstruct velocity induced object phases is investigated. It is hypothesized that reconstruction accuracy with respect to object phase depends on inflow contrast. Using 2D and 3D in-vivo flow data acquired in the aortic arch it is demonstrated that reconstruction error varies significantly depending on amplitude contrast.

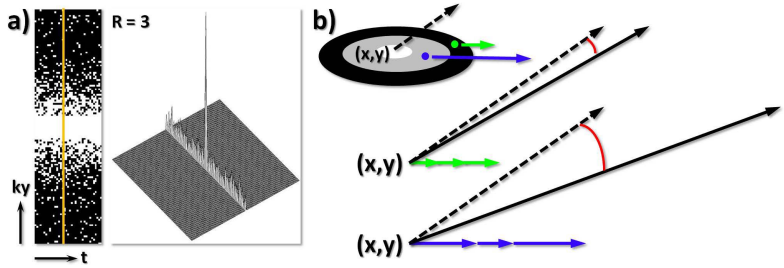

Figure 1: a) Variable density sampling pattern with the corresponding point-spread function (PSF). **b)** Each vector represents a complex number. The complex-valued vector (dashed) at position (x,y) may be superimposed with signal contributions from low (green) and high (blue) magnitude background. As illustrated, the latter leads to higher phase errors at position (x,y).

Theory: In CS the unconstrained Lagrangian L1-norm minimization problem: $\text{argmin}_{\mathbf{x}} \|\mathbf{F_u x - y}\|^2 + \lambda_1\|\mathbf{\Psi x}\|_1 + \lambda_2 TV(\mathbf{x})$ is solved according to [1]. The random sampling requirement causes incoherent artifacts in the image domain, i.e. each complex-valued pixel distributes its energy according to the sampling pattern's point spread function (PSF) over the image. Accordingly, the phase in each pixel represents a magnitude weighted sum of phases from object points folding. This suggests that the object phase in a particular point depends on the magnitude of signal contributions aliasing on top of each other as illustrated in Figure 1.

Methods: Fully sampled 2D and 3D cardiac-triggered Cartesian cine PC-MRI data were acquired on a 3T Philips Achieva system (Philips Healthcare, Best, The Netherlands) (FOV: 250x250mm^2, 7 slices (3D), voxel size: 2x2x8mm^3, 38 heart phases, temporal resolution: 17ms, V_{enc} (feet-head): 180cm/s. Data were decimated according to the variable density random pattern shown in Figure 1. CS reconstruction was performed frame-by-frame using a nonlinear conjugate gradient algorithm [1] implemented in Matlab (Natick, MA, USA). Regularization parameters were set to λ_1=0.01 and λ_2=0.005. A region-of-interest was defined for the descending aorta and the magnitude weighted root-mean-square-error (RMSE) [5] was computed relative to the fully sampled reference.

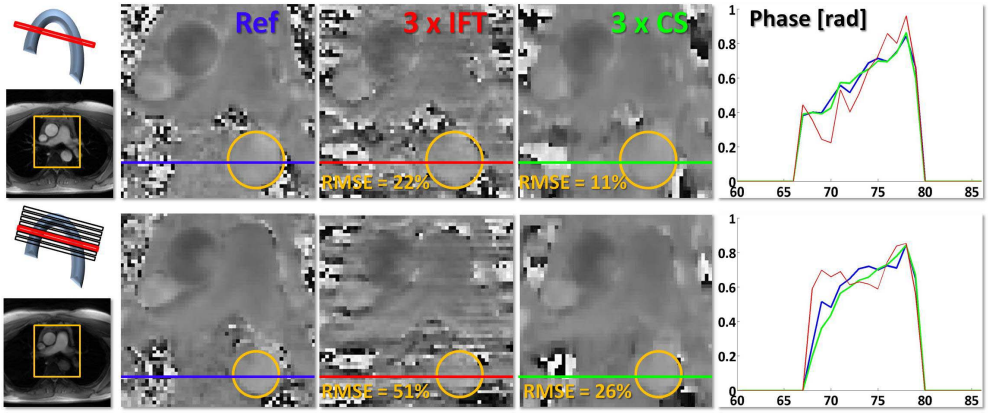

Figure 2: Comparison of phase difference maps from 2D (top) and 3D (bottom) PC-MRI data reconstructed using zero-filling (IFT) and CS from 3-fold undersampled data. Flow profiles in the descending aorta are shown for the different reconsructions. RMS phase errors relative to the fully sampled reference are quoted.

Results: In Figure 2 phase difference maps of a systolic frame are compared for the fully sampled reference (Ref), zero-filling (IFT) and CS reconstructions from 3-fold undersampled data for 2D (upper row) and 3D PC-MRI data (lower row). It is seen that RMSE is more than doubled in the 3D PC-MRI case as a result of reduced inflow contrast. Figure 3 compares mean signal magnitude for 2D and 3D PC-MRI with RMSE of the phase difference for 2- and 3-fold undersampled data reconstructed using zero-filling and CS.

Discussion: Results confirm that inflow contrast determines CS reconstruction accuracy of phase-difference values with decreasing errors for enhanced amplitude contrast in vessels. This effect is predominant in the systolic phases. At peak systole, indicated by the magnitude peak of the inflow signal (Fig.3), the RMSE is minimum. Based on the findings it may be concluded that the L1-norm may not be the optimal norm for phase retrieval. Therefore, the CS framework may have to be modified for PC-MRI to guarantee stable phase reconstruction independent of inflow contrast.

Refs: [1]Lustig M, MRM 58 (2007), [2]Holland DJ, JMR 203 (2010), [3]Alley MT, ISMRM, p.1218 (2011), [4]Hsiao A, ISMRM, p.1190 (2011), [5]Baltes C, MRM 54 (2005).

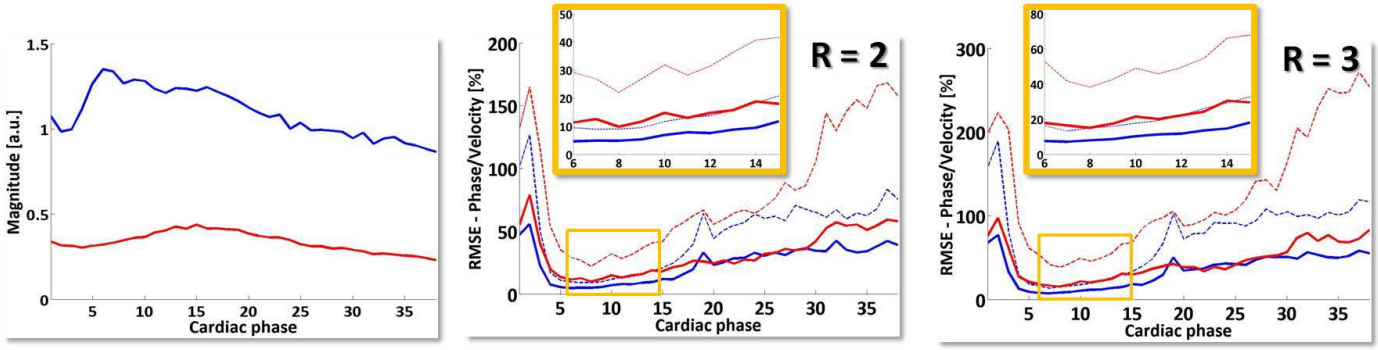

Figure 3: Magnitude signal in the descending aorta from 2D (blue) and 3D (red) PC-MRI demonstrating the difference in inflow contrast. Phase RMS errors for zero-filling (dashed) and CS reconstruction (solid) from 2- and 3-fold undersampling demonstrate an inverse correlation with the inflow contrast.