

Compressed sensing reconstruction with retrospectively gated sampling patterns for velocity measurement of carotid blood flow

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Introduction

Incoherent sampling is known to be beneficial for Compressed Sensing (CS) [1,2]. In MRI, exact incoherent sampling in k-space is difficult. Most studies have used pseudo-random sampling patterns. In retrospectively gated dynamic scans, due to unpredictable heart rate variability, the actual sampling pattern in k-t space appears to be incoherent, which suits the CS framework. In this work, CS sampling and reconstruction is simulated with in vivo data and real sampling patterns from retrospectively gated 2D cine phase contrast scans of carotid blood flow. Both intensity and phase (velocity) errors are examined.

Method

Complex-value raw signal of a single axial carotid slice (matrix 192×192, as shown in Figure (2.a)) was acquired on a GE 1.5T Signa HDx scanner (GE Healthcare, Slough, UK) in a fully sampled 2D phase contrast carotid scan of a healthy volunteer. The raw signal was used to generate a fully sampled data set (24 time frames) as the true signal for undersampling simulations. Since the frequency encoding dimension was fully sampled, inverse Fourier transform was applied in the corresponding spatial dimension (x) to allow separate processing of data at each x position. In y-f space (inverse Fourier transform of k-t space), the true signal is sparse. In a y-f slice (at a single x position) crossing the centre of the right common carotid artery (RCCA), 6.6% of the y-f entries contribute 95% of total signal power, 29.7% of the entries for 98% of the total power, and 46.8% of the entries for 99% of the total power.

Three retrospectively gated sampling patterns recorded in real volunteer scans were used for simulated undersampling. The sampling ratios were 50%, 33%, and 25%. The pre-designed [3] and the actual sampling patterns of the sampling ratio 50% are shown in Figure (1).

In CS reconstruction, the L1 norm of the signal in y-f space was minimized with quadratic constraints corresponding to noise in k-t signal. The basis pursuit denoise problem was solved with the SPGL1 method [4].

Results

Averaged across the RCCA, the root-mean-square (RMS) intensity errors normalized to mean intensity were 3.3%, 7.8% and 8.6% at the sampling ratios of 50%, 33% and 25%, respectively. The RMS (velocity encoded) phase errors normalized to peak velocity were 1.2%, 3.6% and 2.9%. The RMS velocity errors normalized to peak velocity were 1.7%, 4.2% and 4.1%.

Two voxels were selected in the RCCA. The waveforms of (velocity encoded) phase errors and velocity errors at each voxel from all three sampling patterns are shown in Figure (2). At the sampling ratio of 50%, the errors were smaller than 2 cm/s in most cardiac phases. The errors obtained at the ratio of 33% or 25% were generally larger, more than 5 cm/s in several cardiac phases for the voxel near the RCCA wall. The errors obtained at the sampling ratio of 33% were often larger than those at the ratio of 25%. Compared with the peak velocity of 85 cm/s in the RCCA, the results obtained at the ratio of 50% were acceptable, but the other results were less accurate.

Discussion

The simulation results have demonstrated that the retrospectively gated sampling patterns are suitable for CS reconstruction. Good results were obtained with low acceleration (2×), but with further acceleration both the intensity and phase errors increased. The modest performance may be a result of limited SNR level of the true signal. It is also possible that signal phases were less sparse than the intensities. In the wavelet domain, there may be a sparser signal representation. In this work the reconstruction was conducted at each x position separately. Higher performance may be achieved if both spatial dimensions and the temporal dimension are sparsified jointly in reconstruction. Further study will investigate the joint sparsity between the velocity encoded signal and the reference signal in phase contrast scans.

References

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- [3] Tao, Y. et al. Proc ISMRM. 16, 69, (2007)
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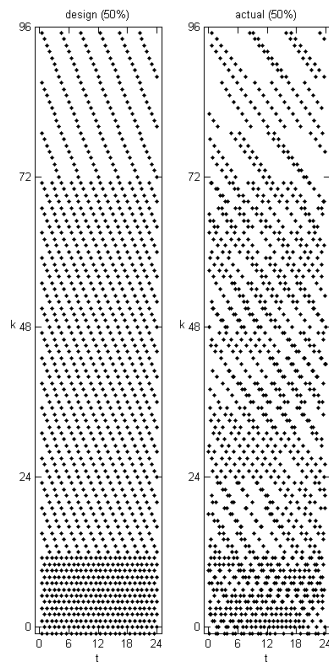


Figure 1: The pre-designed and the actual k-t sampling patterns of the sampling ratio 50%. Each black dot represents a frequency encoding line. Only the upper half of each sampling pattern is displayed.

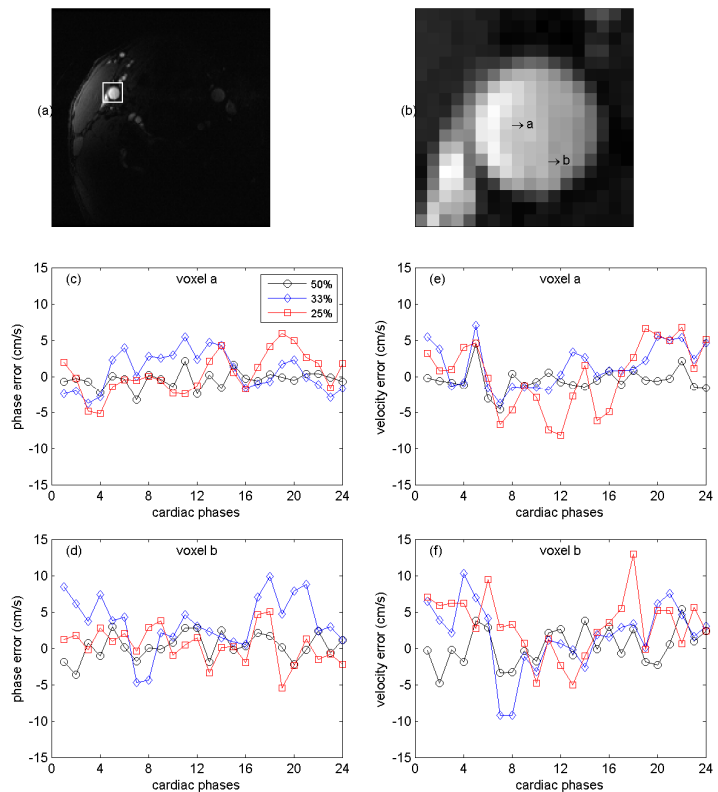


Figure 2: The waveforms of (velocity encoded) phase errors (c, d) and velocity errors (e, f) at two selected voxels from all three sampling patterns. The positions of the voxels are displayed in (a, b).