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Sparse representations for compressed sensing acceleration of Fourier velocity encoded MRI

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Introduction

- Fourier velocity encoded MRI (FVE) [1] is useful in the assessment of vascular and valvular stenosis [2] and intravascular wall shear stress [3,4].
- FVE eliminates partial volume effects that may cause loss of diagnostic information in more conventional phase-contrast MRI [5].
- FVE data has high dimensionality and intrinsic sparseness in image domain. Great potential for compressed sensing (CS) acceleration! [6]
- CS already successfully applied to FVE imaging, using a Fourier transform along the temporal dimension as sparsifying transform [7].
- **Downside**: FVE MRI has not been adopted for any routine clinical applications, primarily because scan-time is prohibitively long.
- **Goal**: To find other suitable sparse representations for FVE data, thus enabling acceleration of the acquisition process in a CS framework.

Test dataset

The investigation was conducted considering a five-dimensional (x,y,z,v,t) FVE dataset of the neck (focusing on carotid flow), reconstructed from the fully-smapled dataset, and used as ground-truth reference (Fig. 1). Reconstruction was performed in MATLAB using the non-uniform FFT toolbox by Fessler JA. Acquisition parameters were as follows:

- Multi-slice cine spiral FVE scans (5 slices);
- 1.4×1.4×5 mm^3 spatial resolution;
- 8×1012-sample variable-density spiral readouts;
- 5 cm/s velocity resolution (32 velocity encodes);
- 12 ms temporal resolution (43 cardiac phases);
- 5 axial slices, 146-second acquisition per slice (256 heartbeats at 105 bpm).

Data acquired on a GE Signa 3T EXCITE HD system (40 mT/m, 150 T/m/s gradients), using a 4-ch neck coil.

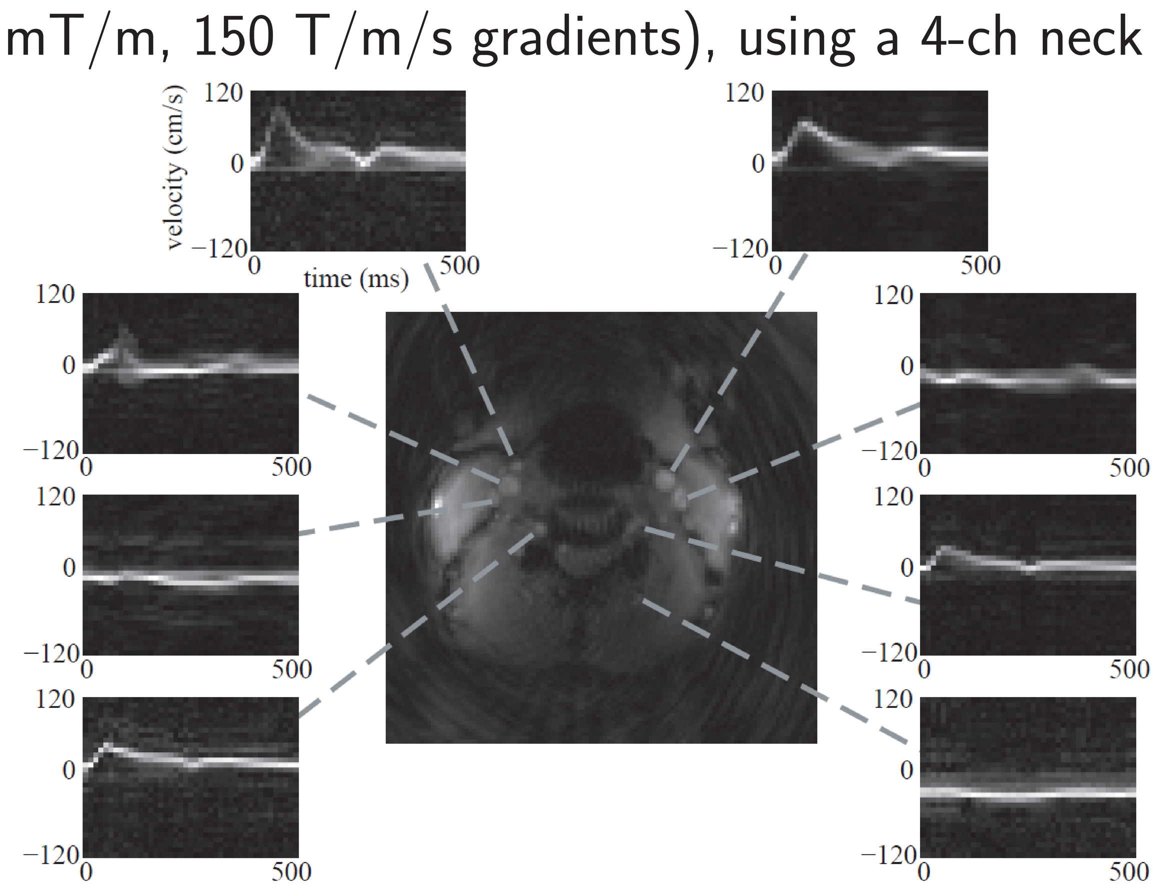

Figure 1: FVE dataset of the neck (one of five slices).

Search for a sparse representation

The data was transformed into several domains, and then tested for energy concentration as a measure of compressibility. Evaluated transforms included:

- Fourier transform;
- Cosine transform;
- Finite differences;
- Several wavelet transforms;
- Several separable combinations of the above transforms, over the five dimensions of the test dataset.

Sparsity for each transform domain was evaluated as follows:

- Energy coefficients were sorted in descending order;
- Cumulative sum of those coefficients was calculated;
- Resulting curve was normalized to 100% of the energy at 100% of the coefficients.

A steep slope at the beginning of the curve, and fast approach to 100% energy, are signs of high compressibility, and suggest a representation that allows for a good sparse approximation.

Results and discussion

- **Energy curves**: Fig. 2 shows the corresponding curves of the two most compressible representations found:
  - Green curve: combination of Daubechies 2 (along x,y) and Haar (along z,t) wavelets.
  - Red curve: combination of biorthogonal 3.1 (along x,y,v) and Haar (along z,t) wavelets.

  Blue curve corresponds to the untransformed data, included for comparison.
- **Qualitative evaluation**: Although Fig. 2 suggests that the bior3.1+Haar representation is more promising, an image domain evaluation (Fig. 3) suggests that the representation using db2+Haar provides better results, including a denoising effect for the 1% coefficients case. With only 0.1% of the coefficients, db2+Haar still outperforms the bior3.1+Haar representation, but significant artifacts arise on both representations.

Conclusion

Several combinations of separable sparsifying transforms for multi-slice FVE data of the neck were evaluated. Two very promising representations were found.

- No significant loss of diagnostic information with only 1% of transformed coefficients.
- Denoising effect observed using a combination of Daubechies 2 (along x,y) and Haar (along z,t) wavelets.

These representations should be further evaluated for other FVE datasets (e.g., patients, other applications).

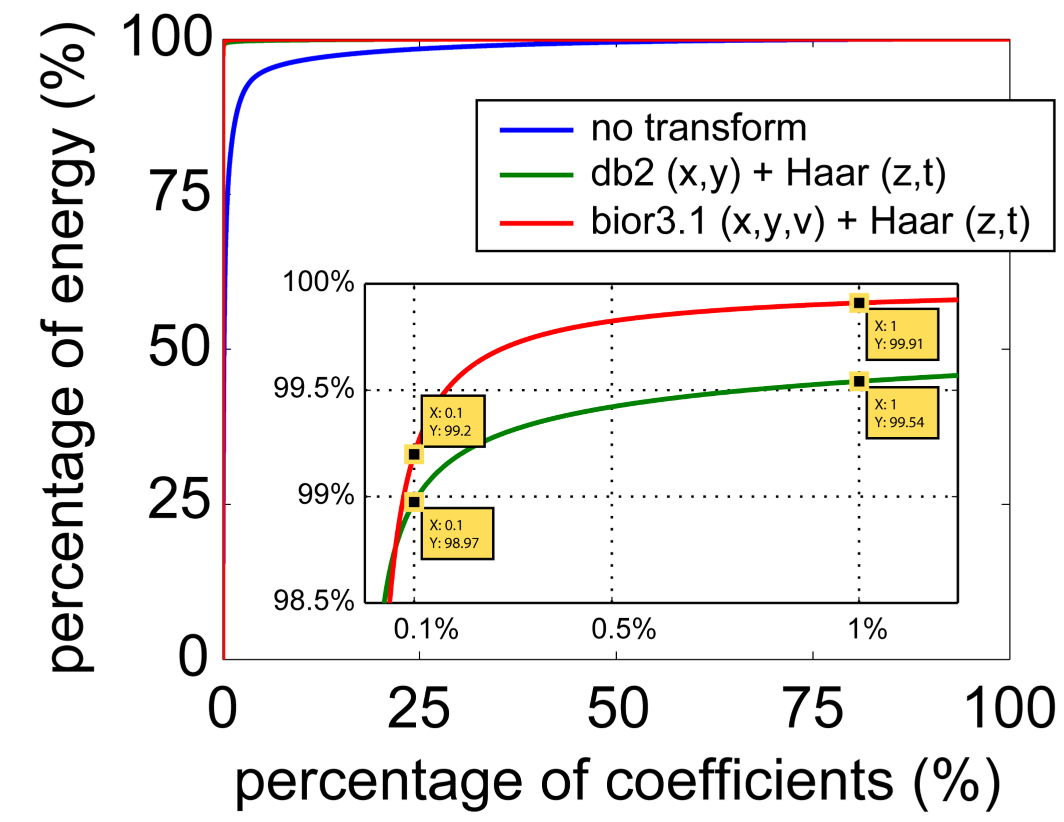

Figure 2: Energy vs. # of coefficients for the two best representations (inset) among those evaluated, and for the non-transformed data (blue curve).

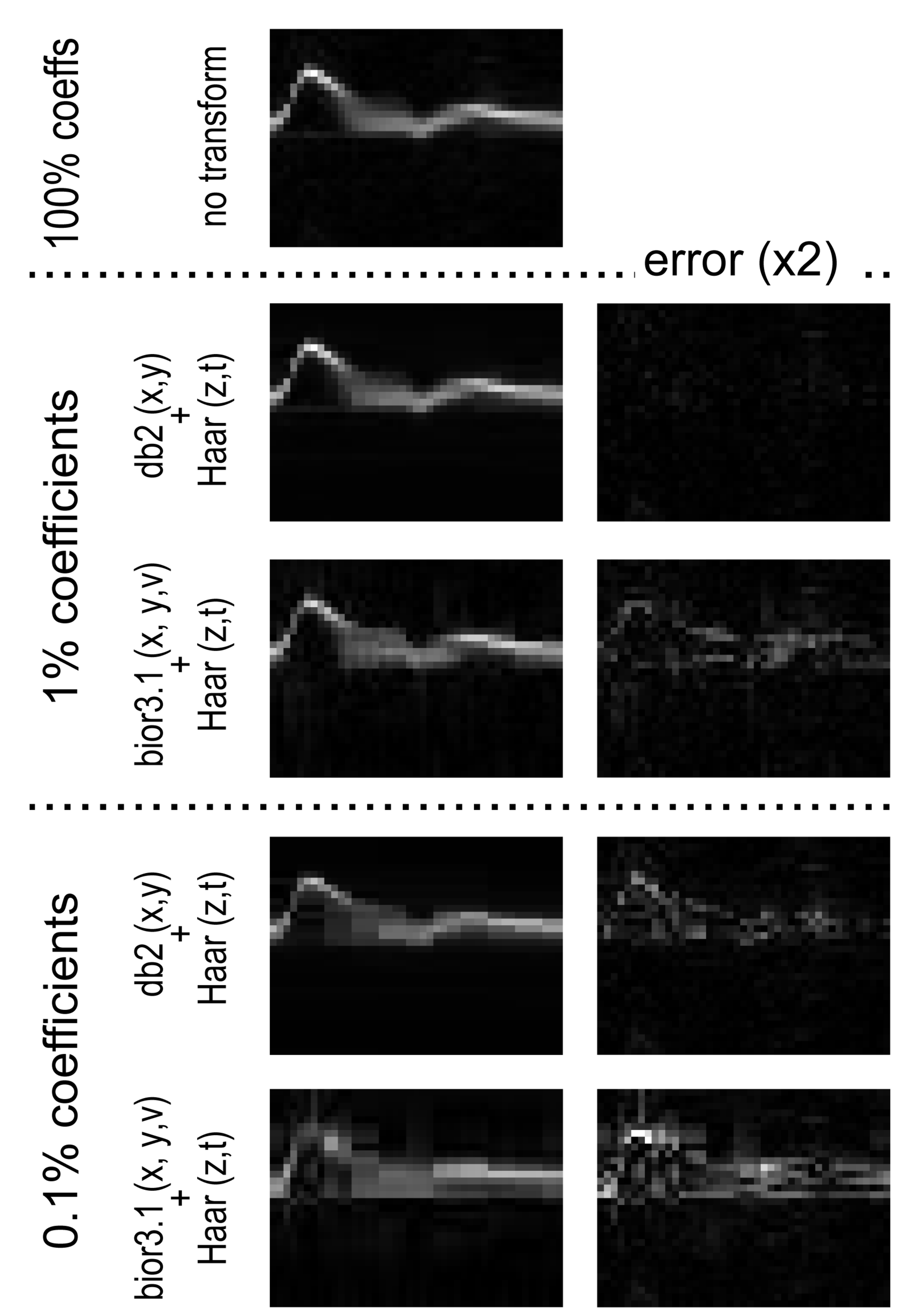

Figure 3: FVE velocity distributions for a voxel at the right carotid bifurcation of a healthy volunteer, reconstructed from only the 1% or 0.1% largest transform coefficients. The two representations highlighted in Fig.2 are compared.

References

[1] Moran PR. MRI 1:197, 1982.
[2] Carvalho JLA et al. MRM 57:639, 2007.
[3] Carvalho JLA et al. MRM 63:1537, 2010.
[4] Frayne R et al. MRM 34:378, 1995.
[5] Tang C et al. JMRI 3:377, 1993.
[6] Lustig et al. MRM 58: 1182, 2007.
[7] Gamper U et al. MRM 59:365, 2008.