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PARALLEL IMAGING ACCELERATION OF SPIRAL FOURIER VELOCITY ENCODED MRI USING SPIRIT

Davi Marco Lyra-Leite[1,2] (davi@ieee.org)
João Luiz Azevedo de Carvalho[1] (joaoluiz@pgea.unb.br)

[1]Medical Imaging and Signal Processing Research Group (GPSIM)
Department of Electrical Engineering
University of Brasília, Brasília–DF, Brazil

[2]Magnetic Resonance Engineering Laboratory
Ming Hsieh Department of Electrical Engineering
Viterbi School of Engineering
University of Southern California
Los Angeles, CA, USA

departamento de engenharia elétrica
faculdade de tecnologia

GPSIM Grupo de Processamento de Sinais e Imagens Médicas

Introduction

Fourier velocity encoding (FVE) [1] is useful in the assessment of valvular disease [2–3], as it eliminates partial volume effects that may cause loss of diagnostic information in phase-contrast imaging [4]. FVE has also been proposed as a method for measuring wall shear rate in the carotid arteries [5].
The scan time in FVE can be significantly reduced using temporal acceleration [6]. The use of parallel imaging may reduce spatial aliasing due to temporal undersampling in temporally-accelerated spiral FVE, therefore improving this technique. We investigate the use of the iterative self-consistent parallel imaging reconstruction (SPIRiT) method [7] to accelerate the acquisition of spiral FVE.

Theory

Spiral FVE:

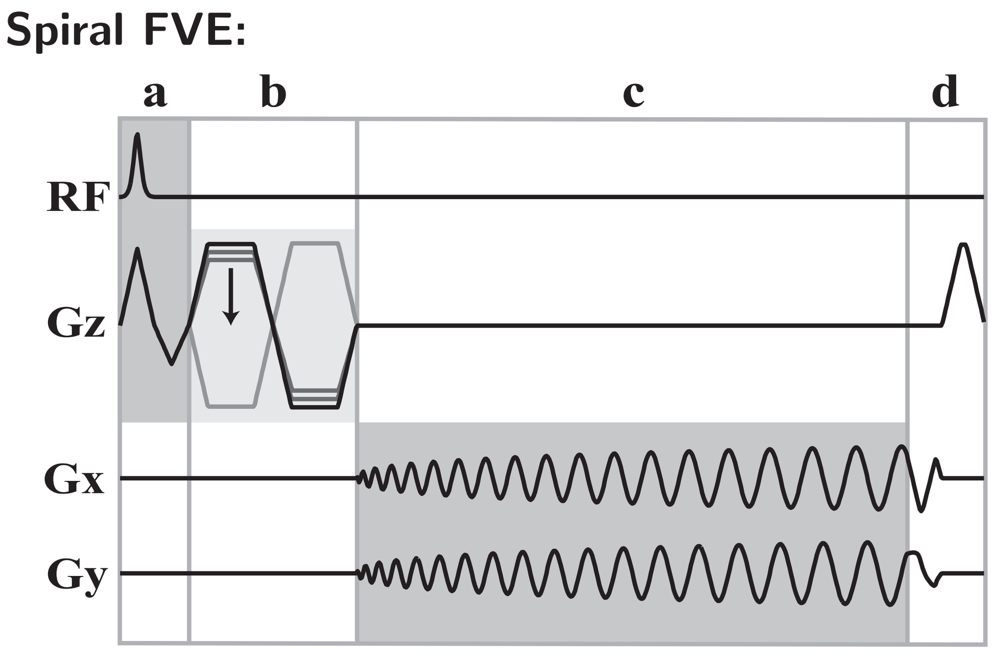

Figure: Spiral FVE pulse sequence. It consists of (a) slice selective excitation, (b) velocity encoding bipolar gradient, (c) spiral readout, and (d) refocusing and spoiler gradients.

The acquired data consist of a temporally-resolved stack-of-spirals in $\mathbf{k_x}$-$\mathbf{k_y}$-$\mathbf{k_v}$ space [2].

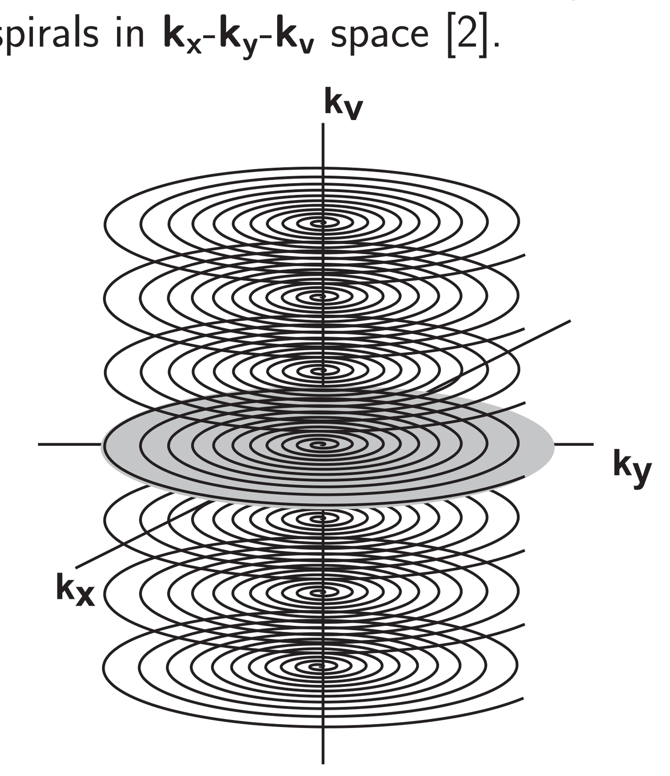

Figure: Trajectory in $\mathbf{k_x}$-$\mathbf{k_y}$-$\mathbf{k_v}$ space.

The algorithm we used presents an inversion in the usual spiral FVE data reconstruction sequence, as a Cartesian inverse Fourier transform along $\mathbf{k_v}$ is now applied before the non-Cartesian inverse Fourier transform [8] along $\mathbf{k_x} - \mathbf{k_y}$. This produces the spatiotemporal-velocity distribution, $\mathbf{m(x, y, v, t)}$.

SPIRiT: The iterative self-consistent parallel imaging reconstruction (SPIRiT) approach [7] is an autocalibrated coil-by-coil parallel imaging reconstruction method, based on self-consistency.

The algorithm uses information from all neighborhood points in all coils — sampled or not — to obtain the missing data [7].

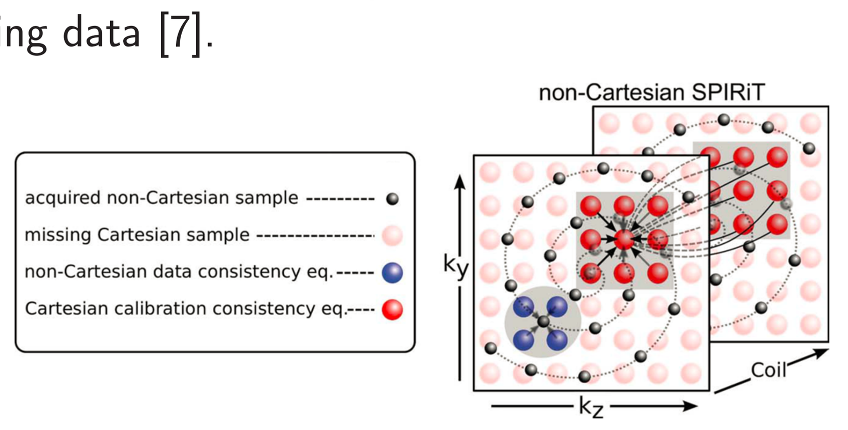

Figure: Non-Cartesian consistency reconstruction. Adapted from [7].

Methods

Parallel imaging acceleration was evaluated using 2-fold and 4-fold spatially-undersampled datasets, derived from a fully-sampled spiral FVE dataset, obtained perpendicular to the neck of a healthy volunteer. Data was reconstructed using two techniques: sum-of-squares (SoS) [9] and SPIRiT [7].
We used image domain SPIRiT, because the data was acquired in a non-Cartesian fashion.

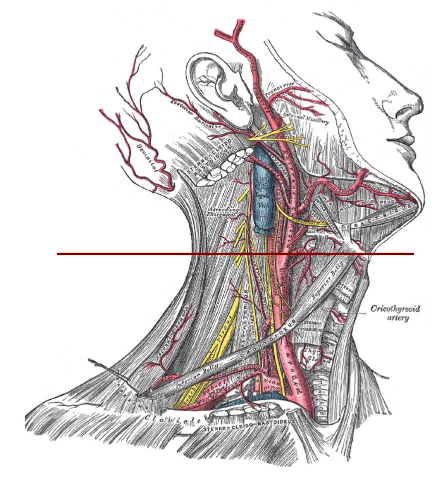

Figure: Neck diagram indicating the acquisition plane.

Data acquisition: Spiral FVE scans were performed on a GE Signa 3T EXCITE HD system (40 mT/m maximum gradient amplitude, 150 T/m/s maximum gradient slew rate), using a 4-channel carotid coil. Scan parameters: 1.4×1.4×5 mm^3 spatial resolution over a 16 cm FOV, 5 cm/s velocity resolution over a 240 cm/s FOV, 12 ms temporal resolution. Scan time was 146 seconds (256 heartbeats at 105 bpm).

Qualitative Results

A qualitative evaluation of the SPIRiT results was performed in both spatial domain and time-velocity domain, based on the results presented below.

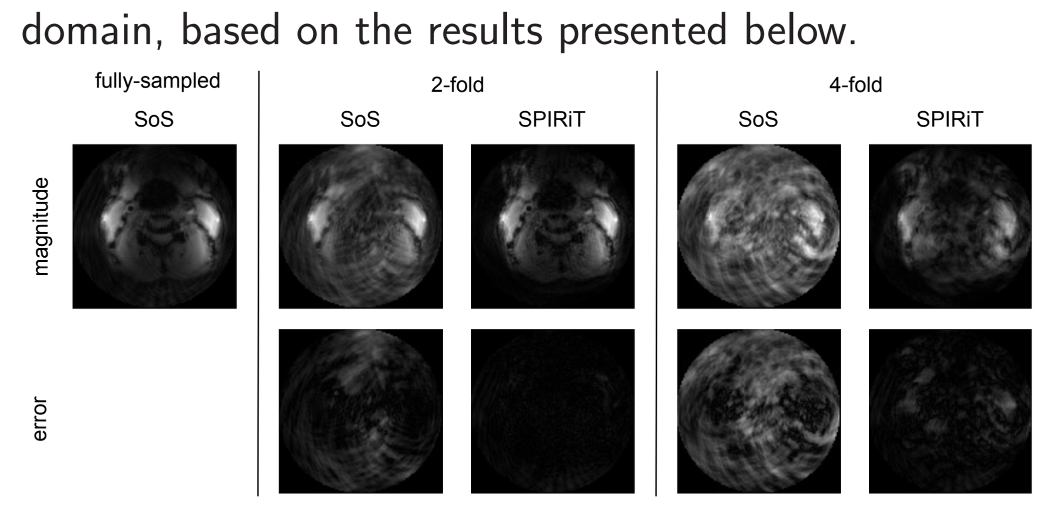

Figure: Axial images of the neck (top row) obtained using sum-of-squares and SPIRiT, with different acceleration factors (fully-sampled, 2-fold and 4-fold). Reconstruction error images for both SoS and SPIRiT are also shown (bottom row). These images were reconstructed from $\mathbf{M(k_x, k_y, k_v, t)}$ for $\mathbf{v = 0}$ and $\mathbf{t = 0}$.

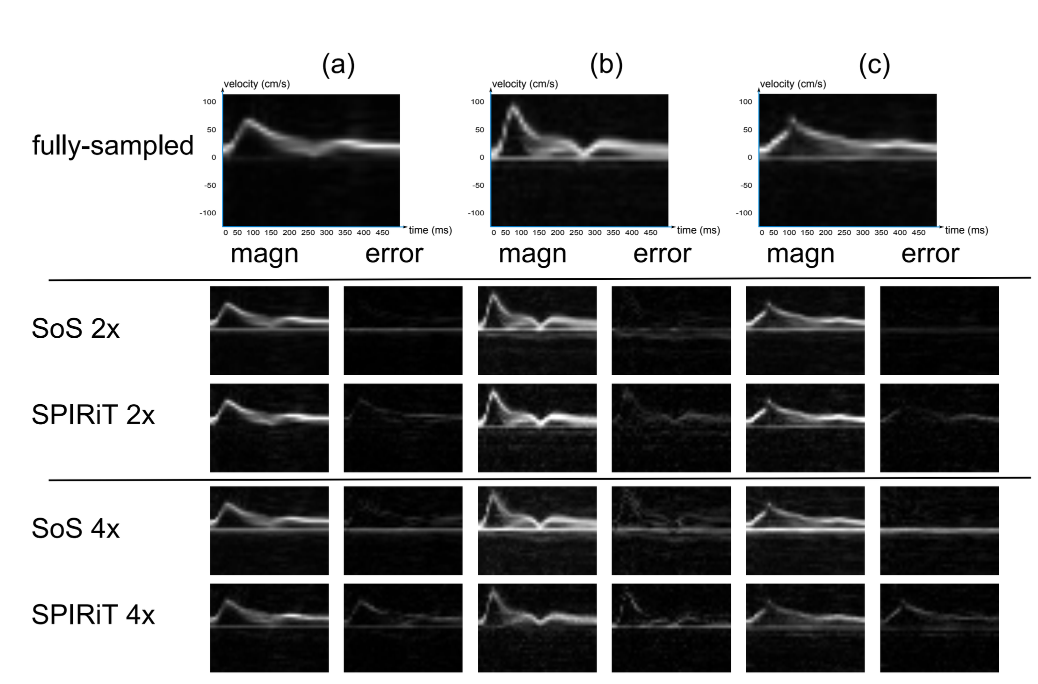

Figure: Time-velocity distributions from select voxels, reconstructed using 2-fold and 4-fold sum-of-squares, and 2-fold and 4-fold accelerated SPIRiT, in comparison with the fully-sampled reference (top row) for: (a) left carotid bifurcation; (b) right external carotid artery; and (c) right internal carotid artery.

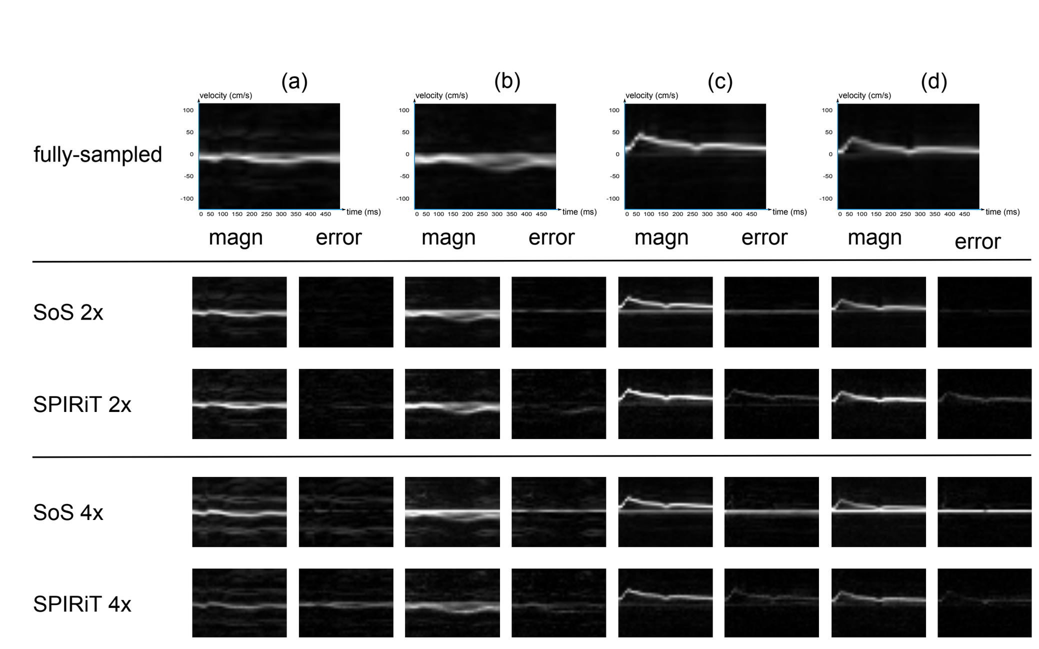

Figure: Time-velocity distributions from select voxels for: (a) right jugular vein; (b) left jugular vein; (c) right vertebral artery; and (d) left vertebral artery.

Quantitative Results

A quantitative evaluation comparing SPIRiT and sum-of-squares is presented in Table 1.

Table: Signal-to-error ratio (in dB) for 2-fold and 4-fold accelerated results, relative to the fully-sampled reference.

accel factor	**2-fold**		**4-fold**	
recon technique	SoS	SPIRiT	SoS	SPIRiT
spatial image	5.03	16.7	-1.3	9.6
lcb	9.0	11.6	6.1	8.7
jv	11.3	12.0	4.3	10
reca	11.2	10.8	5.8	7.7
rica	15.1	11.4	3.0	9.3
rjv	17.5	13.0	7.6	5.8
rva	8.0	9.9	1.8	10.1
lva	16.5	7.8	-2.0	11.8

lcb = left carotid bifurcation.
ljv = left jugular vein.
reca = right external carotid artery;
rica = right internal carotid artery;
rjv = right jugular vein.
rva = right vertebral artery.
lva = left vertebral artery.

Discussion

The SPIRiT results are similar to the sum-of-squares results for 2-fold acceleration, and consistently better for 4-fold acceleration. This demonstrates that parallel imaging can be used in flow distribution studies in order to accelerate data acquisition and reduce scan time. SPIRiT is able to reduce aliasing artifacts, therefore removing false signal at $\mathbf{v = 0}$ cm/s. However, as it produces other types of artifacts, further analysis is required in order to validate its use for spiral FVE acceleration.

Conclusion

We have demonstrated parallel imaging acceleration of spiral FVE using the image domain SPIRiT technique. The results showed that SPIRiT is able to considerably reduce spatial aliasing from undersampled time-velocity distributions and presents good quantitative and qualitative results for 2-fold acceleration.

References

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CNPq Conselho Nacional de Desenvolvimento Científico e Tecnológico

USC University of Southern California