A Through-Plane Acceleration Approach to Increase SNR of Simultaneous Multi-Slice in FMRI

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Hadamard Phase Encoding

- The Hadamard Matrix:

$$H_{2^n} = \begin{bmatrix} H_{2^{n-1}} & H_{2^{n-1}} \\ H_{2^{n-1}} & -H_{2^{n-1}} \end{bmatrix} = H_2 \otimes H_{2^{n-1}}$$

$$H_1 = [1], H_2 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

- The Time Series Hadamard Coefficients:

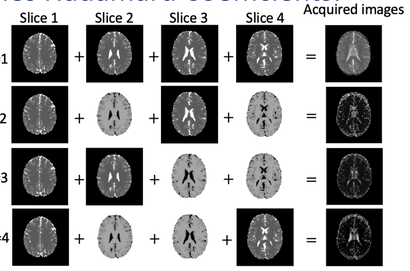
a)

$$H_4 = \begin{bmatrix} + & + & + & + \\ + & - & + & - \\ + & + & - & - \\ + & - & - & + \end{bmatrix}$$

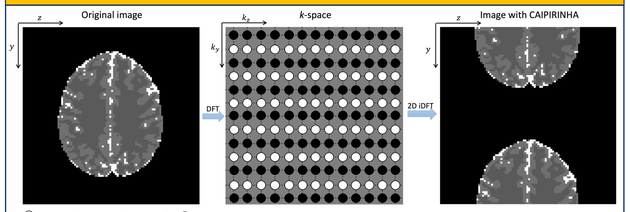
b)

	1	2	3	4
TR=1	+	+	+	+
2	+	−	+	−
3	+	+	−	−
4	+	−	−	+
5	+	+	+	+
6	+	−	+	−
7	+	+	−	−
8	+	−	−	+

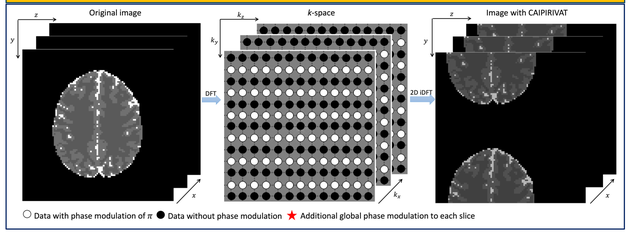
c)



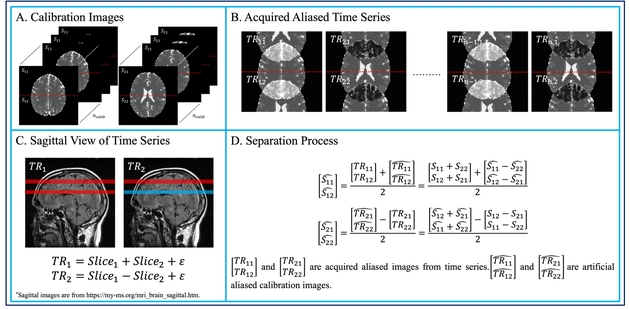
CAIPIRINHA



CAIPIVAT



mSPECS-CAIPIRINHA



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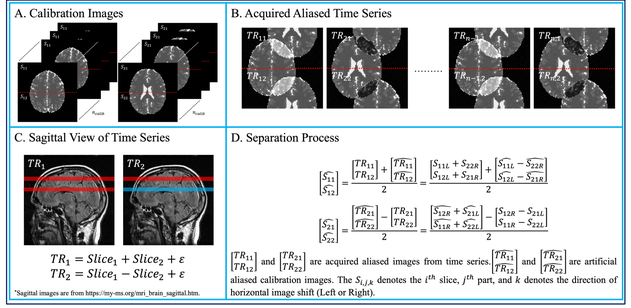
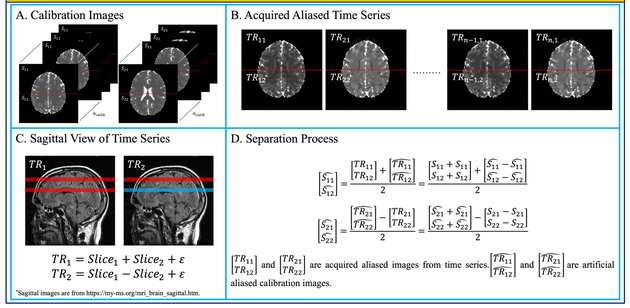


mSPECS



Separation Model

- In the mSPECS-CAIPI model, the bootstrap sampling method and artificial aliasing of calibration images technique will be incorporated with the separation equations.
- The separation process:

$$y = \begin{bmatrix} a \\ v \end{bmatrix} = \begin{bmatrix} X_A \beta \\ C_A \mu \end{bmatrix} + \begin{bmatrix} \varepsilon \\ C\eta \end{bmatrix}$$

$$(X_A)_{\gamma,\delta} = \left[H_{\delta,1} R_{\gamma,1} \begin{pmatrix} S_{1,1} \\ \vdots \\ S_{N_c,1} \end{pmatrix}, \ldots, H_{\delta,N_s} R_{\gamma,N_s} \begin{pmatrix} S_{1,N_s} \\ \vdots \\ S_{N_c,N_s} \end{pmatrix} \right]$$

$$(C_A)_{\gamma,\delta} = \left[\overline{H_{\delta,1} R_{\gamma,1}} \begin{pmatrix} S_{1,1} \\ \vdots \\ S_{N_c,1} \end{pmatrix}, \ldots, \overline{H_{\delta,N_s} R_{\gamma,N_s}} \begin{pmatrix} S_{1,N_s} \\ \vdots \\ S_{N_c,N_s} \end{pmatrix} \right]$$

- The estimated reconstructed images:

$$\hat{\beta} = (X_A' X_A + C_A' C_A)^{-1} (X_A' a + C_A' v)$$

Simulated Study

- The total fMRI time series is 640 TRs, first 40 TRs are used as calibration images
- 32 coils sensitivity maps with different phase for different slice
- 8 sagittal brain images with through-plane acceleration of 2, 4, and 8

Reference

(1) Breuer FA et al. *Controlled aliasing in parallel imaging results in higher acceleration (CAIPIRINHA) for multi-slice imaging*. Magn Reson Med 2005 Mar;53(3):684-91.

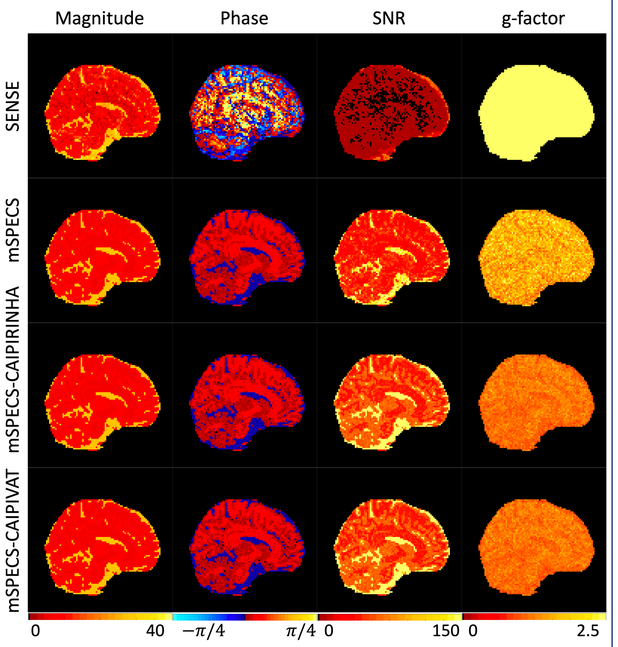
(2) Kim Min-Oh et al. *MultiSlice CAIPIRINHA Using View Angle Tilting Technique (CAIPIVAT)*. Tomography. 2016 Mar;2(1):43-48.

(3) Souza SP et al. *SIMA-simultaneous multislice acquisition of MR images by Hadamard-encoded excitation*. J Comput Assist Tomogr 1988;12;1026-1030.

(4) Rowe DB et al. *A complex way to compute fMRI activation*. Neuroimage. 2004 Nov;23(3):1078-92.

Simulated Results

Resting State Simulated Results



Activation Simulated Results