Separation of Two Simultaneously Encoded Slices with a Single Coil

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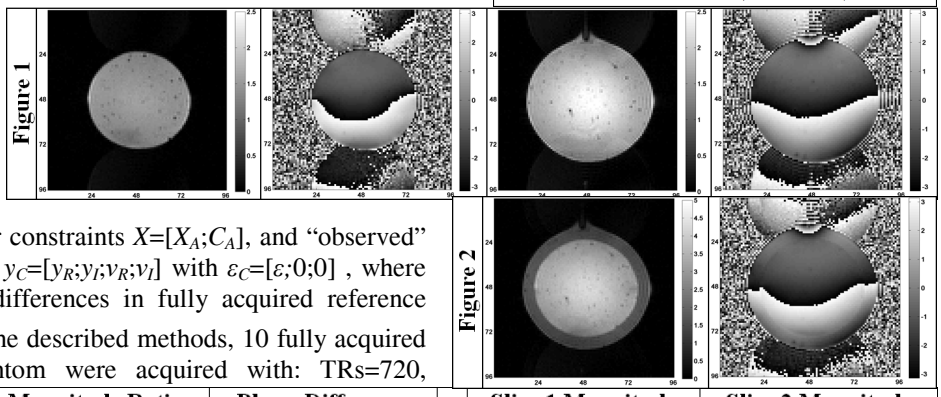
Purpose: In fMRI there have been many efforts to accelerate the acquisition of images of slices that make up a volume. Methods like SENSE[1] have greatly accelerated the acquisition of a single slice in-plane. Recent interest is in the simultaneous acquisition of aliased parallel slices. The separation of two slices from one aliased complex-valued image was recently presented.[2,3] Each aliased voxel is as in Eqn. 1, y_R and y_I are the real and imaginary parts, (ρ_1,θ_1) and (ρ_2,θ_2) are the magnitude and phase for the images of the two true fully acquired slices. Eqn. 1 can be written as $y=X_A\beta+\varepsilon$ and the goal is to estimate β, thus separating the images.

$$\begin{pmatrix} y_R \\ y_I \end{pmatrix} = \begin{pmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{pmatrix} \begin{pmatrix} \rho_1 \cos\theta_1 \\ \rho_1 \sin\theta_1 \\ \rho_2 \cos\theta_2 \\ \rho_2 \sin\theta_2 \end{pmatrix} + \begin{pmatrix} \varepsilon_R \\ \varepsilon_I \end{pmatrix}$$

Equation 1

Methods: As seen in Eqn. 1 we have 2 equations with 4 unknowns, thus the aliasing matrix X_A is not square or invertible (equivalent to least squares). The previous approaches[2,3] remove the even rows of β and the even columns of X_A, reducing the number of unknowns and reconstructing magnitude-only images.[2,3] Since the aliased images as seen in Fig. 2 are the sum of the two true images plus noise, two rows of linear constraints $X=[X_A;C_A]$, and "observed" data is added where $C=[1,0,-1,0;0,1,0,-1]$ and $y_C=[y_R;y_I;v_R;v_I]$ with $\varepsilon_C=[\varepsilon;0;0]$, where $v_R = \overline{y}_{Ra} - \overline{y}_{Rb}$ and $v_I = \overline{y}_{Ia} - \overline{y}_{Ib}$ are differences in fully acquired reference (average of calibration) images. To illustrate the described methods, 10 fully acquired reference slices of a spherical Agar phantom were acquired with: TRs=720, TE=42.5ms, TR=1s, FA=45°, BW=166kHz, FOV=24cm, SLTH=4mm, matrix size 96×96. Images of the 5 aliased slices (1&6, 2&7,...) were acquired with the same settings. The first aliased and the first and sixth fully acquired slices were selected for analysis. The first 5 TRs of the calibration and aliased images were discarded; the next two calibration images were averaged to form reference images as in Fig 1. The magnitude and phase of the first aliased image is in Fig 2. The ratio of the magnitudes and difference in phase of the reference image is in Fig 3.



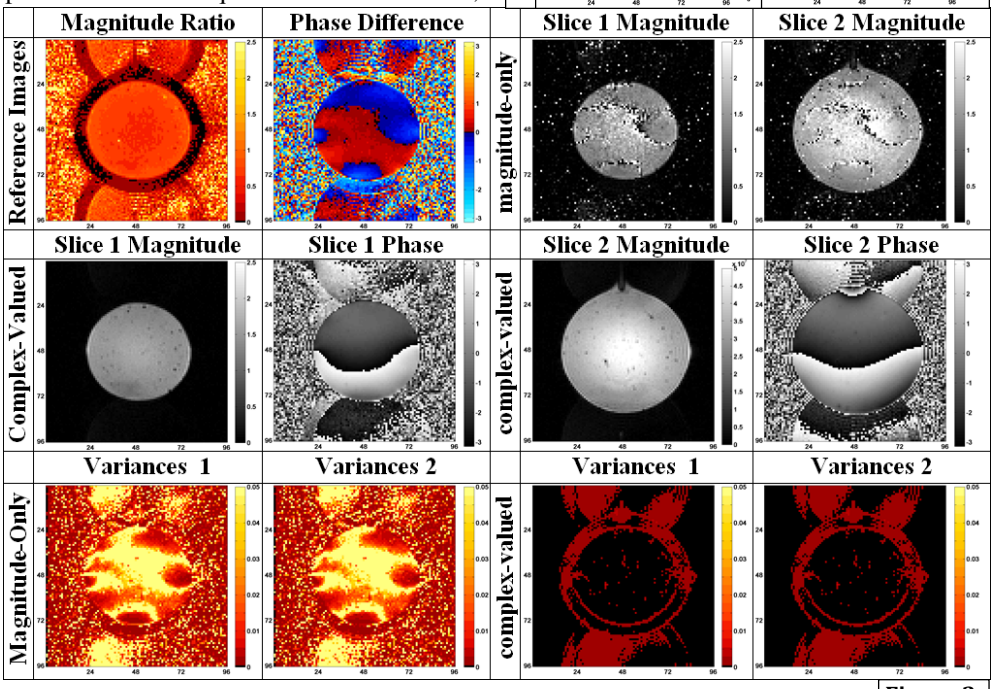


Figure 3

Results: The separated magnitudes from the magnitude-only method have challenges separating the slices when the difference in reference image phase is close to zero. The complex-valued method performs extremely well in separating the images. The means of the separated images (not shown) are similar to the single separated image, with slightly less noise. The variance of the magnitude-only separated images is very high in comparison to the complex-valued method.

Conclusions: Two aliased images can successfully be separated into two complex-valued (magnitude and phase) images. Complex-valued images are important for use in complex-valued fMRI activation methods. The reconstruction of simultaneously acquired slices not only speeds up the acquisition of an entire volume but also alleviates the necessity for slice timing correction in fMRI and fcMRI, thus generating temporally aligned activation and connectivity maps. It should be possible to alias and separate more than two slices.

References: **1.** Pruessmann. MRM 42:952,1999. **2.** Jesmanowicz. BrainConnectivity 1:81,2011. **3.** Islam. ProcISMRM 20:2285, 2012.

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