Auto-Calibrated Multiband Imaging with Phase Tagging and Hadamard Encoding

Andrew S. Nencka[1] and Andrzej Jesmanowicz[1]

[1]Department of Biophysics, Medical College of Wisconsin, Milwaukee WI

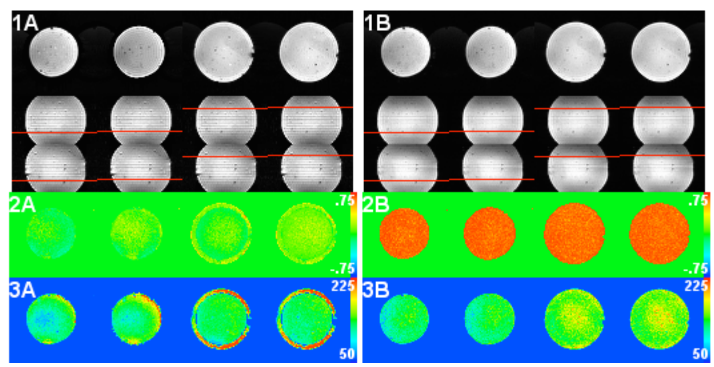
Target audience: This work is applicable to researchers and clinicians acquiring time series of fast images, who can benefit from accelerated volume coverage without the need for separate calibration scans.

Purpose: Advances in multi-band, parallel slice imaging have been offering tremendous opportunities in studies that include acquiring time series of fast images [1,2]. Most methods have relied upon calibration scan data for GRAPPA or SENSE unaliasing. This work was motivated to eliminate the need for separate calibration data. As an extension of the autocalibrating method, two complimentary unaliased data sets with differing noise characteristics can be generated from one acquisition.

Methods: Hadamard encoding [3] was paired with parallel slice imaging with phase tagging [1] in this experiment. Each acquired slice was tagged with a unique radio frequency phase upon excitation, which was modulated over the time series acquisition. Four slices were acquired simultaneously as two doublets of two adjacent slices for a time series of 200 repetitions. Hadamard unaliasing over a moving window of four repetitions was used to yield a time series of 197 images. The Hadamard unaliased images were averaged and used as reference images for the re-separation of all 200 aliased repetitions through the mathematics described in Jesmanowicz et al. [1], with reference image phases modulated in the reconstruction algorithm to account for the temporal modulation of excitation phase. Simulation and phantom studies were conducted and all software were written in the Python programming language. Metrics of temporal signal-to-noise ratio (tSNR) and time series autocorrelation were computed on each time series. *Acquisition:* Axial images of a functional Bioinformatics Research Network (fBIRN) style agar phantom were acquired on a GE MR 750 with a 32-channel MRII head coil. Thirty-six slices were acquired in nine shots, each exciting four slices. The packets of excited slices included two doublets of adjacent slices, with the doublets separated by 18 slices. The phases of the slices in each packet for each shot are shown in the below table. A time series of 200 repetitions of 64x64 matrix were acquired with isotropic 3.75 mm voxels, bandwidth 111.11 kHz, echo time 30.0 ms, and repetition time 2000.0 ms.

Repetition modulo 4 = 0				Repetition modulo 4 = 1				Repetition modulo 4 = 2				Repetition modulo 4 = 3			
0	90	180	270	0	270	0	270	0	90	0	90	0	270	180	90

Results: Images of the unaliased slices from the phantom experiment, with their locations indicated in the perpendicular planes with red lines are shown in Figure 1. Images of autocorrelation with a shift of one repetition for the phantom experiment are shown in Figure 2. Images of tSNR for the phantom experiment are shown in Figure 3. A simulation study was performed with parameters matching the phantom acquisition, but is not shown as it yielded similar results.



Images with unaliasing from SENSE with phase tagging (A) and Hadamard methods (B). ***Figure 1:*** *Unaliased axial slices with the slice locations shown as red lines in the coronal and sagittal planes.* ***Figure 2:*** *Maps of temporal autocorrelation for each slice in the unaliased time series with a shift of one repetition.* ***Figure 3:*** *Maps of temporal signal-to-noise ratio for each slice.*

Discussion and Conclusion: The geometry of displaced doublets is separable thanks to the degree of freedom offered by the unique phase tag given to each slice. Similar shims in neighboring slices allow maximal orthogonality between the magnetizations in the slices, while varying coil sensitivities between the doublets minimizes challenges from magnetization co-linearity. Two distinct time series can be reconstructed from multiband data acquired as described. Data reconstructed with Hadamard methods yield improved signal-to-noise ratio in regions of aliasing, at the cost of increased temporal autocorrelation. Such unaliasing, dependent upon only complex-valued additions and subtractions, could be done for fast real-time analysis, and the enhanced signal-to-noise ratio is beneficial to signal starved acquisitions including long echo time imaging and diffusion imaging. Time series reconstructed with the mathematics described in reference [1] with Hadamard generated reference images yield unaliased images without separately acquired calibration images and with no temporal interpolation. Without interpolation, this second method yields reduced autocorrelation and tSNR. The more computationally intensive unaliasing could be performed offline when autocorrelation is a concern, as it is in functional neuroimaging studies.

References: **[1]** Jesmanowicz et al. Brain Connectivity 1: 81-90 (2011). [2] Feinberg et al. PLoS One 5(12): e15710 (2010). [3] Souza et al. J Comput. Assist. Tomagr. 12: 1026-1030 (1988).

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