Prephased O-space Imaging for Reduction of Asymmetrical Local K-space Coverage

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Target Audience: The parallel imaging and nonlinear gradient encoding communities.

Introduction: It has previously been demonstrated that nonlinear encoding gradient fields lead to spatially-varying resolution represented by a "local" k-space.[1] We present an O-space imaging sequence to decrease local k-space asymmetry at the periphery of the image through additional linear "prephasing" moment to set up the nonlinear gradient readout, an idea first introduced by Gallichan et. al. [1] The nonlinear Z^2 spherical harmonic enables highly accelerated parallel imaging with improved peripheral resolution.[2]

Purpose: The original O-space imaging utilizes the Z^2 ($= z^2-1/2(x^2+y^2)$) non-linear gradient for spatial encoding tailored to complement the parallel receiver array spatial information and maximize data efficiency for high acceleration factors.[1] However, the sequence was theorized via local k-space analysis to be unable to accurately image a regular grid without modification via prephasing.[3] Experiments on a grid phantom confirm that the spatial localization of an 8 channel circumferential receiver array mitigates effects predicted by local k-space, which does not account for coil localization. Prephasing may be applied to reduce local k-space asymmetry, lowering MSE.

Methods: The pulse sequence (fig. 1) a gradient echo O-space projection imaging sequence (no phase encoding) with varying X, Y, and Z^2 gradient amplitudes. Prephasing occurs by changing the linear moment thus changing the phase prior to readout. Prephasing was performed by perturbing the preread amplitude by a tenth of the maximum moment and modulated sinusoidally at twice the frequency of the normal preread strength. Experiments were performed using a Z^2 gradient insert from Resonance Research, Inc. (Billerica, MA, USA) placed in a 3T Siemens MAGNETOM Trio TIM system with a birdcage transmit coil and nested 8-channel receiver head coil. Radial encoding (linear gradients only) was used as a comparison at R=4. The acquisition may be represented algebraically as a system of linear equations, y = Ax, where A is known as the encoding matrix. The Kaczmarz iterative algebraic projection reconstruction technique (ART) was used.[4] Converging to the minimum L2 norm solution[4], the ART method iterates through data provided by each coil. ART has the benefits of parallelizability and low memory requirements compared to computing a pseudo-inverse through conjugate gradients or the Moore-Penrose pseudo-inverse. Local k-space is calculated through the relationship $\mathbf{k}(t) = \nabla\varphi(\mathbf{x},t)$, which is the spatial derivative of the encoded phase.

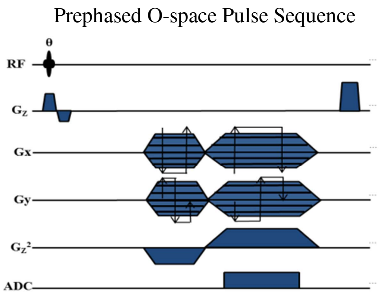

Fig. 1. The unmodified O-space imaging sequence, which has a third encoding magnetic field. Adjusting the linear prephase moment is expected to change the spatially-dependent encoding as seen in local k-space plots.

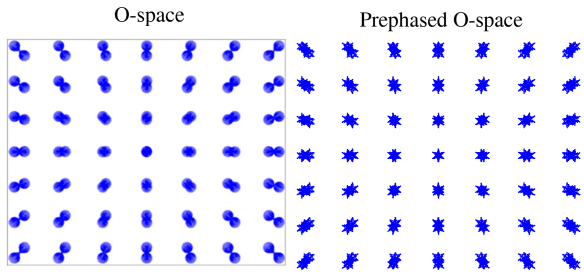

Fig. 2. Local k-space for a 7x7 grid of representative points in the image. The local k-space (spatial derivative of the encoded phase) suggests the reconstruction at a given point will behave according to the k-space displayed at the point. Prephasing the O-space sequence reduces the local k-space asymmetry.

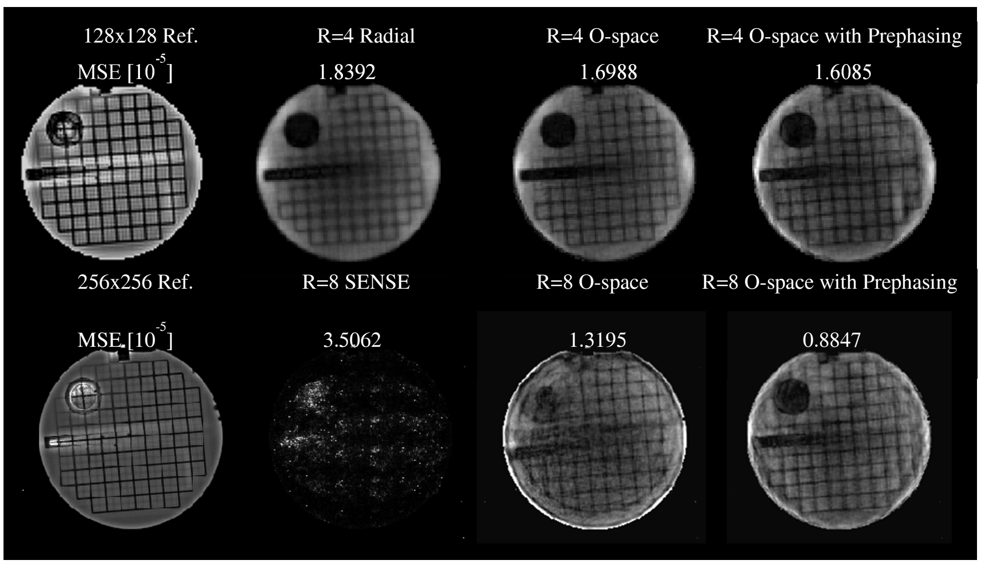

Fig. 3. Comparison of accelerated parallel imaging with an eight channel receiver array. Methods were compared for 32 readouts (R=4 for a 128x128 grid) and 256 samples per readout for the top row and 32 readouts and 512 samples (R=8 for a 256x256 grid) for the bottom row. A reference gradient echo scan is shown on the left. Mean squared error (units of 10^{-5}) compared to the gradient echo scan is listed above the image. O-space with prephasing shows the lowest MSE, though strong asymmetric resolution is *not* observed in traditional O-space.

Results: The prephased O-space sequence (fig. 3) yields lower MSE for R=4 at 128x128 matrix size and R=8 at 256x256 matrix size compared with SENSE or radial respectively. Qualitatively, the gridlines of the phantom appear sharper and have greater contrast. SENSE at R=8 has significant noise amplification due to the acceleration factor is at the number of receivers. Strongly distorted and/or undulating grid lines predicted in the simulation from fig. 5 in (3) were *not* observed at the accelerations or matrix sizes shown here.

Discussion: Prephasing was found to be an effective method to improve O-space imaging, though simulated artifacts from (3) failed to replicate in experiment. The simulations from fig. 5 (3) use a 64 x 64 sample size for a 128 x 128 grid to create artifacts not present in the O-space paradigm, which prescribes a 64 x 256 sampling (as samples in the readout come at no time penalty).[2] Prephased O-space imaging displays 12.5% lower MSE than linear encoding (radial). Further studies may evaluate how prephasing affects algebraic inversion of the encoding matrix with consideration of the receiver profiles that add spatially-weighted parallel data.[5]

References: [1]Gallichan, D., et al. MRM 2010. 65: p. 702-714. [2]Stockmann, J. et. al. MRM 2010. 64: p. 447-456. [3]Gallichan, D., et al. MR Mater Phys 2012. 25: p. 419-431. [4]Herman G.T. et. al. J. Theor. Biol. 42:1. [5]Tam LK, et. al., MRM 2012, 68(4):1166-75.

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