An Assessment of O-Space Imaging Robustness to Local Field Inhomogeneities

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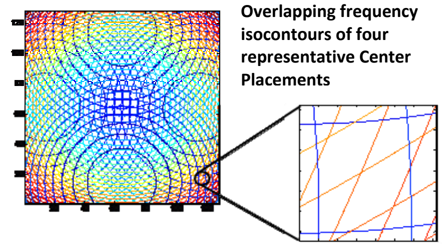
INTRODUCTION: O-Space imaging has recently been proposed as a way to perform highly-accelerated parallel imaging using non-linear gradients that are complementary to the information provided by surface coil profiles [1]. In combination with X and Y gradients, the Z2 spherical harmonic is used to project the object onto sets of concentric rings at different center placements (CPs) in the FOV. Because of the way that frequency isocontours from different CPs overlap to provide signal localization, the method is potentially sensitive to errors in effective field strength. This abstract investigates whether O-Space imaging could plausibly be performed in areas like the head where sinus and ear cavities introduce substantial local inhomogeneities. To date, no combination of active and passive shims has succeeded in entirely eliminating inhomogeneity in these regions [2]. Geometric distortion due to inhomogeneity has been observed in echo planar imaging with linear gradients. Methods to correct for the resulting voxel-wise displacement along the phase encode direction have met with some success [3]. But the complex, spatially-varying point spread functions that occur in O-Space imaging invite inquiry into the susceptibility of this method - and non-linear projection imaging more broadly - to local field offsets.

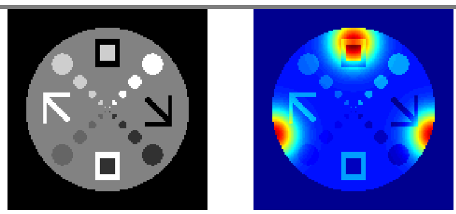
O-space image reconstruction is performed by directly solving the signal equation $s = A\rho$ using the Kaczmarz iterative projection algorithm [4].



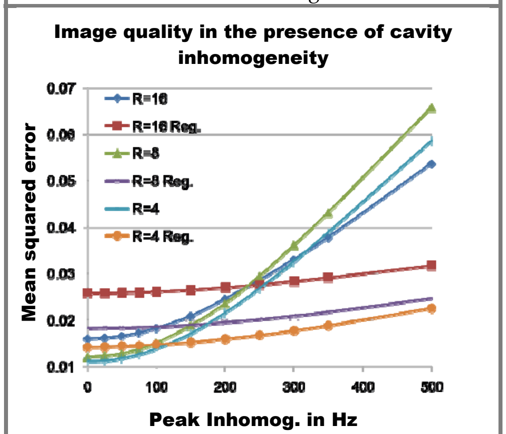
Overlapping frequency isocontours of four representative Center Placements

$$s_{m,l}(t) = \iint \rho(x,y) C_l(x,y) e^{-j2\pi\left[G_{Z2}\frac{1}{2}\left((x-x_m)^2+(y-y_m)^2\right)+\Delta B_0(x,y)\right]t} dxdy = A_{m,l,t}\rho$$

Field errors cause the matrix equation to become inconsistent. When inconsistency arises from random errors in s due to noise, regularization is an effective way to constrain noise propagation. For systematic errors in A such as those caused by field errors, regularization has less utility, but can still be used to find a constrained estimate of ρ when no unique solution to the equations exists. In this work, we use a modified Kaczmarz implementation to perform Tikhonov regularization minimizing the following objective function [5]:

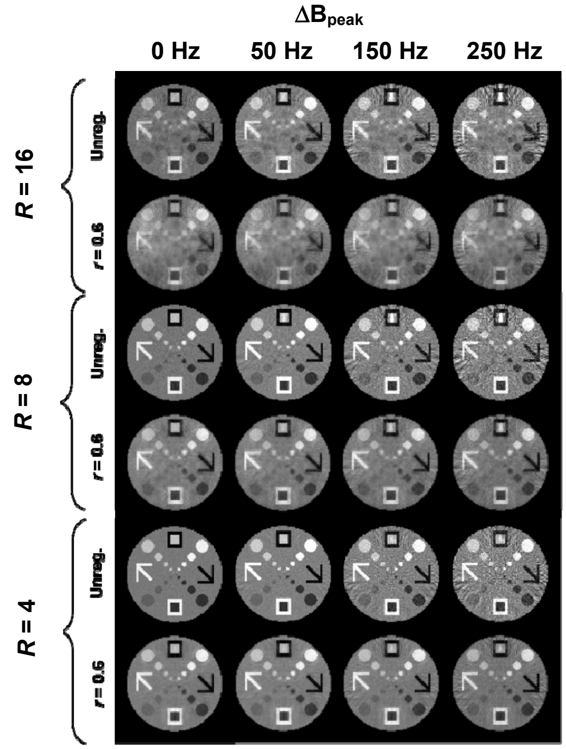


128×128 Phantom | Phantom with cavity inhomogeneities overlaid



$$\Delta B_0(\bar{r}) \approx \Delta B_{peak} \exp\left(-\frac{\bar{r}-\bar{r}_0}{FOV/20}\right)^2$$

METHODS: A 128×128 numerical phantom is used to highlight potential feature distortion and noise amplification caused by field errors. The field inhomogeneity ΔB_0 of the sinus and ear cavities is modeled as a gaussian shape rolling off radially from the point of peak field offset. The peak offset ΔB_{peak} is varied between 0 and 500 Hz and the mean squared error is computed to assess artifact levels and distortion in each reconstructed image. Acceleration factors of R={4, 8, 16} are simulated with and without regularization for an array of 8 surface coils (R factors correspond to 32, 16, and 8 echoes, respectively). A noise floor with standard dev. equal to 5% of the mean phantom intensity is added. Readout BW is 150 KHz.



DISCUSSION: Artifacts manifest themselves as noise-like graininess, with some ripple artifacts in the region of the greatest field deviation. But geometric distortion is not observed and the shapes of object features are largely preserved. Unregularized images show noticeable artifact levels for ΔB_{peak} > 100 Hz. Although the MSE grows with ΔB_{peak} for all R factors, visual inspection reveals that artifacts grow somewhat more severe with increasing R. Regularized reconstructions, by contrast, degrade gracefully with ΔB_{peak} for all acceleration factors, showing only modest MSE and artifact increases up to ΔB_{peak}=300 Hz. As expected, regularization does come at the cost of some image resolution. But this work shows that O-Space imaging is feasible for practical levels of cavity inhomogeneity in the human brain. We hypothesize that this resilience to geometric distortion arises due to the spatially-varying nature of the O-Space point spread function, a property that it shares with conventional non-Cartesian trajectories such as spiral. Future work will investigate the sensitivity of O-Space imaging to field errors introduced by gradient strength calibration errors, gradient pulse timing errors, and eddy currents.

REFERENCES: [1] Stockmann JP, Constable RT. Proc. ISMRM 2009, p. 2857. [2] Koch K. Ph.D. Thesis, Yale Univ., 2006. [3] Jezzard P, Balaban RS. MRM 1995;34:65-73. [4] Herman GT *et al*. Comput. Biol. Med. 1976;6:273-294. [5] Censor Y. SIAM Review. 1981;23(4):444-466.