Turbo Spin Echo O-Space: Avoiding artifacts and enhancing contrast

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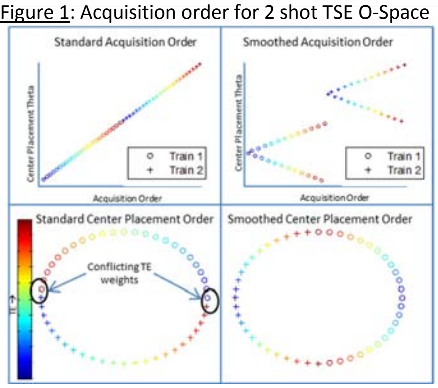
Target Audience: Image reconstruction, parallel imaging, and especially nonlinear gradient communities

Purpose: Nonlinear gradient encoding, such as that of O-Space imaging, has been shown to provide good images with highly undersampled datasets[1,2]. Acquiring echoes in a turbo spin echo train is a very flexible way to further speed acquisition time[3]. However, combining these strategies presents significant challenges, both in terms of artifacts and also as a loss of defined contrast mechanisms. We present strategies in both pulse sequence design and image processing to mitigate these effects.

Methods: Data was simulated for a 48 echo 8-channel O-Space acquisition acquired in a two shot TSE pulse sequence (echo train length =24) and used to reconstruct a 128^2 matrix. We investigated the effect of artifacts by performing simulations on brain and geometric phantoms. For these images, a global T2 decay was simulated both within the echo (.005*T2) and between echoes (0.05*T2, 0.07*T2 and 0.1*T2, so the last of these would correspond to a 7.5ms echo spacing for spins with a T2 of 75ms). Contrast sensitivity was interrogated by performing reconstructions of a 4 compartment phantom with differing T2 that corresponded to 0.6, 0.9, 1.1 and 1.4 times the base T2. All calculations were performed in Matlab, and reconstruction was done with a Kaczmarz algorithm.

Figure 1: Acquisition order for 2 shot TSE O-Space



We describe and evaluate four strategies, both in the pulse sequence and reconstruction, to reduce artifacts and improve contrast in an O-space TSE acquisition. They are:

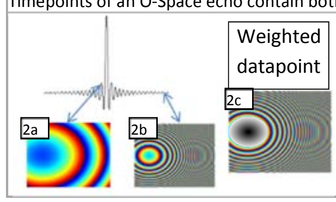
1) Ordering center placement acquisition to maximize the distance between different T2 weightings (Figure 1)

2) Spatially varying weights on the reconstruction update of each encoding time point, so time points at the edge of the echo are windowed to their high frequency information. (Figure 2) This is implemented by using a spatially varying lambda in the update step of each row of the encoding matrix. Thus, whereas recon would normally proceed by adding a shape like that of 2b, we can instead add a windowed shape, like that of 2c.

3) In addition, the weightings can also vary with echo number, so low spatial frequencies contribute only at a particular echo time.

4) Progressively offsetting the z2 and linear echoes in time so that datapoints corresponding to minimal modulation occur at a defined echo time

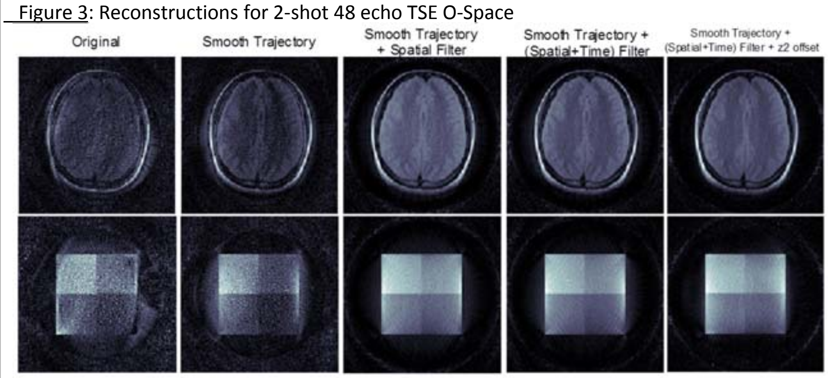
Figure 2: Windings associated with an O-Space echo Timepoints of an O-Space echo contain both high and low frequency data. Weighting can be applied to each update, so the estimate is only updated to reflect the high frequency part of the encoding function.



Results: Preliminary results from these strategies, as they manifest in the brain and a contrast phantom for a TE step of .07*T2, are shown in Figure 3. Detailed metrics on the performance of each strategy reveal synergies between these methods.

Discussion: Like radial trajectories, each echo of the O-Space trajectory goes through the center of k-space, so TSE acquisitions present two problems. Data with very different T2 weightings crowd together in the nonlinear analog to k-space (stamp-space [4]), which can create artifacts. In addition, low frequency information is collected at a range of echo times, which can interfere with relaxation based contrast. O-Space imaging is further complicated by the fact that each time point is a mix of both high and low frequency information; even the at the edge of an O-Space echo, the spins near the center placement are not very modulated. The strategies presented here improve both the artifacts and the relaxation based contrast observed in TSE O-Space acquisitions.

Figure 3: Reconstructions for 2-shot 48 echo TSE O-Space



References: [1] Stockmann, MRM 2010; [2] Tam, MRM 2012; [3] Constable, MRI 1992. [4] Galiana, Concepts in MR 2012.