Rapid 3D Non-Cartesian SENSE Reconstruction

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Introduction Both non-Cartesian trajectories and SENSE hold tremendous promise in 3D magnetic resonance imaging. However, the time-consuming reconstruction which is necessary when these methods are combined often prohibits their joint use. We outline a method for such 3D reconstructions which gives an order-of-magnitude speed improvement while maintaining high accuracy.

Theory The complexity of the reconstruction processes necessitates that an iterative approach be used in 3D non-Cartesian SENSE [1]. Speeding up an iteration boils down to speeding up the gridding and FFT calculations required for each iteration. We have found that, in 3D, the time required for both gridding and FFT is limited, not by the ability of the processor to accomplish the computation, but *by the time it takes to get the appropriate data from memory to the processors for the computation*. Typically, 3D data is stored in the line-by-line format shown in Fig. 1a. In this format, data is very spread out in memory when traversing the data perpendicular to the lines. By storing the data in a block format as shown in Fig. 1b, data likely to be accessed concurrently is put in the same page of memory. Figure 1c shows how the number of pages accessed during the gridding process is reduced by using the block format, speeding up the entire reconstruction.

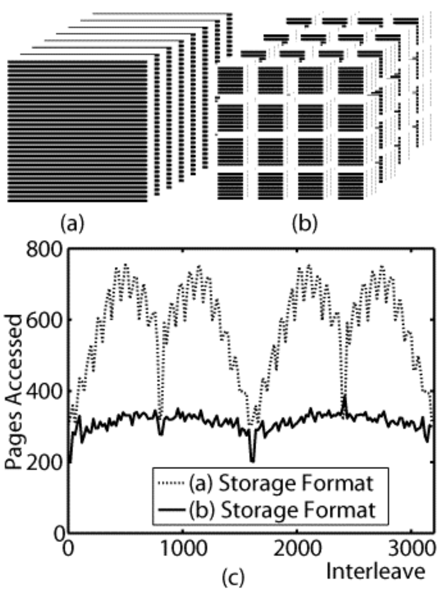

Figure 1 By storing and processing the image in contiguous 3D blocks (b), rather than the conventional line-by-line format (a), we can access the data more efficiently. (c) shows that for the Spiral-PR trajectory (Fig. 2), we need access far less pages while gridding the interleaves. This leads to over 2X acceleration in gridding speed.

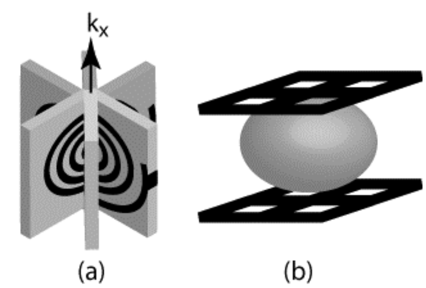

Figure 2 (a) The Spiral-PR 3D non-Cartesian trajectory used. (b) Coil configuration for the 8 coils.

Methods We used the spiral-PR trajectory in Fig. 2a (1mm isotropic resolution, 13 cm FOV) and computed simulated data for a 3D Shepp-Logan head phantom for 8 coils, configured as in Fig. 2b [2,3]. The phantom was reconstructed as a 256x256x256 image (1 mm resolution, 25.6 cm FOV) using the Conjugate Gradient iteration method. Our grid oversampling ratio was 1.25, with an optimal sampled kernel, width 4 [4]. Our block size was 8x8x8, corresponding to one 4K page of memory. Reconstruction was performed on an Apple Xserve with dual 2GHz G5 processors.

Results and Discussion The Conjugate Gradient SENSE method successfully removed the artifacts due to the reduced FOV trajectory, as shown in Fig. 3. We were able to achieve 40 s per iteration, which is a substantial improvement—in 2001, Pruessman *et al.* reported 68 s per iteration with 6 coils and a 256x256 2D image [1]. Last year, Arunachalam *et al.* reported a reconstruction time of 6 min. per iteration for a 256x256x256 image using the VIPR trajectory and 4 coils [5]. Considering that we are using 8 coils, we have achieved about an 18 times acceleration in the reconstruction time, over Arunachalam. On the down side, we have found that the larger image size appears to increase the required number of iterations; we needed 30 iterations to completely remove the artifacts, giving a total reconstruction time of 20 min. We are currently reviewing ways of reducing the number of iterations.

Conclusion With a 20 minute reconstruction time, we are still not able to give the immediate feedback possible with 2D imaging. However, in reducing such reconstructions from hours to minutes, we have diminished the reconstruction barrier for combining non-Cartesian trajectories and SENSE in 3D.

References
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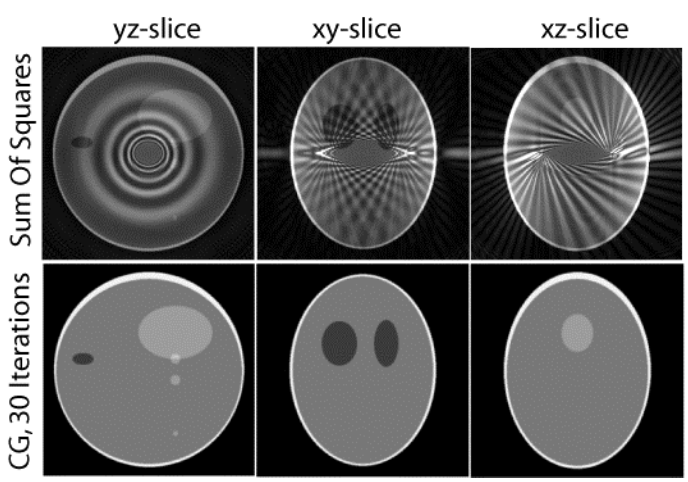

Figure 3 Images of the central slices of the 3D Shepp-Logan numerical phantom after sum-of-squares reconstruction (top row) and Conjugate Gradient (CG) SENSE reconstruction (bottom row) with 30 iterations. While the CG method removes the artifacts in 3D, the number of iterations required is greater than in the 2D case.