Accurate Reconstruction in PR-MRI despite Truncated Data

J. K. Barral[1], H. H. Wu[1], G. E. Gold[2], N. J. Pelc[2], J. M. Pauly[1], and D. G. Nishimura[1]

[1]Electrical Engineering, Stanford University, Stanford, CA, United States, [2]Radiology, Stanford University, Stanford, CA, United States

Introduction: In computed tomography (CT), artifacts due to truncated projections are a concern. A new algorithm that reconstructs a region of interest (ROI) from truncated data in an exact mathematical way has recently triggered a lot of interest [1]. The same truncation problem arises in 2D Projection Reconstruction Magnetic Resonance Imaging (PR-MRI), whenever the object is elongated in one direction and not fully encompassed in the FOV (coronal or sagittal plane). In this work we introduce the Derivative Back Projection-Finite Hilbert Inverse (DBP-FHI) algorithm to accurately reconstruct from truncated MRI data, and we compare it to the conventional Filtered Back-Projection (FBP) algorithm.

Methods: The 1D radial inverse Fourier transform of PR-MRI k-space data gives projection data (sinogram) analogous to a CT parallel-beam geometry acquisition. The FOV is determined by the sampling rate and bandwidth of the anti-aliasing filter. When images from truncated projection data are reconstructed by FBP, the rho filtering operation spreads out the inconsistency of the projection data over the entire FOV, resulting in image shading. A way to avoid the rho filter $|\rho|$ is to replace it by $-i*\text{sign}(\rho)*(i\,\rho)$. In Fourier space, $(i\,\rho)$ corresponds to a derivative and $\text{sign}(\rho)$ to an inverse Hilbert transform [2] - hence the two steps of the DBP-FHI algorithm as shown in Figure 1. The derivative is a local operation that does not spread the error as the rho filter does.

The inverse Hilbert transform can not be performed directly, since we only know the Hilbert image after derivative back projection (DBP) on a finite segment (given by the FOV). However, if the object has a limited extent within this segment, a Finite Hilbert Inverse (FHI) can be used [3]. Therefore, the DBP-FHI algorithm holds only for oblong objects where one direction is free from truncations. The direction in which the 1D Hilbert transform is performed is determined by the boundaries of the backprojection.

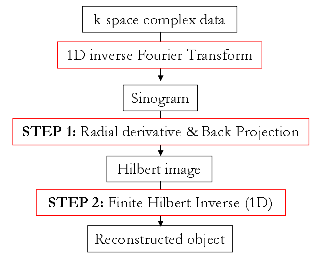
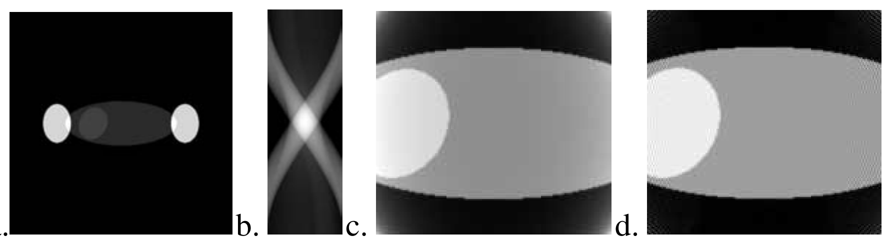


Figure 1: *DBP-FHI algorithm*

Results: We compared our DBP-FHI results to FBP. In most cases FBP behaves as gridding and 2D Discrete Fourier Transform (DFT) [4]. Simulations were performed using a "Popeye" phantom (Fig. 2a). The anti-aliasing filter was considered ideal (rect), and we truncated the sinogram on both sides before reconstruction (Fig. 2b). DBP-FHI (Fig. 2d) provides significant improvement over FBP (Fig. 2c). All the shading artifacts disappear, and no new artifacts are introduced.



a. b. c. d.

Figure 2. *Truncated sinogram (b), FBP (c) and DBP-FHI (d) reconstruction of the "Popeye" phantom (a). Since FBP needs to redistribute data from an inconsistent sinogram, it overestimates the object, especially at the edges, hence the shading artifacts seen in c.*

Truncation artifacts can create a false laminar appearance in cartilage [5]. Figure 3 shows a 2D PR coronal view of the knee. Note that the angular undersampling creates some streaking artifacts in the lower part of the image (with both reconstructions). The noise level appears slightly higher in the DBP-FHI image, but the difference image shows that some subtle truncation artifacts have been removed. Phase cancellation of the inconsistent data might explain this surprisingly low truncation artifact level. We believe that non-negligible artifacts will appear in contrast-enhanced imaging, when the bolus is outside or at the edge of the FOV, and that the DBP-FHI algorithm will then be more effective.

Figure 3. *FBP (left), DBP-FHI (middle), and difference image (right). PR 256*256. Coronal view, 16 cm FOV, 62.5 kHz BW. The difference image presents some structure indicating that truncation artifacts were present in the FBP image.*

Discussion: The robustness to noise of this algorithm is limited by the inverse Hilbert transform. Another concern is the phase shifts introduced by gradient delays in PR trajectories, since unlike CT data, MRI data are complex [6]. The FHI step is already sensitive in CT and several methods have been recently proposed to alleviate the constraint of a priori knowledge (object fully included in the FOV for one direction) [7]. In MRI, the image obtained by DBP might not be the Hilbert transform of the object if phase errors are too significant. To circumvent this problem, the magnitude value of the projection data can be used. Alternatively, knowing that the DBP should give a Hilbert image could be used to phase-correct the original data.

Conclusion: The Derivative Back Projection-Finite Hilbert Inverse algorithm provides an accurate reconstruction for Projection Reconstruction truncated data within a region of interest, provided that a given orientation is free from truncation. DBP-FHI reconstruction will be particularly useful in ultra-short TE (UTE) imaging - which uses PR to acquire data right after excitation - where it will allow smaller FOVs and shorter scan times.

References :

1. Noo, F *et al.* PMB 49 (17) 3903-3923, 2004.
2. Kak A, and Slaney M. Principles of Computerized Tomographic Imaging, p 68, 1988.
3. Mikhlin, SG. Integral Equations and Their Applications, p 126-131, 1957.
4. Joseph, PM. MRM 40 (3) 460-466, 1998
5. Frank, LR, *et al.* AJR 168 547-554, 1997
6. Peters D, *et al.* MRM 50 (1) 1-6, 2003
7. You J, *et al.* Inverse Problems 22 7-10, 2006