Reducing artifacts from varying projection truncations

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Summary: We study samples with full and partial occlusion causing streak artifacts, and propose two modifications of filtered backprojection for artifact removal. Data is obtained by the SPring-8 synchrotron using a monochromatic parallel-beam scan [1]. Thresholding in the sinogram segments the metal, resulting in edges on which we apply 1) a smooth transition, or 2) a Dirichlet boundary condition.

1. INTRODUCTION

Metal artifacts in computed tomography are primarily caused by a large absorption of the X-ray beam. Secondary causes are beam hardening, scattering, Poisson noise, partial volume effects, and undersampling. The artifacts appear typically as bright and dark streaks emerging from the metal object in the reconstruction [2]. Common methods for artifact removal are data completion methods [3] and iterative reconstruction methods [4]. We study data of 1-3 mm³ porous rocks obtained using the SPring-8 synchrotron with a monochromatic parallel-beam scan configuration. Our study is part of an analysis of fluid flow through the pores, and data acquisition requires special hardware containing four metal bars positioned approx. 16 mm away from the sample. At some projection angles the beam is occluced fully or partially, yielding blank or partial projections, see Figure 1(a). An example of a truncated projection is shown in Figure 1(b). The resulting artifacts cause segmentation problems, and here, we propose two solutions which are effective, fast, and simple to implement.

2. METHOD

The synchrotron data represent photon counts, and some counts are zero because the X-rays are blocked by the metal bars. Thus, we must segment the data before applying the log-transform in order to obtain attenuation values by Lambert-Beer's law. A segmented sinogram is shown in Figure 1(c) in which the horizontal axis is projection angles over 0 to 180 degrees and the vertical axis is detector position. As seen in the zoom, the discretization leads to staircasing. Reconstruction by filtered backprojection (FBP) gives streak artifacts, as seen in Figure 1(e) (the streaks stand out more clearly in the difference image in Figure 1(g)). They are caused by the sharp transition in the detector direction introduced by the segmentation. We consider this as a boundary value problem and suggest two different ways to handle this: **Dampened filtered backprojection** (DaFBP): A function which attenuates the pixel values nearest to the truncated projection edges and assures a smooth transition across the edges, seen in Figure 1(d). This was inspired by the work by Frikel and Quinto [5]. They used microlocal analysis to characterize limited-angle artifacts and proposed a local, smooth cut-off across discontinuities in the angular direction for reducing the artifacts. Here, we introduce a smooth cut-off in the detector direction prior to reconstructing. Dirichlet filtered backprojection (DiFBP): The high-pass ramp filter in FBP emphasizes the truncated projection boundaries by introducing large negative and postive values to the sinogram. This results in pairs of dark and bright streaks across the reconstructed image. To counteract this, a Dirichlet boundary condition was imposed to the truncated projections by padding (a Neumann boundary condition has a similar effect). This is a standard method to handle region-of-interest effects, and our problem may be viewed as a variant of the region-of-interest problem in which the size of the region of interest varies across the projections. After filtering, the padding was removed before backprojecting.

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3. RESULTS

Figure 1(e) shows the reconstruction based on the sinogram in (c), that is, before handling the vertical detectordirected edges. Streaks with angles of about 45 degrees and 135 degrees are present and are caused by the detector-directed intensity edges in the sinogram found in the truncated projections at these angles. The reconstruction in Figure 1(f) is the result of applying DiFBP. Figure 1(g) is the difference of the reconstructions in Figure 1(e) and (f). The result of DaFBP is very similar, and is not shown here. The difference between DaFBP and DiFBP is shown in Figure 1(h). Since DaFBP decreases pixel values near the edges in a smooth way, and DiFBP only works on the boundary, this results in the smooth appearance of the image. We observe that the range of Figure 1(h) is approximately 40% of the range of Figure 1(g). We have studied quantitative measures of artifact reduction by simulation. Both methods remove artifacts sufficiently for subsequent segmentation without use of inpainting or iterative methods.



Figure 1: (a) Acquisition set-up, leading to a truncated projections as in (b). This results in the data (c) after segmentation. Smoothing across edges leads to the sinogram in (d). Reconstruction after segmentation of the metal but before handling the edges is shown in (e). In (f), DiFBP is applied and (g) shows the difference between reconstructions in (e) and (f). (h) shows the difference between DaFBP and DiFBP.

References

- Y. Yang, S.S. Hakim, S. Bruns, K. N. Dalby, K. Uesugi, S. L. S. Stipp, H. O. Srensen. Wormholes grow along paths with minimal cumulative surface. In preparation. 2016.
- [2] T. H. Buzug. Computed Tomography From photon statistics to modern cone-beam CT. Springer, Berlin, Germany, 2008.
- [3] W. J. H. Veldkamp et al. Development and validation of segmentation and interpolation techniques in sinograms for metal artifacts suppression in CT. *Med. Phys.* 37(2), 620–628, 2010
- F. E. Boas & D. Fleischmann. Evaluation of two iterative techniques for reducing metal artifacts in computed tomography, *Radiology*, vol. 259(3), 894–902, 2011.
- [5] J. Frikel, E. T. Quinto. Characterization and reduction of artifacts in limited angle tomography, *Inverse Problems*, 29(12), 125007, 2013.