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Sparse X-Ray Phase Contrast Computed Tomography (XPCT) Using Iterative Reconstruction

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Summary: X-ray interferometers enable non-destructive testing with biomedical and materials science applications. In addition to absorption, they measure phase shifts caused by refraction to reveal the internal structure of objects such as tissues. X-ray phase contrast computed tomography (XPCT) provides 3D volumetric detail of samples. However, computed tomography requires many angles to be measured, which is a time-consuming process. To reduce the number of views, we will compare iterative reconstruction algorithms that add constraints on the smoothness of images and speed acquisition time.

There are three types of image products in X-ray phase contrast imaging (XPCI): absorption (or tau), differential phase (or refraction), and dark field (or microstructure scattering). The absorption image shares the same downside as conventional X-ray imaging: it suffers from low contrast in soft tissues. The differential phase image shows improved contrast in soft tissue because it measures the phase shift induced by an object. The dark field arises from small angle scattering of the sample. One approach for XPCI is to use gratings in a Talbot-Lau interferometer to produce a Talbot self-imaging effect.

In a Talbot-Lau system, a laboratory X-ray source passes through three gratings (G0, G1, G2, in order) onto a focal plane detector. Grating G0 provides spatial coherence. The sample is placed between G0 and G1. G1 is a diffraction grating that creates a periodic pattern on the X-ray beam. G2 samples the periodic interference pattern from G1, by stepping a translation stage through various positions. The three image products are encoded in the interference pattern, and they are extracted by processing the measurements taken from translations of G2.

The sample consists of a cup of polypropylene balls and rotates through 451 uniformly spaced angles between 0 and 360 degrees. For each angle, the three image products are computed based on translations of G2 across 40 steps of the period of the grating. We reconstruct the 3D volume using computed tomography for each image product. Different algorithms are tested, as described below.

We design our experiments to study the reconstructions when the number of angles or views is sparse. The ground truth uses the entire 451 views with the Feldkamp, Davis, and Kress (FDK) method. The absorption and dark field products are tested with 57 views, or one out of every eight measurements from the full set. The differential phase is tested with 226 views, or one out of every two measurements; empirically, this product seems to degrade quickest as the number of views is reduced.

The experiments compare several CT reconstruction methods, in addition to the standard FDK approach. The ordered subset simultaneous algebraic reconstruction technique (OS-SART) updates the image using subsets of projections. Alternating steepest descent by projection onto convex sets (ASD-POCS) constrains image smoothness with total variation [1]. Two other algorithms, ordered subset ASD-POCS (OS-ASD-POCS) and SART total variation (SART-TV), are families of total variation regularization [2].

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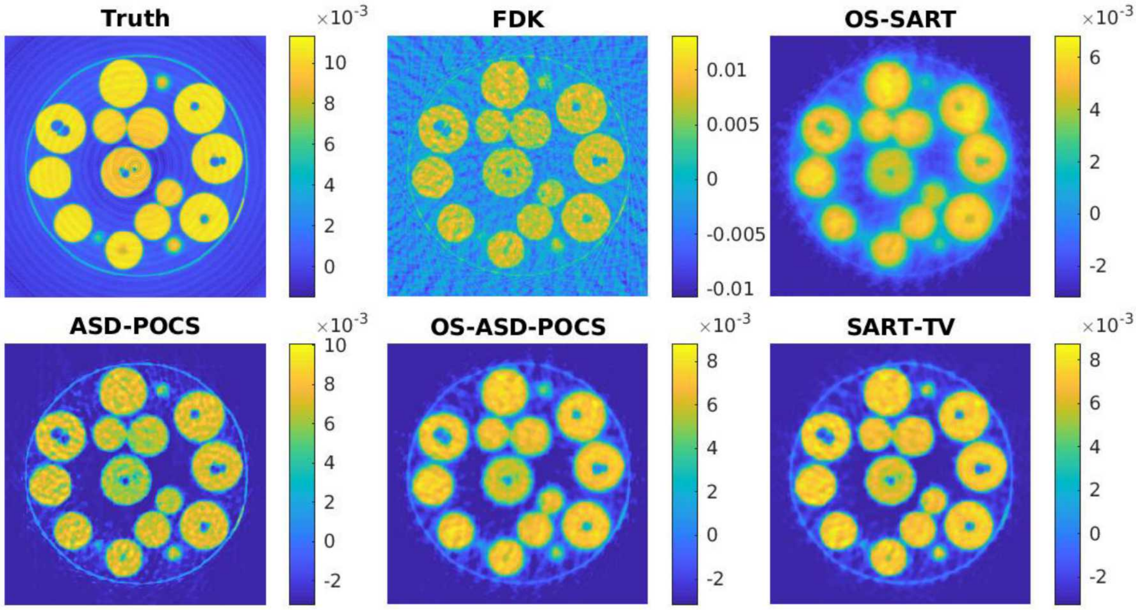

Figure 1: Absorption reconstruction with 57 views. Truth is based on FDK with 451 views. The sample is a cup of polypropylene balls, and the images are one slice of the 3D volume.

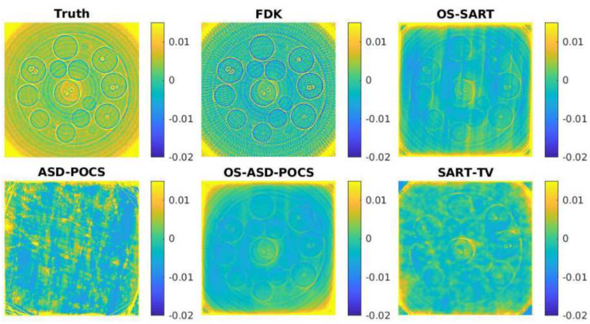

Figure 2. Differential phase reconstruction with 226 views. Truth is based on FDK with 451 views.

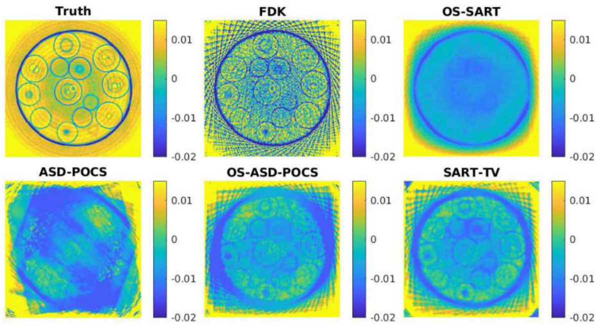

Figure 3. Dark field reconstruction with 57 views. Truth is based on FDK with 451 views.

Figures 1, 2, and 3 show the reconstructions for the absorption, differential phase, and dark field image products, respectively. The entire 3D volume is reconstructed, and the figures show one slice of the volume. Figure 1 shows the absorption images of the polypropylene balls, where voids are visible in some balls and the outline of the cup appears around the balls. The ASD-POCS algorithm smooths the aliasing artifacts from sparse sampling while maintaining sample sharpness. OS-ASD-POCS and SART-TV show improvement over FDK with some residual blurring. In the differential phase and dark field images (Figs. 2 and 3 respectively), OS-ASD-POCS seems to reduce ringing artifacts while preserving the sample. Our experiments demonstrate that the algorithms based on total variation, such as OS-ASD-POCS, show promise for sparse view XPCT.

Acknowledgements

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References

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