METHOD FOR EXTENDING THE FIELD OF VIEW FOR X-RAY COMPUTED TOMOGRAPHY WITH SUBMICRON RESOLUTION

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Abstract: Computed tomography allows for nondestructive evaluation of samples. It is commonly used for many industrial and scientific applications. Some devices are capable of submicron resolutions, but this often comes at the cost of a limited field of view. Techniques that extend the field of view can greatly enhance the versatility of these scanners. One such technique is presented here. It is implemented on the Rigaku Nano3DX, almost doubling its lateral field of view. The method utilizes a standard reconstruction algorithm, and yields faithful reconstructions of scanned samples without the need for a larger detector.

Keywords: X-ray, computed tomography, field-of-view extension, offset scan

1 INTRODUCTION

Transmission X-ray computed tomography (CT) is an imaging modality used for non-destructive visualization of internal structures of objects. It is commonly used in medicine, various industrial fields, and scientific research. [1] Some specialized submicron CT scanners are capable of producing high-resolution images, with resolutions below a micrometer. [2]

The field of view (FoV) of standard CT scanners is limited mainly by the size of a scanner's detector array. For submicron CT scanners, the widths of FoVs are often in the range of single millimeters or smaller, which is a major restriction. Increasing the FoV by using a larger detector is straightforward in principle, but often impractical or not feasible in reality. An alternative approach, which uses the original detector, can greatly increase the versatility of these devices without requiring complicated hardware modifications.

This work presents an FoV extension method that allows for a nearly two-fold increase of the FoV. It is based on offsetting the sample, and its axis of rotation (AoR), to one side. The approach is implemented using the Rigaku Nano3DX X-ray microscope. Trials on simulated data show the method faithfully reconstructs cross-sections of large samples and yields images comparable in quality to ones created using a larger detector array. The method is referred to as an offset scan from this point.

2 MATERIALS AND METHODS

2.1 Rigaku Nano3DX

The Rigaku Nano3DX [3] is an X-ray microscope capable of high-resolution CT measurements. The sample is placed close to the detector, and at a much greater distance from the X-ray source, leading to greater measurement stability, higher X-ray flux, and a low amount of beam divergence. The Nano3DX offers five degrees of freedom: 3-D translation, rotation around an axis parallel to the detector plane, and translation of the AoR in the T-stage, which is parallel to the detector plane, and perpendicular to the AoR. This T-stage enables the presented FoV extension approach. [3]

2.2 Test Data

The offset-scan approach was tested on four synthetic images, listed in table 1. Two projection datasets were formed for each image, simulating the geometry of the Nano3DX, and with the same amount of views across a 2π angular range. The first, offset-scan dataset simulated an AoR offset and 1.8-fold FoV extension. The second, full-detector dataset had no offset, and the detector used was 1.8 times wider than in the first case. The presented method was used for the offset-scan dataset, and the Feldkamp-Davis-Kress algorithm (FDK) was used for reconstruction of both sets, using the same settings each time. Images were assessed both subjectively by comparing both reconstructions for each image, and objectively through peak signal-to-noise ratio (PSNR) and feature similarity index (FSIM). [9] Additionally, a sample of a tablet was scanned using the standard and extended FoVs to validate the practical merit of the offset-scan method. The presented method was implemented using Matlab R2018b, and the ASTRA toolbox was used for reconstruction. [4, 5]

3 FIELD-OF-VIEW EXTENSION METHOD

The presented FoV extension method depends on offsetting the AoR of the sample. It is based on approaches such as the one described by Chen et al. [6] Projections are acquired over an angular range of 2π. The next steps of the method are estimation of the AoR's position, a transform onto a virtual detector, weighting of redundant data, padding, and finally reconstruction using an appropriate algorithm, such as FDK (fig. 1).

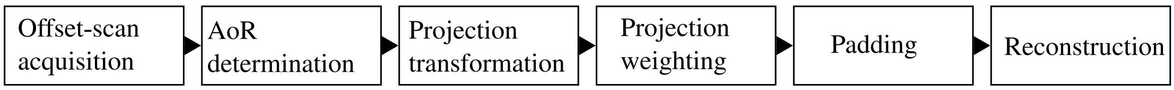

Figure 1: Flowchart of the presented method.

3.1 Axis-of-Rotation Position Estimation

Upon acquisition, offset-scan data are analyzed to determine where the AoR projects onto the detector. This is crucial, as an incorrect AoR position results in double edges or tuning-fork artifacts in the reconstruction. A reasonable compromise is to apply an automatic method for a rapid first estimate, and follow this by a manual check to ensure good accuracy.

Donath et al. [7] propose an AoR estimation method based on evaluating reconstructions for different AoR estimates. Three metrics are suggested in [7], but a different one has been applied here: the mean gradient magnitude of the reconstructed image. A curve formed by mean gradient magnitudes of reconstructions at a range of AoR estimates is detrended, its envelope is calculated, and the AoR at the maximum of the envelope is taken as the final AoR estimate.

3.2 Virtual Detector Transform

Reconstruction algorithms based on filtered backprojection (FBP) assume the central ray of the X-ray beam intersects the AoR at a right angle, and is orthogonal to the detector plane. [1] This is not the case when the AoR is offset relative to a stationary source and detector. Therefore, projections are transformed onto a slightly rotated virtual detector. Cone angles in the Nano3DX are relatively small, so the applied transform is subtle.

3.3 Projection Weighting

In the offset-scan approach, there is an overlap in the data around the AoR. Rays in this region are recorded twice over a 2π scan, whereas outer regions of the sample are scanned only once. The central region needs to be weighted to account for data redundancy. [6]

Simply removing redundant parts of projections would result in streak artifacts in FBP-based reconstructions. [8] Such artifacts are avoided when a smooth, typically sine-based weighting function is applied. Such a function must also ensure that it assigns a weight of 1 to non-redundant data, and that weights for two corresponding redundant datapoints add up to one. [6, 8]

3.4 PADDING AND TOMOGRAPHIC RECONSTRUCTION

After AoR determination, projection transform, and weighting of redundant data, the dataset is padded by zeroes to move the AoR to the middle of projections. The cone-beam reconstruction algorithm FDK is then applied. [6] For one-dimensional projections, this reduces to a fan-beam weighted FBP.

4 RESULTS AND DISCUSSION

Objective metrics for the two sets of synthetic images (Table 1) show that both reconstructions in each set are close in quality. Values of metrics for offset-scan data are slightly lower than full-detector values, most likely because every ray in full-detector data was measured twice across a 2π range, leading to lower noise. This is not the case for most of the FoV in offset-scan data.

Apart from the marginally higher amount of noise in offset-scan data, there is no significant difference between the two types of images. There is no difference in scale between offset-scan data and full-detector reconstructions, and any loss of resolution caused by interpolation during the detector transform step is negligible for this particular scan geometry.

Reconstructed cross-sections in fig. 2 show the amount of FoV extension enabled by the presented method. The offset-scan method also helps reduce artifacts caused by truncated data, which are apparent in fig. 2A. This may be crucial in applications that benefit from undistorted gray values in the reconstruction, such as segmentation.

Table 1: Objective image quality metrics for simulated data (FD - full detector, OS - offset scan).

Dataset	PSNR (FD) [dB]	PSNR (OS) [dB]	FSIM (FD) [-]	FSIM (OS) [-]
Concentric rings	22.8400	22.1467	0.9994	0.9993
Grid	14.3180	13.9362	0.9987	0.9983
Siemens star	16.2160	14.4491	0.9975	0.9950
Shepp-Logan	28.2391	27.2125	0.9898	0.9888

5 CONCLUSION

An FoV extension approach for CT was presented, based on offsetting the AoR of a sample while scanning. The method was tested on synthetic data and yielded images on par with datasets that used a 1.8-times wider detector. Using the described approach, the Nano3DX is capable of performing scans of larger samples at very high resolutions, expanding the range of applications of this machine. Further testing on real datasets is planned in order to verify the functionality of the offset-scan method.

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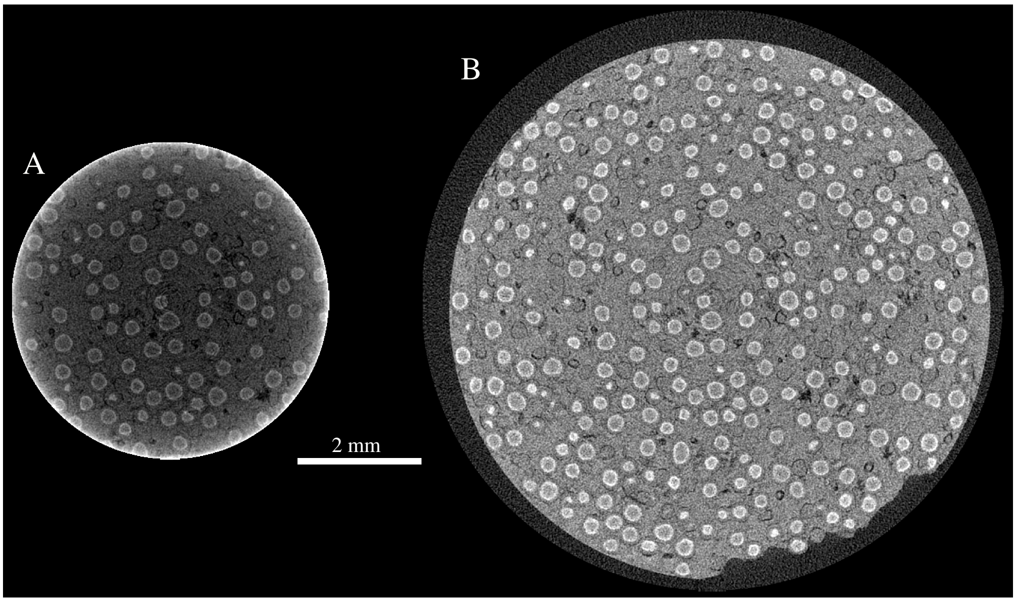

Figure 2: Reconstructed cross-sections of a tablet (original FoV in A, extended in B).

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