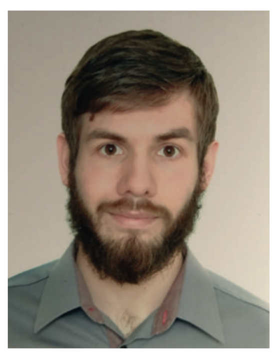
Voxel Size Calibration for High-resolution CT



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Abstract

In cone-beam X-ray computed tomography (CT), distances between the source, object, and detector influence the visual fidelity and voxel size of a reconstructed volume. Calibration using reference objects is an appropriate tool for preventing errors in the estimates of these distances. There is, however, a lack of such objects for high-resolution systems with a small field of view (FoV). In this work, we propose a method to measure the distances mentioned above, improving the determination of voxel size. We use a custom reference object suitable for a FoV of around one millimeter.

Many approaches have been developed for this calibration task and discussed in the literature, but none apply to CT scanners with a small FoV and a cone-beam magnification close to one. The proposed method thus aims to provide a calibration procedure for such devices. A Rigaku Nano3DX CT scanner has been calibrated through this method and used for practical validation of the method's accuracy. Results have shown that this approach allows for accurate calibration, which leads to improvements in reconstruction quality and accuracy of voxel size determination.

Image courtesy of imaging-git.com: "Rigaku Introduces nano3DX True X-ray Microscope"

Introduction

The source-origin distance (SOD) and source-detector distance (SDD) of a CT scanner can be used to determine the voxel size *v* as

$$v = \frac{p}{M},$$

where *p* is the pixel pitch, and M is the cone-beam magnification, the ratio of SDD and SOD. Thus, calibrating the SOD and SDD of a scanner leads to better determination of the voxel size, as well as an improvement in the quality of CT reconstructions. [1]

Many methods for calibrating the SDD, SOD, and additional parameters of conventional cone-beam CT scanners, are known. [1, 2, 3, 4] None of them, however, apply to scanners with values of M close to one and small fields of view. Such devices need smaller reference objects.

Materials and Methods

Rigaku Nano3DX X-ray Microscope

- Capable of sub-micrometer resolutions
- Small difference between SOD and SDD
- Fixed SOD, only SDD can be changed (as in fig. 1).

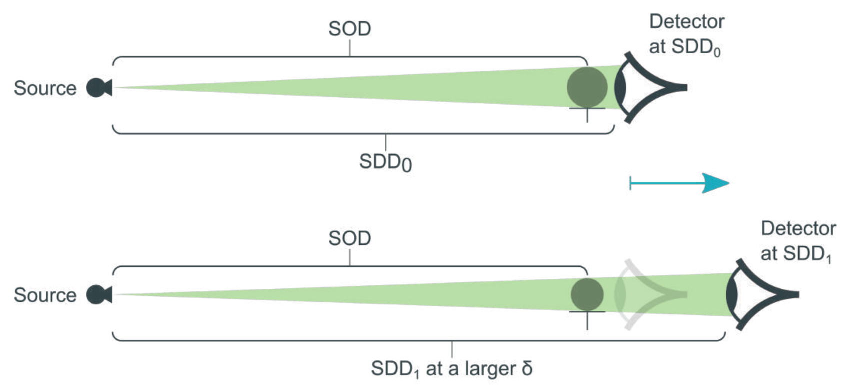

Figure 1: Illustration of the geometry of the Nano3DX. The SOD is large, and only slightly smaller than the SDD. The detector can move along an axis parallel to the X-ray beam, while the sample stays fixed.

Calibration Object

- Two ruby balls (nominal diameter 0.3 mm, shown in fig. 2)
- Center-to-center distance (579.18 ± 0.06) μm
- Measured using a SIOS NMM-1 nano-CMM
- Already utilized in a previous contribution [5]

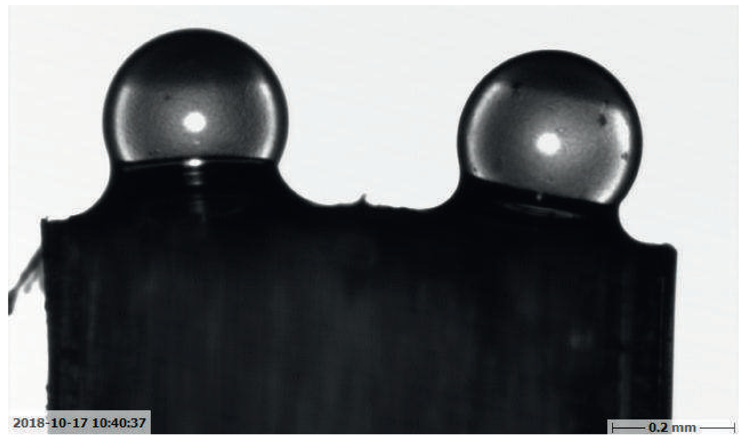

Figure 2: Photograph of the reference object

Calibration Method

Several parameters must be known before applying this calibration procedure. These are the pixel pitch of the detector, the shift *δ* of the current SDD from the reference SDD_0 (the shortest SDD allowed by the scanner), and the reference distance between centers of the reference spheres *d*.

Calibration consists of acquiring and processing data in several steps, as shown in fig. 3:

- The phantom is aligned parallel to the detector plane (roughly at first, then more precisely).
- Multiple projections of the phantom are acquired, several for each of multiple values of SDD.
- Projections are processed (fig. 4):
  - The phantom is segmentedand its outline is extracted.
  - Boundaries of spheres against the background are found in the outline. The rest of the outline is discarded.
  - These boundaries are then used to fit circles on.
- Using knowledge of the pixel pitch, the center-center distance d_p of fitted circles is extracted from each image.
- Linear fit of the relationship between *δ* and d_p:

$$d_p(\delta) = k \cdot \delta + q$$

- Calculation of SDD_0 and SOD from the linear fit:

$$SDD_0 = \frac{q}{k} \qquad SOD = \frac{d}{k}$$

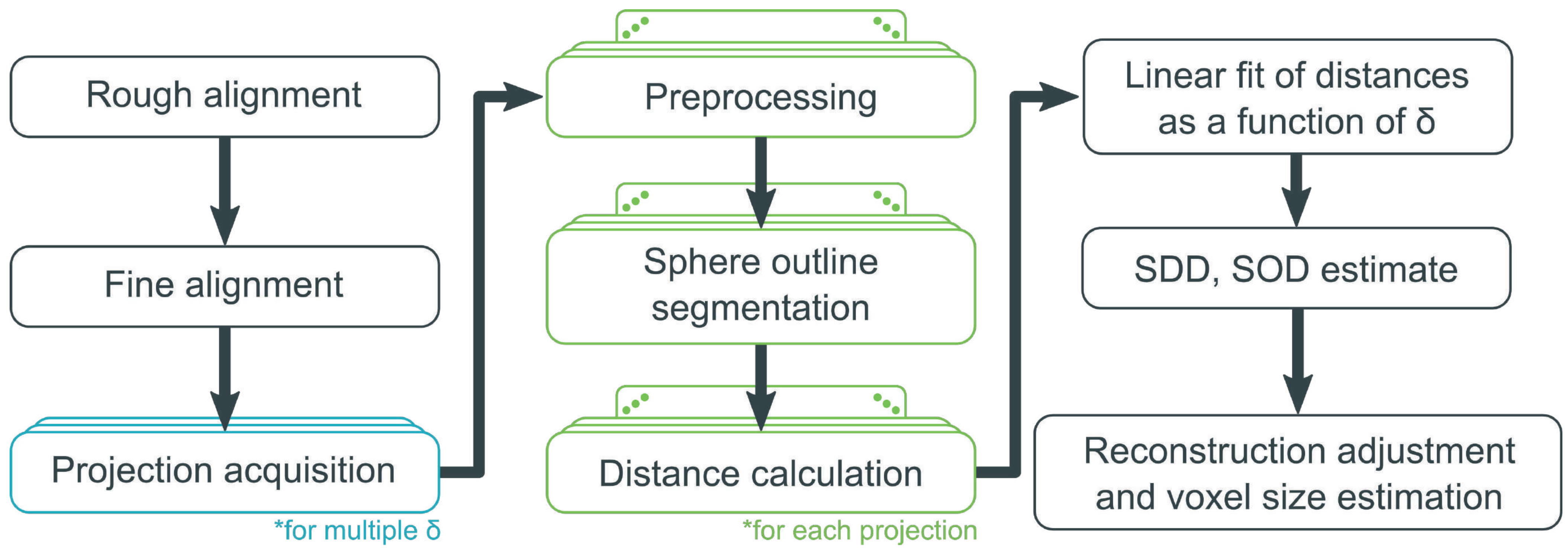

Figure 3: A simplified flowchart of the proposed calibration procedure.

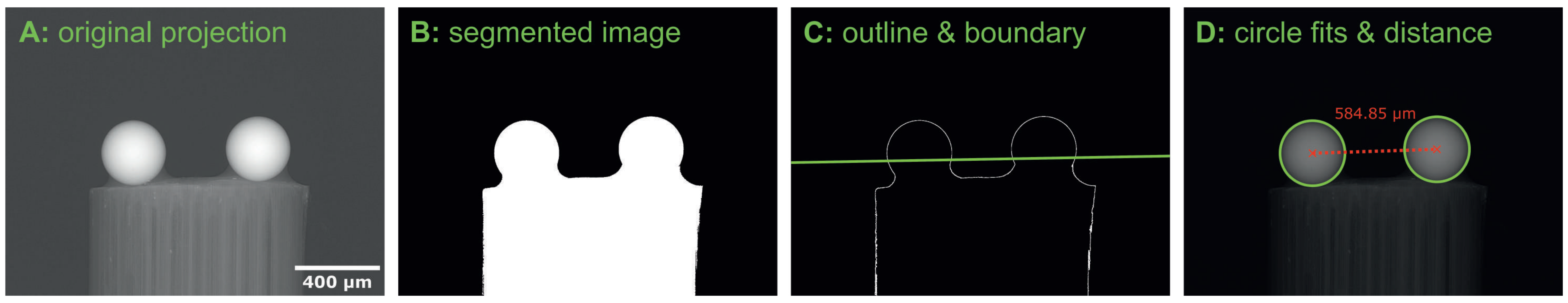

Figure 4: Several major steps of projection processing. A) A radiograph of the phantom. B) Binary mask of segmented phantom. C) Outline of the phantom. Outlines of the two spheres above the green line are used for circle fitting, the rest is discarded. D) Circles are fit on the projections of spheres, and the distance between their centers is calculated

Results and Discussion

The proposed method was used to calibrate a Nano3DX with a Molybdenum target (50 kV, 24 mA), a 1.8-by-1.4 mm field of view, and a 0.54 μm pixel pitch (at binning 1).

A total of 30 projections were acquired, ten for three *δ* of 1 mm, 10 mm, and 20 mm. These were used to calibrate the SOD and SDD_0. The measured values d_p correspond well with the linear fit (fig. 5). After calibration, three CT measurements were performed to validate the calibration accuracy (table 1).

The projections used for calibration must be of sufficient quality. For instance, blur due to unsharpness degrades projection images, skewing the results. This can be avoided by keeping the detector reasonably close to the sample.

The calibrated voxel size appears slightly biased towards smaller values. This might be due to an inherent bias in finding the centers of projections of the spheres, which is a major step of the proposed method. [6] There may also be deviations in the reference distance *d*, pixel pitch, and values of *δ*, due to effects such as thermal expansion. This can be avoided by e.g. maintaining constant temperature during measurement, measuring *δ* by interferometers, or other remedies.

Table 1: Calibrated SOD and SDD, and corresponding center-center distances of the phantom measured in CT reconstructions.

Scan Number	SOD [mm]	δ [mm]	SDD [mm]	Center-center distance [μm]	Error [μm]
1	263.35	1.00	265.93	579.16	-0.02
2	263.35	1.50	266.43	579.15	-0.03
3	263.35	2.00	266.93	579.13	-0.05

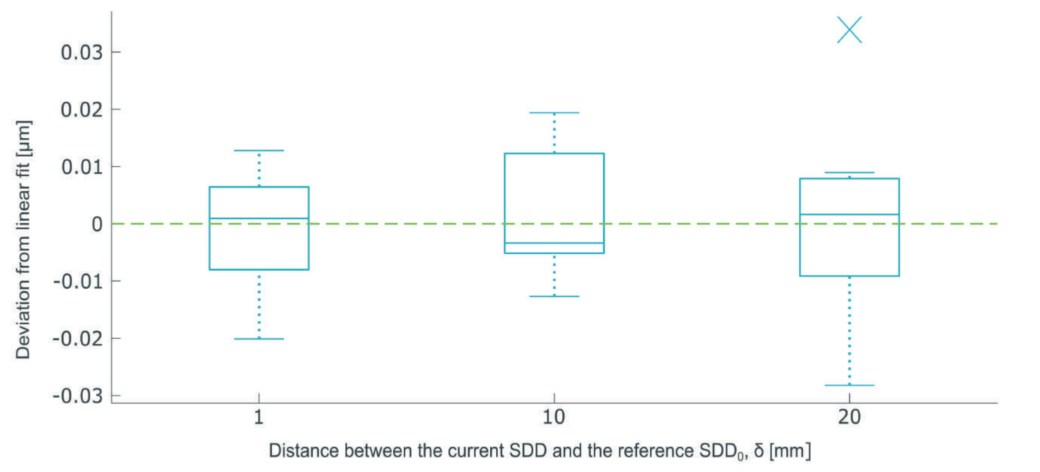

Figure 5: Box plots showing good correspondence between datapoints d_p (three blue boxes, one for each distance *δ*) and the linear fit (dashed green line).

Conclusion

A method was proposed for calibrating the SOD, SDD, and voxel size of a CT machine, using projections of a reference object. It is suitable for scanners with a small FOV and cone-beam magnification close to one. Based on analyzing projection data, it allows for faster voxel-size calibration than a reconstruction-based approach. Moreover, the quality of reconstructed data is improved by more accurate estimates of SDD and SOD for the reconstruction algorithm. The method was applied to calibrate a Rigaku Nano3DX, the results were tested on CT scans of the reference object and yielded satisfactory results.

References:

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