Scale Correction for Submicron Computed Tomography

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Introduction

Computed tomography (CT) facilitates dimensional measurements of scanned samples and their features. The scale of these measurements is influenced by uncertainties in the scan geometry, tolerances of scanner components, etc. The scale of CT data is typically corrected using CT scans of reference objects (phantoms) with calibrated dimensions [1]. This approach to scale correction is straightforward and effective [2].

However, the limited field of view (FoV) of submicron CT scanners with voxel sizes below a micrometer (submicron CT) renders most existing phantoms too large for use with this modality, which hinders the use of CT for dimensional measurements at this scale. In this study, a miniature reference object is used to overcome this issue and perform scale correction and more accurate dimensional measurements in submicron CT with a sub-millimeter FoV.

Materials & Methods

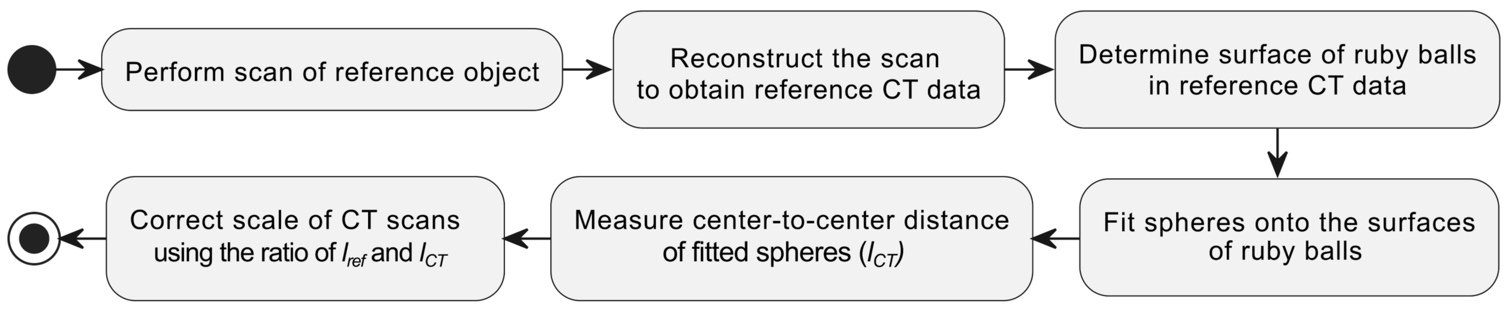
Submicron CT: *Rigaku* nano3DX X-ray microscope

- 1200 W *MicroMax-007 HF* X-ray source
- 0.270 μm nominal effective pixel size
- Quasi-parallel X-ray beam geometry
- Sub-millimeter FoV (0.9×0.7 mm)

Phantom: Unique miniature two-ball object manufactured by *CactuX, s.r.o.*

- Designed for scale correction of submicron CT with a sub-millimeter FoV.
- Distance l_{ref} between centers of ruby balls calibrated using a tactile CMM [3].

Scale correction:

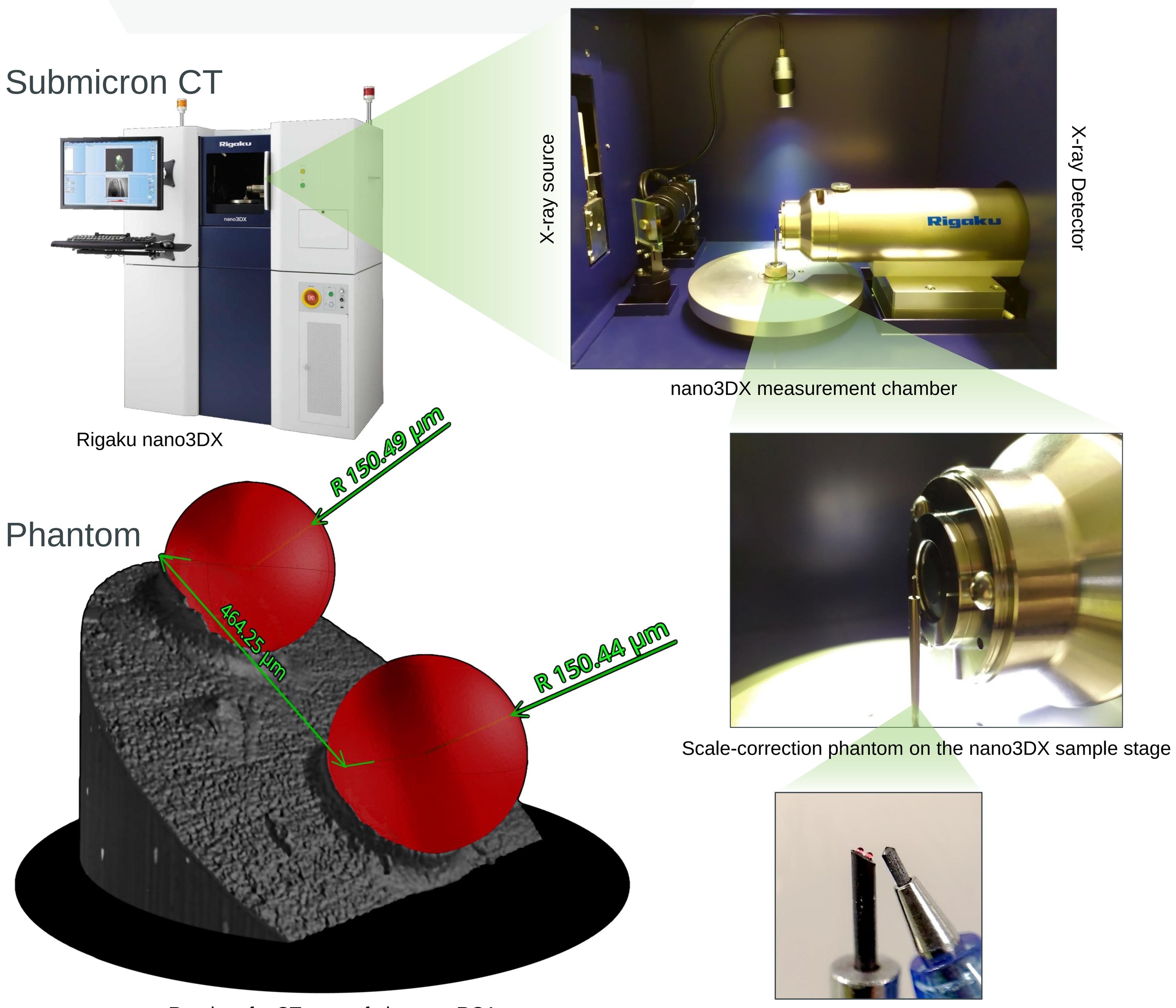


- The last step consists of adjusting the voxel size v [2] of a CT scan, assuming its scan conditions are consistent with the reference scan, as follows:

$$v_{corr} = v \cdot \frac{l_{ref}}{l_{CT}}$$

Experimental setup:

- Three phantoms: **RO1**, **RO2**, **RO3**
- Three trial sessions: all phantoms scanned sequentially in each session
- RO1 is scanned first and used to calibrate scans of RO2 and RO3
- Scan parameters listed to the right were used for all scans.



Render of a CT scan of phantom RO1, with measurements of l_{CT} and ruby sphere radii

The phantom next to a 0.7 mm mechanical pencil

Scan parameter	Nominal Value	Scan parameter	Nominal Value
Tube voltage	50 kV	Projection number	800
Tube current	24 mA	Scan range	180°
Target material	Mo	Exposure per projection	15 s
X-ray beam filter	0.1 mm Al	Nominal voxel size*	0.5285 μm
Source-object distance	275 mm	Source-detector distance	281 mm

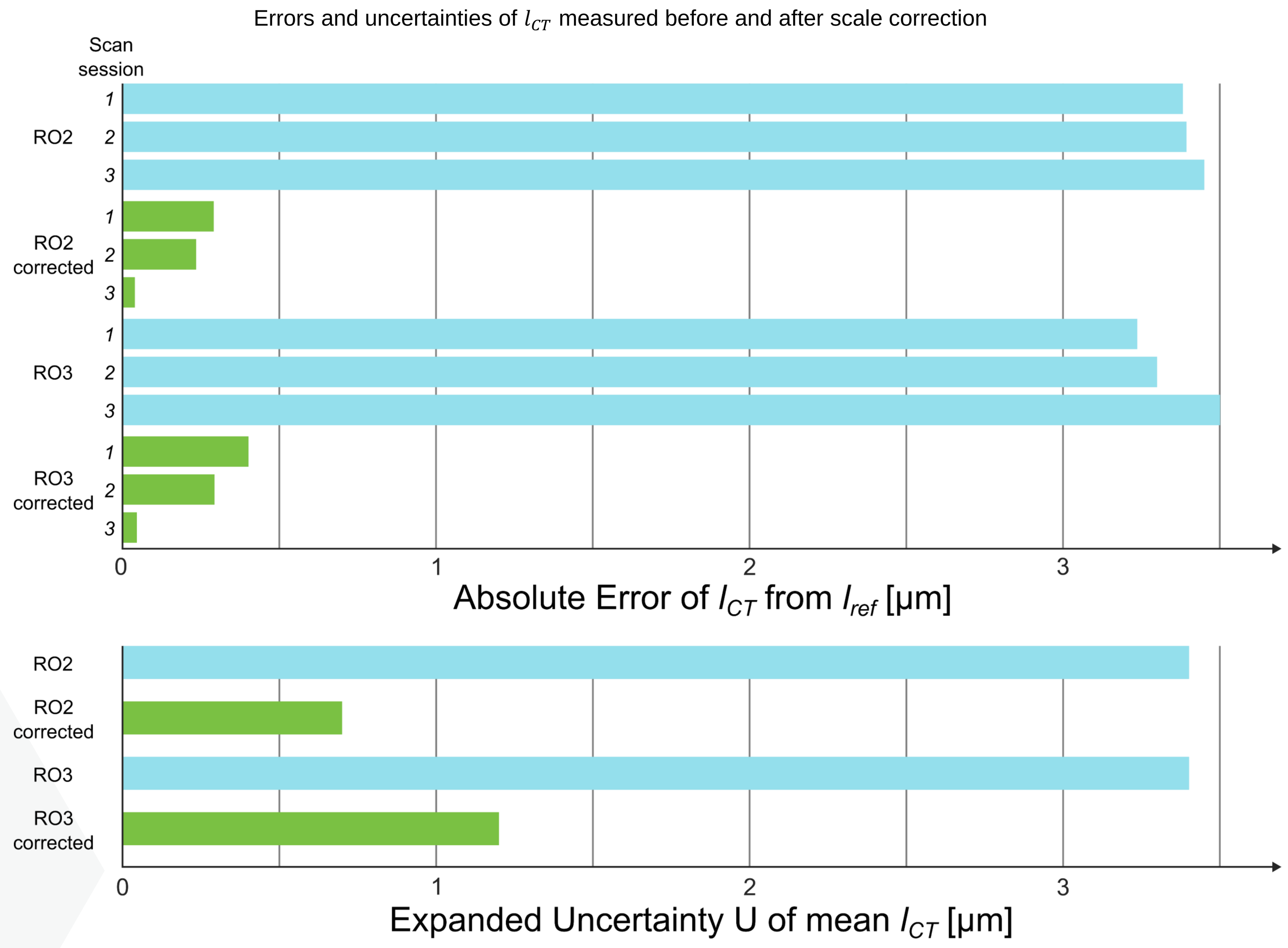
*Using a nominal effective pixel size of 0.54 μm at the detector (2×2 binning mode)

Results & Discussion

The table and bar graph to the right demonstrate a reduction of the absolute dimensional error of reference distances l_{CT} (when compared to l_{ref}) by an order of magnitude after scale correction. The uncertainty of these measurements was also reduced by approximately two-thirds after correction, as shown by the lower bar graph. These results demonstrate the feasibility of scale correction in true submicron CT with a FoV which is limited in all dimensions to less than a millimeter in size.

In this case, the scale of CT data was corrected using a single reference measurement (one length in a single direction). Using a phantom with multiple calibrated distances can increase the reliability of scale correction, decreases measurement uncertainty, and complies with current norms for evaluating of the performance of metrological CT. However, this would also lead to a more complex phantom and more expensive calibration. At the target scale (sub-millimeter FoVs), calibration would also have to be done using other means than a tactile CMM.

Reference Object	l_{ref} [μm]	l_{CT} [μm] (mean of three sessions)	
		Uncorrected	Corrected using RO1
RO2	(475.89 ± 0.07)	(472.5 ± 3.4)	(476.1 ± 0.7)
RO3	(471.22 ± 0.07)	(467.9 ± 3.4)	(471.4 ± 1.2)



Bibliography

1. W. Dewulf, H. Bosse, S. Carmignato, R. Leach, CIRP Annals 71 (2022) 693–716. doi: 10.1016/j.cirp.2022.05.001.
2. P. Müller, et al., CIRP Journal of Manufacturing Science and Technology 10 (2015) 68–76. doi: 10.1016/j.cirpj.2015.04.004.
3. F. Meli, A. Kueng, R. Thalmann, in: J.E. Decker, G.-S. Peng (Eds.), San Diego, California, USA, 2005: p. 58790S. doi: 10.1117/12.618692.

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Acknowledgements
This work was supported by MEYS CR [grant number LM2023051]; and Brno University of Technology [grant number FSI-S-23-8389].