euspen's 22nd International Conference & Exhibition, Geneva, CH, May/June 2022
www.euspen.eu

Influence of magnification and focal spot size on measurement errors of X-ray computed tomography systems with known geometrical misalignments

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Abstract

To enhance the accuracy of dimensional measurements performed using X-ray computed tomography (CT) systems, a number of influence factors have to be studied, including the system geometry. Geometrical misalignments of X-ray source, rotation axis and X-ray detector may lead to image artefacts in the reconstructed volume and to measurement errors. Starting from the geometrical parameters which were found critical in a previous study, this work investigates how the measurement errors of CT systems with known geometrical misalignments are affected by the influence of the magnification factor and the focal spot size. A simulation campaign was carried out using the geometry of a reference object specifically designed for CT systems testing.

X-ray computed tomography, geometrical misalignments, dimensional metrology

1. Introduction

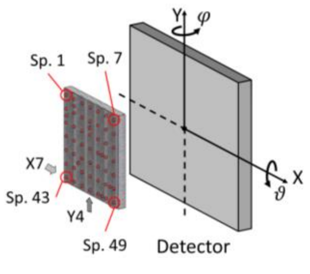
X-ray computed tomography (CT) is increasingly used in the field of manufacturing metrology, as it enables advanced and non-destructive analyses, including dimensional measurements of parts characterized by complex free-form shapes or features not accessible with conventional coordinate measuring systems [1]. In order to enhance the accuracy of CT-based dimensional measurements, a number of influence factors have to be studied, including the system geometry, and particularly the relative positions of the hardware components [2]. Geometrical misalignments of X-ray source, rotation axis and X-ray detector may lead to image artefacts in the reconstructed volume and to measurement errors. Several studies in the literature analysed the influence of specific geometrical misalignments of CT system hardware components on dimensional measurements results [3,4]. However, the connection of geometry-related effects with specific measurement conditions needs specific investigations. This work is a part of a wider study aiming at achieving a clear and complete comprehension of the effect of system geometry deviations on CT measurement results. Starting from the geometrical parameters which were found critical in previous work [5], this paper investigates how the measurement errors of CT systems with known geometrical misalignments vary under the influence of the focal spot size and the magnification factor, which results from the distance between the source and the object in the studied CT system configuration. A simulation campaign was carried out based on the geometry of a dedicated reference object specifically developed for CT systems testing.

2. Materials and methods

The simulation setup presented in [5] was adopted. A ball plate characterized by 56 spheres of 1 mm diameter, 49 of which placed in a regular 7×7 grid and equally spaced by 5 mm, was specifically designed for the wider research project. The position of the object model was chosen in order to homogeneously cover the area of the detector, with the central row and central column of the spheres projected onto the central row and column of the detector, respectively (see Figure 1b). The analyses were performed simulating the two angular misalignments of the detector which resulted critical from previous studies [5]: the tilt around the X-axis (ϑ) and the slant around the Y-axis (φ). In particular, the detector tilt was found responsible for the most severe effects on the sphere centre-to-centre distance (C2C), while the detector slant resulted critical also for the sphere form errors. In order to effectively appreciate the impact of the magnification factor and the focal spot size on the results, relatively high angle amplitudes were chosen: ϑ = 1.5° and φ = 1.5°. Four different magnification factors (and corresponding voxel sizes, see Figure 1a) were analysed using an ideal point-shaped focal spot (nominal spot size = 0). The highest magnification factor (corresponding to the lowest voxel size) tested was then chosen to analyse the effect of different focal spot sizes, as seen in Figure 1a.

Focal spot size / µm	Voxel size / µm
0	20
0	30
0	40
0	50
5	20
10	20
15	20
20	20
25	20
30	20
35	20
40	20

a



b

Figure 1. Simulation parameters (a) and schematic representation of the object positioned in the system coordinate frame (b)

The software tool aRTist 2.0 (BAM, Germany) was used to run the simulations. The volume data were reconstructed using the filtered back-projection algorithm implemented in CTPro 3D (Nikon Metrology, UK), assuming the system ideally aligned. The surface determination by means of a local-adaptive algorithm and the dimensional measurements were performed using VGStudio MAX 3.2.3 (Volume Graphics GmbH, Germany).

3. Results

The C2C errors determined in the case of a 1.5° detector tilt showed a similar trend increasing the source to object distance. Figure 2 shows an example related to the spheres in the Y4 column.

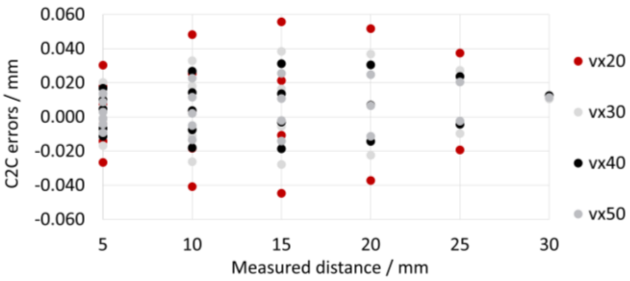


Figure 2. Sphere C2C distance errors determined along the direction Y4 with an induced tilt of the detector of 1.5° with different voxel sizes (vx)

Varying the voxel size, the measurement results obtained along the X direction exhibit similar trends, but with higher errors in absolute value. Figure 3 illustrates for a greater detail the maximum C2C errors obtained for each measured distance along the direction X7, for different magnifications (and hence voxel sizes). The effect of ϑ on the results was found to decrease for lower magnifications (higher voxel sizes), but remains visible even if only a small part of the detector is interested by the projection of the ball plate. Deviations up to 100 µm, 67 µm, 51 µm and 40 µm for voxel sizes respectively of 20 µm, 30 µm, 40 µm and 50 µm were determined measuring the longest distance.

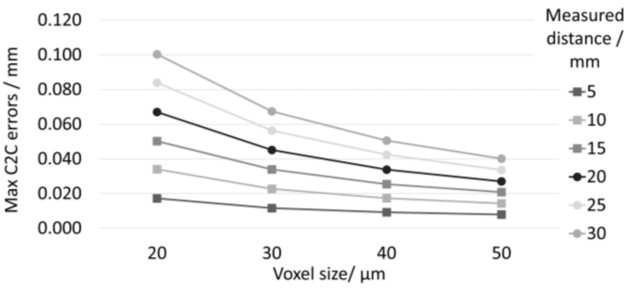


Figure 3. Maximum sphere C2C distance errors determined along the direction X7 for different magnifications (decreasing with increasing voxel size) and for different measured distances

The effect of a slant of the detector was found to be influenced by the object distance from the source which determines the magnification. The results obtained calculating the C2C distance along the Y direction proved that a reduction of the magnification factor corresponds to smaller errors, with deviations up to 13 µm for a voxel size of 20 µm and 10 µm for a voxel size of 50 µm.

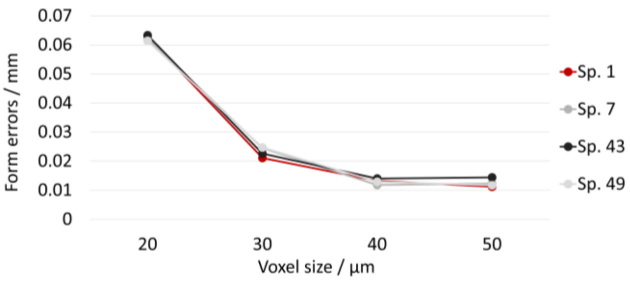


Figure 4. Sphere form errors determined for the spheres no. 1, 7, 43 and 49 with an induced slant of the detector of 1.5° for different voxel sizes

It is known from previous studies that the form error induced by φ increases radially from the centre of the detector, and hence form the central sphere which is projected in the central point of the detector [6].

Figure 4 illustrates the form errors obtained for the four most critical spheres (i.e. spheres at the corners: Sp.1, 7, 43 and 49 shown in Figure 1), for decreasing magnification (i.e. increasing voxel size). As shown, the form error decreases drastically reducing the magnification. This effect is also visible in Figure 5. However, decreasing the magnification factor leads to higher errors for the diameter of the spheres.

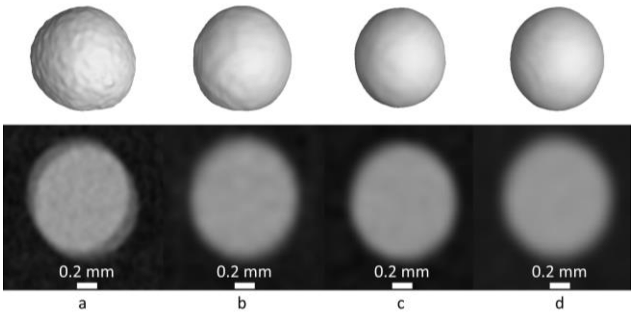


Figure 5. 3D reconstructed volume after the surface determination and 2D cross-section of the sphere no. 1 with voxel sizes of 20 µm (a), 30 µm (b), 40 µm (c) and 50 µm (d)

The effect of the focal spot size was found of minor relevance with the scan parameters adopted, resulting in an increased blurring of the 2D image that can be appreciated only with a spot size of 40 µm. The results showed that no significant additional effects, compared to the effects found with the aligned system, were induced on CT dimensional measurements with tilt and slant of the detector.

4. Conclusions

This work presented the results of a simulation campaign performed to analyse how the measurement errors of CT systems with known geometrical misalignments vary with varying magnifications and focal spot sizes. The study highlights that the impact of geometrical misalignments on dimensional measurements is strongly related to the magnification adopted. The effect of the focal spot size was found of minor relevance with the scan parameters adopted. Other simulations are needed to further investigate the role of the focal spot, testing higher dimensions. Future work is planned to study the combined effect of spot size and magnification on misaligned systems, as well as the impact of other factors such as detector pixel size and scan noise.

References

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