Investigation on the effects of X-ray CT system geometrical misalignments on dimensional measurement errors

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Abstract

X-ray CT measurements are affected by a multitude of influence factors, among which the correct estimation of the CT system geometry is of major importance. The presence of geometrical misalignment and/or the wrong estimation of system geometry, indeed, leads to artifacts and distortions in the measured volume, and to measurement errors when performing metrological tasks. That is why it is important to quantify the effects of geometrical misalignments or misestimation on CT measurement accuracy. In this work, the effects of detector misalignment are experimentally investigated on a metrology CT system. Physical misalignments were purposefully induced on a flat-panel detector for investigating the influence of a detector out of plane rotation on measurement results. The experimental results show the effects of the induced detector misalignment on center-to-center measurements, diameter and form measurements on a calibrated ball bar. The effects of the amplitude of the angular misalignment induced are also shown.

Keywords: X-ray computed tomography, dimensional metrology, accuracy, geometrical misalignments, traceability

1 Introduction

CT measurements are affected by a multitude of influence quantities (e.g. scanning parameters, workpiece material and size, geometrical misalignments, etc.) that make the traceability to the unit of length one of the major challenges for metrological applications. Among these influence factors, the correct estimation of the CT system geometry is of major importance as it provides the necessary information to fully describe the geometry of data acquisition and performing the tomographic reconstruction on which all the following dimensional analysis are based. In fact, an error in the estimate of the CT system geometry (i.e. set-up) or the presence of geometrical misalignments not accounted for during the reconstruction affect all the subsequent steps in the measurement chain and could lead to artifacts and distortions in the reconstructed volume, and to measurement errors when performing metrological tasks [1]. That is why it is important to quantify the effects of geometrical misalignments or misestimation on CT measurement accuracy. The geometry may be incorrect due to system misalignment and imperfect mechanical calibration or a misestimation. The mechanical calibration consists of precisely calibrating all axes of the system, e.g. source-to-detector and source-to-rotary table distance, etc. This calibration is routinely checked and fed into the reconstruction routine. Alternatively, the geometry may be estimated directly from images. For example, several studies are available in which different methods based on the acquisition of single or multiple projections images of test phantoms, generally composed of high density point-like objects (e.g. spheres), are proposed for estimating cone-beam CT systems geometries [2,3]. In [1] the effects of geometrical misalignments and errors on CT system geometry are studied on simulated CT data. The authors investigate the influence of positional errors of the X-ray source, object and detector and the effects of detector angular misalignments and center of rotation errors on CT dimensional measurements. Different ball bars with varying length ranging from 2 mm to 100 mm were there simulated. The authors show how, when considering detector angular misalignments, the detector out-of-plane rotations have significant effects on dimensional measurements. In this work, the effects of detector misalignment are experimentally investigated on a metrology CT system, a NSI CXMM50. Reference CT measurements of a CMM calibrated ball bar were acquired with the system aligned according to the manufacturer’s guidelines. Physical misalignments were then induced on a flat-panel detector, and sphere center-to-center measurements, diameter measurements and form measurements were then calculated and compared to the reference measurements.

2 Experimental set-up

For the experimental investigation, the effects of detector angular misalignments were studied. A tactile CMM calibrated ball bar consisting of seven equally spaced spheres was used (with nominal sphere diameter equal to 1.59 mm, and with spheres center-to-center nominal distances ranging from 5 mm to 30 mm). CT reference scans of the ball bar oriented in the vertical direction and positioned off-center from the center of rotation were acquired with the system aligned according to the manufacturer’s guidelines. The flat-panel detector was then physically misaligned in order to study the influence of the detector out of plane rotation about the X axis on the measurement result (Fig.1). Three angular misalignments of approximately 0.5°, 1° and 1.5° were chosen to investigate the influence of the misalignment with varying angles. These values were chosen in order
to correlate the influence of the angular misalignment for reasonable angles, i.e. angles smaller than those easily eliminated by mechanical assembly. For each misaligned configuration one scan was acquired with the ball bar oriented in the vertical direction and positioned off-center from the center of rotation. This was done to reveal the error from misalignment about the X axis, which is expected to be maximal on the vertical direction, as reported in [1]. The ball bar was positioned so that the middle sphere (number 4) was roughly centered on the middle plane of the detector in the aligned configuration, sphere 1 was positioned close to the upper edge of the detector and sphere 7 was positioned close to the lower edge of the detector. For each scan a procedure to estimate the geometry of the system was applied as per the system manufacturer’s guide. In this procedure, out of plane rotation of the detector was disabled from the geometry estimation. Therefore, the detector misalignment about the X axis was not accounted for, whereas magnification errors at the center of the detector were taken into account. The acquired information was then used to perform the reconstruction.

3 Main results and conclusions

In this work, the effects of detector angular misalignments induced on a flat-panel detector were investigated and compared to the reference results obtained with the system aligned according to manufacturer’s guidelines. Three different angular misalignments of approximately 0.5°, 1° and 1.5° were physically induced on a flat-panel detector in order to study the effects of an out of plane rotation about the X axis of the detector. A CMM calibrated ball bar consisting on 7 equally spaced spheres was used for the experimental investigation and scanned off-center form the center of rotation and placed in the vertical orientation in the measured volume. The experimental results show that the out of plane rotation about the X axis has a significant influence on measurements when scanning an object in the vertical orientation. When increasing the angular misalignment induced in the flat-panel detector, the measurement errors consistently increase. The sphere center-to-center measurements with a detector tilt of approximately 0.5° show errors up to 12 µm. Increasing the amplitude of the misalignment to 1° causes the errors to reach 18 µm, errors get to 28 µm for 1.5° (see Fig.2a). The experimental results show also that for the angular misalignments up to 1.5° considered in this study, the sphere center-to-center measurements exhibit a clear trend with a signed error that is symmetric about the center of the detector.

When analyzing diameter errors (Fig. 2b), it was also found that spheres which occupy similar regions on the detector in the aligned configuration, but at opposite sides vertically, show diameter errors with opposite signs. For the maximum misalignment considered in the study, i.e. 1.5°, the diameter errors reach 5.3 µm. Form measurements were also investigated, and no clear trend was found between the aligned and misaligned configurations. It can be concluded that the detector out of plane rotation considered in this study has a significant effect when dealing with metrological applications. In particular, it is shown how the investigated out of plane rotations influence the measured errors of features scanned in the vertical orientation. Future works will be focused on analyzing the influence of different angular misalignments (i.e. detector yaw and detector roll) and the influence of sample orientation on the measurement results.

Figure 1: Representation of the detector angular misalignment studied in the experimental investigation.

Figure 2: a) sphere distance errors and b) diameter errors. In both graphs in the y axis the measured errors (CT values – CMM values) are plotted for all the angular misalignments considered in the study. The errors obtained from the reference CT scans with the system in the aligned configuration are also reported.

References