An experimental study of computed tomography error sources by using an open CT system

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Abstract

Computed tomography (CT) in the dimensional metrology field is becoming a consolidated technique that offers great advantages over the traditional ones, highlighting the ability to perform internal and external measurements simultaneously and without contact. However, the CT process for metrology applications is complex and affected by many factors that influence its measurement uncertainty.

In this paper the influence of some sources of error has been studied from experimental work with an open CT system and a calibrated reference standard. A set of experiments has been developed comprising different elements, namely: surface extraction applied technique, CT acquisition parameters, detector type. From the results, both qualitative and quantitative conclusions about the influence of those parameters in the final accuracy have been obtained.

1. Introduction

X-ray CT is increasingly used in industry for dimensional metrology purposes. However, due to their complex and numerous error sources [1], the measurement results and metrological performance of CT systems are difficult to evaluate. Some approaches have been addressed in order to quantify the influence of every factor in the final measurement result. The CT Audit intercomparison presented in [2] is a perfect example of that. However, numerical relations between the scanning factors and the final accuracy of the results has not been established yet, partly due to the difficulty to actually access to the inner information of commercial CT systems.

In this paper an open CT system has been used to measure a calibrated reference standard according to a design of experiments (DOE) where different parameters have been varied and the error in some of the dimensions have been analysed as the objective functions.

2. Materials and methods

The reference standard used consists of three ruby spheres of different diameters, made of synthetic ruby monocrystal and supported by a carbon fibre bar. The three diameters (D1, D2 and D3) and the distances between the centres of the three spheres (L12, L13, L23) had been previously calibrated by a CMM with 0.1μm in resolution and a length MPE = 2.30 μm + (L/300) μm (L in mm). Their nominal values are shown in Figure 1 (left). A general purpose 225 kV CT system (Fig. 1 right) was used for the measurements, with both a linear and a flat panel detector (fan and cone beam geometry, respectively). The CT system has variable magnification, which allows to vary the voxel size.

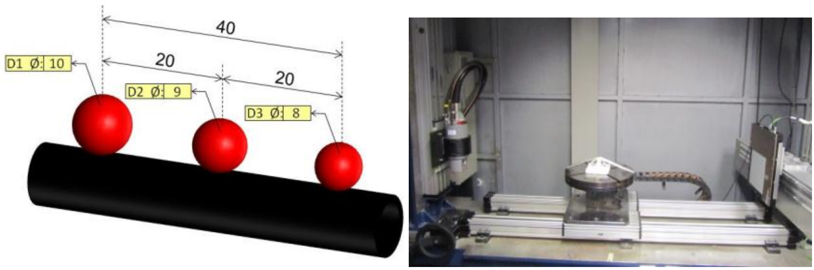

Figure 1: Calibrated standard (left) and CT system (right)

Different sets of parameters have been preliminary tested in order to select the most influent factors to be analyzed in the DOE. The reference standard was measured by using: three different voltages (90 kV, 150 kV and 200 kV); two different sensors (a flat panel 2D sensor and a linear sensor); two different angles of increment in the case of the flat panel (0.5 degrees and 0.4 degrees); and two different surface extraction methods (an adaptive local optimal threshold determination method and a 3D Canny adapted method as described in [3]). No physical filters were used for these parameters' configuration, while the X-ray current was adjusted depending on the exposition time and the energy for both detectors. Acquisition parameters (X-ray current, integration time, voxel size) were chosen for optimizing the detector signal and minimization of the image blurring. Chosen voxel sizes were 100 µm and 200 µm respectively for the fan beam and cone beam configuration. All the three diameters (D1, D2 and D3), as well as the three distances (L12, L13, L23) were calculated and compared to the reference measurements obtained from the calibration. The standard deviation of the measurements and the form errors of all the three spheres were also included in the analysis. From these preliminary results it was observed that all the measurements showed a similar behavior regarding deviation with respect to the reference (i.e. systematic error) and standard deviation results. Consequently, the minimization of the deviations of D2 and L13 were selected as objective functions of the DOE analysis, since they showed average results. From the study of the main influences in the final result, the finally analyzed parameters in the DOE are those shown in Table 1 (i.e. 3 parameters and 2 levels per parameter):

Table1: Parameters and values used for the DOE

Parameter	Voltage (kV)	Type of detector	Surface extraction method
Level -1	90	Linear	Local threshold
Level +1	150	Flat panel (angle of increment = 0.4º)	Canny adapted

3. Results

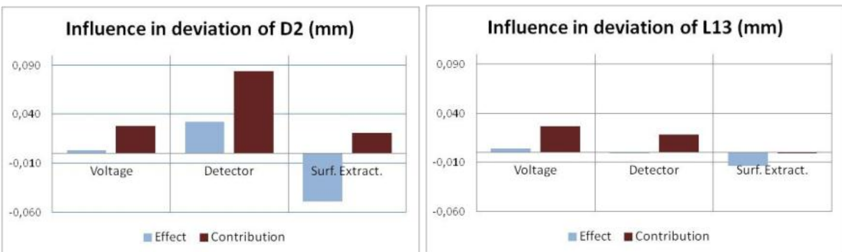

Figure 2: Effects and contributions for deviation of D2 (left) and L13 (right)

The results obtained show that the main influence factor to decrease the deviation when measuring diameters, such as D2 (i.e. multidirectional measurement) is the detector type, with the best results for the flat panel (Fig. 2 left). The surface extraction may also influence the result, obtaining better results with the Canny adapted method for this type of dimensions. For both, L13 (i.e. a unidirectional measurement) and D2, better results are obtained when using 150 kV and in both cases the contribution of this influence is similar. For L13 (Fig. 2 right), the influence of the type of detector and the surface extraction method is almost negligible. Regarding the surface extraction method, this same conclusion was also obtained in [3] for dimensions where the determination of the local threshold does not influence the final result, such as L12, L23 and L13.

The analysis of variance shows that the best repeatability results are obtained when using the flat panel detector and the Canny adapted surface extraction method, with almost no influence of the voltage.

All the other diameters and lengths measured showed similar qualitative and quantitative results to the ones presented for D2 and L13.

4. Conclusions

A systematic technique for the influence analysis of measuring factors in CT has been presented. The flexibility of the open CT system allowed the use of different parameters and the most influent ones for the reference standard measured have been determined both qualitatively and quantitatively. This technique may be very appropriate to established error limits in CT measurements that could be used as a reliable approach for a future Montecarlo simulation in order to determine the measurement uncertainty of general purpose CT systems.

Further work must be carried out in order to establish the robustness and reproducibility of the results obtained when other geometries and materials are measured. In addition, other parameters will be also studied and the regression and analysis of variance will provide valuable information for a further analysis of the measurement uncertainties.

References:

[1] Kruth JP, Bartscher M, Carmignato S, et al., 2011, Computed Tomography for Dimensional Metrology, CIRP Annals, 60/2:821–842.

[2] Carmignato S, 2012, Accuracy of industrial computed tomography measurements: experimental results from an international comparison, CIRP Annals, 61/1:491-494.

[3] Yagüe-Fabra JA, Ontiveros S, Jiménez R, et al., 2013, A 3D edge detection technique for surface extraction in computed tomography for dimensional metrology applications, CIRP Annals, 62/1:531-534.