How accurate is Computed Tomography? Main findings from the *CT Audit* intercomparison

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Abstract

This paper presents a summary of the final results obtained from the *"CT Audit"* project, the first international interlaboratory comparison of Computed Tomography (CT) systems for dimensional metrology.

1 Introduction: the *CT Audit* intercomparison

The *CT Audit* intercomparison of CT systems for dimensional metrology was organized by University of Padova and carried out in the period from September 2009 to June 2011. The intercomparison involved 15 CT systems, from expert users in Europe, America and Asia, including national metrology institutes, research institutes, CT systems manufacturers, and industrial users. The *CT Audit* project and the four calibrated samples used in the intercomparison were previously presented in [1]. Further details are available in [2].

2 Main results

The intercomparison allowed testing several measurement characteristics with the 15 participating CT systems, for a total of more than 5000 dimensional measurement results collected from the participants. Figure 1 illustrates two examples of deviation charts comparing the results of all *CT Audit* participants. The figure refers to the case of diameters measurements of tubes of *CT Audit* sample 2 (the *Pan Flute Gauge*).

As visible in Figure 1, a systematic trend takes place in the CT measurement of diameters of the glass tubes of the *Pan Flute Gauge*: in this case, deviations of outer diameters measurements are always more positive than deviations of inner diameters measurements. Causes of this systematic trend and other measurement errors were discussed with the *CT Audit* participants at the "*CT Audit International Workshop on*

Computed Tomography for Dimensional Metrology", which was held in Padova on October 26th, 2011.

The complete report of the intercomparison results is given in [2]. Further elaborations of *CT Audit* results are discussed in [3].

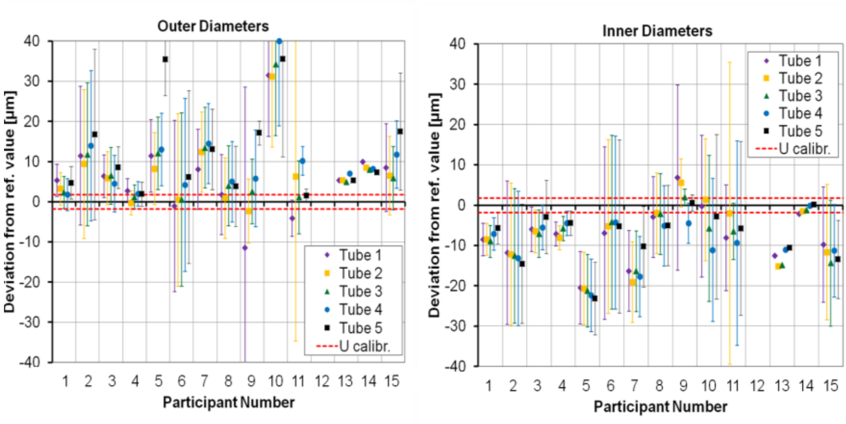

Figure 1: Deviation charts comparing the results of all participants: cases of outer and inner diameters' measurements of the five tubes of the *CT Audit* sample 2 (the *Pan Flute Gauge*). Error bars represent expanded uncertainty stated by the participants.

3 Measurement uncertainty

For each measurement result, the *CT Audit* participants were asked to state the expanded measurement uncertainty and to declare which method was used for uncertainty evaluation. Figure 2 reports the uncertainty evaluation methods that were used by the participants, where:

- U_A = GUM method with analytical calculation of uncertainty contributors;
- U_B = substitution method based on the use of similar calibrated objects;
- U_C = method based participant's experience on similar measuring tasks;
- U_D = method based on maximum permissible errors of the CT system;
- *No U* = the participant did not state the measurement uncertainty.

Figure 3 reports the overall distribution of E_n numbers for all the *CT Audit* measurement results. The E_n number is defined, according to [4], as

$$E_n = \frac{x - X}{\sqrt{U_{lab}^{\ 2} + U_{ref}^{\ 2}}}$$

where: x is the participant's result;

X is the reference value (from calibration);

U_{lab} is the expanded uncertainty of the participant's result;

U_{ref} is the expanded uncertainty of the reference value.

E_n numbers express the validity of the expanded uncertainty estimate associated with each result [4]. If $-1 < E_n < 1$ then there is good agreement between participant's results and reference value (both with their expanded uncertainty); otherwise the agreement is unsatisfactory.

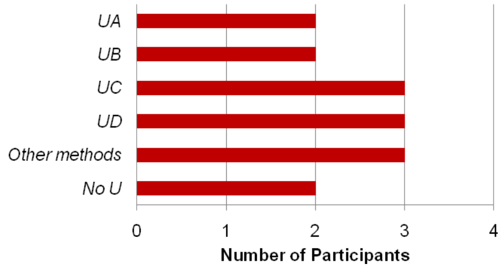

Figure 2: Uncertainty evaluation methods used by the *CT Audit* participants.

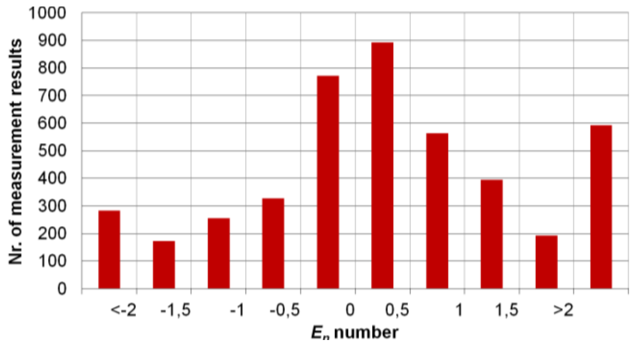

Figure 45: Histogram of E_n numbers for all the measurement results reported by the participants in the *CT Audit* intercomparison.

The total number of measurement results provided by the participants was 5308; 48.1% of them have $|E_n|<1$, 35.7% have $|E_n|>1$ and the remaining 16.2% are without uncertainty statement. From these data it is clear that almost half of measurement results have $|E_n| > 1$, which reveals an invalid evaluation of the uncertainty associated with the measurement result. This demonstrates that typically the participants have difficulties in evaluating measurement uncertainty appropriately and confirms that traceability of dimensional measurements is still a major challenge in CT scanning, even for experienced users.

4 Conclusions

The first international comparison of CT systems used in dimensional metrology produced a number of important results, including: (a) quantification of specific errors occurring in CT metrology, (b) evaluation of uncertainty calculation methods, (c) contribution to standardization of testing procedures, and (d) establishment of an international network of experts in CT dimensional metrology.

A general comment on the *CT Audit* results is that users have difficulties in evaluating the measurement uncertainty appropriately. Even though most participants perform CT dimensional measurements with sub-voxel accuracy (as demonstrated in [3]), traceability of CT measurements is still a major challenge, due to many different and complex error sources affecting CT measurements.

Acknowledgements

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References:

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