Doctoral Program in Metrology (35th Cycle)

Dimensional measurements with X-ray Computed Tomography and application to Cultural Heritage

By

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Politecnico di Torino 2023

Summary

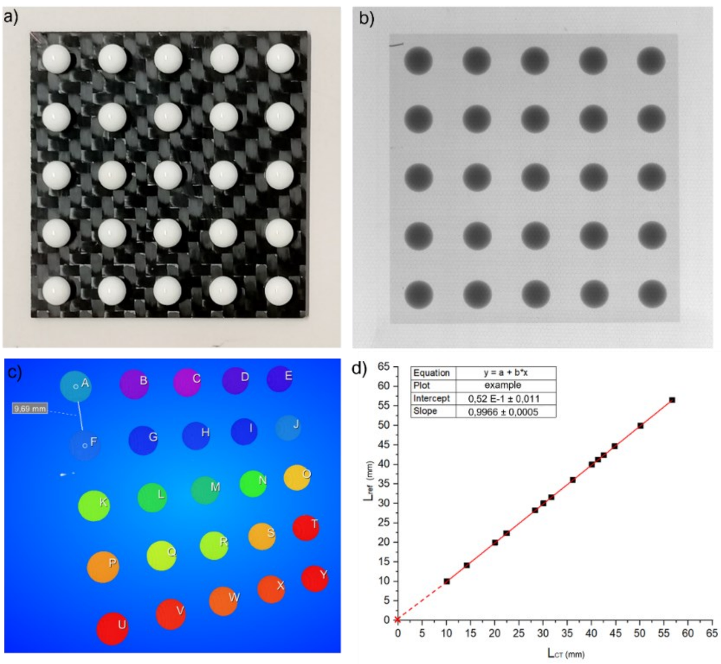
Computed Tomography (CT) is a non-invasive X-ray technique that makes it possible to obtain information about the internal structure of the object under study without taking samples. CT is now used in many applications for the study of different types of samples (industrial workpieces or archaeological artefacts). Since the data from CT contains complete volumetric information about the measured part, after reconstructing the two-dimensional projection images, it is possible to perform dimensional measurements of the external and internal structures and provide accurate dimensional and geometric information. For this reason, CT is often used for quality control in industrial applications, to detect defects in manufacturing and to perform measurements on parts with difficult-to-access internal microstructures. To achieve this goal, it is necessary to evaluate and analyse different aspects of a tomographic measurement, also using standard reference objects. This methodological approach is increasingly used in industry, but rarely in the field of cultural heritage; however, in some applications, a quantitative assessment of some features through dimensional CT measurements is of great importance. This is the case for wind instruments to obtain playable 3D printed replicas with acceptable tolerances compared to the originals. In this work, a woodwind instrument from the end of the 18th century, a "Piccolo", is studied.

For the reasons described above, the principles of the analysis of industrial dimensional CT were adopted for the characterisation of the parameters during the acquisition and reconstruction phases. To this end, two reference objects for the performance characterisation of CT systems were developed as part of this work: a "ball bar" and a "ball plate", which were used to identify, characterise and correct measurement errors in the CT volume and to evaluate the dimensional reproducibility of measurements. Their application seemed to be suitable for this task, especially the use of the ball plate, with which several CT tests were performed to analyse different CT parameters such as source voltage, magnification and sample orientation. Since the two objects are realised with ruby spheres and carbon fibres, volume segmentation of the spheres is easier for evaluating sphere-to-sphere distances, which is a robust quantity for determining a correction factor for CT dimensions. Using this quantity, a scale error correction method was implemented to correct the original reconstructed volume datasets by correcting the voxel size when the distance between sphere centres measured by CT is compared to calibrated measures (in this case, the reference

distances were measured using a non-contact structured light 3D volume scanner).

Once determined which factors affect dimensional CT measurements, the developed correction method was first applied to a LEGO brick, to test it on a regularly shaped object, and then to the musical instrument using the calibration objects scanned before and after the sample and together with it; a third test on the LEGO brick was performed using a calibrated feature of the sample itself. These tests were conducted to determine the best correction method.

At the same time, X-ray tomography has also been used to investigate and analyse different types of archeological artefacts from archaeological excavations and museum collections. These projects provided more important knowledge of the CT technique applied to different materials and with different aims, and different strategies have been implemented and used to achieve optimal results. During the PhD work, imaging analysis was also conducted using neutrons, which can provide complementary information with respect to X-rays for certain types of investigated material. In the framework of the INFN-CHNet NICHE project, a neutron imaging beamline was developed and characterised at the LENA centre in Pavia.



(a) CT calibration object (ball plate, a) and (b) a CT projection; (c) CT reconstructed 3D model where spheres are segmented and with an indication of center-to-center spheres indication and (d) example of correction factor calculation.