Quantification of the uncertainty due to the geometrical influence factors for dimensional measurements using computed tomography

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X-ray Computed Tomography (CT) is a non-destructive imaging technique that employs penetrating electromagnetic radiation to visualize, analyse and quantify both internal and external structures of a test object. In recent years, increased focus on the application of CT for dimensional quality control has motivated research on acceptance of CT scanners as metrological instruments. A main driving factor is the application of CT for non-destructive inspection of parts with complex inner geometries in relatively short time. Tomographic reconstruction generates a 3D volumetric representation of the measured object from a series of 2D projections acquired at different perspectives. Edge-based segmentation is used to define transitions between materials, which results in a surface model of the object. Surface sampling is then used to extract a point cloud representation of the surfaces, which can be used to perform coordinate measurements.

One of the more common tomographic reconstruction algorithms for cone-beam CT is filtered back-projection (FBP), which maps 2D projections onto 3D space. The accuracy of the reconstructed volume by FBP relies on the accurate knowledge of the geometrical CT acquisition parameters, *i.e.* relative position and orientation of X-ray source, rotation axis and detector. Calibration procedures provide users with estimates of the CT geometry. However, uncertainties in the estimated geometrical parameters propagate to uncertainties in the reconstructed volume and, consequently, to dimensional measurements performed on the volumetric data. Quantification and propagation of such sources of uncertainty must be considered to provide a complete uncertainty analysis and to establish confidence intervals for dimensional measurements obtained from volumetric data. Due to the complex dependence between geometrical parameters and dimensional measurements, analytical expressions linking geometrical parameters to dimensional measurements are currently not available; therefore, the conventional GUM method cannot be applied. The use of Monte Carlo (MC) computer simulation is a valuable alternative to the GUM method. However, the computational load associated with CT metrology chain does not allow a direct application of MC simulation. The required computational resources and time would be prohibitive once all image processing steps are included in the stochastic simulation.

In this study, we propose a simplified CT model for quantification of uncertainty in dimensional measurements due to the uncertainty in the parameters of the data acquisition geometry. Since dimensional measurements are performed on the point cloud corresponding to segmented surface, *i.e.* in coordinate space, we propose to omit the computationally expensive reconstruction of the full CT volume and quantify uncertainty directly in the coordinate space. During the CT reconstruction, each ray recorded by the detector is traced back to the measurement volume. If CT acquisition and reconstruction parameters are consistent, all the rays from different projections corresponding to one point in the measurement volume will intersect in this point. In the presence of deviation of parameters, the point will be back-projected as volumetric distribution of points. This distribution is used to determine a three-dimensional confidence interval for each point in the volume. The efficacy of the proposed approach was confirmed on simulated data in the presence of individual uncertainty contributors.