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Automated detection of artefacts for computed tomography in dimensional metrology

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Abstract

Artefacts within CT volume data have a large impact on the results of dimensional measurements. To avoid measurement deviations, it is therefore crucial to identify regions affected by artefacts. The presented method analyses the volume data in the proximity of an extracted surface point to calculate a Local Quality Value (LQV). Using this method, surface points affected by artefacts are identified and highlighted in 2D and 3D visualisations. As only the volume data and the extracted surface are required to calculate the LQV, no additional knowledge like a CAD model or a reference measurement is necessary and the analysis can be carried out automatically. CT scans of calibrated gauges blocks that exhibit large errors in the segmented surface dataset due to artefacts are used to demonstrate the capability of the presented method. It is shown that it is possible to increase the accuracy of dimensional measurements by considering the information provided by the LQV.

Keywords: dimensional metrology, computed tomography, artefacts, surface point quality, surface point uncertainty

1. Introduction

For about half a century now, computed tomography (CT) is being used in medicine and non-destructive testing (NDT). Additionally, in the last ten years, the application of computed tomography for dimensional metrology has become increasingly widespread, especially due to its ability to measure internal geometries non-destructively [1].

The quality of the CT volume data is crucial for all applications, as low data quality complicates or even inhibits a correct interpretation of the data. This applies in particular for CT in dimensional metrology, as the tolerances of the geometrical features to be measured are often in the range of a few micrometres.

To facilitate a dimensional measurement, it is necessary to determine the exact position of the surface from the transition from low to high grey values in the CT volume data. In this step, the information from the volume data is reduced to an extracted surface dataset. Naturally, a low quality of the volume data leads to an increased uncertainty of the extracted surface points. As a dimensional measurement is carried out by associating standard geometries to the surface data, the single point uncertainty is a dominant factor influencing the precision of the final measurement results. According to ISO 14253-1 [2], the measurement uncertainty has to be taken into consideration for the decision about the conformity of a part. Therefore, a low volume data quality ultimately complicates the conformity assessment.

A large variety of artefacts may decrease the quality of CT volume data, while their severity may vary locally within a single dataset. Examples for artefacts are beam hardening caused by the polychromatic spectrum of the X-rays, photon starvation due to long penetration lengths and/or heavily absorbing material of the part, noise, cone beam artefacts and artefacts caused by scattered radiation. A more complete overview of data artefacts in CT and possible countermeasures can be found elsewhere [3], [4], [5].

Keeping in mind that the tolerances for modern products are frequently very tight, it is crucial for the use of CT in manufacturing metrology that the volume data are of high quality. Even weak artefacts may render dimensional measurement results useless, as the required precision is not achieved. This is of greatest importance for the area of the volume data, from which the

surface data is determined, namely the voxels in the proximity of the surface of the part to be measured. Consequently, it is necessary to identify regions with data artefacts in the volume data, especially in the proximity of the extracted surface points.
Different approaches are known to quantify the quality of CT volume data automatically and objectively. These approaches use for example the modular transfer function (MTF) [6], examine the grey value distribution within the volume data [7], [8], or use a Bayesian classification [9]. Another approach marks voxels, that are affected by an artefact correction method, in an uncertainty map, as in these regions a decreased data quality is expected [10].

2. Local Quality Value

2.1 Overview

The Local Quality Value (LQV) was already introduced and described in another article [11]. The idea behind the LQV is to analyze the volume data in the proximity of an extracted surface point. For an ideal, artefact-free dataset, a symmetric, high-contrast, noise-free and sharp transition from low to high grey values perpendicular to the surface is expected, representing the transition from air to the material of the part. In general, artefacts within the volume data cause (frequently restricted to small regions) deviations from this ideal behaviour and therefore decrease the LQV, respectively increase the uncertainty of the surface point investigated. However, this also implies that areas with a low LQV are most likely affected by data artefacts. This makes the LQV a tool capable of detecting regions affected by artefacts within CT volume data.

2.2 Latest development stage of the method

Since the last article [11], the method has been further developed. The flexible algorithms to analyse the volume data were reworked to deliver more precise results for a broad range of different artefacts. Additionally, it is now possible to visualise the LQV within the volume data.
The results from a CT scan of two touching steel spheres (diameters of 6.0 mm and 5.0 mm; tube voltage of 130 kV) have already been presented in [11]. Due to the limited energy of the photons and beam hardening-effects, severe artefacts are present in the volume data. These artefacts cause deviations in the extracted surface dataset (a small gap between the spheres and deviations at the streaks, see Figure 1).

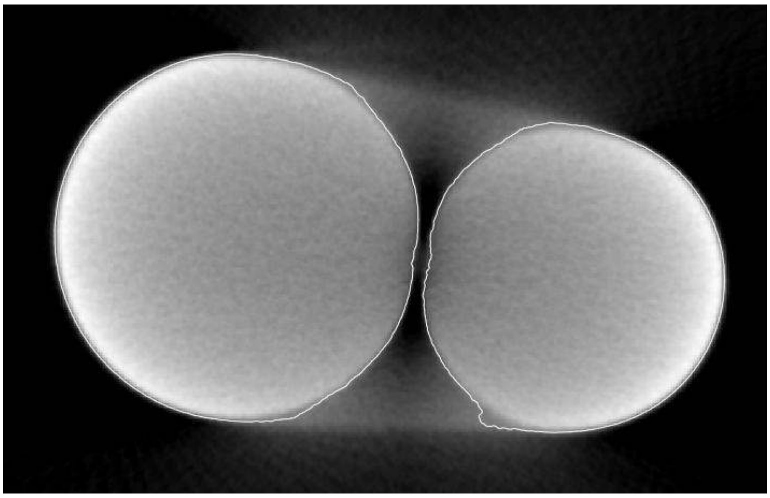

Figure 1. Cross section from a CT scan of two steel spheres.

Applying the algorithm to the dataset yields the results presented in Figure 2. The above mentioned areas that are affected by data artefacts are identified and highlighted according to the colour scale in yellow and red. Surface points of high quality (unaffected by artefacts for the most part) are marked in green.

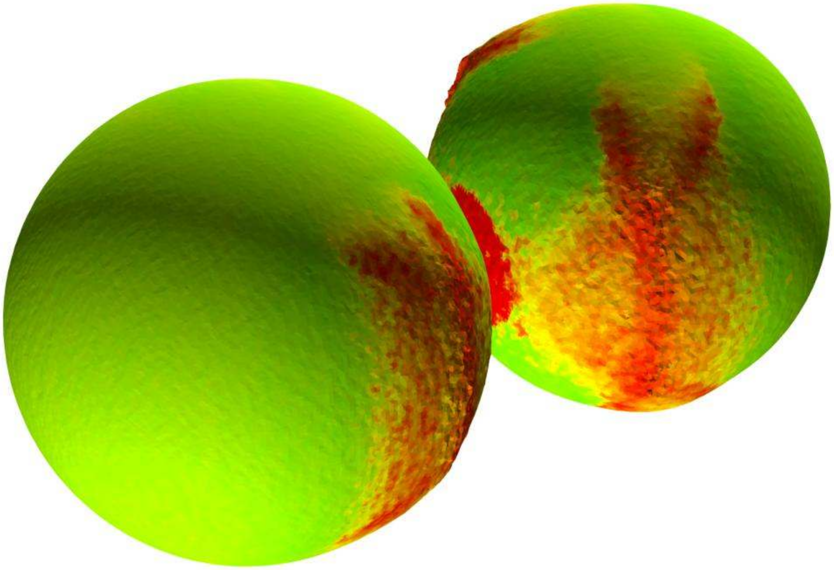

Figure 2. 3D visualisation of the calculated Local Quality Values. Yellow and red areas indicate regions of surface points affected by artefacts within the volume data.

The newly implemented 2D visualisation makes it possible to highlight the artefacts directly within the volume data (see Figure 3).

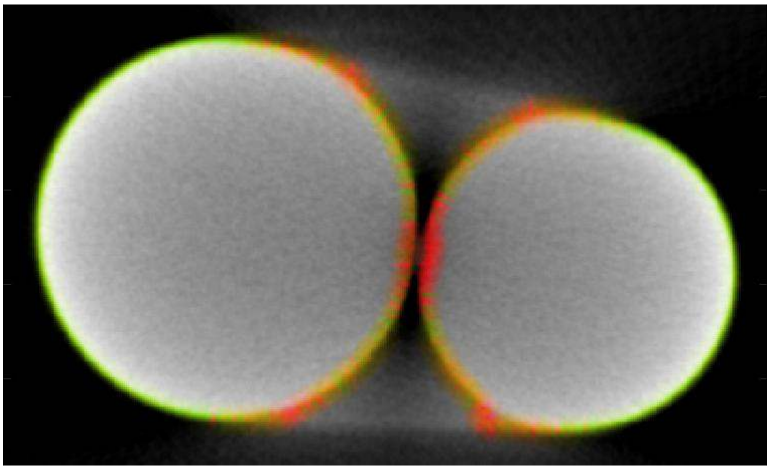

Figure 3. 2D visualisation of the calculated Local Quality Values.

2.3 Measurement of a gauge blocks

To demonstrate the capabilities of the method, two calibrated gauge blocks (steel; 1.10 mm and 2.00 mm; width of 9 mm; ISO 3650:1998 [12]) were scanned (16 µm voxel size; 130 kV tube voltage; 0.5 mm steel prefiltration). As it has been reported in [1], steel gauge blocks are objects difficult to measure. As expected, severe artefacts are present in the volume data (see Figure 4).

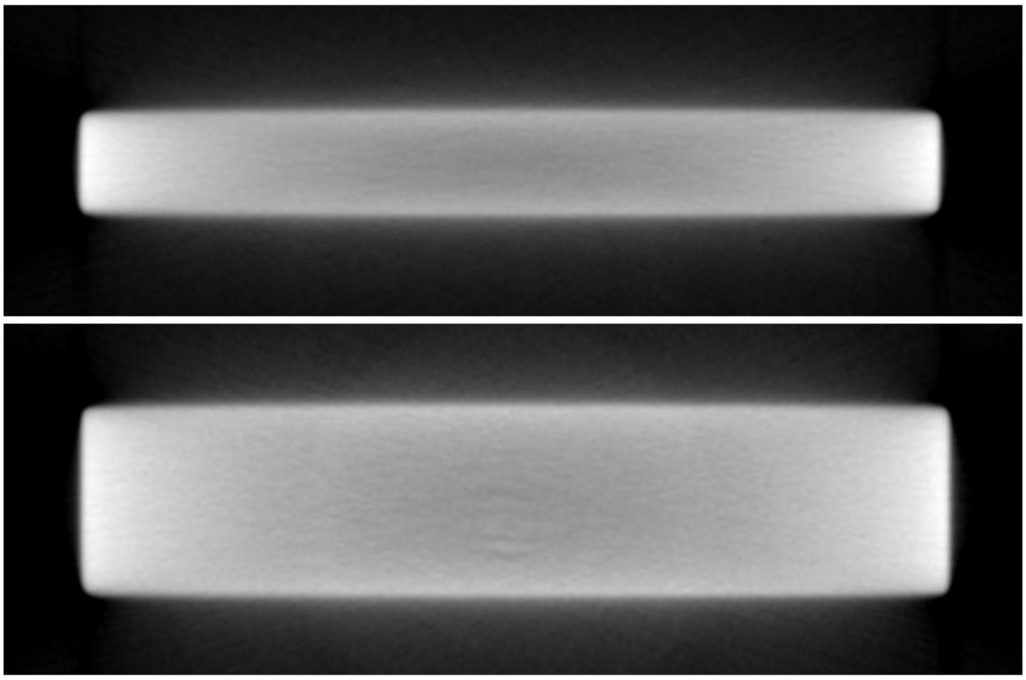

Figure 4. Cross sections from CT scans of two calibrated gauge blocks.

Subsequently, errors are present the extracted surface, as it is revealed by a nominal/actual comparison (carried out in VGStudio MAX) with the calibrated length of the gauge blocks (see Figure 5). In accordance to the results presented in [1], the largest deviations are detected near the centre of the end faces (surface points are detected too far outside the object) and at the edges (surface points are detected too far inside the object). However, in-between these areas (at the outer regions of the end sides), the surface determination delivers correct results.
In general, it is clearly visible that the deviations for the larger gauge block are larger (especially at the side faces).

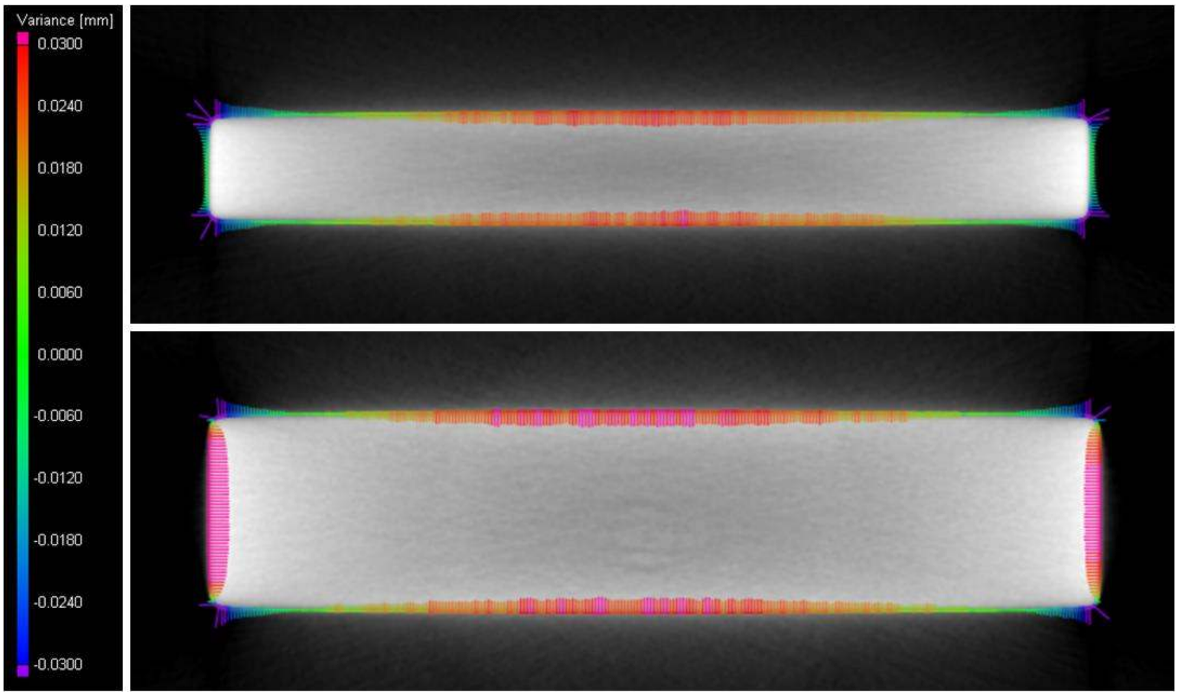

Figure 5. A nominal/actual comparison of the extracted surface with the calibrated length reveals errors of the extracted surface due to the artefacts.

2.4 Local Quality Value for CT scans of gauge blocks

The CT scans of the gauge blocks were analysed to determine the Local Quality Values. The results of the analysis (3D and 2D visualisation) are depicted in Figures 6 and 7.

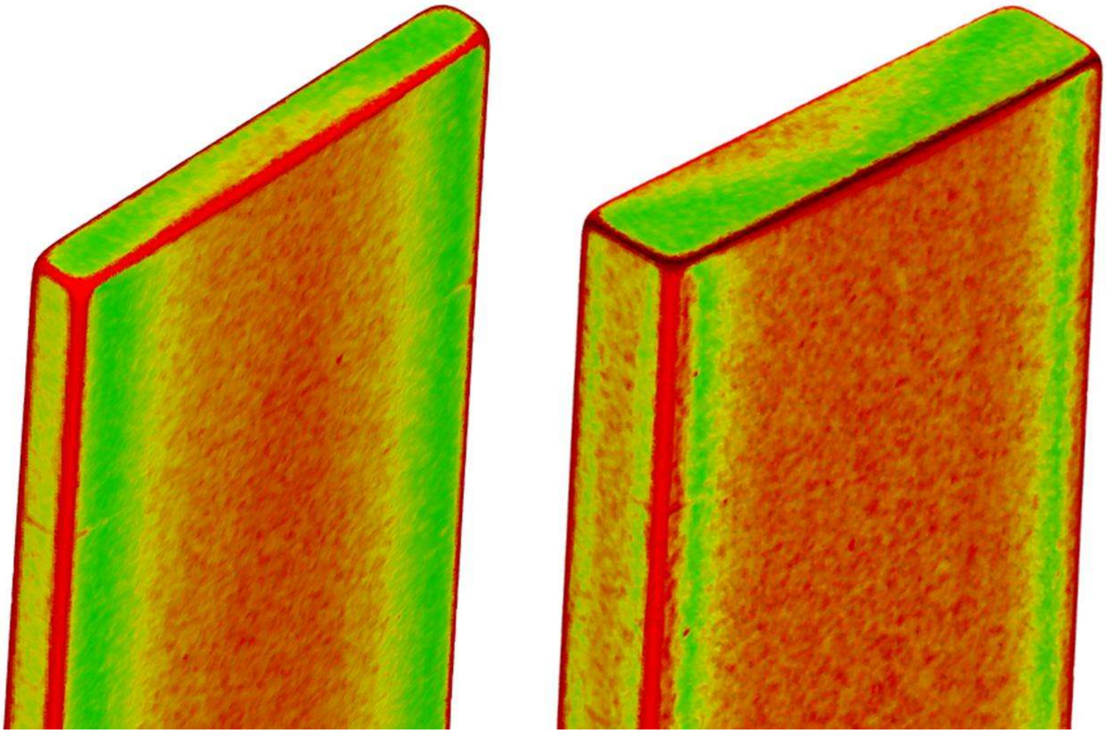

Figure 6. 3D visualisation of the calculated Local Quality Values.

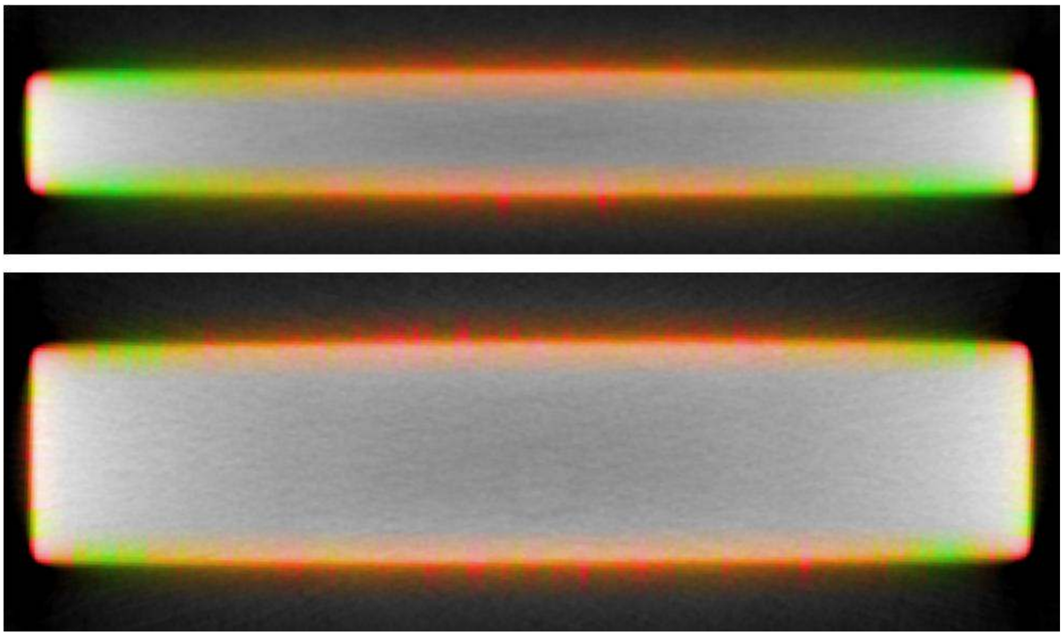

Figure 7. 2D visualisation of the calculated Local Quality Values.

Although only the information from the volume data and the extracted surface dataset and no additional knowledge (e.g. the calibrated lengths of the gauge blocks or CAD data) was used to calculate the Local Quality Values, the results show a very good agreement with the nominal/actual comparison:

- In general, the Local Quality Values are lower for the larger gauge block, as it is harder to penetrate by X-rays.
- Low Local Quality Values are assigned to areas with incorrectly extracted surface points (near the centre of the end faces and at the edges).
- For the areas with correctly extracted surface points (outer regions of the end sides), high Local Quality Values have been calculated.

This shows that the colour coded visualisation of the LQV allows a quick identification of regions affected by artefacts (and therefore of regions, where the data cannot be trusted when it comes to precise dimensional measurements) in the volume data.

2.5 Improving the accuracy of dimensional measurements

To demonstrate a possible application of the LQV, the length of the gauge blocks were measured using VGStudio MAX. Least square fits were carried out to associate planes with the surface points at the end faces extracted from the CT scans. In the next steps, the distance between the planes was calculated.
The conventional strategy takes all extracted surface points (regardless of their quality respectively single point uncertainty) at the end faces into consideration when carrying out the least square fit. In the presented method, only surface points with a LQV larger than a specific threshold were taken into consideration (all the surface points highlighted in red were neglected). Table 1 shows the results from the dimensional measurements. For the cases investigated, considering the LQV when carrying out the dimensional measurements significantly increased the accuracy of the measurements, as the measurement deviations were reduced by 50 % respectively 90 %.

Table 1. Results from length measurements of the gauges blocks.

evaluation strategy	measured length in mm	calibrated value in mm	measurement deviation in mm
conventional	1.124	1.100	**0.024**
	2.022	2.000	**0.022**
new method	1.098	1.100	**-0.002**
	1.989	2.000	**-0.011**

3. Conclusion

Artefacts are a common problem in industrial computed tomography. In dimensional metrology, they have a strong impact on surface determination and therefore on the final measurement results. If the real geometry of the part is known (e.g. the calibrated length of the gauge blocks), it is possible to carry out a nominal/actual comparison to identify errors of the extracted surface caused by artefacts.
However, in the majority of cases, this information is not available. An alternative approach is to analyse the volume data in the proximity of the extracted surface points and to assign a Local Quality Value to each surface point. Surface points with a low LQV indicate areas of increased single point uncertainty due to the negative effect of artefacts on surface

determination. As no additional information besides the volume data and the extracted surface is needed to calculate the LQV, it is an efficient approach for the detection of artefacts within the volume data. This enables an objective and locally resolved assessment of the reliability of the results drawn from a CT scan.
Two different methods to visualise the LQV (2D and 3D) that allow a clear highlighting of areas affected by artefacts have been presented. Additionally, it was shown that it is possible to increase the accuracy of dimensional measurements significantly when considering the additional information provided by the LQV.
Besides, other possible applications of the LQV are to increase the accuracy of data fusion by lower weighting or deletion of uncertain surface points, to use it as an evaluation criterion for measurement task specific optimisation of acquisition parameters or to estimate the single point uncertainty and the task specific measurement uncertainty by using the LQV as input information.

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