1.9.5. UNCERTAINTY VISUALIZATION OF COMPUTED TOMOGRAPHY DATASETS FROM COMPLEX COMPONENTS USING STATISTICAL ANALYSIS

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Introduction and motivation. Dimensional measurements concerning inner and outer geometry of a specimen is an integral part for the development and quality control of new industrial components. Usually tactile or optical coordinate measurement devices are widely spread in the area of metrology. However, both tactile and optical methods are limited to measuring accessible and visible parts of the component's surface. In order to eliminate this disadvantage, 3D computed tomography (3DCT) is used to support or even replace common methods of metrology.

Within the last decade industrial 3DCT was successfully introduced in industrial metrology. The principle of 3DCT, also referred to as cone beam CT, is summarized as follows: The specimen on the rotary plate is penetrated by X-rays. The X-ray radiation is attenuated on the way through the specimen and recorded in a penetration image. For each angular position of a 360 degree turn of the specimen, a penetration image containing the corresponding X-ray attenuation is generated. Using the generated penetration images a 3D grid of greyvalues is computed representing the spatial density distribution.

3DCT points out a solution for several problems of dimensional measurement, e.g. small parts, deformable components, inner geometry/hidden structures, optical reflective or transparent components. However 3DCT also introduces several method specific drawbacks: The most critical problem, which industrial 3DCT is currently facing is the issue of artefacts and their effects on the quality of the resulting dataset. Artefacts are artificial structures in the scan result, which do not correspond to reality. Industrial 3DCTs, which are based on cone beam geometry and matrix detectors, are prone to artefacts like noise-induced streaks, aliasing, beam hardening, partial volume and scattered radiation effects. Artefacts have direct influence on the quality and precision of dimensional measurement results and are therefore one of the most critical for metrology. Several groups are currently working on the topic of artefact reduction for 3DCT data of single material and more recently of multi material components.

In this work we focus on a related topic in the context of industrial metrology, which is usually neglected: The lack of uncertainty information of an extracted surface and in consequence of an extracted dimension. In typical industrial applications usually a single greyvalue threshold is used to distinguish between two materials. An isosurface is extracted along a global threshold, which is used as basis for further dimensional evaluations. More recently local surface extraction methods were presented, which try to adapt the surface extraction locally according to regional changes in the dataset. Both methods have in common that they extract a sharp border between the considered materials, leaving the quality of the interface aside. Neglecting the data's inherent uncertainty information leads to a complete loss of the interface quality in the resulting dataset.

Approach. In this work we present an approach, which allows to generate uncertainty information on industrial 3DCT data providing insight using different means of uncertainty visualization (see fig. 1). In order to generate information on uncertainty a statistical analysis is carried out. The statistical analysis consists of three major steps:

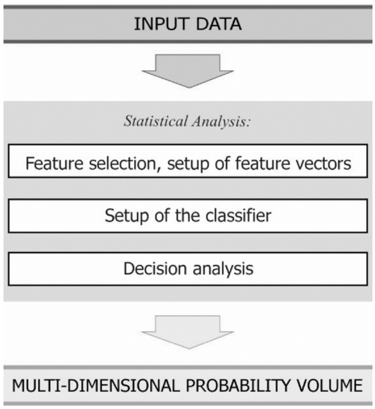

**Fig. 1. Principle scheme of the pipeline for statistical analysis of complex components.
Input: raw volume dataset, Output: multi-dimensional probability volume**

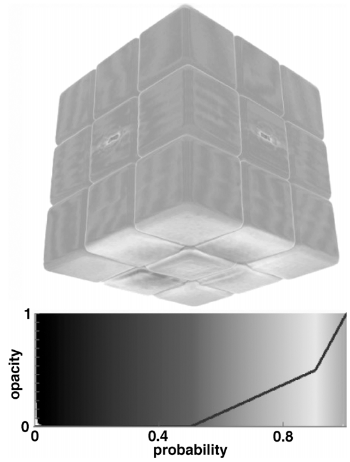

Fig. 2. Direct volume rendering (DVR) of a probability dataset using color and opacity transfer functions. The bottom area with elevated uncertainty is due to greyvalue modifications caused by the specimen holder

First of all, the features to set up the feature vectors have to be selected. These features have to be discriminative, easy to extract and after all reliable for the classification task. In the case of industrial 3DCT, greyvalues, gradient magnitudes, derivatives or similar features may be used. Each component of the feature vector contains the value of the feature at the considered position in the dataset.

Second, the feature vectors are distinguished and classified using a reliable classifier. A “good” classifier is commonly defined to be scale-, position- and orientation invariant. In the case of industrial 3DCT, the used features show a strong tendency to be continuously distributed. Therefore the classifiers are estimated as class conditional probability density functions, which are represented by Gaussian distributions for each material.

Third, the extraction of the spatial probabilities and in consequence the uncertainty information is accomplished using Bayesian classification. Bayes’ decision theorem allows to calculate a multidimensional probability volume of the input data, containing a vector of scalar probabilities for each single material at each spatial position of the dataset. The components of the probability vector describe the probability of a voxel of belonging to the corresponding material.

In order to depict the dataset’s uncertainty information different means of visualization are applied on the generated multidimensional probability dataset. Using direct volume rendering (DVR) the overall quality of a dataset may be evaluated, depicting the expected uncertainty of a dimensional measurement feature. Figure 2 shows the DVR of the generated probability volume applying the presented pipeline on a Rubik’s cube dataset. The spatial probabilities are color-coded using a color and opacity transfer function. Green depicts high probabilities of 95 – 100%, while red depicts probabilities down to 50% of the considered material. Elevated uncertainty is clearly visible in the bottom, which is because of greyvalue modifications due to the specimen holder.