Computed Tomography as a tool for industrial measurement

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Abstract. We present a prototype of a micro focus CT system that was designed especially for applications in metrology. The system comprises a high precision sample manipulator, a high resolution flat panel detector, and a stable micro focus X-ray source. Due to careful alignment and the choice of the hardware components the accuracy of the data is already very good. The accuracy is further enhanced using information from an additional shape measurement sensor. Furthermore, beam hardening and scattering effects are reduced through an automated artefact reduction algorithm. This leads to highly accurate CT data. We also present a software toolbox that allows automatic extraction of the object information as a triangulated point cloud. In addition, the toolbox provides tools for precise measurements of geometrical objects and for comparison of the measured data to the model data.

1. Introduction

In recent years X-ray Computed Tomography (CT) became a broadly established tool for non destructive inspection in industry. The main advantage is that complete objects can be digitalized and then analyzed without the need to destroy the object. Using a 2D X-ray detector a full 3D scan is possible with just one rotation of the object. The 3D-CT data consists of voxels, the 3D analogon of pixels. The values of the voxels roughly correspond to the density of the material. It is the perfect technique for qualitative analysis of complete parts as well as detecting and localising cracks, blow holes or cavities. Now, demand is rising to use CT also for quantitative geometric measurements. However, the use of traditional CT systems for metrology is difficult since the accuracy of the CT data is usually very low and moreover difficult to determine.

In order to establish CT-Technology as a tool for coordinate measurement the complete process-chain starting from the CT hard- and software up to the measurement must be examined and optimized for metrology. Therefore, the Fraunhofer Institutes Fraunhofer EZRT and Fraunhofer IPA have joined forces to develop the CT-technology further for metrological applications.

Currently a new prototype of a micro focus CT system is set up, especially built for applications in metrology. It will be presented in the following section. Algorithms are developed to reduce artefacts online as described in section 3. Furthermore, an additional shape measurement sensor will be integrated as described in section 4 and last but not least, a software toolbox for automatic extraction of the object information (section 5) as a triangulated point cloud and tools for precise measurements of geometrical objects and for comparison of the measured data to the model data are developed as presented in section 6.

2. The Prototype CT-System

The prototype system is designed to measure objects of a diameter of up to 100mm with an accuracy of better than 10µm in less then 30 minutes.

It consists of a high precision manipulator with three axes. The position accuracies of the axes are very high. Special care is also given to the rotation table and the alignment of the detector. Simulations [1] have shown that the rotation axis must be known precisely in all projections. A tilt of the axis, as small as one degree, resulted in a relative measurement error of 4%. The alignment of the detector in respect to the manipulator is better than 10µm. In order to achieve this, special tools and methods had to be used.

In order to record the radiographs a digital flat panel detector with up to 2k x 2k resolution is used. It is illuminated by an X-ray source which has a very stable and sharp focus. For the actual CT reconstruction, the Fraunhofer version of the Feldkamp [2] algorithm is used.

3 Online Artefact Reduction

No matter how accurate the alignment and the manipulator are, physical artefacts will always occur. The CT reconstruction process is based on the assumption that attenuation at a point is independent of the path by which the X-rays have reached the point. But this is true only for a beam consisting of mono-energetic radiation. For polyenergetic X-ray beams used in the field of nondestructive testing (NDT), the source spectrum becomes harder, while the beam propagates through the object, because lower energy photons are attenuated more strongly. This effect is called beam hardening (BH) and, if not corrected, gives rise to artefacts, i.e. observable errors in the reconstructed volume. Even in homogeneous objects it appears that inner regions are less dense than border areas. This effect is known as cupping artefact.

A correction method is the linearization technique, using a correction function to transform poly-energetic to mono-energetic projection data. In order to derive this function, usually a suited reference object is measured, an expensive and tedious process.
A better alternative is the iterative artefact reduction [3]. Here, the correction function is computed using several post-processing steps that are applied to the reconstructed volume. This method is further developed to correct the radiographs online using a priori information. It is presented in more detail in [4].

4. Additional Shape Measurement

Additionally a noncontacting 3D shape measurement system [5] by Fraunhofer IOF is integrated into the system. It is self calibrating and allows precise measurements of the shape of the objects surface. A big advantage is that the shape measurement system has a known uncertainty of better than 10µm. This allows us to use its data in order to judge the accuracy of the CT-data and by merging the two datasets, to improve the overall accuracy of the CT-data.

The CT-Rotation table is used to handle the object for both, the CT and the shape measurement. The two coordinate systems, the CT-system and the Stripe-System are registered so both systems deliver data in a common coordinate system.

5. Surface Extraction

A critical step in the whole process is the extraction of measurement points out of the voxel data. Usually a global threshold is used to extract an iso-surface of the border. In most cases, this threshold is determined manually or with user interaction [6]. That way the measurement results are user dependent and unreliable.

Furthermore, even artefact reduced CT-data of objects of uniform density show variations in grey value and the threshold that defines the border between object and air varies over the range of the volume.

In order to overcome these weak points, algorithms are developed, that automatically determine local thresholds by analysing the data using local statistics and neighbourhood relations. Also the results of the shape measurement system are considered in the computation of the local thresholds. These thresholds are then used by an adapted marching cube algorithm to extract the surface as a triangulated point cloud as STL file. In a post processing step, this point cloud can be corrected using the information of the shape measurement system.

In the iso-surface extraction process usually up to several million triangles are produced. In order to facilitate the handling of these files, software algorithms have been developed, that analyse the local curvature and based on that information reduce the number of triangles without significant loss of information.

6. Measurements

Now that the measurement points of the object are computed, actual measurements can be undertaken. A Software toolbox is developed that allows very precise measurement of geometric and combined features based on best fit [7]. Together with the curvature analysis, an automated reduction of the point cloud into a geometric description is possible.

Also a complete comparison of the measured point cloud to the model data is possible. In order to perform this comparison, usually the user has to register the two data sets either using 1-2-3 alignment or best fit. This is a time consuming process and due to the user interactivity not reproducible. To overcome this, automated routines for registration of the two data sets are developed. In the end, the user should be able to get a comparison report by the push of a single button.

7. Conclusion

In order to facilitate metrological applications using X-Ray computed tomography, a new CT system is being developed that covers the whole process chain. Starting from accurate CT hardware, online artefact reduction, optimised surface extraction using information of an additional shape measurement system and ending with the automated comparison of the object to model data, the whole process is optimised in respect to quality, accuracy, speed and automation. It will allow the digitization of an object and its comparison to model data with an accuracy better than 10µm in less than 30 minutes, fully automated.

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