Computed Tomography for Quality Inspection in Rapid Manufacturing

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Abstract

In many industrial sectors geometric inspection of complex parts is still solved by using Coordinate Measuring Machines (CMM). This process is quite time-consuming and expensive. In many cases a CMM can only be used with great disadvantages compared to non tactile technologies. Internal geometries of complex parts can only be digitised after the object is cut, which automatically leads to losses in information and difficulties in post-processing. Furthermore it results in a destroyed part, which is often not wanted, especially in the prototype-state of the product development process chain.
The large number of parts, which all have complex outer and inner geometry, and the increasing competition on the global market force the industry to find faster and cheaper inspection methods in order to bring their products to the market. In recent years, industry, in particular automotive industry and their suppliers, became more and more familiar with the computed tomography technology (CT). But this new technology has to be integrated into the existing workflow. This paper will demonstrate a way to integrate CT for measurement and quality inspection in the existing process chain and show how it can be used for different kinds of industrial applications in RPD.

Introduction

Within the last years computer assisted product design and engineering technologies such as 3D-CAD modelling, Reverse Engineering, Rapid Prototyping, Rapid Manufacturing, Finite Element Method analysis (FEM), simulation tools etc. have been developed to reduce time to market for new industrial and consumer products. Applying these technologies, several physical parts (design models, different kind of prototypes, first article parts etc.) have to be scanned during the product development process to generate the required virtual data. Therefore metrology techniques for volumetric data acquisition have become increasingly important. Furthermore, to improve the quality, reliability and safety of new products, powerful non-destructive testing devices are required for fast analysis at any stage of the product development process. But the most commonly available data acquisition technologies (tactile, optical, destructive) are limited. Industrial CT is the only non-destructive technique which is able to generate volumetric information including material properties of parts of any complexity containing inner structures. The availability of 3D-CT data at different stages of the product development process allows not only high quality surface modelling or geometrical inspection but also the analysis of flaws, material inhomogeneity or material structures and helps to optimise the manufacturing parameters especially for new materials.

CT Inspection process chain

In this section the process chain of the industrial CT is described, starting with the data acquisitions and direct output formats. The industrial CT technology and data acquisition differs from medical systems. Normally a complete 2D X-ray image is taken in one shot before the object is rotated through a small angle. By repeating this until one full turn is done, 2D-radiographies are taken from every angular position. Via mathematical reconstruction methods, including radiation artefact reduction, a so called voxel model can be generated which consists of volumetric units with associated grey values. This means, the resulting CT-data deliver a 3D grey value model of the captured object with all inner structures. Already this data format allows the investigation of the complete object. By cutting it in slices, it is possible to have a look on inner structures, contacts, material quality and more. Moreover standard image processing methods, e.g. like filters, can be used to evaluate these 2D-slice images.

Some commercial software tools offer the possibility of rendering the full voxel volume and of further 3D-data analysis e.g. arbitrary cuts through the model. But the voxel data information is also the input for the generation of 3D surfaces of the object. A well-known and useful instrument for this problem is the marching cubes algorithm. With a global threshold, it interpolates between the voxels the borderline of materials and generates triangle meshes of this surface, mostly given in STL-format or as point cloud in ASCII. In figure 2 an example of the described data formats is illustrated.

Figure 2: Photo of gripper (left), 2D-X-ray image (middle), cutted voxel model (right)

Now, these surface models can be used practically or evaluated in CAD- or simulation software. In the next step, measurement applications can process the surfaces or point cloud data. This process chain from the data acquisition to nominal actual comparison is shown in figure 1.

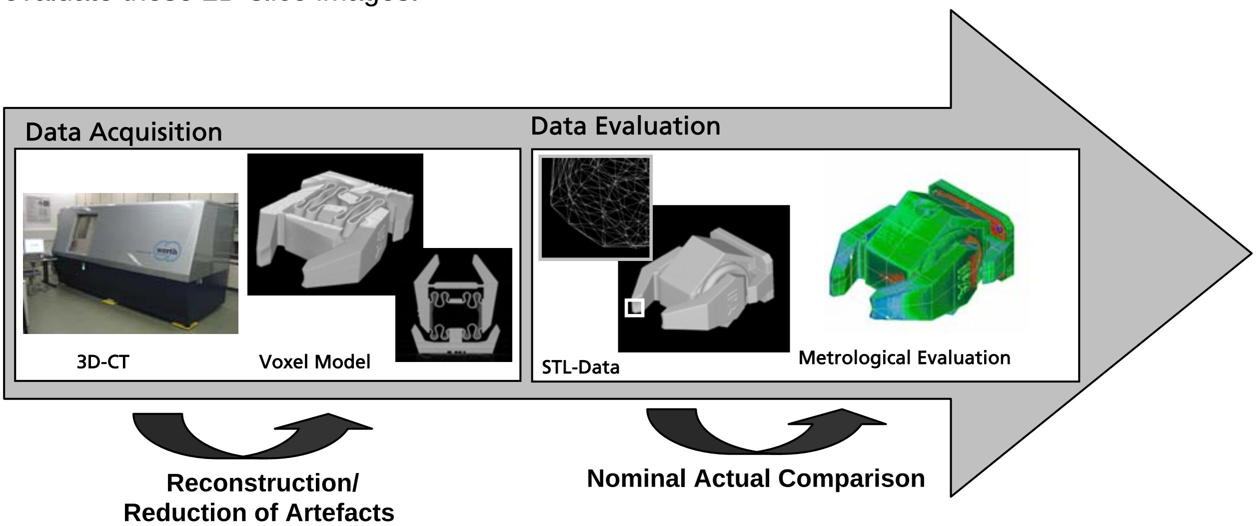

Figure 1: CT Inspection process chain

Integration of CT technology in the RPD process chain

At Fraunhofer IPA, the limits of what is currently possible using rapid processes are examined and increasingly approved for practical applications. Rapid technologies are generative manufacturing methods already familiar in the area of "Rapid Prototyping" in which CAD data is used to develop items directly layer-by-layer without necessitating any of the diversions represented by tools or semi-finished products. Tool-free construction also means the ability to build without any geometric restrictions. Thanks to developments by machine manufacturers both in terms of processes and material development, a wide variety of materials is available today for manufacturing using rapid technologies.

In order to do a non-destructive testing or complete inspection of a rapidly manufactured part using CT technology different forms of analysis are possible. After the CT scanning is performed there are now two different possibilities to proceed: visualisation or measurement. If visualisation is the goal, the next step is to import the scan-data into a visualisation software tool. By this means for example holes and cracks can be located quite easily by just browsing through the set of CT images or by cutting the reconstructed 3D voxel model (see figures 3 and 4).

Figure 3: slice of voxel model with unwanted residues of the production process

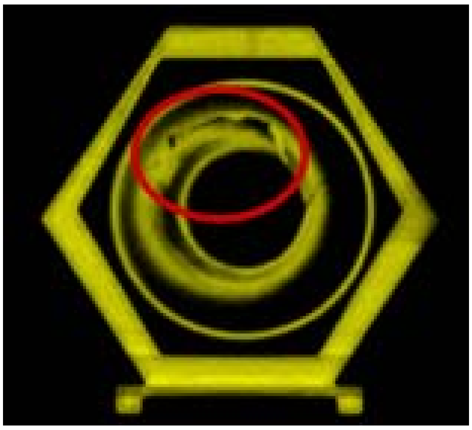

Figure 4: Slice of voxel model showing inner defects

In addition the 3D visualization of CT data is done by generating a mesh of triangles, representing the surface of the scanned part (see figure 5). The file format of such a triangulation is a so called STL and is well known in the world of Rapid Prototyping, as it is the input data format of most of the RP machines.

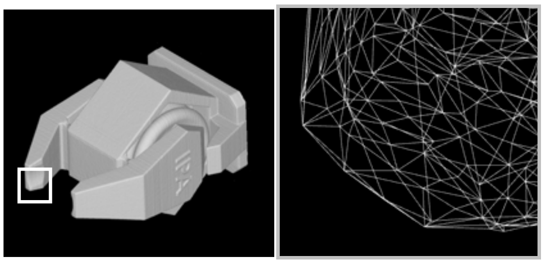

Figure 5: generated surface model (STL) and zoomed in selected part of the STL

Since the 3D-CT voxel models generated by modern CT systems are often bigger than 1 GByte the data handling for the surface extraction is a problem. The corresponding triangle meshes have millions of triangles, which are too large for many existing software systems. To make a further processing possible, it is necessary to reduce the meshes. But to preserve the relevant information and the precision, we have to choose intelligent methods, which take care of the object form and curvature. An adequate algorithm for this problem is the reduction using a quadratic error metric developed by [Garland 1997]. By realising this algorithm and an efficient memory management already good results can be reached.

Furthermore time and high memory requirements are associated directly, e.g. because of time consuming memory swapping. To avoid this, Fraunhofer IPA realised dynamic procedures. That means the voxels are loaded and the surface is generated slice by slice, while the resulting mesh is reduced automatically and in run-time. So, the surface stays small enough during the creation process which makes the practicable use of the process possible.

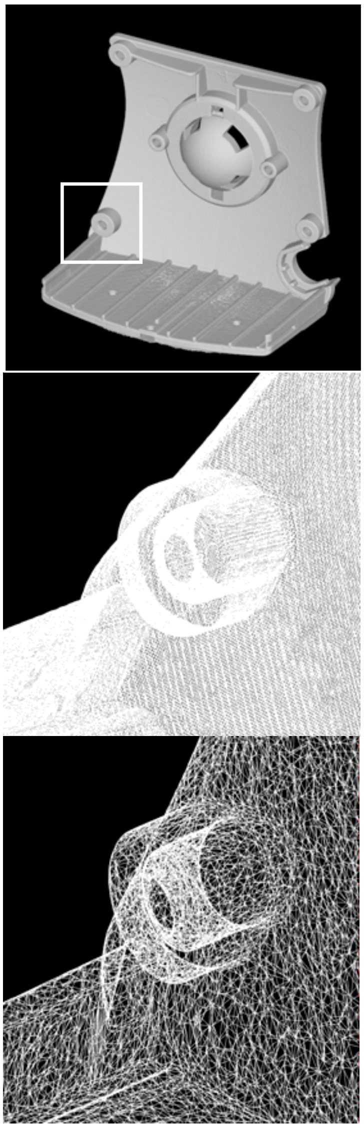

Figure 6: rendered STL-surface (above), shown as mesh without any reduction (4 million triangles) (middle), with reduction (260 000 triangles) (below)

The extracted surface data are also the basis for futher dimensional inspections. So a nominal actual comparison can be performed or also specific geometric features can be evaluated: Here Fraunhofer IPA has developed a software tool for the efficient and precise evaluation by best-fitting geometric primitives like planes, cylinders, cones or tori in the measure point cloud. In this way form tolerances can be calculated and are shown in a colour-coded visualisation (see figure 7).

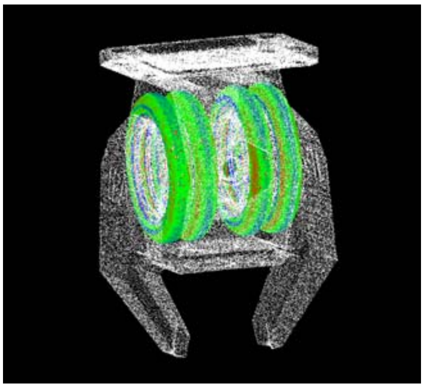

Figure 7: gripper with best-fitted inner tori and shown deviations

Summary

Computer Tomography is a powerful tool to analyse the complete geometry of complex parts of a wide range of different materials. The latest CT hard- and software developments lead to a growing number of industrial applications based on 3D CT technology. So CT technology gains more and more in importance for the industry.
In particular in the field of rapid manufacturing, quality control plays an essential role and here CT offers the possibility to inspect rapidly manufactured parts completely and without destroying them.

References

[Garland 1997] Michael Garland and Paul S. Heckbert: Surface Simplification Using Quadric Error Metrics; ACM Computer Graphics Proc., Annual Conference Series (SIGGRAPH ’97 Proceedings), S. 209-216, 1997