Additional Methods to Analyze Computer Tomography Data for Medical Purposes and Generatively Produced Technical Components

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Abstract. The result of a computer tomography (CT) record is an image layer stack, which can be applied for medical diagnostic purposes, as well for virtual 3D object representation (e.g. for a skull bone) depending on the used threshold values. Based on these representations, medical 3D objects could be easily produced by generative manufacturing processes. The additive manufacturing of individual implants is also based on the use of CT data for the representation of the remaining bone. This knowledge was further used for the evaluation of industrial CT data.
For technical applications, the industrial computer tomography becomes more and more important. Compared with devices from the medical area, industrial CT devices have a significantly higher radiation power and a much higher resolution. Thus, these data are not only suitable for the reconstruction of a 3D model in the sense of reverse engineering, but also for the inspection of components of metal workpieces (density differences, cavities, joint connection). The known CT evaluation procedures from medical use have been qualified and further modified in the research group. The developed software solution allows the generation of free-form sections through a layer image stack e.g. to evaluate the quality of a soldered connection in a tube. This procedure is also suitable to detect and determine density differences and the detachment of individual layers of a generative produced component. The topic is illustrated by selected practical examples.

Keywords: Computer tomography, Reverse Engineering, 3D-Inspection

1 INTRODUCTION

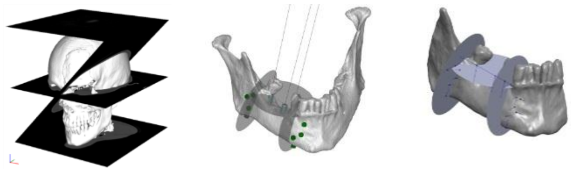
In the context of industrial manufacturing and assembly, continuous quality analysis is absolutely necessary to guarantee the production guidelines predefined in an operation. Optical 3D measuring systems for contactless measurement of component geometries and surfaces are increasingly being applied in the production process. These measuring techniques are also being used more and more often in combination with automated manufacturing supervision processes to maintain consistently high standards of quality [1].

adfa, p. 1, 2011.

One disadvantage of such systems is that it is only possible to inspect visible regions of the manufactured object. It is impossible to check inner areas of components or joints, such as welded, soldered or adhesive joints, by means of these nondestructive measuring techniques. Here, it makes sense to inspect the formation of blowholes or inclusions in pre-series manufacturing to optimise the production process or to safeguard the quality standards during series manufacturing [2].

Computer tomography (CT) is an imaging technology that provides a proven solution to this problem. State of the art in the medical environment, this technology has become more and more established in other technological fields. However, in mechanical engineering, we are faced with other requirements that must be fulfilled by the procedure, both in terms of the definition of the measuring task and strategy and with consideration of the issue of measuring uncertainty.

Because high accuracy is needed, micro CT systems are frequently used, resulting in huge data volumes in the form of high-resolution slice images. However, increases in the capacities of computer systems in recent years make image analysis, as well as 3D modelling, based on these slices images a promising technology. Consequently, it is necessary to develop efficient analysis strategies for data gathered by means of imaging techniques to find new strategies for quality assurance and process optimisation.



a) Model reconstruction and – processing

b) Execution of operation planning

c) Reverse engineering for design

Fig. 1. – Application of medical CT for operation planning [4]

The Reverse Engineering team at the Chair of Engineering Design and CAD of the Dresden University of Technology has been studying the analysis and screening of CT data, at first mainly from medicine [3, 4], for several years. An example is given in Fig. 1, in which a discrete 3D model is generated from CT data. In this process, the calculation of the iso-surfaces is performed by means of the Marching Cubes Algorithm [5]. In the next step, the segmented model of the lower jaw bone is used for operation planning and the design of an individual implant for the patient.

Due to industry demand, processing of CT image data in the technical realm is becoming more and more important. The paper elucidates opportunities for component investigation from CT data by means of efficient image processing strategies and methods using the example of a soldered tube joint.

2 FUNDAMENTALS

Computer tomography (CT) is an imaging technique. As a result of its application, we obtain stacks of slice images. As a rule, these data are available in the DICOM format, which has been established in medical applications. Apart from the intrinsic image data, it includes a file head, incorporating the most essential information about the generated image. Relevant information here includes patient data, image position and size, pixel or voxel distance and colour intensity. In the industrial realm, the images are frequently saved as raw data (RAW) or in a standardised image format, such as TIFF. For ongoing processing of the image data in the context of the three-dimensional object, additional geometric data (pixel distance, image position etc.) must be available separately. The colour intensity values of the image data, which depend on density, are saved in various colour intensities (8 bit and higher). In medical applications, a 12 bit scale is often used.

Characteristics	Medical CT of a skull	Industrial CT of a tube joint
Image format	DICOM	RAW, TIFF
Image size	512 x 512 pixels	991 x 991 pixels
Pixel size	0.44 x 0.44 mm	0.08 x 0.08 mm
Distance between images	1 mm	0.08 mm
Image number	238	851
Data volume	121 MB	1550 MB
Measuring volume	about 225 x 225 x 238 mm	about 80 x 80 x 68 mm

Table 1. - Comparison of a medical and an industrial CT data record

Table 1 offers an example outlining the difference between a medical CT and an industrial micro-CT based on two typical data records. In this representation, the differences in accuracy can be seen. It is possible for high-resolution industrial CTs to achieve measuring inaccuracy values of less than 80 µm. This results in a clearly higher data volume, which is frequently many times that of a medical CT (in the example shown in Table 1, it is approximately 13 times greater). It is very difficult to handle such a flood of data. Consequently, either we have to have available powerful computer systems capable of handling huge data volumes, or data stock has to be reduced, which, in turn, leads to losses in accuracy. For the latter option, one solution is to remove individual layers off the slice stack, thereby reducing image resolution or colour intensity.

Evaluation of CT data is often made more challenging by measuring noise and the formation of artefacts due to outshining. It is impossible to solve these problems simply by using individual image filters. For this reason, noise and artefact reduction are discussed in many publications [6].

In the following, the authors elucidate the CT data analysis methods implemented as program modules to read, process and display CT data developed at the Chair.

3 INSPECTION OF A SOLDERED TUBE JOINT

The task was to inspect two soldered flange joints on a pipe elbow in co-operation with a manufacturer and supplier of hydraulic hose pipes (see Fig. 2). The goal was to dimension the tube joint to withstand higher pressure values. It was first necessary to demonstrate impermeability. What this means, in practical terms, is that the quantity and size of blowholes or inclusions of air (area per image, volume in the slice stack) in the soldering joints have to be inspected in order to guarantee that a closed soldering circle of about 3…4 mm can be maintained. It is possible to execute the measurements using pre-series parts, sample parts from production, or parts returned due to complaints.

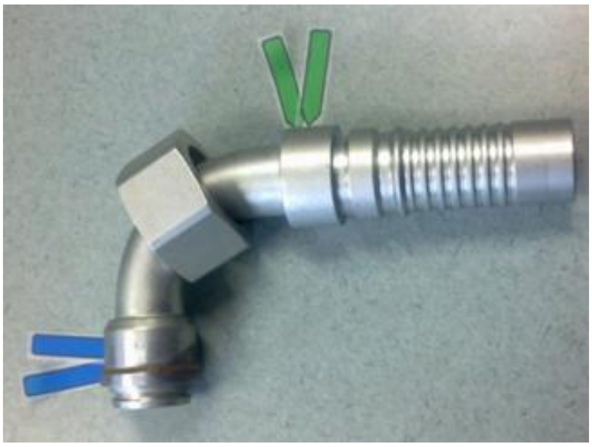


Fig. 2. - Tube joint with two soldered flanges

It was impossible to solve the problem by means of the optical measuring instruments available at the chair, so the measurement was performed by the measuring firm Werth Messtechnik GmbH by means of the WerthTomoScope 200. As a result, we obtained 2D slice images in the RAW format with a resolution of approximately 80 μm and a slice image distance of about 80 μm. Data volume per measuring position is about 1.5 GB assuming approximately 850 images [7].

3.1 Methodes for blowholds

A slice image resulting from the CT record is shown in Fig. 3. On the right side, one may clearly see inclusions in the region of the soldering joint. It is necessary to detect these positions and to quantify their area. If this is done using several images in the slice stack, we can draw conclusions regarding the blowholes' volume.

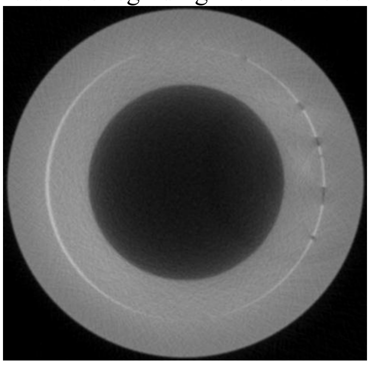
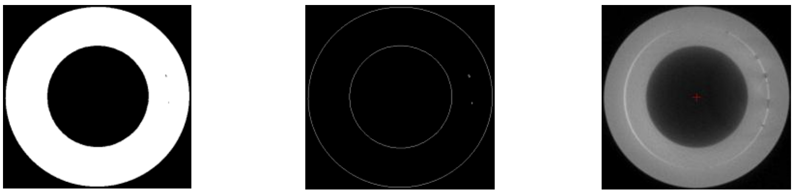


Fig. 3. – Slice image with blowholes in the soldering region

To guarantee that only the zone of the soldering joint was considered for the detection of air inclusions, instead of erroneously detecting inclusions in the tubes themselves, we first determined the tube's centre point in the cross section at first. This approach only works if the slices are perpendicular to the tube centre line, so that the internal contour of the tube forms a circle. The centre point is determined as follows (Fig. 4):

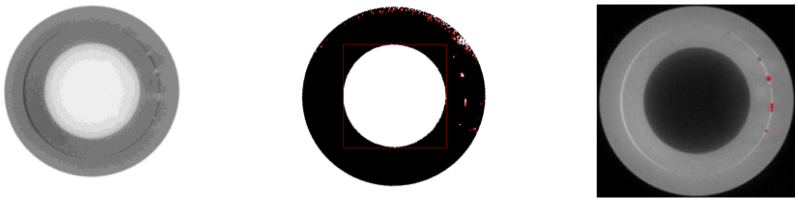
a) A threshold filter is applied. For our example, we chose a threshold of 1600 in the 12 bit colour range. As a result, we obtain a binary image.
b) Next, the outer and inner contours of the tube joint are segmented by a cut off filter.
c) Afterwards, the centre of the inner contour is determined by means of a Hough transformation based on the specification of the known tube inner diameter.



Application of a thresh-old filter	Application of a cut off filter	Centre point obtained by means of Hough transformation

Fig. 4. – Determination of the tube centre point in the slice image

Having determined the centre point, the blowholes are identified by defining a thresh-old. The sequence of the individual procedural steps is shown in Fig. 5.



Inverting of imgage and smoothing | Calculation of a threshold and “BLOBS” filter | Image with identified blowholes

Fig. 5. –Sequence of image filtering to identify blowholes

a) First, the image is inverted and smoothed.
b) Afterwards, the threshold is calculated. To do this, the image is subdivided into two segments based on a predefined value (in the example: 2240 at a colour intensity of 12 bits). Next, bright ranges in the image are localised by means of a “BLOBS“ filter [8]. This filter detects each separate object in an image. The objects are marked with polygons (in our example, rectangles).
c) Then the identified objects lying in the soldering region are found as a function of the calculated centre point and the given soldering circle diameter (= outer diameter of the inner tube). In this search, a tolerance is added to the soldering circle diameter (in our example: ±10%). Our goal is to record only the soldering joint rather than to detect inclusions in the tube itself. Now, the bright pixels (in our example with gray scale 4095) are identified inside the rectangle. They represent the air inclusions, for which we are searching. It is possible to quantify the area of the blowholes in the image using the known pixel width in both image directions.

The result of blowhole detection is especially dependent on the choice of an adequate threshold. This threshold has to be predefined by the user. If this threshold must be used over several slice images, the value has to be adjusted again if necessary.

3.2 3.2 Generation of 3D freeform cross sections

Analysis of planar (2D) cross sections using the CT data record does not allow for a complete analysis of cylindrical or freeform inner structures in one view. Especially when evaluating a soldered joint, alternative slice images provide a way to represent the area to be soldered in a manner rolled out on a plane. To do this, slice images are generated, which cope with Spline surfaces according to their mathematical representation. The basis for this approach is that all slice images with their local, two-dimensional co-ordinate systems <st> are transformed into a global co-ordinate system <xyz> (Fig. 6).

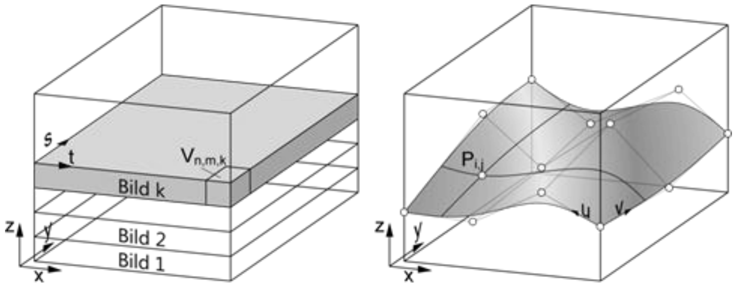


Fig. 6. –Representation of the slice images in a compound of slice images
Left: In a global reference co-ordinate system, all slice images are unambiguously defined. This way, indexing of a voxel V is possible (feasible) by indexing n, m, k. Right: In this global reference system, one may define an arbitrary Spline surface, whose discrete surface points P may be unambiguously transformed into the reference system.

Consequently, each image pixel of a slice image k can be represented as a three-dimensional voxel V by its co-ordinates [n,m,k]. This voxel is also defined in three-dimensional space. In this reference system, one may define any Spline surface of the type F(u,v) (Bezier, Hermite, etc.). In the case investigated here, we used Hermite surface patches, which are described by defining a mass point matrix Gab. It is possible to calculate discrete points Pi,j on the patch surface. These points are also defined in the global reference system. The quantity of points on the Spline surface in u- or in v directions determines the resolution of the desired slice image. The gray intensity values for one patch point can be determined by trilinear or tricubic interpolation of the gray intensity values of the adjacent voxel.

The procedure to create a freeform slice through the slice image stack can be described as follows:

1. In one or more CT slice images, the soldered joint is marked by a Spline curve (shown in red colour in Fig. 7). In this process, the quantity of defined curves is arbitrary. The quantity of supporting points per layer has to be the same in order to establish the mass point matrix Gab.

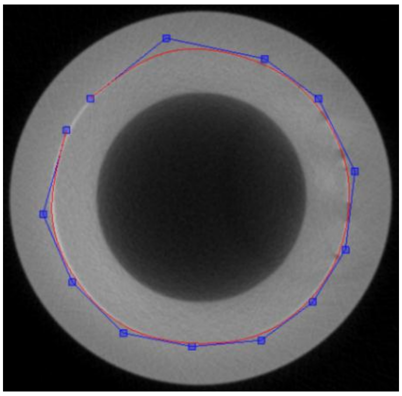


Fig. 7. – Marking of the soldered joint in the CT image

2. Now we can calculate the Spline surface with the help of the mass points. Subsequently, on this surface, discrete points are calculated by iteration of the <uv> coordinates. As a result, a point cloud of three-dimensional points is created, which can be visualised both in 2D as a curved slice image (Fig. 9), and in 3D space as a triangulised object (Fig. 8).

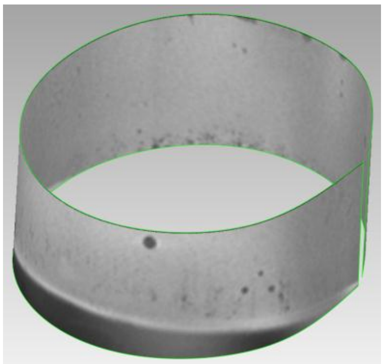


Fig. 8. - 3D cross section through a tube joint in the region of the soldering position

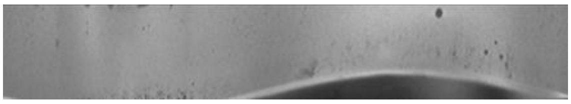


Fig. 9. – Rolled out cross section of a tube joint

Thus, it is now possible to make qualitative statements about the joint's impermeability. Furthermore, one may perform an analysis to measure, for example, the size of the blowhole on the generated slice image. However, if this cross section is executed repeatedly in the region of the soldering position, concentric to the originally defined cross section, then we obtain a number of these three-dimensional panorama views of the soldered joint. Visual inspection of these views in their entirety, without taking into account further evaluation strategies, may provide an initial estimate of impermeability.

4 SUMMARY

The use of computer tomography in industry offers a great potential for contactless and nondestructive recording of non-visible component regions. Since it is possible in this context to apply a significantly higher radiation level than for medical CTs, measuring uncertainty may be clearly reduced and data volumes concomitantly increased. Additionally, since the test objects are mostly stationary, as a rule, movement blurs can also be avoided [2].

The results provided by computer tomography can be used equally effectively for various tasks. In the narrower sense of Reverse Engineering, it is possible to use the data for modelling, for example. However, the most common applications come from measuring analyses, such as wall thickness analyses and test methods within the context of quality assurance. The example discussed in the paper shows that the implementation of efficient analysis strategies is essential for process monitoring and automation. The option of generating arbitrary freeform cross sections by means of a slice image stack particularly opens up new strategies for component investigation.

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