Parametric design in Reverse Engineering based on CT data

Dirk Hofmann, Philipp Sembdner, Stefan Holtzhausen, Christine Schöne, Ralph Stelzer
Department of Mechanical Engineering, Institute of Machine Elements and Machine Design, Dresden University of Technology, 01062 Dresden, Germany,
e-mail: {dirk.hofmann, philipp.sembdner, stefan.holtzhausen, christine.schoene, ralph.stelzer}@tu-dresden.de

Abstract
The paper will present a concept showing the use of CT data for creating a CAD model without having been previously transferred. It also introduces a prototype-like application demonstrating the methods practicability, as well as outlines the advantages in comparison with the state of the art techniques. Furthermore, predictions are also given regarding ongoing complements supporting the work of the designing engineer when using this technology.

Keywords: CT data, CAD, Reverse Engineering, Parametric design

1 Motivation
The trend towards lean, flexibly designed process flows in product development is also identifiable in the field of Reverse Engineering. The capture and analysis of components is being executed more and more using automated and non-destructive capturing methods, such as industrial use of computer tomography (CT) [1]. Making use of this technology, one can capture 3D information from inner geometries and structures, such as of channels and defined cavities, in order to detect and quantify in terms of size and number blowholes, inclusions and other porous material characteristics for purposes such as quality assurance [2]. Application-specific tools for a number of problems can be generated by means of basic image processing and 3D data analysis algorithms [3].

2 Reverse Engineering – Data conditioning
Reverse Engineering describes the procedure of recording a 3D object, conditioning the digitised data to create CAD models, and using such data in an ongoing process chain – from design through production planning and manufacturing up to product quality inspection [4].
The approach used up to now to condition and utilise CT data is to generate isosurfaces for a discrete model representation out of a image stack of CT data by means of established algorithms (such as Marching Cubes) [5]. In the next step, the polygons are edited, resulting in a mesh that is free of errors. The reverse engineering process is then carried out to obtain a solid model. This model is the basis for subsequent operations, such as design or simulation (see Figure 1) [6]. The disadvantage of this strategy results, among other things, from the fact that data transfer in the respective types of representation is connected with losses in information content and, consequently, in accuracy (e.g. due to the definition of thresholds, in the case of parts made of different materials). Furthermore disadvantages results in the use of several software tools that requires comprehensive knowledge and have a steep learning curve. It is also necessary to load and visualise all of the tomographic images of the solid data in order to convert it into discrete representation types. Depending on the properties (such as resolution or colour intensity) and the CT data quality, this process can be very costly computationally and time-consuming.

There are several options to bypass these difficulties. Either powerful computer systems can be used or the data volumes can be reduced. The latter can also result in lower accuracy and thus a loss of information. For design work due to quality assurance measures, such as the later manufacturing of a hole or the design modification in certain part regions (due to crack formation or material agglomeration), the use of limited areas of tomographic images would be one way to cope with this problem.
3 Engineered process chain

The task is to make use of individual tomographic images from the original CT data for CAD modeling without having converted them into other representation types [7].

When taking into account the existing functionalities of CAD systems, the feasibility of numerous functions was already verifiable using this strategy. However, for goal-oriented processing, the approach faces some obstacles that are illustrated in part by an example in the CAD system SolidWorks in Figure 2. These obstacles result from

- the limited opportunity to import image data or data from imaging methods (thus, for instance, it is impossible to import DICOM (.dcm) or raw data formats (.raw)),
- the inaccurate determination of body or part boundaries in the image and, as a result, a deviation from the original part structure (see Figure 2),
- an imprecise generation of contiguous shapes from known object boundaries – they form a poor design basis (see Figure 2),
- the fact that import and use of a number of connected tomographic images can only be done manually, as well as that only knowledge of the tomographic image distance or another geometry reference specifies the distance of one image from another (such as the height in a feature).

Moreover, reading and further processing of 3D information (such as the image distance) and other header data (such as the recording power etc.) is not possible. Furthermore, the images that are available can only be used in the form that they are stored in the volume. As a result, there is no way to use other Cartesian views for processing. It is also impossible to precisely determine either the location of the part in the image or their basic shapes. This means that there is the risk that, for example in the case of round-shaped parts, a circle or an ellipse cannot be unambiguously distinguished.
A modular application that can be integrated across the boundaries of CAx systems was generated to implement the concept. It consists of several functional modules, which are elucidated in Figure 3.

![Diagram](image)

**Figure 3: Modules of the developed application.**

The application begins via an interface in the CAD system through which the desired tomographic images can be selected and imported. In this process, it is possible to import not only the typical image data formats (such as .tiff and .png), but also those that are commonly used as a result of the CT recording, such as .dcm or .raw files. Information can also be read out of the header, or the properties of the tomographic images can be read out and made available for further use. Of the overall volume of recorded tomographic images, often only a small part is used for the object representation. A large part contains no information at all. Consequently it makes sense to focus on the object at an early point in time. Using an alignment, one can orientate the objects orthogonally to the Cartesian main axes and thus guarantee that an exact geometric representation is applied. Since a limited area is visualised, the tomographic images or their region can be selected. Afterwards, another limitation on the region of interest focussing on the range that is relevant to the respective task can be done. Thanks to the application of different image filters, in the next step, the edges of the part boundaries are determined on the selected tomographic images. In a follow-up object recognition process, known objects (such as lines, circles or similar) are searched for in the images and are represented. Finally, the parameters, such as the position and the location of centre points, diameter and length values of the objects detected are transferred to the CAD system via the add-in function, and a sketch is generated. The sketch, in turn, is available for later modelling and thus the task at hand.
This variant is advantageous insofar as the CAD system application can also be used and integrated also beyond the original purpose. Consequently, it can also be applied to other tasks in the CAx environment. The modular structure makes it possible to extend functionalities aimed at task-oriented CT data conditioning and processing. Thus, it is not only possible to consciously apply diverse standard target system functions, such as import and export of different data formats, but also the generation of auxiliary and reference elements like axes and planes to the functional scope of the CAD system used in the project described in this paper. Consequently, these functions do not have to be integrated later on. This way the designing engineers could remain in their original working environment (field of action, typical procedures) and does not need to put time and effort into becoming familiar with other systems or procedures to convert data from other systems.

4 Demonstrator

A prototype application from an industrial environment that illustrates the concept explained here and is based on the process chain described is depicted in the following. The prototype was integrated using the SDK (Software Development Kit) of the SolidWorks CAD software and can be activated via a button.

First the tomographic images are selected specifically according to their size and the information content included in the images. A preview supports the preselection of the relevant region in the form of one or several tomographic images. What is important here is that when selecting more than one tomographic image, only contiguous regions are used to provide a homogeneous data record and, ultimately, the part (see Figure 4). During the import procedure, additional information, such as the tomographic image distance or header data, is also captured.

![Launch application window](image)

After having imported the selected tomographic images, their content is visualised along the three Cartesian main axes. Frequently, only a small portion of the measured volume is fully used so it seems reasonable to reduce the tomographic image stack. To provide a suitable size to cut, the part location in the data record has to be checked according to its alignment. Parts are often deliberately subjected to tomography in a skewed position relative to the building space arrangement to provide a very low beam reduction due to summing up of part thicknesses or to avoid the risk of artifact formation. However, as a consequence, the parts are also shown in the data record in a skewed position. To obtain a positioning that generally corresponds to the Cartesian main axes, the data record can be rotated or turned by means of a scroll bar and in this way the parts can be pre-aligned. Following this method, a new coordinate system is defined, and a newly aligned image stack is thereby generated. Furthermore, a range including the essential part information (see Figure 5), can be selected via boundaries. As a result, the aligned and reduced data record is recalculated and visualised.

![Figure 4: Launch application (e. g. CAD system SolidWorks)](image)
After having limited the tomographic images only to the object range, the region relevant to processing by design is defined. The desired image or region is selected by means of scroll bars to pass through the image stack. It is possible to delimit a specific region in order to carry out task-oriented manufacturing such as to produce a thread hole. Delimitation is achieved by setting points of support that are connected to a spline. Based on this spline, targeted requests can be created, such as to search for objects inside or outside this defined region. Using several edge detecting methods (like the Canny filter), the part contour can be determined almost exactly in the selected area. To obtain contiguous shapes at the end, objects are also recognised by a variety of different methods, too (such as the Hough transformation) (see Figure 6). For the example in this paper, edge detection and object detection were performed by means of the Open-Source-Framework Aforge.Net and EmguCV (based on OpenCV), which comprises a large collection of libraries in the field of image editing and processing, particularly related to filtering techniques and image recognition [8, 9].

After having created the desired objects, the parameters (such as coordinates of the circle centre points, diameter values etc.) are exported to SolidWorks through the add-in function. This step provides a sketch in the CAD system with defined references (see Figure 7).

The sketch, in turn, is the basis for design tasks, such as for an adaption or change in design. To do this, all available functionalities of the CAD system can be utilised. The result is an application through which history-based parametric designs can be generated based on CT data.
5 Summary and outlook

This paper describes a concept for the parametric design of CT data. In the introduction, the previous strategy and its drawbacks were explained, and a solution approach was deployed by means of a process chain. The implementation of the approach was elucidated by means of a demonstrator that includes purposeful functionalities for CT data conditioning and processing and can be integrated into an existing CAD system.

Current projects are focused on the refinement and addition of individual functionalities (e.g. alignment, selection of segmenting/region of interest) of this application. Furthermore, the edge and contour recognition functions are constantly being refined to reproduce the desired part shape as exactly as possible. Additionally, a task- and thus function-oriented integration of individual virtual assistants (Wizard) whose task is to support the designing engineer in the different processing steps, will be implemented.

References


