

ACQUISITION OF 3D MODELS OF PARTS BY REVERSE ENGINEERING PROCESS

Martina HAJKOVÁ¹, Róbert DRLIČKA¹, Martin KOTUS¹, Monika TÖRÖKOVÁ², Juraj CANDRÁK

¹*Institute of Design and Engineering Technology, Faculty of Engineering, SUA in Nitra, Tr. A. Hlinku 2, 949 76 Nitra, Slovakia*

²*Department of Computer Aided Manufacturing Technologies, Faculty of Manufacturing Technologies of the Technical University of Kosice with a seat in Prešov, Bayerova 1, 080 01 Prešov, Slovakia*

Abstract

Currently, there are many situations in which we do not have documentation for some element, object, and we need it for various reasons. The article describes the procedure of using data from 3D scanning in a non-contact way for the reconstruction of a 3D model in modeling CAD software. The degree of approximation is determined by comparing the 3D model and the 3D scan. The accuracy of the work is checked by comparing the 3D model with the original CAD data. Obtained models can serve as data for computer-aided production, or digital imaging, for example, in virtual reality.

Key words: object; 3D scanning, CAD software; data inspection.

INTRODUCTION

Reverse engineering is a common approach in many fields, such as software engineering, computer, electronics, chemical industry. It is also used in automotive or general engineering production (Babjak, 2006). Reverse engineering does not only apply to processes working with material objects, but its application is known primarily in the areas of software, where it involves the examination of codes and processes through analytical procedures.

In engineering, we understand that reverse engineering (RE) as the process of duplicating an existing component, assembly or product, without drawings, documentation or a computer model being available. However, the possibilities of using RE technologies go beyond the scope of product design, with appropriate application they can also be used as a tool for design, safety and production management (Dado et al., 2018). A typical example is the use of 3D scanners in production lines as a tool for quality control when comparing actually produced parts with production documentation, or 3D CAD models. In this way, it is then possible, for example, to determine the rate of tool wear in a quick way, moreover, without the need to interrupt the production process. Suitable device with advanced software support can scan the physical product within a few minutes, compare it with the CAD model and even automatically generate an inspection report (Babjak, 2006). 3D scanning processes can be used to generate inspection reports, verify CAD models, create digital objects for virtual and mixed reality.

The aim of the paper is to describe the process of creating a digital 3D model of a component using reverse engineering technologies.

MATERIALS AND METHODS

Engineering is the process of designing, manufacturing and maintaining products, assemblies and systems. Standard engineering („forward engineering“) is the traditional process of moving from high-level abstractions and logical designs to the physical system implementation. Definition of reverse engineering is the process of obtaining a geometric CAD model from 3D points acquired by scanning existing parts/products. In reverse engineering, the physical model is the source of information for the CAD model (Fig. 1).

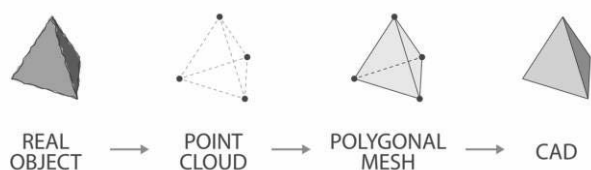


Fig. 1 3D Reverse engineering from real object to CAD

The starting point for creating any model using RE is to obtain input data in the form of spatial coordinates of the surfaces of the object (cloud of points). There are many principles, procedures and devices for obtaining this geometric data. Currently, non-contact optical 3D scanners are readily available, most often working on the principle of triangulation, optical interferometry, or measuring the time of flight of modulated light (*Telišková et al., 2018*). The light source can project light patterns or lines and have the nature of structured ambient light or laser beams of different colours and intensities. The simplest devices are starting at the price of several hundred euros, while serious quality can be obtained with devices costing couple of thousand euros.

For our experimental work, we used a dual-camera HP 3D SLS PRO S3 device using 3D triangulation using a structured light beam emitted by a projector and captured on a surface by 2 industrial cameras. It is a static system requiring subsequent positioning of the object and scanning in these positions, followed by combining individual scans. By merging these scans in the program, a closed polygon is created. The system offers the possibility of using interpolation of gaps and smoothing filters, which can make scanning even more accurate. The 3D model obtained in this way can be saved, including the scanned texture, in various formats, e.g. stl, obj, plt.

We used Rhinoceros 3D software to create a CAD model from the scanned data. It is a middle-range 3D CAD system with a wide application area, including mechanical engineering. Rhinoceros specializes in free-form non-uniform rational B-spline (NURBS) modelling. There is also over 100 third-party plug-ins available, including rendering plug-ins for Maxwell Render, V-Ray, Thea and lots of other engines. Additional plug-ins for CAM and CNC milling are available as well. Its advantages are an affordable price and a favourable licensing policy for schools and students, allowing keep a full license even after the end of the academic career. We used the Mesh2Surface plugin to work with the point cloud. Mesh2Surface simplifies reverse engineering in Rhinoceros and helps convert digitized objects from non-contact scanners to CAD models. The typical workflow comprises importing data into Rhinoceros and Mesh2Surface, alignment, creating shapes, splitting surfaces, creating a solid model, rounding edges and exporting CAD model. The plugin offers a number of useful functions: extraction of shapes such as surfaces, spheres, cones, cylinders and free-form surfaces, object symmetry search, object alignment to a coordinate system. To obtain the geometric elements of the model, we combined the use of automated recognition and creation of geometric primitives with manual creation of geometry by translating the forming curve of the surface by cutting a polygonal mesh of points. We supplemented the basic shape with shape and cosmetic elements using standard modelling tools.

We compared the model created in this way with the original CAD data using the freely available version of the GOM Inspect software for 3D point cloud inspection and mesh processing enabling dimensional analysis of 3D point clouds obtained from optical scanners, laser scanners, computed tomography CT and other sources.

RESULTS AND DISCUSSION

Basic shape of the selected part (Fig. 2a) combines a simple cylindrical surface and a shaped rotary surface. It was manufactured by machining and has a smooth and shiny surface. The latter is problematic for scanning with normal structured light due to unwanted light reflections. Therefore we covered it with white chalk spray for scanning purposes (Fig. 2b). The spray adds a layer to the surface causing a uniformly distributed systematic change in dimensions of the order of thousandths to hundreds of mm, which is below or on par of the level of the best accuracy of the scanner.

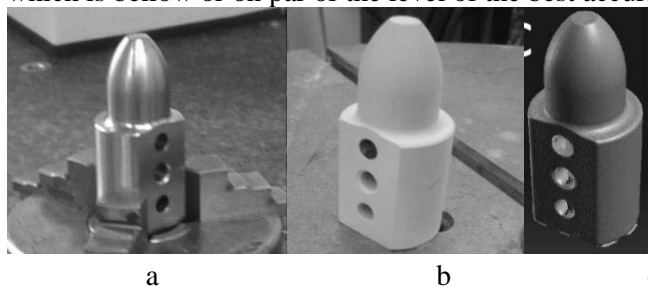


Fig. 2 Machined sample (a), coated sample (b), scanned sample (c)

After a successful scan (Fig. 2c), we imported the data in the .obj format into the Rhinoceros program.

Work with the mesh is handled by the Mes2Surface plug-in module, simplifying the initial alignment of the scan with the CAD coordinate system. Adjustment of the position was done by aligning the selected or created element with the selected plane of the modeller (Fig. 3a).

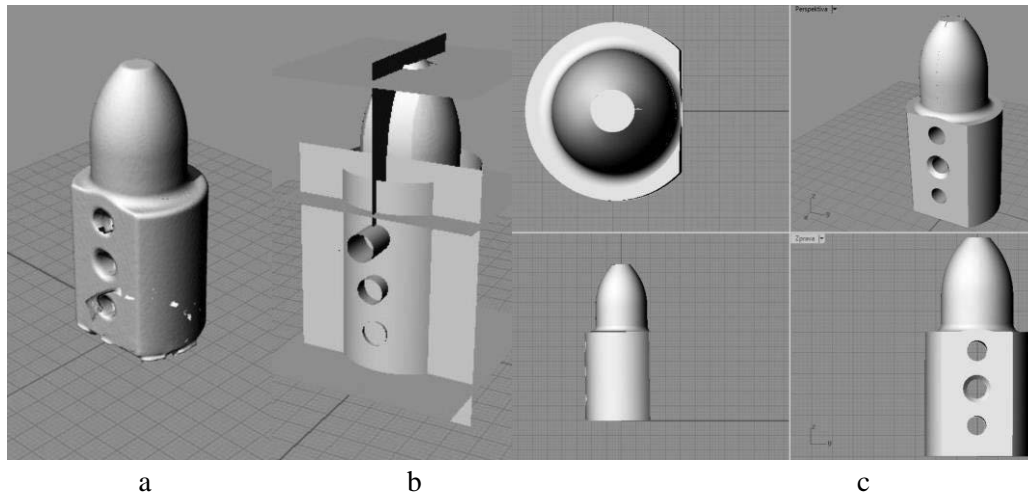


Fig. 3 Polygonal mesh aligned to WCS in Rhinoceros (a), surfaces wrapping the mesh (b), resulting 3D model (c)

Designing on the basis of a polygonal mesh starts in selection of the area for translation of the basic geometric entity. The surface creation wizard (Magic Wang) then allows the selection of the type of geometric element to be created, in our case a cylindrical surface, the shape and dimensions of which can be modified interactively. To create a continuous model, it is optimal to generate the basic surfaces so that they intersect each other and later cut them at the intersections. The surface is then created with the Create Surface tool. In addition to the cylindrical surface, we used plane surfaces (Plane) for design and the Free Form tool for the shaped surface.

The result of these steps can be seen in Fig. 3b. The last step is to trim the protruding parts forming the surfaces in the intersections, which is a routine matter. The resulting model is shown in Fig. 3c.

Comparing the created model with the source CAD data, we found a complex deviation consisting mainly of deviations of the physical object manufacturing, errors created in the process of scanning and scan processing, as well as errors in the creation of geometry based on the scan. The comparison process in the GOM Inspect program includes the definition of the nominal geometry (of the original CAD model), loading of the compared model (created by the reverse engineering process), the choice of the model alignment method and conditions. We can see the result in Figs. 4a, 4b.

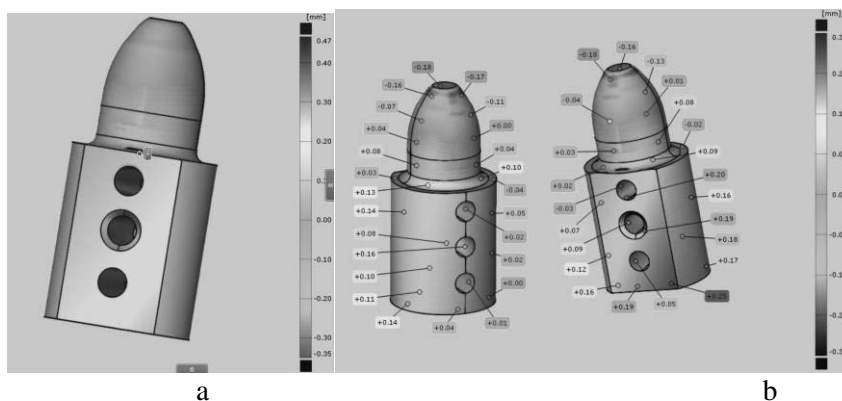


Fig. 4 Colour coded differences of original CAD model and RE acquired model surfaces (a) with error values labels (b).

Before the scanning process, we applied two coats of chalk spray to the part. This layer had a certain thickness. According to *Dokoupil (2013)*, who dealt in his work with the determination of measurement



deviations due to the use of chalk and titanium matting powder, the value of the thickness of one layer of chalk spray was 0.003 mm. However, with the second layer of spray, the thickness increased largely and reached a value of 0.031 mm. The scanning device itself has a certain value of accuracy (0.1% of the object size, up to 0.05 mm). Another source for the inaccuracies generation was the composition process of scans and the design process. In his work, *Grujičić (2014)* investigated the accuracy of the designing itself on the obtained cloud of points. The maximum value of deviations in his case reached - 0.14 mm and +0.12 mm. However, when considering the digitization of objects for graphic use, for example in virtual and mixed reality, the use of special metrology scanners is unnecessarily expensive (*Török et al., 2017*).

CONCLUSIONS

Based on the output of the GOM Inspect program in the form of a colour scheme of the part with tolerances, we found largest cumulative upward deviation value of +0.25 mm and the largest downward deviation value of -0.18 mm. It can be stated we have created a fairly accurate 3D model with very small values of deviations compared to the real part. These deviation values are within the general tolerances according to STN EN 22768-1 and STN EN 22768-2 standards.

In addition to the above-mentioned shortcomings, scanning with the mentioned technology also has a problem with uniform shapes due to a small number of reference points for composing scans, which then need to be added by as reflecting scanning targets. Higher class hand scanners with blue laser usually perform better in direct light conditions and/or reflective surface due to better contrast. The means and procedure presented in the paper are completely sufficient for obtaining sufficiently accurate models for virtual environments. Considering the number of objects, the efficiency of the mesh-based design process is rather important. There are also more advanced software tools with more sophisticated algorithms for automated recognition of elementary elements in scans, but they are an order of magnitude more expensive. However, currently there is no tool for fully automated RE process available. Nevertheless, the RE process remains very important, since the mesh files are usually several orders of magnitude larger than the corresponding CAD model files.

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Corresponding author:

doc. Ing. Martin Kotus, PhD., Institute of Design and Engineering Technology, Faculty of Engineering, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, Nitra, 949 76, Slovak Republic, phone: +421 37 641 5689, e-mail: martin.kotus@uniag.sk