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The possibility of using 3D laser scanning as support for reverse engineering

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Abstract: This paper describes laser scanning technology as a tool for reverse engineering. The content includes theoretical starting points and knowledge about 3D models, reverse engineering and laser scanning. Furthermore, a method of reverse engineering using 3D laser scanning is proposed, compared with the standard reverse engineering process. The main contribution is comparing the use of hardware in the form of a scanner and software for post-processing.

1 Introduction

Reverse engineering using 3D laser scanning has been known in industrial practice for more than ten years. However, technologies, hardware and software solutions developed a lot during these ten years. Organizations of various natures have designed and applied reverse engineering process and combinations. With the advent of 3D laser scanning, this process has become faster and more efficient. This work aims to describe what is represented by the term 3D model, reverse engineering and 3D laser scanning. The following section describes the proposed reverse engineering process using FARO Focus hardware and software in conjunction with Bentley's MicroStationV8 graphics software. At the end of the work, a comparison of the proposed process and the process used by a competing company is given.

2 Methodology

2.1 3D model

After 3D modelling creates a 3D representation of any surface or object by manipulating polygons, edges and vertices in a simulated 3D space. 3D modelling is accomplished by hand using specialized 3D production software that allows the artist to create and deform polygonal surfaces or by scanning real-world objects into a set of data points used to represent the objects digitally. 3D modelling is used in various fields, including engineering, architecture, entertainment, film, special effects, game development, and commercial advertising. 3D modelling uses software tools, such as computer-aided design (CAD) programs, to create 3D digital representations of objects [1].

Although 3D modelling software is based on a complex set of mathematical functions, programs automate calculations for users and have tool-based user interfaces. 3D models are the output of 3D modelling based on various digital representations. Boundary representation (B-rep) uses mathematically defined surfaces such as cones, spheres, and NURBS (non-uniform rational base splines) connected by topology to represent objects as watertight volumes accurately. B-rep models are the preferred solution for engineering and many 3D modelling applications for the design, simulation and manufacturing of consumer and industrial products. Faceted models approximate surfaces using connected planar polygons and are the preferred solution for less accurate, high-speed shape representations used in games, animations, and digital mockups [2].

Virtual 3D models can be turned into physical objects using 3D printing or traditional manufacturing processes. Models can also be converted to static images using 3D rendering, commonly used to create photorealistic displays for sales, marketing and e-commerce applications. 3D models can be created through a reverse engineering process in which 3D scanning technology is used to create digital replicas of real-world objects, including manufactured parts and assemblies, free-form models designed from clay, and human anatomy [3].

2.2 Reverse engineering

Reverse engineering is one of the progressive technologies of production systems. It represents a technological process using which it is possible to create a CAD model of an existing product or draw documentation according to specific customer requirements. It is used to create drawings of spare parts, the relevant technical documentation that is either destroyed, incomplete, or never created [4]. Likewise, creating a complex hand-shaped model from modelling clay or other prototype parts. The data obtained can be used to produce parts with a small number in a batch on a 3D printer.

Use of reverse engineering:

- creation of drawing documentation of prototype parts,
- shortening the development and innovation cycle of the product,
- modernization of the production process,
- design of new parts adapted to existing parts,
- update drawing documentation of pressing forms.

Digitization, as the main activity in the process of reverse engineering for the field of engineering products, and the collection of input data from a real object is possible in several ways, such as manual measurement, semi-automatic measurement with a touch probe, laser surface scanning, optical 3D surface scanning or CT scanning [5].

Currently, the most used digitization method for reverse engineering is laser scanning of the surface using a 3D laser scanner. Thanks to powerful technologies and a proven methodology for 3D measurement and 3D digitization, we can transfer complex shaped objects from the real world to digital form. Virtual 3D models are characterized by high accuracy, a prerequisite for their effective use in CAD systems. We digitize accurate models from the level of a polygonal network (mesh) and mathematically described objects (surfaces, holes, bevels) to editable models in CAD systems, all using combined contact measurement and scanning techniques and advanced reverse engineering methods.

2.3 Laser scanning

Laser scanning, especially 3D, is one of the technologies of reverse engineering, which represents a modern approach to the digitization of spatial information about an object, which can be used for 3D product and production systems, with a focus on the very realization of objects (industrial, artistic and historical), with demanding focusing. Accessible and dangerous spaces, animation and creation of 3D and simulation models [6,7]. We divide the digitization process according to the following steps:

Step 1 represents scanning preparation. The described technology represents high dimensional accuracy of 3D models up to 3 mm. However, we consider 2-5 cm to be sufficient accuracy. Subsequently, this accuracy affects the quality of the scan. At the beginning of each project, it is necessary to agree on all the conditions under which the models will be created or how they will be used in the future. The model can be helpful, for example, for reorganization or production planning, creating object libraries or analyzing static structures.

Step 2 is the creation of a reference grid. Before the actual scanning, reference points must be placed throughout the hall to create a reference grid. Each reference point is located at a specific location and has its coordinates and marker. This creation of a reference grid is later used when stitching scans and specifies the future virtual model. In the future, the business can use the reference grid to accurately position production equipment, conveyors, transportation systems, etc., created in the 3D model. When placing reference points, it is essential to distribute them so that there are not enough (minimum of three) needed to accurately position the scanner in space. From one scanning position, it is essential to see at least four reference points, the distance of which is less than fifteen meters from the scanner.

Step 3 represents laser scanning. The origin of the coordinate system is at the center of the scanning mirror in the device. The software can automatically recalculate the transformation matrix so that all reference points have an absolute coordinate system. The core of the entire system is a built-in operating system that ensures the collection and storage of all data, scanning and simple data transfer to an external computer. This technology enables efficient, fast and accurate scanning of the entire production hall. Scanning is not only about a black and white photo but also about a color representation of measured spatial points - scans [7].

Step 4 represents the registration and connection of scans. Each scan point has five values: reflection, X, Y, Z and distance from the scanner. After scanning, it is essential to link the scans. This process creates a panoramic image, and each point shows one coordinate. FARO Scene Software for scanners from FARO is used for connecting scans, their overview and navigation in the scanning hall, measuring the distance and dimensions of objects, and exporting points to the CAD system. A FARO Scene is a graphical representation of visual perception used to compare reference points against which other objects can be evaluated. The goal of registration is to place individual scans in a predetermined coordinate system and link them and insert them into a fixed single coordinate system. A correctly registered (record of scans consists in their linking) scan is uniformly placed at the level of the "z" axis with other scans and with the correct link to other scans.

Step 5 represents the export of data from the graphic presentation to the CAD system. Usually, the data is exported to the CAD system: AutoCAD, MicroStation, Intergraph, CATIA, etc. With the help of 3D scans, a new medium is created that is a true reflection of reality. This medium is rendered into a CAD drawing that represents reality. This drawing is divided into layers according to the nature of the drawn object and can be dimensioned. Various parametric object libraries like TriCAD are used to reduce modelling time. This library consists of an extensive catalogue of 3D objects such as pipes, ventilation systems, electrical wiring, steel structures, conveyors, transportation systems, etc. [8].

This 3D laser scanning process works with FARO Focus brand scanners.

3 Results and discussion

The reverse engineering process begins with selecting a tangible object for which it is necessary to develop technical documentation. An object can be a component, assembly, machine or building, ventilation, pipe system, etc. For research purposes, a set consisting of six components was chosen. This assembly serves as an intermediate piece for a piping system in an industrial plant. The first step is to disassemble the assembly from the entire system and store the assembly in the area where the 3D laser scanning will be performed. Next is the creation of a reference grid around the assembly. A reference grid consists of an arrangement of reference points. In this case, reference bodies are spheres. From every position of the scanner, the sphere has the same shape, which makes it an ideal reference body. After the creation of the reference network, i.e. after the placement of the reference bodies, 3D laser scanning follows. The positions of the scanner are selected according to the need to focus the object and according to the rules of the reference network. After scanning and data transfer to the FARO Scene software, the scans are registered. After the overall registration, a 3D point cloud (Figure 1) of the real object is created.

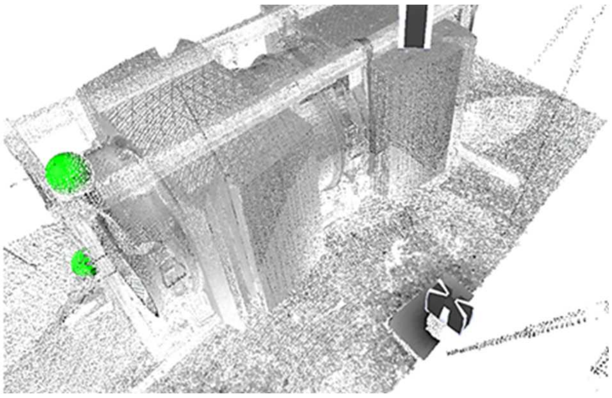

Figure 1 3D point cloud displayed in FARO Scene software

The next step is to create a 3D model in the MicroStation V8 software environment (Figure 2). The point cloud is exported from the FARO scene software to the graphics software.

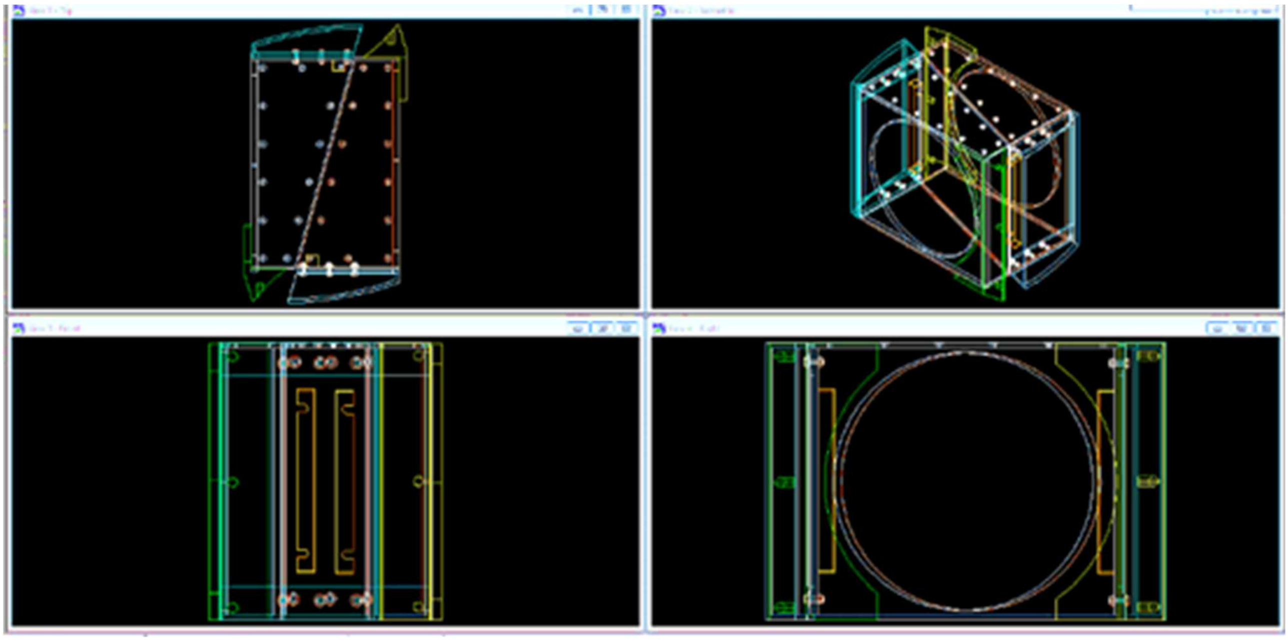

Figure 2 3D model of the assembly in the MicroStation V8 software environment

In graphics software, a 3D model is created according to the actual object, in the exact scale and the real position relative to the zero point. This 3D model is measurable and dimensional and can be seen in figure 2 in the MicroStation V8 environment [9]. This graphics software offers modelling in all six views of the body. Four are primarily used, top, front, right and isometric.

Without a doubt, we need to check the accuracy of the data before completing the reverse engineering process. It is possible to export the created 3D model in VRML format to the FARO Scene software (Figure 3). The exported model can be placed in a point cloud and visually checked for deviations and inaccuracies between the dimensions of the actual object and the model. When creating technical documentation, the deviation should not exceed 1 mm. In this environment, moving the entire cloud and inspect the model from all sides is possible. We can also target these deviations using a set of measuring tools in the software.

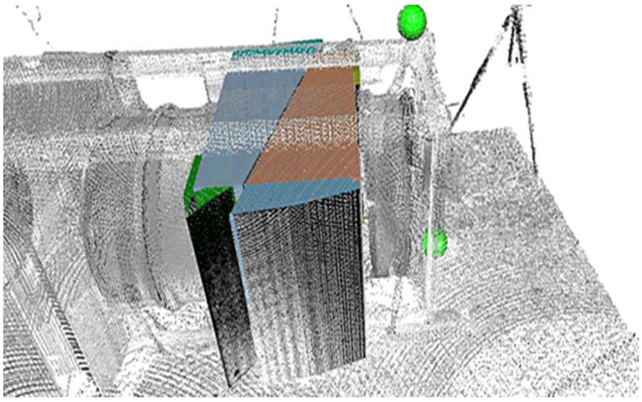

Figure 3 Displaying the 3D model in the point cloud in the FARO Scene software environment

If the model passes inspection, the final output and the last step of the reverse engineering process is the drawing documentation. Drawing documentation, as part of technical documentation, is used in 2D. This 2D drawing can be created in MicroStation V8 simply by exporting the visible and hidden edges in each view that the creator needs to create the 2D drawing. The drawing is created in HLN format, which is a 2D drawing format. However, other software cannot process it effectively, so after creating a 2D drawing, it needs to be exported to DGN format to work flexibly for further use, such as construction.

4 Conclusions

The proposed procedure differs from the standard procedure used for reverse engineering. To compare the standard 3D laser scanning process used by a competing company and a competitively capable reverse engineering process, table 1 was compiled.

Table 1 Comparison of standard and proposed reverse engineering process

Process parameter	The standart process	The proposed process
Use of 3D laser scanning	Yes	Yes
Brand of scanners used	Leica Camera AG	FARO Focus Laser Scanners
The price of scanners	Higher	Acceptable
Scanning accuracy	Good	Very good
Point cloud software	Leica Cyclone	FARO Scene
Compatibility of cloud computing software with graphics software	Medium	High
The price of software for working with the cloud	High	Medium
Graphics software used	AutoCAD	MicroStation V8
Controllability of the software when creating 3D models	Hight difficulty	Medium difficulty
Compatibility of graphics software with other graphics software	Very low	High
Saving models to standard formats	Low	High
Creating a 2D drawing from a 3D model	Yes	Yes

The proposed procedure with the use of hardware and software from FARO Focus and MicroStation V8 graphics software from Bentley brings the possibility of better and more accurate targeting of objects, high compatibility of used software with the possibility of fast data transfer and model export to all standard formats for the use of models in graphics, visualization and simulation software. It also precisely controls the model's dimensions by comparing the actual condition displayed in the points cloud.

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Single-blind peer review process.