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# Approach for reverse engineering of complex geometry components

Yavor Sofronov<sup>1</sup>, Mihail Zagorski, Georgi Todorov and Todor Gavrilov

Lab. CAD/CAM/CAE in Industry, Technical University – Sofia, 8 Kl. Ohridski Blvd.,  
1797 Sofia, Bulgaria

<sup>1</sup> E-mail: ysofronov@tu-sofia.bg

**Abstract:** This paper study present an approach for part recognition, process known as “Reverse engineering” using turbine blade component as an example. It has a complex geometrical shape and it’s produced from specific material, who should work under high thermodynamical stress. To fulfil the task different 3D scanning technologies were evaluated and as a result the laser triangulation was used for geometry acquisition. Geometry creation in mesh to CAD software was explained step by step. Elemental analysis with Energy-dispersive X-ray spectroscopy (EDX) for material characterization was used. The result from presented approach for reverse engineering is a solid CAD model with defined material, capable for production.

## 1. Introduction

The development of the computer technologies over the last few decades leads to radical changes on a global scale, digitizing the world. At the threshold of the so-called Industry 4.0, a number of professions, including the engineering sciences, are changing dynamically. A mechanical engineer is more often working with a variety of software products – a modern designer knows at least a few CAD products, the analysts are using variety of CAE solutions, as well as technologists – increasingly intuitive CAM software. The basis of all these technologies is the 3D model. The reverse engineering does not stay on a side of these processes too. Reverse Engineering is a process of reworking and reconstructing the principles and the mechanisms, that are used to create a specific object, i.e. when a specialist (designer, analyst or technologist) has at his disposal a final product, but not its documentation, it is necessary to create a digital model of the product, in order to be able to implement it for processing in CAD, CAM or CAE software [1-3].

In mechanical engineering, the reverse engineering or the reconstruction typically consists of accurately recreating the geometry of an object and assigning properties that match its working parameters and characteristics [4].

The reconstruction process begins with the digitization of geometry. When a complex geometry object is under study, several basic non-contact 3D image creation methods are used, merged under the name 3D scanning. One of these methods is the so called photogrammetry, which uses a camera shots from different angles of the subject, and subsequently, by the use of specialized software, a three-dimensional image as a cloud of points is reached.

Two other basic methods for 3D scanning are LiDAR scanners and scanners with laser triangulation. The common feature is that both types of scanners use a laser light to capture the geometry of the object. Differences between these methods are how the distance between the scanner and a given surface is measured. In the table 1 is shown a comparison between the three methods [5].

**Table 1.** Comparison of 3D scanning methods.

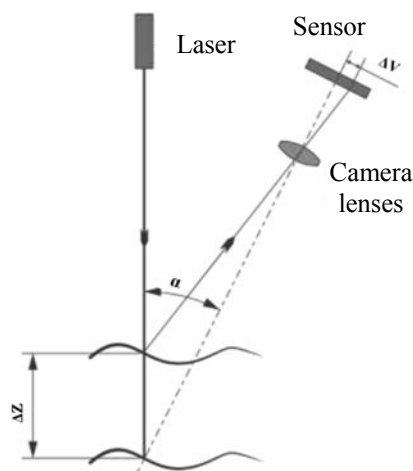
|   | Photogrammetry | LiDAR           | Laser Triangulation |
|---|----------------|-----------------|---------------------|
| Sensitivity to the type of lighting                 | High           | Low             | Low                 |
| Texture reproduction capability                     | High           | Low             | Low                 |
| Accuracy for the purposes of mechanical engineering | Low            | Low             | High                |
| Software and equipment prices                       | Relatively low | High            | High                |
| Scanning ability for small objects                  | Average        | Low             | High                |
| Scanning ability for large objects                  | High           | High            | Relatively low      |
| Generating point cloud timing                       | Fast           | Fast            | Slow                |
| Level of detail                                     | Average        | Average         | High                |
| High qualification of the staff                     | No             | Yes             | Yes                 |
| Subsequent software processing timing               | Slow           | Relatively fast | Relatively fast     |

### 1.1. Purpose of the development

The aim of the present work is to develop a methodology for reconstruction a complex geometry part with high accuracy requirements.

## 2. Methodology of work

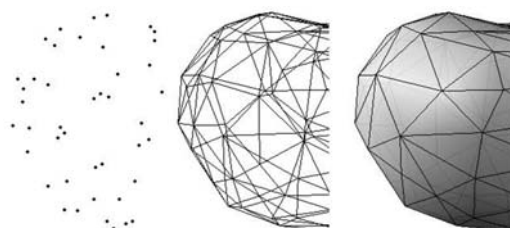
For the reconstruction of a small size part with high accuracy requirements, a laser triangulation scanner is the most suitable choice. The principle of work of a laser triangulation scanner is shown on figure 1 [6].



**Figure 1.** Principle of work of a laser triangulation scanner.

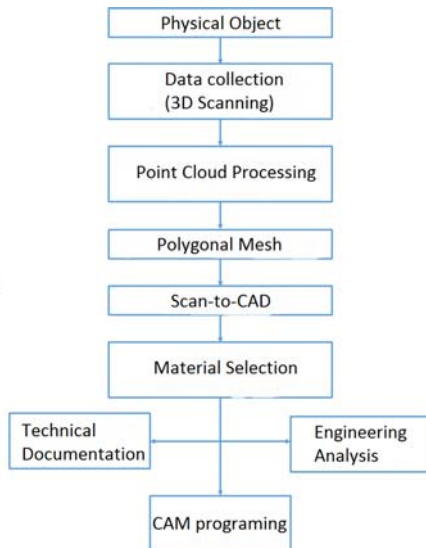
During the scanning process a point cloud is created. The number of points in the cloud sometimes exceed several million points which is making the cloud really difficult for future processing.

After the point cloud is created and cleared from the noises, a polygonal mesh (usually composed of triangles) based on the cloud is generated. This step is necessary because the polygonal mesh is easier for processing. In figure 2 [7] a scheme of the process is shown.



**Figure 2.** Generating a mesh from a cloud of points.

The next stage is related to construction of a surface model on the polygonal mesh, its subsequent transformation into a solid model and the placing of radii, fillets, inclines, etc. The last step is the selection of identical material or such one with the required characteristics. After the product reconstruction cycle is completed, its model can be used for various engineering purposes, as example creating a technical documentation, developing a manufacturing technology, calculating engineering analyses in order to optimize construction, and more. In figure 3 a summary of the process methodology for part reconstruction is shown.



**Figure 3.** Methodology of the reconstruction process.



**Figure 4.** 6-axis coordinate-measurement machine Romer Absolute Arm.

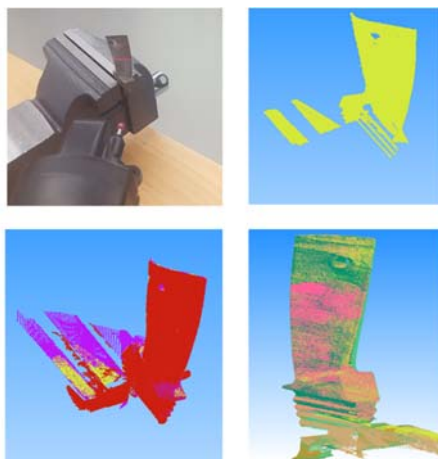
### 3. 3D scanning

The 3D scanning of the part – turbine blade was performed using a 6-axis ROMER Absolute Arm, portable coordinate measuring machine and a laser triangulation scanner, model 7320SI, similar to that shown in figure 4. The scanning, the generation of the mesh and the comparison were performed using the software solution 3D Reshaper.

For the purpose of this study, a scanning accuracy of 0.05 mm is required and achieved.

After the scanning process is done (figure 5), a point cloud of about 1400000 points was obtained.

The next step is cleaning the point cloud and generate a polygonal mesh – figure 6.



**Figure 5.** Stepwise scanning of the turbine blade.



**Figure 6.** Final appearance of the mesh.

#### 4. Creating a solid CAD model on a computer mesh (Scan-to-CAD)

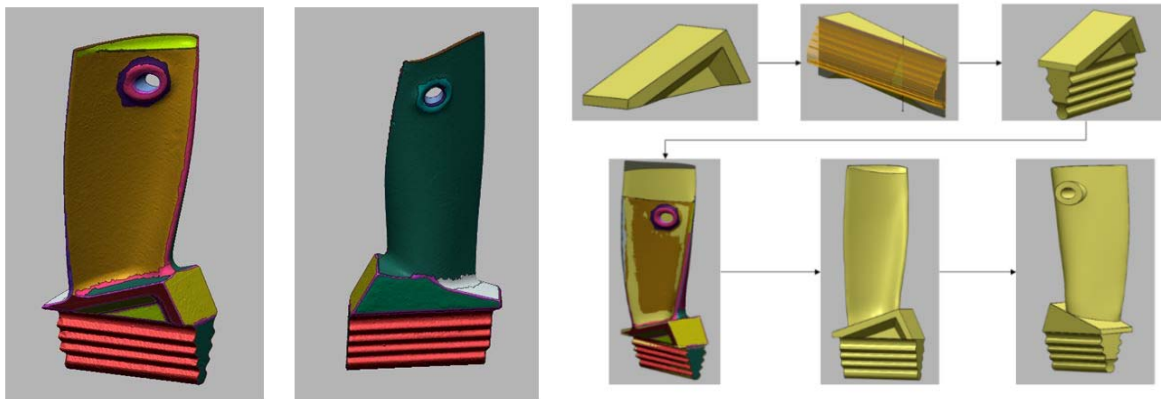
The creation of a solid CAD model from a polygonal mesh is achieved by using specialized software – Geomagic Design X, which is able to capture the geometry from the mesh. It is possible to use functions for both for parametric and for freeform modelling, as for complex parts often the combination of both is needed. These products are called Scan-to-CAD software. The process of creating a solid model goes through several stages:

##### 4.1. Dividing the mesh on regions

The first stage is related to the division of the mesh of regions. This action is necessary in order to be able to use several regions to create different surfaces (figure 7). For the purpose the feature “Auto Segment” under the menu “Region”. This feature allows the separation of the geometry in primitives – planes, fillets, parts of sphere, etc. The regions are later used as a base for the construction of a surface model.

##### 4.2. Construction of surfaces on the polygonal mesh

For the construction of a surface model of the turbine blade, Scan-to-CAD software’s options are used to directly intercept surfaces on the mesh. Also, features such as “Extrude”, “Revolve”, “Sweep” and others are used. The first step is to create the middle part of the model using the instrument “Mesh fit” under the menu “Model”. This feature intercepts the regions and creates primitives – planes. The second step consists of modelling of the “tail” of the turbine using a section sketch and a guiding path – the so-called “Sweep” feature. The next step is the creation of the turbine profile. For the purpose “Mesh fit” instrument is used. After the generation of the surfaces, “Boolean” feature is used in order to cut the unnecessary elements of the created areas. Finally, the hole is created using the “Revolve” feature. In figure 8, the stepwise construction of the surface model on the polygonal mesh and the finished surface model are shown [8].



**Figure 7.** Result of the the regions processing. **Figure 8.** Stepwise surface model creating on a polygonal mesh.

##### 4.3. Creating a solid CAD model

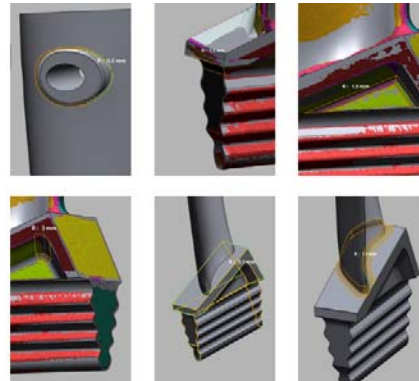
In order to create a solid 3D model, first it is necessary to proceed the work in another CAD software, because the Scan-to-CAD software used in the previous steps does not have the required functionality. For this purpose, the created surfaces are saved in a neutral file format – in this case “Parasolid” format is used. The next step is to open the file in CAD environment in which it is possible to transform the surface model into a solid one. For the purposes of the current study Solidworks CAD software solution was used [9]. The feature “Knit Surface” under the “Surface” menu is used. All surfaces are selected and the options “Try to form solid” and “Merge entities” are chosen. In figure 9, a cross-section view of the newly-created solid model is shown.

#### 4.4. Placing the fillets and chamfers in the solid model

In the environment of the specialized software for reconstruction, the fillets and the chamfers are placed. In order to achieve this purpose, the mesh and the solid model are compared. In figure 10, fillets' and chamfers' placement is shown stepwise. The used features are "Fillet" and "Chamfer".



**Figure 9.** Cross-section of the solid CAD model.



**Figure 10.** Stepwise fillet placing.

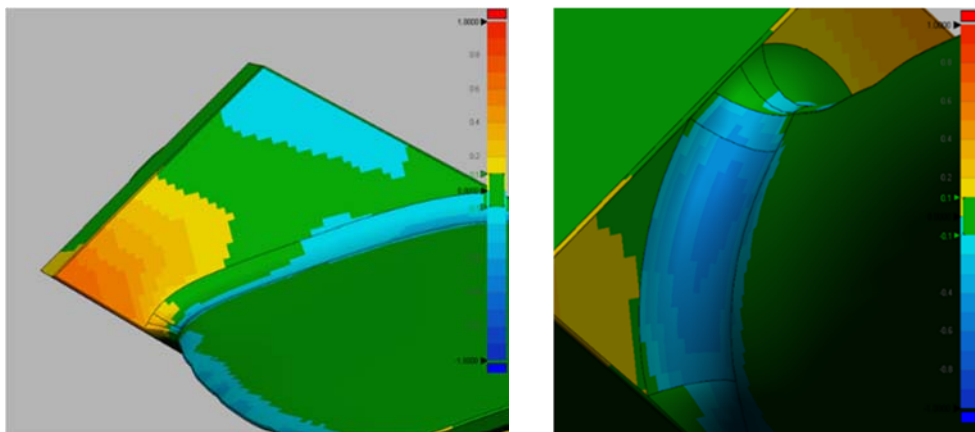
#### 4.5. Accuracy analysis

One of the last steps in the reconstruction of a complex part is the accuracy analysis. For the purpose, a comparison between the polygonal mesh and the solid model is made. The characteristics of the deviations, examined under Gauss's law are presented in table 2.

**Table 2.** Accuracy analysis.

| Parameter           | Deviation |
|---------------------|-----------|
| Max. negative value | -0.567 mm |
| Max. Positive value | 0.764 mm  |
| Average value       | 0.019 mm  |
| RMS                 | 0.115 mm  |
| Standard deviation  | 0.113 mm  |

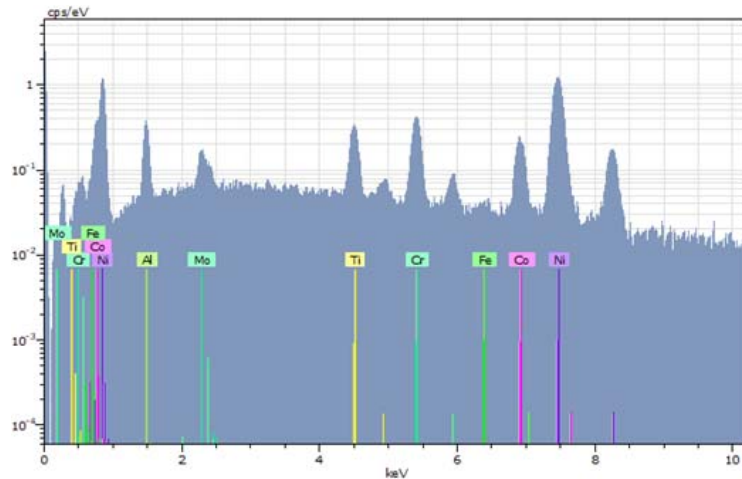
The data in table 2 shows the presence of relatively large maximum positive and maximum negative deviations. Due to the results a geometry analysis has been performed and it is estimated that areas with large deviations do not belong to the main working area of the turbine blade and can therefore remain unchanged (figure 11).



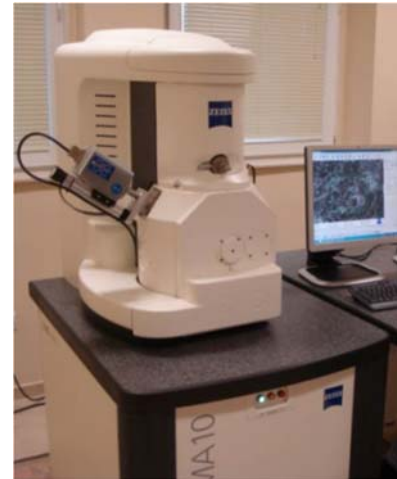
**Figure 11.** Zones with maximum positive and negative values.

## 5. Material Selection

The final stage of the reconstruction of the part is related to the material selection that should be as close as possible to the structure and properties of the original. For achieving this goal, the chemical composition of the original material (figure 12) has been determined by means of a scanning electron microscope EVO MA 10 with the CARL ZEISS EDX system (figure 13) [10].



**Figure 12.** Graphical representation of the results.



**Figure 13.** Scanning electron microscope EVO MA 10.

From the analysis, it is found that the material is a nickel alloy with a high content of nickel (Ni), cobalt (Co) and chromium (Cr). Such a chemical composition is particularly characteristic of the so-called “Super alloys” – specially developed materials, which are used for producing parts in turbochargers, jet engines and others. The nickel based “Super alloys” have a stable behaviour in continuous operation at high temperatures (above 500 ° C), which determines the use of similar material for the turbine blade [11].

## 6. Conclusion

The presented methodology facilitates the creation of a computer model of a part with complex surfaces and no available documentation, which is subsequently used for various engineering purposes. The described methods require the availability of a laser scanner and specialized software. 3D scanning tools allow a component with complex geometry to be thoroughly surveyed geometrically.

Skills to handle a variety of specialized software are required.

During the model creation, mistakes are accumulated, which leads to geometry deviations of several tenths of a millimetre, which is insufficient accuracy for certain dimensions of a part and in particular, for determining the type of joining in an assembled unit.

## Acknowledgments

This work has been supported by Sofia Tech Park and the National Science Fund of Bulgaria under the Project DH-17-23 “Developing an approach for bone reconstruction and implant manufacturing through virtual engineering tools”.

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