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Application of reverse engineering method on agricultural machinery parts

Ozgur Verim [a,*] ***and Ozan Sen*** [b]

[a]*Afyon Kocatepe University, Faculty of Technology, Department of Mechanical Engineering, Afyonkarahisar and 03200, Turkey*
[b]*Çelikform Gestamp Otomotiv A.Ş., Bursa, 16140, Turkey*

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ABSTRACT

Reverse engineering, the production of parts without CAD data, the reproduction of damaged parts, the creation and production of new parts by making innovations on parts with CAD data is a significant area. Considering the field of mechanical engineering, the surface and geometric properties of an existing part can be reconstructed by reverse engineering application. Within the scope of this study, the possibilities offered by reverse engineering are used to create a three-dimensional (3D) model of an agricultural part and the production of its prototype. The agricultural part was scanned in 3D with the help of a scanner, and a mesh model was created. Afterward, the solid model of the part was created, and the prototype was produced with the help of a 3D printer. The deviations of geometric dimensions between the mesh and solid models were analysed, and their convergence levels were determined. At the end of the study, the geometric values between the solid model and the prototype model were compared, and the deviations from the actual value were determined. Thus, it has been shown that both surface modelling studies and solid model designs can be integrated with reverse engineering software.

1. Introduction

Today's production environment is a highly competitive, dynamic and uncertain process. In an environment where competition in the global market is high and customer expectations are constantly changing, a production system must be flexible and reconfigurable [1]. These conditions have led companies to new ways to reduce design times, enable rapid prototyping, and provide commercial benefits [2]. Reverse engineering is used to redesign an existing part, reproduce damaged parts, develop a different product from the existing part, etc. Reverse engineering has a wide range of uses such as machinery, aviation, medicine and archaeology [3,4]. The main purpose of reverse engineering is to create a 3D CAD model suitable for the design of the object. The first stage of reverse engineering is scanning the surface of the part with the help of contact or non-contact scanners. The second stage is the arrangements made to increase the similarity of the model obtained as a result of scanning to the original product. The data obtained at the end of this stage is in the form of points and these data are called point clouds. The third stage is the conversion of the obtained point cloud to the mesh structure and the creation of the CAD model by processing this structure (Figure 1). The last stage is the creation of the prototype of the product by taking the CAD model as a reference [5,6].

Since the reverse engineering method has a wide field of study, it is frequently used in interdisciplinary studies. Önçağ et al. [2] analyzed literature studies using reverse engineering method for redesign or repair of mechanical parts that are widely used in industry and created a workflow. They used their workflow to create a turbocharger elbow part. They produced the solid model obtained with the reverse engineering approach with the help of 3D printers in 1/1 scale. Kaplan et al. [7] utilized reverse engineering processes in the repair of impeller blades of water turbines in a hydroelectric power plant undergoing maintenance work. By using reverse engineering method, the impeller blades of the water turbine were repaired. Mian et al. [8] combined contact system (with probe) and laser non-contact scanning (without probe) in their work and used contact system for digitization of geometric shapes and non-contact scanning for non-geometric surface forms. They have obtained an advantage for reverse engineering by scanning the part with complex surface form, which is relatively inefficient to scan with the help of the contact system, with the help of the non-contact system.

* Corresponding author. Tel.: *+90 272 218 25 10*; Fax: +90 272 218 26 93.
E-mail addresses: ozgurverim@aku.edu.tr *(F. Author)*, oozansenn@gmail.com *(S. Author)*
ORCID: 0000-0002-1575-2630 *(F. Author)*, 0000-0002-9913-664X *(S. Author)*
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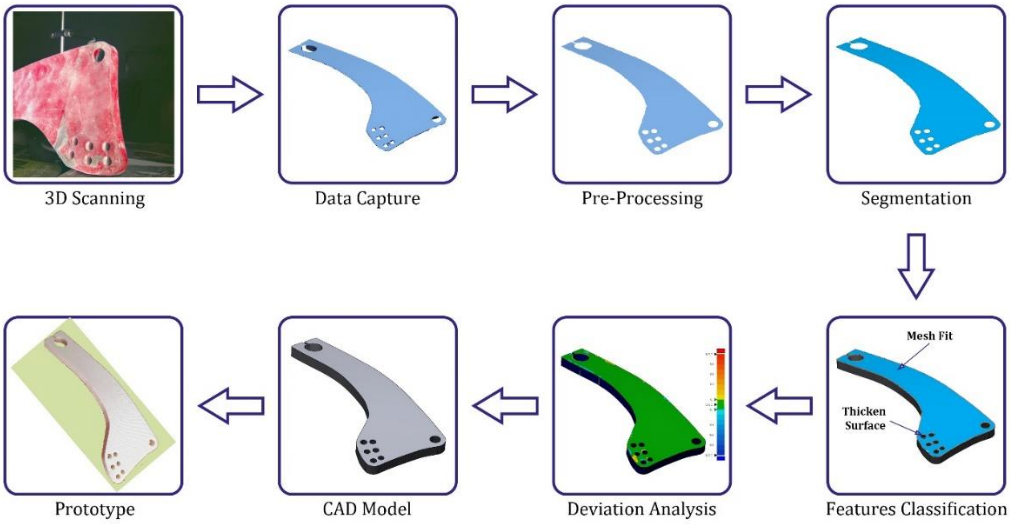


Figure 1. Flowchart of general reverse engineering approach

For the study, although reverse engineering was applied to many fields, we thought there was a shortage of parts in the agricultural field. Because, due to the production processes of the parts in the agricultural field, they usually consist of inhomogeneous geometries. In our study, we tried to apply the reverse engineering method on a non-homogeneous (produced by forging) agricultural piece.

2. Materials and Methods

In order to create a 3D model of a part in a computer environment, it is necessary to take the image of the part down to the smallest detail. Reflections that occur during the scanning of metal parts can prevent reliable data from some parts of the part. As a result, incomplete data formation occurs because sufficient data cannot be obtained from certain parts of the part. In order to eliminate this problem, after the surface of the part was cleaned, the surface of the part was matted. Then, markers were attached to both surfaces of the part to facilitate part image matching (Figure 2). The purpose of the marking process is to ensure that the scanning data overlaps as a result of different scanning operations. As a result of these processes, the agricultural part was fixed on the movable scanner table and made ready for scanning.

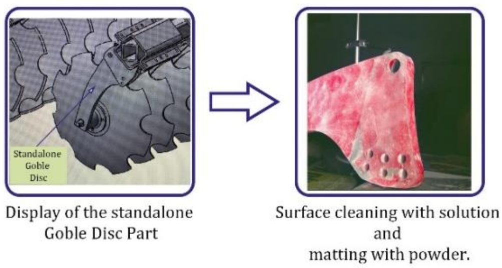


Figure 2. Preparing the agricultural machine part for 3D scanning

2.1 3D Scanning, Data Capture and Pre-Processing

The scanning process of the agricultural part was made with the NextEngine (NextEngine Inc.) device, which scans with a noncontact method. The scanner in question sends laser beams on the part with its 3 detector eyes. While doing this, it detects the surfaces and details on the part according to the angle of reflection of the beams and the angle of incidence of the returning beams. It converts this mathematical data into small triangle particles called "mesh" and transfers it to the computer program. At this point, it is necessary to check whether the details of the part are captured by the scanner. Because during the scanning process, due to parameters such as the quality of the scanner, surface roughness, color, transparency and brightness of the scanned part, situations such as obtaining more or less data than necessary may occur. In cases where more data is obtained, a decrease in the processing speed of the computer can be observed with the increase in file size. On the other hand, in cases where less data is obtained, problems such as not creating the 3D model properly may occur. For all these reasons, it is necessary to plan the scanning process well and to organize the data obtained after the scanning process before proceeding to 3D modeling. Data processing was carried out in the reverse engineering software Geomagic Design X. In this program, the data processing part is carried out with a certain hierarchy (Figure 3).

All scans made on the part surface from different angles were combined in the "Mesh Healing" section in the program, unwanted data on or around the part were cleaned and the noises found were removed. In the “Global Remesh” section, the triangle edge length must be below the current length value for the surface features to be more pronounced.

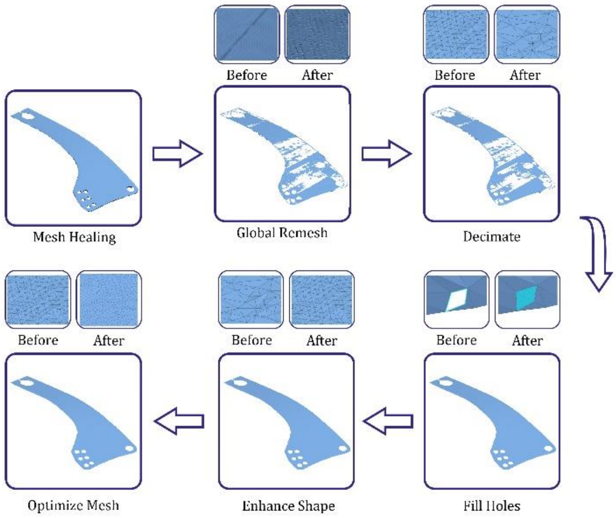


Figure 3. Data processing flowchart in reverse engineering

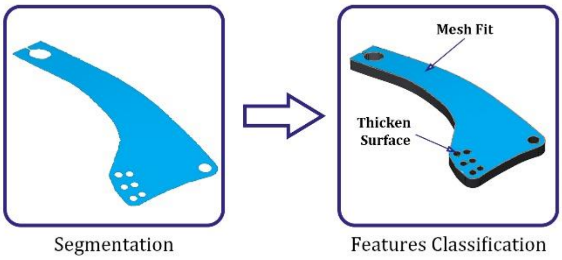


Figure 4. Applying segmentation and feature classification processes to the agricultural part

As a result of these operations, the number of meshes may increase and slow down the processing speed of the computer. Reducing the mesh size in the "Decimate" section speeds up the operations on the model and causes deformities on the model. Therefore, in this study, mesh size reduction was not done manually by us, but it was reduced automatically within the program. Then, with the "Fill Holes" process, the existing gaps on the mesh surface of the model are automatically determined and filled by the program. In the “Enhance Shape” section, the mesh structure is rebuilt and the quality of the mesh structure is improved. In the “Mesh Optimization” section, the mesh structure is optimized and the most suitable mesh structure is created by eliminating the errors (Figure 3).

2.2 Segmentation and Feature Classification

Segmentation can be described as dividing an image into meaningful regions, each of which contains different features, using point cloud and mesh structure data, and plays an important role in reverse engineering [9,10]. The segmentation process regulates the setting of region recognition and parameters that affect the type and size of defined regions [11]. Since the feature classification process was carried out using the segmentation method, segmentation was applied on the agricultural part after the data processing part (Figure 4).

2.3 Modeling

After determining the mesh model properties, firstly, plane and 2D drawings of the part were created. This step needs to be done very carefully and carefully, as the surface formation can differ significantly depending on the strategy chosen during the modeling of the surfaces. Since it is necessary to scan the surfaces in detail in surface modeling, the number of elements is high. The large number of elements causes an increase in surface irregularity and makes it difficult to define surfaces [12]. For the detailed description of irregular surfaces, NURBS (Non-uniform rational B-spline) method was used as surface modeling method and part surfaces were created (Figure 5).

2.4 CAD Model and Rapid Prototyping

The final stage of the reverse engineering process is the creation of the CAD model and the production of the created CAD model (Figure 6). The creation of the CAD model is carried out using heterogeneous methods (parametric or non-parametric), depending on the reverse engineering strategy. Procedures applied at this stage; clamping adjacent surfaces, creating radius and chamfers, and realizing geometric constraints [13]. Rapid prototyping is an integral factor of the reverse engineering process. Rapid prototyping is the process of rapidly producing a physical part with CAD data [14]. Thanks to the production realized in a short time, rapid prototyping has a wide range of uses such as automotive, aviation, medicine, and pharmaceutical industries [5].

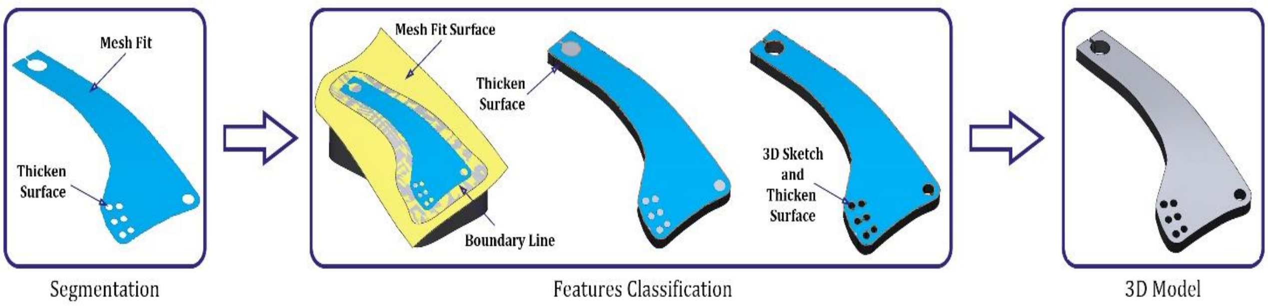


Figure 5. Modeling processes in reverse engineering

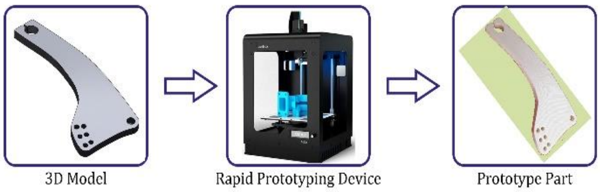


Figure 6. Reverse engineering processes of agricultural part

Rapid prototyping has been an interesting field of study for reverse engineering in recent years. With the rapidly developing technology and the gradual expansion of the application area, many rapid prototype production technologies have been developed. These systems can be listed as Stereolithography Apparatus (SLA), Solid Ground Curing (SGC), Fused Deposition Modeling (FDM), Laminated Object Manufacturing (LOM), Selective Laser Sintering (SLS), Electron Beam Melting (EBM), Shape Deposition Manufacturing (SDM) Direct Metal Laser Sintering (DMLS) and Three-Dimensional Printing (3DP) [5,15–17]. In this study, the prototype of the part was created using the FDM method. The geometric accuracy of the part could be achieved by many additive manufacturing methods. In our study, the availability of the device, the accuracy of the part geometry, the ease of material supply, etc. We chose the FDM method, taking into account the factors. Many studies have been carried out on the advantages of the FDM method and the reasons for its use in the study [18,19]. In FDM process, a plastic material is extruded through a nozzle that follows the cross-sectional geometry of the part. A thin plastic filament is used as the model material [20]. PLA material, which has better mechanical characteristics than ABS material, was used in the study [19]. Properties and process parameters of PLA filament material were determined as nozzle temperature 200 C^0, Table temperature 60 C^0, ambient temperature 23 C^0, material density 1.2 kg/m^3, Tensile strength 62 MPa, infill density 50%, printing speed 45 mm/s [21,22].

3. Results and Discussion

In this study, an agricultural part was scanned with a 3D laser scanner, converted into mesh form, and then a 3D model was created. The prototype of the part was produced with the help of 3D printer from the rapid prototyping tools and 3D created part model. The fact that the part does not have a flat form in the reverse engineering process complicates the scanning process and thus increases the applied processing time. The agricultural part used in the study also caused an increase in the processing time due to its difficult geometry. The dimensional accuracy of the part is extremely important as a backward modeling is done in reverse engineering. The combination of devices, software, and/or operator-induced errors used in the reverse engineering process gives the total error in the resulting model. For this reason, careful examination and analysis should be made for each stage applied. The accuracy analysis between the mesh model and the solid model created by the reverse engineering method was performed and the results are shown in Figure 7.

Looking at the color scale of the deviation analysis results given in Figure 7, it is seen that the green area is the desired region. It is seen that the divergence values of the geometric form of the part increase as one goes from green to red or blue tones. When the part surface is looked at, the abundance of green regions means that the model accuracy is high. A number of different color tones can be seen around the small and large hole circles of the part. Since the part has a non-uniform structure as a whole, modeling was also difficult. The difference in deviation values in the hole circles is due to the difficulty of modeling. The deviation analysis provides a detailed comparison of the mesh and the part. Since only the visible surface of the real part (Figure 1) was scanned, the deviation analysis was also created for this surface only.

The differences between the dimensions of the 3D model created by the reverse engineering method and the dimensions of the part created by rapid prototyping were revealed by morphometric comparison (Table 1). Some dimensions are important for the identification of the part and these dimensions are given in Table 1. The deviation values between the solid model and the prototype model are shown as distance (mm) and percent (%). According to the values in Table 1, the average deviation distance was 0.5 mm and the average deviation percentage was 97.63.

The close relationship between 3D digitization and rapid prototyping makes it easy for us to model 2D and 3D parts with difficult and complex geometries. By combining these two techniques, the creation of 3D solid models necessary for the modification or reconstruction of parts forms the basis of reverse engineering [23]. In this context, increasing the prevalence of studies in the field of reverse engineering provides more accurate results in the field of design and production. This issue is at the forefront of the results of our study. When we examine Table 1, it is seen that the deviation percentage values are above 95. This value is the result of how closely we produce this part with accuracy. In addition, the accuracy analysis results in Figure 7 show how accurate the transition to 3D solid model geometry is in the mesh structure.

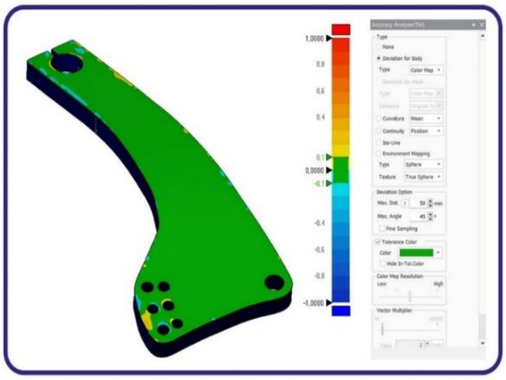
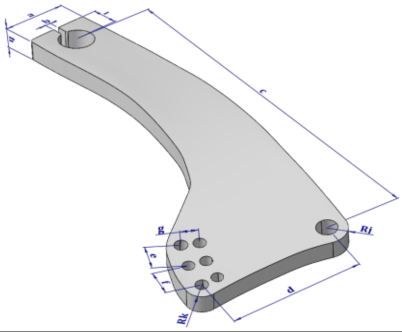


Figure 7. Deviation analysis results between mesh and solid model

Table 1. Morphometric comparison of Agricultural Machinery part



Parameters	Dimension on 3D Model (mm)	Dimension on Prototype Model (mm)	Deviation (mm)	Deviation (%)
a	67.39	66.72	0.67	99
b	5.99	6.3	0.31	95
c	381.51	380.8	0.71	99
d	140.37	139.6	0.77	99
e	29.33	28.97	0.36	98
f	29.33	28.97	0.36	98
g	18.08	18.27	0.19	98
h	20.46	21.07	0.61	97
i	29.18	29.27	0.09	99
Rj	20.99	21.6	0.61	97
Rk	17.99	17.1	0.89	95
		Average:	0.5	97.63

The 3D model developed with the CAD program was produced with 3D Printing technology. FDM method was used in production and PLA was chosen as the material. The accuracy of the part geometry produced in 3D Printing technology depends on many factors. In our study, we used the parameter values that are frequently selected during the printing process.

4. Conclusions

In our study, we examined the processes of creating a 3D solid model and prototype of a non-uniform agricultural machine part by reverse engineering method and comparing them with each other. In the reverse engineering method, 3D scanning and solid modeling methods [24–27] and rapid prototyping methods [28,29] were examined and procedures were carried out using the systems available in our institution. In the study carried out, the active and passive aspects of the processes were evaluated and certain gains were made. These gains constitute a preliminary experience for future studies.

Declaration

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The authors also declared that this article is original, was prepared in accordance with international publication and research ethics, and ethical committee permission or any special permission is not required

Author Contributions

O. Verim and O. Sen. Authors developed the methodology. O. Verim performed the analysis, supervised and improved the study. O. Verim and O. Sen wrote the manuscript together. O. Verim proofread the manuscript.

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