THE USE OF REVERSE ENGINEERING TO CREATING A DIGITAL MODEL OF FACE GEAR FROM 3D POINT CLOUD

[1]Sylwia SIKORSKA-CZUPRYNA, [2]Aneta GĄDEK-MOSZCZAK

[1]*Rzeszow University of Technology, Faculty of Mechanical Engineering and Technology, Stalowa Wola, Poland, EU, sylwiasc@prz.edu.pl*

[2]*Cracow University of Technology, Faculty of Mechanical Engineering, Cracow, Poland, EU, aneta.gadek-moszczak@pk.edu.pl*

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Abstract

This paper describes the use of reverse engineering to creating a digital model of face gear from 3D point cloud. The construction of a computational model of a physical object was carried out using an optical three-dimensional scanner. Based on the cloud of points obtained in the process of scanning, a spatial digital model reflecting the geometry of an existing element was developed. Polygonization and mesh reconstruction allowed to create a discretized model that enabled the precise reproduction of the scanned object. The created model could be subsequently used to conduct appropriate analysis and simulation to verify the correctness and possible modification of the construction of scanned elements. Coordinate measurement technology to digitize surfaces in order to compare and evaluate real component parts with their theoretical data using a PC is needed in many different industrial sectors like design, construction, manufacturing, quality assurance etc.

Keywords: Reverse engineering, 3D scanning, 3D point cloud, digitization method

1. INTRODUCTION

Reverse engineering is a very important branch of geometrically design and manufacture application area, and this technique has been widely recognized as being an important step in the product development cycle. The use of RE will largely decrease the manufacturing time and costs. Many authors have researched regarding the reverse engineering, especially by focusing on scanning methods describing advantages and weaknesses of different scanning systems [1–5], reverse engineering applications based on image processing and vision aided [6,7], data-point preprocessing and reduction methods [8,9], surface fitting algorithms [10,11], multi-probing approaches [12]. There are many issues that come up in the process of reverse engineering.

Reverse engineering allows to obtain reconstruction of surface in three dimensions that uses the so-called point clouds. This technique converts a large number of measured data points into a concise and consistent computer representation [13]. This process has to be adapted to the 3D mesh structure, which depends on the creation or discretization process. For a scanned physical object, the 3D point cloud is generally very dense but composed of points whose coordinates may be disturbed by acquisition noise. There are two kinds of reverse engineering results: “simple surfaces”, such as planes, and general “free-form surfaces”, like B-Splines or NURBS as in [14]. For the second case, many methods to fit free-form surfaces on a 3D mesh exist, for example 15]. Although they are efficient for obtaining a good-looking reconstruction of a 3D mesh and allow modeling of some features. This was described in [16,17], they do not contain information on the shape what is essential for many CAD applications. In particular, the identification of the object shape for example is: a sphere or plane, the computation of shape parameters like a radius or an axis of revolution or the definition of relationships between different are not possible with these methods.

There was used the ATOS (Advanced Topometric Sensor) to digitize measuring objects with a high local measuring point resolution and accuracy. Mainly, the ATOS system works according to the triangulation principle, this means that each single 3D measuring point is captured via two different methods in a quasi-triangular measurement. A surface that was constructed from scanned points in the three-dimensional space was converted into a geometrical shape as shown in **Figure 1**.

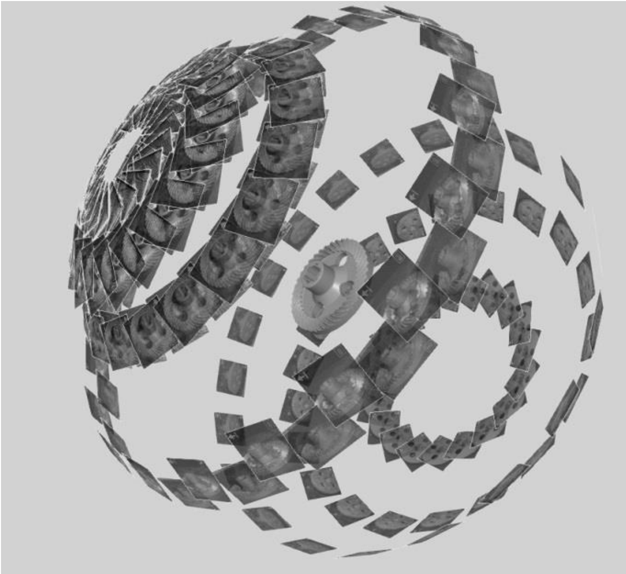

Figure 1 Assembly of the model from several dozen scans

During the measurement, a fringe pattern that is captured by two cameras, in the three-dimensional (3D) scanner, is projected onto the surface of the measuring object (**Figure 2**). Each single measurement creates up to 800 thousand 3D points. In order to complete digitize a measuring object several individual measurements are required from different directions.

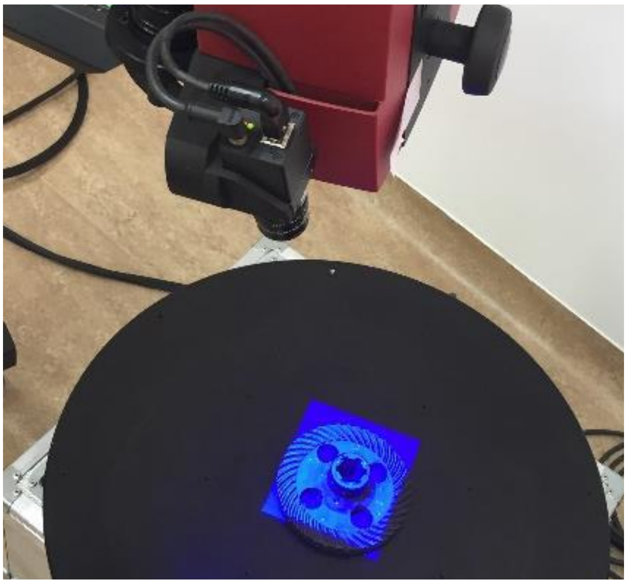

Figure 2 A view of the face gear measurement using an ATOS 3D scanner on a standard rotation table

One from two elements of spiroid gears, face gear, in real is shown **in Figure 3**. Furthermore, there will be described the process of creating digital model of spiroid gears.

Figure 3 One element of spiroid gears: face gear in real

2. METHODS

The construction of a computational model of a physical object was carried out using an optical 3D scanner [18]. Based on the obtained results, in the process of scanning point cloud, a spatial digital model reflecting an existing element was developed (**Figure 4**). Polygonization and mesh reconstruction [19] allowed create a model that enabled the precise reproduction of the scanned object. The created model was subsequently used to conduct appropriate analysis and simulation to verify the correctness and possible modification of the construction of both elements of spiroid gears: worm thread and face gear.

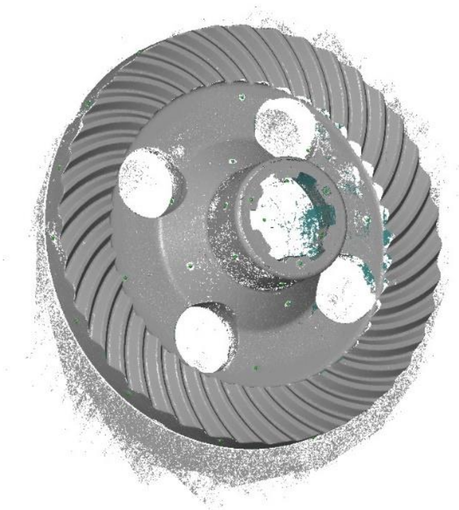

Figure 4 Raw data of point cloud consists of 2049659 points

For completely capturing complex model geometry, different partial views need to be combined. Using reference points, the software transforms the single measurements into a global coordinate system. The number of such individual measurement is determined by how completely the measuring object is scanned.

When the captured object is complete, polygonization can be started. The single measurements are available as separate preview meshes. The preview mesh is edited automatically and converted into a single mesh of nonoverlapping triangles. With these curvatures of the measuring spiroid gears, the triangle mesh has a high density. Polygon meshes can be smoothed, thinned, and refined as shown in **Figure 5**.

Figure 5 Raw data of point cloud (left), polygonized surface of the measurement object with the polygons displayed (middle), and the object after polygonization (right)

Some corrections of surface discontinuities of the measuring object such as dust, scratches, shavings, dents, etc. were carried out using the ATOS Professional software. In addition, holes in the mesh were filled and curvatures were extracted. The mesh was processed using curvature-based algorithms [20] and tolerances. It was also refining mesh done what increase the polygon density in the selected surface, e.g. to refine the shapes of edges and radius of worm thread and face gear. Ones iteration increased the number of polygons in the selected area three times. However, there was a need to refine the resolution on the edges to be able to mil directly and to get a tooth outline, which is shown in **Figure 6**.

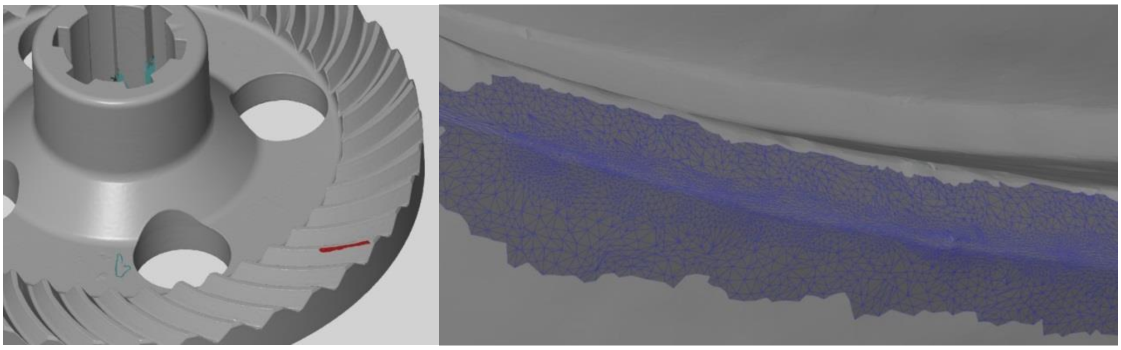

Figure 6 Refining mesh to increase the polygon density

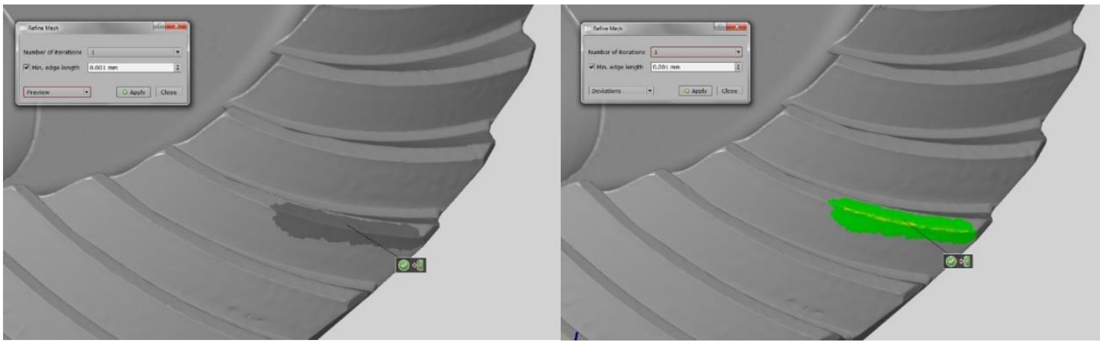

Figure 7 Polygonization of spiroid gear with a local, numerical visualization of the deviation in the selected surface

The mesh can be smoothed based on the adjustable surface tolerance. In case of a corner, the effects of the smoothing are only visible in the coloured deviation view (**Figure 7**).

3. CONCLUSION

Based on the obtained results in the process of scanning point cloud, a spatial digital model reflecting an existing element was developed. Polygonization and mesh reconstruction allowed digitize model that enabled the precise reproduction of the scanned object. The created model will be subsequently used to conduct appropriate analysis and simulation to verify the correctness and possible modification of the construction of one element of spiroid gears: face gear. Moreover, these assumptions will then be checked for the gear worm and other scanning, tomography and coordinate machine methods to compare precise of the obtained results.

REFERENCES

[1] MOTAVALLI, S. Review of reverse engineering approaches. In: *23rd International conference on computers and industrial engineering*. 1998, vol. 35, no. 1–2, pp. 25–28.

[2] WANG, G., ZHENG, B., LI, X., HOUKES, Z. Modeling and calibration of the laser beam scanning triangulation measurement system. *Robot Auton Sys.* 2002, vol. 40, pp. 267–277.

[3] CHANG, R. S., SHEU, J. Y., LIN, C. H., LIU, H. C. Analysis of CCD moire pattern for microrange measurements using the wavelet transform. *Optics & Laser Technology*. 2003, vol. 35, pp. 43–47.

[4] ZHANG, J., DJORDJEVICH, A. Study on laser stripe sensor. *Sensors and Actuators*. 1999, vol. 72, pp.224–228.

[5] ZHANG G., WEI Z. A novel calibration approach to 3D vision inspection. *Optics & Laser Technology*. 2002, vol. 34, pp. 373–380.

[6] ZHENKAI, L., LIHUI, W., BINGHENG, L. Integrating cross-sectional imaging based reverse engineering with rapid prototyping. *Computer Industry*. 2006, vol. 57, pp.131–140.

[7] PENG, Q, LOFTUS, M. A new approach to reverse engineering based on vision information. *International Journal of Machine Tools and Manufacture*. 1998, vol. 38, pp. 881–899.

[8] BUDAK, I. Development of a system for reverse engineering based design of complex shapes with emphasis on data-point pre-processing. In: *Proceedings of 11th international CIRP life cycle engineering seminar product life cycle–quality management issues.* Belgrade, 2004. pp. 223–229.

[9] PERCOCO, G., SPINA, R. A genetic algorithm approach for the reduction of point clouds of scanned complex shaped parts. In: *Annals of DAAAM for 2001*. Vienna, Austria, 2001, pp. 355–356.

[10] BRADLEY, C., VICKERS, G. W. Free-form surface reconstructIon for machIne vision rapid prototyping. *Opt. Eng*. 1993, vol. 32, no. 9, pp. 2191–2200.

[11] BRADLEY, C., VICKERS, G., MILROY, M. Reverse engineering of quadratic surfaces employing three-dimensional laser scanning. In: *Proceedings of the Institution of Mechanical Engineers*. 1994, vol. 208, pp. 21–28.

[12] CHAN, V. H., BRADLEY, C., VICKERS, G. W. A multi-sensor approach to automating coordinate measuring machine-based reverse engineering. *Computer Industry*. 2001, vol. 44, pp. 105–115.

[13] BÉNIÈRE, R., et al.: A comprehensive process of reverse engineering from 3D meshes to CAD models. *Computer-Aided Design*. 2013, vol. 45, pp.1382-1393. Available from: https://doi.org/10.1016/j.cad.2013.06.004.

[14] VÁRADY, T., MARTIN, R., COX, J. Reverse engineering of geometric models—an introduction. *Computer-Aided Design*. 1997, vol. 29, pp. 255-268.

[15] ECK, M., HOPPE, H. Automatic reconstruction of B-spline surfaces of arbitrary topological type. *Proceedings of the 23rd annual conference on computer graphics and interactive techniques*. 1996, pp. 325-334.

[16] VERGEEST, J.S.M., HORVÁTH, I., SPANJAARD, S. Parameterization of freeform features. *SMI 2001 international conference on Shape modeling and applications*. 2001, pp. 20-29.

[17] LANGERAK, T.R.. Local parameterization of freeform shapes using freeform feature recognition. *Computer-Aided Design*. 2010, vol. 42, pp. 682-692

[18] Scanning with ATOS – Basic, V7.5 SR1 Manual. GON mbH, Germany.

[19] PARK, J.M., et al. Surface reconstruction from FE mesh model. *J. Comput. Des. Eng*. 2019, vol. 2, pp.197-208.

[20] GAUTHIER, S., et al.: Analysis of digitized 3D mesh curvature histograms for reverse engineering. *Computer Ind*ustry. 2017, vol. 92-93, pp. 67-83.