Comparison and Error Analysis of Blade Model Reconstruction

Xiangyuan Guan [1], Jiangwei Chu [2], Hongliang li [3] *

[1] School of Traffic and Transportation Engineering, Northeast Forestry University, Harbin, Heilongjiang, 150040, China

[2] School of Traffic and Transportation Engineering, Northeast Forestry University, Harbin, Heilongjiang, 150040, China

[3] School of Transportation , Nantong University, Nantong, Jiangsu, 226000,China

*Corresponding author's e-mail: 1363032071@qq.com

Abstract. Surface reconstruction is the core of reverse engineering. Based on Geomagic Studio software for point-stage processing, polygon stage processing and surface construction, two different surface reconstruction methods, the precise surface reconstruction method and the B-spline surface reconstruction method, are discussed. Reconstruction and error analysis were performed on the same blade model. The analysis shows that the overall reconstruction error of the blade reconstructed model based on the approximate surface reconstruction method is 4.91%, and the overall reconstruction error of the blade reconstructed model based on the B-Spline reconstruction method is 28.83%. Obviously, the exact surface reconstruction is more suitable for the reconstruction of complex surfaces than the B-spline reconstruction method..

1. Introduction

The reverse engineering is the most important technology to realize product innovation based on the prototype. Through reverse engineering, the reconstruction model can be analyzed, modified and redesigned to achieve the purpose of innovation [1], and the remanufacturing process of the worn parts can also be assisted [2]. Surface reconstruction is an important area of reverse engineering, which mainly generates digital models of mechanical parts from measured data points [3]. The selection of the surface reconstruction method is related to the reconstructed model error, which is one of the most important steps in reverse engineering [4]. According to the different topological forms of the surface, the method of surface reconstruction can be divided into two types: the approximate surface reconstruction method based on the triangular mesh and the free surface reconstruction method based on the spline surface [5], in which the free surface reconstruction divided into triangular Bezier surface reconstruction, B-Spline (B-spline) surface reconstruction and NURBS (Nonuniform Rational B-spline) surface reconstruction. The approximate surface reconstruction method can ensure the integrity and accuracy of the model data, and generate a model with less error and high quality. The B-spline surface reconstruction method is easy to operate and has good local modification, but the error is relatively large, which is suitable for the rapid reconstruction of the regular geometric model.

At present, the most widely used the free surface reconstruction is B-spline surface reconstruction method and NURBS surface modeling method. Researchers from around the world view these two approaches as the benchmark for surface reconstruction, and on the basis of innovative development of algorithms or applications. Zhongwei Yin et al. provided a new algorithm for fitting NURBS

surfaces to scattered points using minimization of deviation under boundary constraints, solved by the method of Lagrange multipliers [6]. Xiuyang Zhao et al. proposed a new immune genetic algorithm (IGA) for point cloud fitting that fits a noisy 3D point cloud using a B-spline surface with approximate G1 continuity is presented [7]. Qing Wang et al. proposed a deformation-based methodology for reconstructing the substitution features. By means of the character lines and the limiting lines, we construct the curve-based representation of the objective point cloud, and then the secondary surface is reconstructed based on the curve-driven deformation [8]. Francesco Buonamici et al. proposed a reverse engineering method based on 3D mesh data reconstruction CAD model. The reconstruction process is performed relying on a CAD template, whose feature tree and geometric constraints are defined according to the a priori information on the physical object. The CAD template is fitted upon the mesh data, optimizing its dimensional parameters and positioning/orientation by means of a particle swarm optimization algorithm [9].

In this paper, we use Geomagic Studio software, on the basis of preprocessing of point cloud data, respectively, using B-spline surface reconstruction method and the approximate surface reconstruction method of NURBS surface modeling method, on the same blade point cloud data generation reconstructed model, and the reconstructed model is compared with the original point cloud for error comparison.

2. 3D scanning data preprocessing

The process of reverse engineering is first using laser scanners to survey the sample or model known in order to obtain its 3D section curve points cloud data; then making data process and CAD model reconstruction cooperating with software of reverse engineering, more after making precision analysis, appraising construct effect and redesigning for the curved surface reconstructed. Finally creating data with the format of IGES or STL, and it can be machining by numerical control or rapid molding to obtain entity model [10].

The OKIO-F three-dimensional scanner was used to acquire point cloud data by non-contact measurement. Its measurement accuracy was 0.01 to 0.03 mm. In this paper, the solid model is a propeller blade. The curved surface is complex and the curvature changes greatly. The actual object is shown in Figure 1.

(a) Left view (b) Main view (c) Right view
Figure 1 Object of propeller blade

The point cloud data obtained by the three-dimensional scanner be imported into Geomagic Studio software for data preprocessing, including point phase and polygon phase. The specific process is shown in Figure 2. The pre-treated blade model is shown in Figure 3.
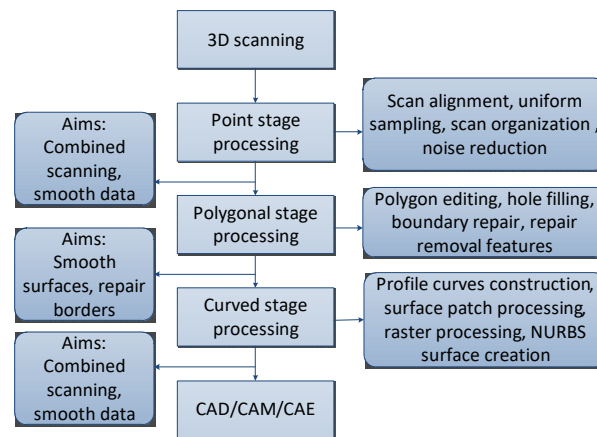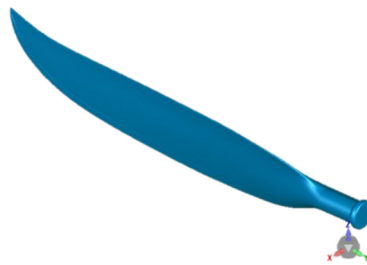
Figure 2 Geomagic Studio workflow

Figure 3 Pre-processed blade point cloud model

3. Two kinds of surface reconstruction methods

3.1 B-spline surface reconstruction method

In the Geomagic Design X software, the B-spline surface reconstruction method is adopted, and the complex surface blade is used as an example for surface reconstruction.

The B-spline surface consists of a B-spline curve, and a B-spline curve is constructed multiple times in two directions. Determine the u-directional knot vector U= [u0, u1, u2,……, um+p] and the v-directional knot vector V= [v0, v1, v2,……, vn+q], and p * q-order B-spline surface definition [5] :

$$P(u,v) = \sum_{i=0}^{m}\sum_{j=0}^{n} P_{ij}N_{i,p}(u)N_{j,q}(v)\,, (u,v) \in [u_0,u_m] \times [v_0,v_n]$$

（1.1）

In the formula, P_{ij} (I=0,1,...,m;j=0,1,...,n) is the control set-points, sequentially connected with line segments counterparts, same row of adjacent two control points resulting polyline said control mesh; $N_{i,p}(u)$ and $N_{J,q}(v)$ are the basis functions of the B-spline surface, which are recursively derived from the nodal vectors U and V according to the Boor-Cox recurrence formula.

When using the B-spline surface reconstruction method to directly fit the sample point on the surface, if the axial alignment of the data point pair is not performed, the Warping phenomenon will occur, and it will not fit into the surface we desire. At this point, it is necessary to align the interpolation points of each layer from the starting point [11]. Pay attention to the following questions:

(1) The distance between adjacent pairs of matching points should be as small as possible, especially the important position of curvature change;

(2) The matching points of the two section curve lines rotate in the same direction;

(3) The matching points do not intersect between the connecting segments.

B-spline surface reconstruction process is as follows:

(1) Coordinate alignment. In this paper, manual alignment is adopted to set the front axle on the blade handle to facilitate the subsequent cutting section, as shown in Figure 4.
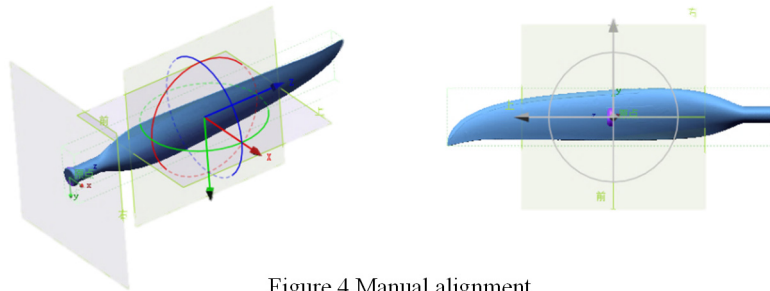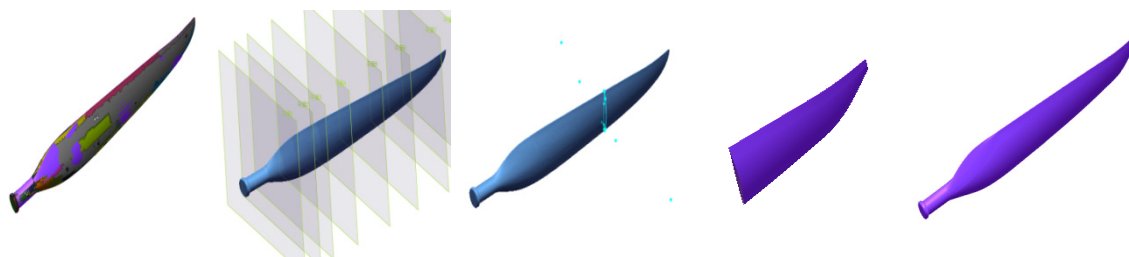
Figure 4 Manual alignment

(2) Divide field groups. For complex geometries, the field group operation can be used to automatically segment the geometry field by curvature and separate or insert new fields. The field group of the blade point cloud model is shown in Figure 5 (a).

(3) Create shear planes. Establishment of the segmentation plane is the basis for the subsequent extraction of the section curves, and it should be ensured that the spacing between adjacent planes is as small as possible, especially where the curvature changes. The shear plane of the blade is shown in Figure 5 (b).

(4) Extract the section curves. More precisely, it is simplified as the section curves to make the objective point cloud operation easier in surface deformation. The essence of our method is to make the reconstructed surface to approximate the objective point cloud within a given error. Hence, the distribution of the extracted section curves should mostly reflect the shape of the objective point cloud [4]. On the basis of the shearing plane, create a Slice sketch and extract the profile curve on the sketch. There are two main extraction methods: one for Automatic sketch operation and the other for manual drawing. In this paper, the section curves are extracted by Automatic sketch operation, and manual adjustment is made to make the section curves more accurate, and the section curves are obtained, as shown in Figure 5 (c).

(5) Surface lofting. Extract the section curves on each shear plane. The adjacent section curves by Surface lofting (as shown in Figure 5 (d) operation generated B-spline curved surface, sections of B-spline surface fitting through sew operation to complete reconstruction surface, as shown in Figure 5 (e).

(a) Divide field groups (b) Shear planes (c) Extract section curves (d) Surface lofting (e) Reconstructed model
Figure 5 B-spline surface reconstruction processes

3.2 The approximate surface reconstruction method
In the Geomagic Studio software, the approximate surface reconstruction method in the NURBS surface modeling method is adopted, and a complex surface blade is used as an example for surface reconstruction.

The approximate surface reconstruction method is based on the polygon mesh painting ways of rapid reconstruction using spatial triangles to approximate point cloud model, mesh structure directly

from the triangle partial curve, the model surface data block and quadrilateral domain division, then directly with the NURBS surface fitting model, complete the surface reconstruction [12].

The surface expression of NUBRS is as follows [10]:

$$P(u, w) = \frac{\sum_{i=0}^{n} \sum_{j=0}^{m} B_{i,k}(u) B_{j,l}(w) W_{i,j} V_{i,j}}{\sum_{i=0}^{n} \sum_{j=0}^{m} B_{i,k}(u) B_{j,l}(w) W_{i,j}} \tag{1.2}$$

Where: $B_{i,k}(u)$, $B_{j,1}(w)$ —u, w, B-spline base functions,

K—the number of b-spline bases in the u-direction;

1—w-direction B-spline base;

V—control point column;

W—weight factor.

The non-uniform of NURBS refers to the distribution of its node parameters along the parameter axis. The rational is that the weight factor W_1 on its control curve can take different values.

The approximate surface reconstruction process is as follows:

(1) Profiles creation. In Geomagic Studio software, there are three methods for profiles curve construction: one is to detect curvature, which is suitable for curved surfaces with large curvature changes; the other is to detect profile curve, which is suitable for surfaces with obvious profile curve and little curvature changes; the third is by drawing the profile curve manually, this method has a higher requirement for the operator, and the drawn profile curve can reflect the characteristics of the model well.

Since the profile curve of the blade is obvious, in order to reduce the error caused by the manual drawing, the method of detecting profile curve is adopted. Firstly, through the extract command, the automatically generated blade profile curve is obtained. Using the Edit profile curve command, the profile curve is manually corrected to make it more perfect.

(2) Surface patches processing. Then we use the construct surface patch command and move the panel to modify relax the surface patch, it is more uniform distribution and curvature change of the surface patch and the size is more appropriate.

(3) Mesh processing. The smoothing effect of the mesh aims to improve the quality of the surface generated, that can be applied automatically by user input and produces global effects [13]. And the mesh command is used to divide the surface patches into the finer points. The points in the mesh can be used as control points of the NURBS surface. The curve can be adjusted by changing, the number of control points in such manner that if the control points are added; the degree of shape inosculating is good and if the control points are reduced, the curve is smoother [14]. The number of meshes depends on the size of the surface patches. Too few features may miss some features.

(4) NURBS surface creation. Finally, use the fit surface command to fit the surface patch to a NURBS surface. In the process of fitting the surface, the constant option is recommended (the surface that is fitted using the constant option can be modified, otherwise it cannot be modified) [15]. To ensure that the details of the model are accurate, the surface tension is minimized and the number of points is maximized to reduce the loss of detail features.

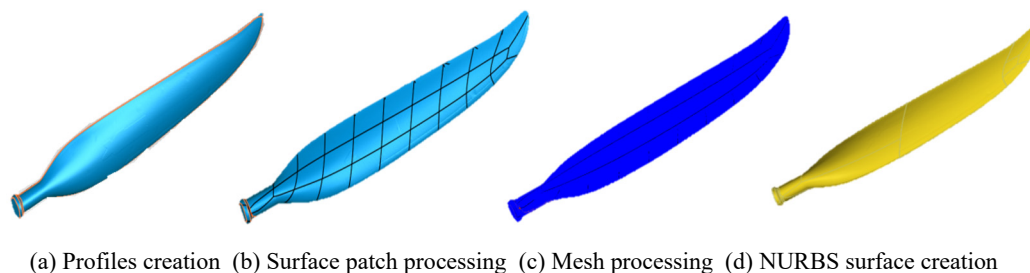The reconstitution process of the blade is shown in Figure 6.

(a) Profiles creation　(b) Surface patch processing　(c) Mesh processing　(d) NURBS surface creation

Figure 6　The approximate surface reconstruction process

4. Error Analyses

4.1 Errors based on B-spline surface reconstruction method
(1) 3D error analysis of the blade reconstruction model

In this paper, Geomagic Control software is used to compare the error of reconstructed models based on B-spline surface reconstruction method and the approximate surface reconstruction method of the same blade. When the two kinds of reconstructed models of the blade were imported in the Geomagic Control software and the original point cloud model was set as a reference, execute the 3D Compare command. The upper and lower deviation values and the number of deviation labels can be set. In the text, the upper and lower deviations are set to ±0.3 mm.

The 3D comparison deviation chromatogram of the reconstructed model is shown in Figure 7 (a). From Figure 7(a), it can be seen that on the deviation chromatogram of the blade reconstructed model, blue (below the lower deviation) and red (above the upper deviation) regions appear locally, and the reconstruction error in this region is large.

The overall distribution of the 3D comparison error of the reconstructed model is shown in Figure 8 (a). Figure 8 (a) shows that the tolerance of 0.6 mm blade reconstruction model and upper and lower deviation is + / - 0.3 mm (set in the text), the average error is 0.03 mm, and the errors are mainly distributed in the range of 1.47 mm to 1.47 mm.

The overall error of the reconstruction of the model is shown in Table 1. From Table 1, we can see that the reconstructed model of the blade has 28.83% of the overall error of the reconstruction, and 12.53% of which is less than the lower deviation.
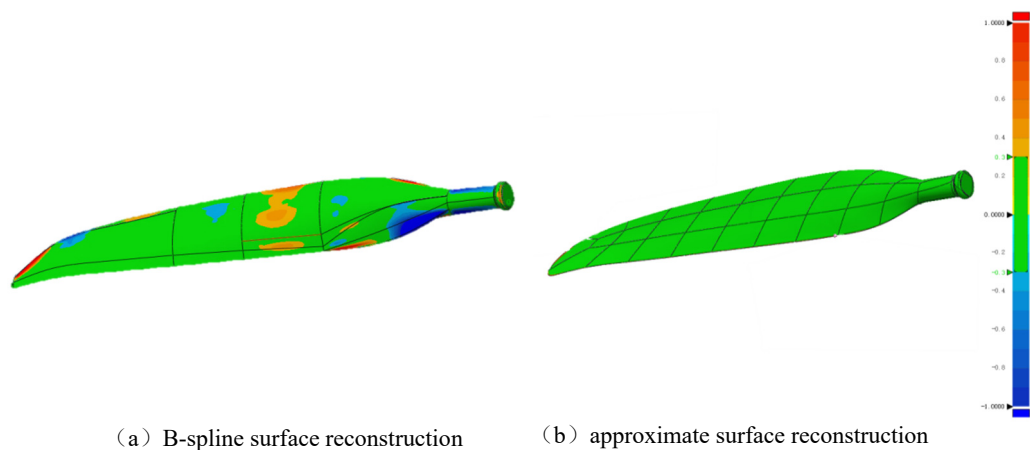

（a）B-spline surface reconstruction   （b）approximate surface reconstruction

Figure7 3D comparison deviation chromatograms of two reconstruction methods

| | -1.47 | mean: -0.03 | 1.47 | | -0.35 | mean: 0.04 | 0.35 |

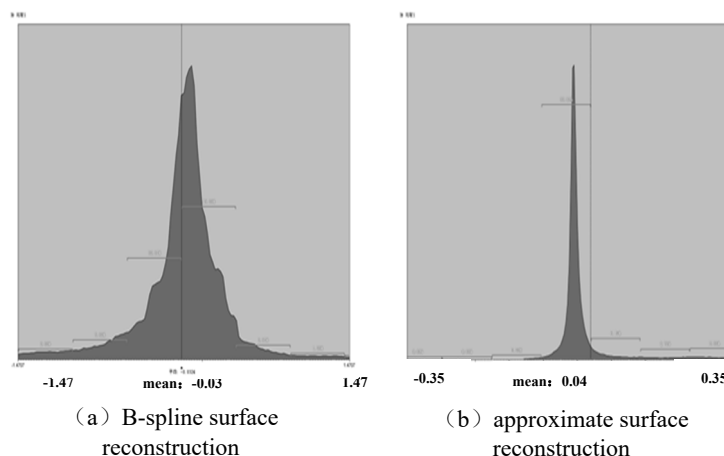（a）B-spline surface reconstruction   （b）approximate surface reconstruction

Figure 8 Total distributions of 3D comparison errors for two reconstruction methods

Table 1 .The total errors of B-spline surface reconstruction.

Error		Deviation	
Maximum	2.97	Tolerance (%)	71.17
Minimum	-2.94		
average	-0.03	Out of tolerance (%)	28.83
RMS	0.481		
standard deviation	0.479	Less than the lower deviation (%)	12.53
Discrete	0.23		

(2) Analysis of characteristic cross section error of the blade reconstruction model

The section size and shape of the propeller blade at 0.7R is a key parameter for component design, performance analysis, and inspection, that is, a characteristic section of a complex curved surface of the blade. Therefore, the section at 0.7R (as shown in Figure 9) is used to perform 2D error analysis. The deviation chromatogram of the characteristic section is shown in Figure 10. From Figure 10 (a), it can be seen that on the deviation chromatogram of the blade reconstruction model, a blue area (below the lower deviation value) appears locally, indicating that the reconstruction errors in this area are large.
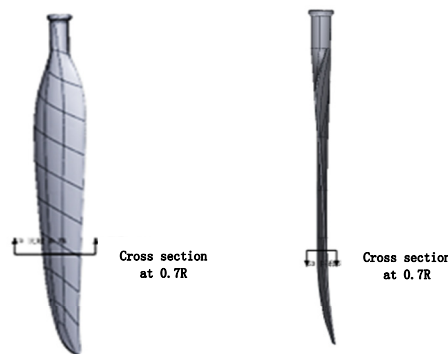

Figure 9 Selection of characteristic cross section

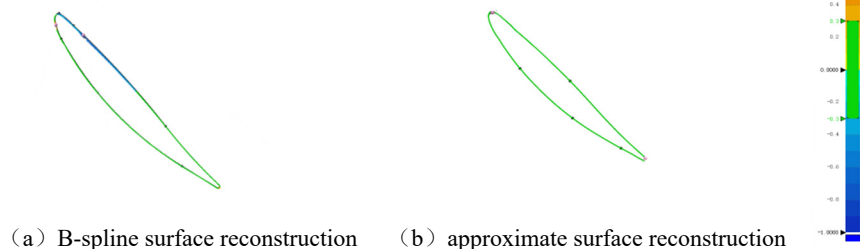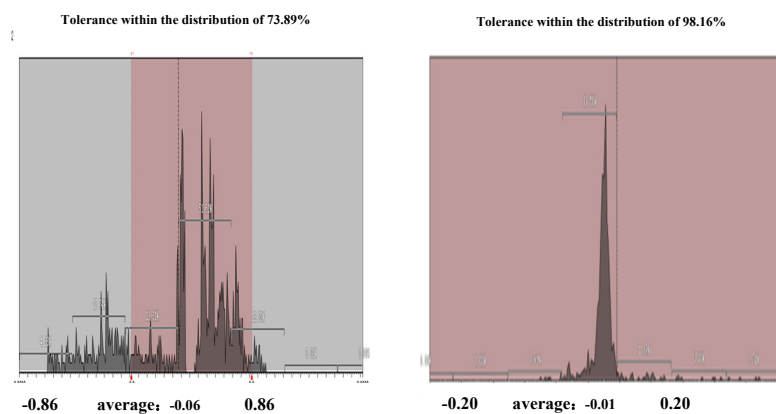（a）B-spline surface reconstruction   （b）approximate surface reconstruction

Figure 10 Characteristic cross-sectional deviation chromatograms for two reconstruction methods

The overall error in the reconstruction model in the 0.7R section is shown in Figure 11 (a). From Figure 11 (a), we can see that when the tolerance of the blade reconstruction model is 0.6mm and the vertical deviation is ±0. 3mm (set in the text), the average error is -0.01mm, and the errors are mainly distributed in the range of -0.86mm to 0.86mm.

（a）B-spline surface reconstruction   （b）approximate surface reconstruction
Figure 11 Cross-sectional error distributions at 0.7R

The error values of the characteristic section of the reconstructed model are shown in Table 2. As can be seen from Table 2, 26.11% of the total reconstruction error of the blade reconfigured model is accounted for, and 23.49% of which is less than the lower deviation.

Table 2. Cross-sectional errors at 0.7R based on B-spline surface reconstruction method.

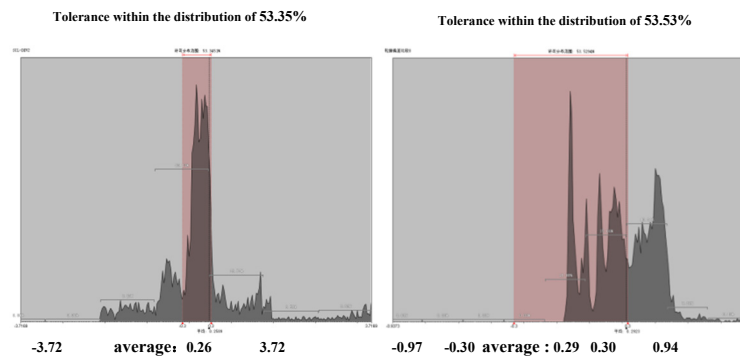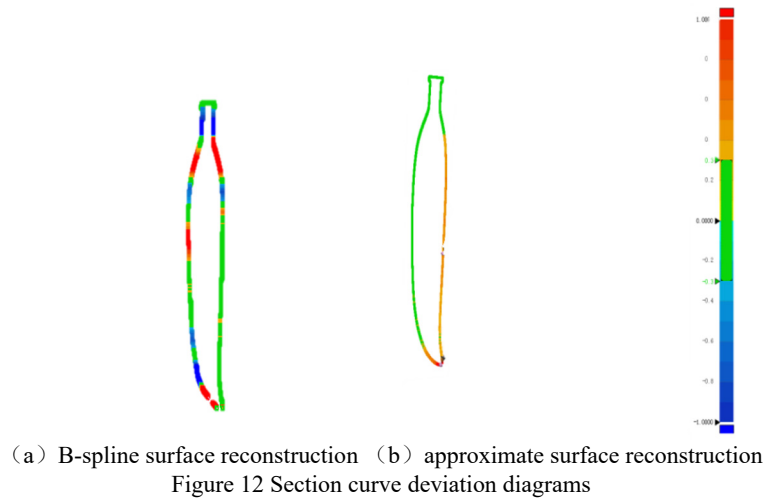| Error		Deviation	
Maximum	0.37	Tolerance (%)	
Minimum	-0.71		73.89
average	-0.06	Out of tolerance (%)	
RMS	0.27		26.11
standard deviation	0.26	Less than the lower deviation (%)	
Discrete	0.07		23.49

 (3) Analysis of the section curves deviation of blade reconstruction model
The overall error distribution for the comparison of section curve deviations is shown in Figure 13 (a); the overall deviation of section curve deviations is shown in Table 3.
From Figure 7 (a), it can be seen that red (above the upper deviation) and blue (below the lower deviation) regions appear on the deviation chromatogram of the blade reconstruction model.
From Figure 13(a), it can be seen that when the tolerance of the blade reconstruction model is 0.6mm and the vertical deviation is ±0.3mm (set in the text), the average error of the section curve is 0.26mm, and the relatively large errors distribution are relatively concentrated.
Using the section curve deviation command in the comparison module, the section curve deviation chromatograms of the reconstructed model are obtained, as shown in Figure 12 (a).

（a）B-spline surface reconstruction （b）approximate surface reconstruction

Figure 12 Section curve deviation diagrams

（a）B-spline surface reconstruction （b）approximate surface reconstruction

Figure 13 Overall distribution of section curve deviation

From Table 3, it can be seen that the blade reconstruction model has a total reconstructed error of 46.65%, of which 21.64% is less than the lower deviation, and the error is larger

Table 3. Overall errors of section curve deviations.

Error		Deviation	
Maximum	5.54	Tolerance (%)	53.35
Minimum	-2.03		
average	0.26	Out of tolerance (%)	46.65
RMS	1.18		
standard deviation	1.15	Less than the lower deviation (%)	21.64
Discrete	1.33		

4.2 Errors based on the approximate surface reconstruction method

(1) 3D error analysis of the blade reconstruction model

The 3D comparison deviation chromatogram of the reconstructed model is shown in Figure 7 (b). From Figure 7(b), it can be seen that the deviation chromatogram of the blade reconstructed model is basically green (within the upper and lower deviation).

The overall distribution of the 3D comparison error of the reconstructed model is shown in Figure 8 (b). Figure 8 (b) shows that the tolerance of 0.6 mm blade reconstruction model and upper and lower deviation is + / - 0.3 mm (set in the text), the average error is 0.04 mm, and the errors are mainly distributed in the range of -0.35 mm to 0.35 mm.

The overall error of the reconstructed model is shown in Table 2. From Table 4, it can be seen that the blade reconstructed model has an overall error of 4.91% of the reconstruction.

Table 4. The total error of approximate surface reconstruction

Error		Deviation	
Maximum	0.77	Tolerance (%)	
Minimum	-0.14		95.09
average	0.04	Out of tolerance (%)	
RMS	0.11		4.91
standard deviation	0.10	Less than the lower deviation (%)	
Discrete	0.01		4.91

(2) Analysis of characteristic cross section error of the blade reconstruction model

It can be seen from Figure 10 (b) that in the deviation chromatogram of the blade reconstruction model, the overall color is green, indicating that the reconstructed deviation value of this position is within a reasonable range, and the reconstruction effect is better.

The overall distribution of errors in the reconstruction model on the 0.7R section is shown in Figure 11 (b). It can be seen from Figure 11 (b) that the reconfiguration model of the blade is 0.6mm in tolerance and the vertical deviation is ±0. 3mm. The average error is -0.01mm and the errors are mainly distributed within the range of -0.20mm~0. 20mm.

The error value of the characteristic section of the reconstructed model is shown in table 5. It can be seen from table 5 that the reconstruction model of the blade is 1.84%.

Table 5 .The overall error of the B-spline approximate surface reconstruction.

Error		Deviation	
Maximum	0.38	Tolerance (%)	
Minimum	-0.07		98.16
average	0.01	Out of tolerance (%)	
RMS	0.06		1.84
standard deviation	0.06	Less than the lower deviation (%)	
Discrete	0.004		0

(3) Analysis of the section curves deviation of blade reconstruction model

It can be seen from Figure 7 (b) that the red region (above the upper deviation value) appears on the deviation chromatogram of the blade reconstruction model.

As can be seen from Figure 13 (b), when the tolerance of the blade reconstruction model is 0.6mm and the vertical deviation is ±0. 3mm (set in the text), the average error of the section curve is 0.29mm, and the errors are concentrated in the range of -0.3 to 0.94mm.

From Table 6, we can see that the reconstructed model of the blade has an overall reconstructed error of 46.47%, all higher than the upper deviation.

4.3 Comparison of reconstructed model errors of two methods

(1) 3D error analysis of the blade reconstruction model:

As can be seen from Figure 7, the deviation chromatogram of the blade reconstructed model based on the approximate surface reconstruction method is basically green (indicating that the deviation is within the set reasonable range), and the green area is larger, so we can see that the reconstruction error is smaller. Figure 8 shows: based on the approximate surface reconstruction method of error distribution of blade reconstructed model, more concentrated and the error range is smaller. It can be seen from Tables 1 and 2 that the overall reconstruction error of the blade reconstruction model based on the approximate surface reconstruction method is smaller.

(2) Analysis of characteristic cross section error of the blade reconstruction model

It can be seen from Figure 10 that the deviation chromatogram of the characteristic cross section obtained based on the approximate surface reconstruction method is basically green (indicating that the deviation value is within the set reasonable range), so it is known that the reconstruction error is small. From Figure 11 we can see that the error distribution of the feature section based on the approximate surface reconstruction method is more concentrated and the error range is smaller. From Tables 3 and 4, we can see that the reconstruction error of the blade reconstruction model based on the approximate surface reconstruction method is much smaller than that based on the B-spline surface method.

(3) Analysis of the section curves deviation of blade reconstruction model

As can be seen from Figure 7 , the section curve deviation of the blade reconfiguration model based on the approximate surface reconstruction method shows only a red region (above the upper deviation value), no blue region (below the lower deviation), and a deviation region. The length is smaller than the B-spline surface method.

It can be seen from Figure 13 that when the tolerance of the blade reconstruction model is 0.6mm and the vertical deviation is ±0. 3mm (set in the text), the section curve deviation value of the blade reconstruction model based on the approximate surface reconstruction method is smaller and the range is more concentrated. There is no site below the deviation.

From Table 5, it can be seen that the overall section curve deviation of the blade reconstruction model based on the approximate surface reconstruction method is smaller.

From the analysis of (1), (2) and (3), it can be known that the reconstruction error of the blade reconstruction model based on the approximate surface reconstruction method is smaller, and it is closer to the original point cloud model.

5. Conclusions

In this paper, based on the Geomagic Studio software for point stage processing, polygon stage processing and surface construction, the approximate surface reconstruction method (though Geomagic Studio software) and B-spline surface reconstruction method (though Geomagic Design Software) of the surface stage are mainly discussed. Two different methods of surface reconstruction and error analysis of the same blade model (though Geomagic Control software). The main conclusions are as follows:

(1) The deviation of the blade reconstructed model based on the approximate surface reconstruction method is basically green on the chromatogram (within the upper and lower division), the error distribution is more concentrated and the error range is smaller, there is 4.91% of the overall error of the reconstruction.Its overall error, characteristic section error, and section curve deviation are all smaller. Compared with B-spline surface reconstruction method, it is more suitable for the rapid reconstruction of complex surface.

(2) Based on the B-spline reconstruction method, the deviation of the chromatogram of the blade reconstructed model shows blue (below lower deviation) and red (higher than the upper division). The error distribution is more dispersed and the error range is larger, 28.83% of the overall reconstruction error. Its overall error, characteristic section error, and section curve deviation are all larger. It is more suitable for the rapid reconstruction of regular geometric models, rather than complex surface body.

References

[1] Li, M., Li Q. (2013) Realization of 3D Reconstruction of CAD Model Based on Slicing Data. In: Qi, E., Shen J., Dou R. (eds) The 19th International Conference on Industrial Engineering and Engineering Management. Springer, Berlin, Heidelberg.

[2]Lingling Li, Congbo Li, Ying Tang, Yanbin Du.An integrated approach of reverse engineering aided remanufacturing process for worn components. Robotics and Computer–Integrated Manufacturing 48 (2017) 39–50.

[3]István Kovács, Tamás Várady, Péter Salvi. Applying geometric constraints for perfecting CAD models in reverse engineering. Graphical Models 82 (2015) 44–57.

[4] Wang, Q., Li, J. & Ke, Y. J. Zhejiang Univ. Sci. A (2008) 9: 1214. https://doi.org/10.1631/jzus.A0820244

[5] Yuan Jing, Du Na, Dong Wenzhong, et al. Design and realization of B-spline surface reconstruction algorithm based on cloud data [J]．Journal of Shenyang Normal University (Natural Science Edition), 2015,33 (04): 253－256．

[6] Zhongwei Yin. Reverse engineering of a NURBS surface from digitized points subject to boundary conditions. Computers & Graphics Volume 28, Issue 2, April 2004, Pages 207-212.

[7] IGA-based point cloud fitting using B-spline surfaces for reverse engineering. Xiuyang Zhao, Caiming Zhang, Li Xu , Bo Yang, Zhiquan Feng. Information Sciences 245 (2013) 276–289.

[8] Deformation-based freeform feature reconstruction in reverse engineering. Qing WANG, Jiang-xiong LI, Ying-lin KE. Wang et al. / J Zhejiang Univ Sci A 2008 9 (9): 1214-1228.

[9] Buonamici, F., et al. Reverse engineering of mechanical parts: A template-based approach. Journal of Computational Design and Engineering (2018), https://doi.org/10.1016/j.jcde.2017.11.009.

[10] Chen-Xuefang, Sun-Chunhua: The application of reverse engineering and rapid molding technologies. Publishing company of mechanical industry, Beijing (2009).

[11] Ye Lin yuan．Research on B-Spline Surface Segmentation Fitting Technique for Complicated Section Curve Data [D]．Nanjing: Nanjing University of Aeronautics and Astronautics, 2012．

[12]Mo Hai jun，Zhou Jiajun，Lin Zhisheng．Compare of surface model reconstruction methods and error analysis [J]．Modern Manufacturing Engineering, 2015, (06): 84－88．

[13] Relvas, C., Ramos, A., Complete, A. et al. Int. J. Precis. Eng. Manuf.(2011)12:1035. https://doi.org/10.1007/s12541-011-0138-0

[14] Mei Z., Jing hua W. (2017) Mickey Mouse 3D CAD Model Reconstruction Based on Reverse Engineering. In: Xhafa F., Patnaik S., Yu, Z. (eds) Recent Developments in Intelligent Systems and Interactive Applications. IISA 2016. Advances in Intelligent Systems and Computing, vol 541. Springer, Cham

[15] Peng Wei．Research on NURBS Surface Reconstruction in Reverse Engineering [D]．Nanjing: Nanjing University of Science and Technology, 2004.

[16] Zhang,R.H., He, Z.C., Wang, W., You F., Li, K.N. Study on self-tuning tyre friction control for developing main-servo loop integrated chassis control system, IEEE Access, 2017,5: 6649-6660.

[17] Sun, X.J., Zhang, H., Meng, W.J., Zhang, R.H., Li, K.L., & Peng, T. （2018）. Primary resonance analysis and vibration suppression for the harmonically excited nonlinear suspension system using a pair of symmetric viscoelastic buffers, Nonlinear Dynamics, https://doi.org/10.1007/s11071-018-4421-9