Hybrid Reconstruction and Evaluation of 3D Model of Equipment Parts for Virtual Maintenance System

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Abstract. The research and application of reverse engineering technology are more and more extensive, but its process is still not fully mature. Aiming at the complexity of equipment parts and the diversity of accuracy requirements, the method of hybrid reconstruction and evaluation of 3D model of equipment parts for virtual maintenance system is illustrated. The general process is given. Taking the two-stage bevel gear worm reducer as the research object, the research on three-dimensional scanning, data processing and model reconstruction is carried out. This paper focuses on the reconstruction process and methods such as regional division, solid model construction based on maximum outer contour, creation of basic surface, patch fitting and so on by taking the bevel gear in the reducer as an example. Finally, 3D comparison, 2D comparison, cross-section accuracy and size of the reconstructed solid model are evaluated. The results show that the hybrid reconstruction method has strong adaptability and high efficiency. Reverse modeling and forward design are organically combined to give full play to their advantages, and the hybrid reconstruction method can effectively reverse the original design intention of the product and improve the parameterization ability of reverse modeling. It can meet the requirements of different precision models developed by virtual maintenance system, structural wall chart and atlas, multimedia and so on.

1. Introduction
Virtual maintenance system has the characteristics of high training efficiency, low cost and good safety. It effectively provides a realistic training environment for equipment operation training and maintenance training. It overcomes many adverse factors brought by the number of machinery and the training site environment, greatly reduces the repeated disassembly and assembly of equipment, and provides an efficient and economic maintenance support training means for new equipment. One of the bottlenecks of virtual training system is the construction of 3D model. In view of the complexity of equipment parts and the diversity of accuracy requirements for virtual maintenance system, structural wall charts and atlas, the 3D laser scanning technology is used to collect the 3D model data of parts efficiently and accurately, and then the large-scale point cloud data is processed. The 3D model hybrid reconstruction technology is used to carry out reverse reconstruction to obtain the parametric model, and the reconstructed model is evaluated and analyzed to provide necessary model resources for the development of virtual maintenance training system, structural wall chart and atlas.

At present, there are many reverse modeling software on the market. But the reverse modeling methods are different. Geomagic Design Direct is a forward and backward hybrid design software based on direct modeling technology. Through calculating and extracting the curvature and normal direction of different regions in the triangular mesh surface model, the corresponding 3D regular entity features are fitted. Geomagic Studio divides triangular mesh model according to the geometric features, then fits the corresponding 3D surface features, and finally reconstructs the surface model. Compared
with the surface model, the solid model can express the 3D shape of the model more completely and strictly. Compared with them, this hybrid reconstruction method combines solid modeling and surface modeling, can quickly create the original model, and can guarantee the precision of the model, and can do the direct design on the basis of the reconstructed model.

2. Hybrid Reconstruction Process

2.1. General Process

The surfaces of a large number of parts in engineering equipment are relatively regular, there are few free-form surfaces, and there will be no large transition surfaces between faces. Basically, they transition with small fillets, showing obvious edges. The parts with this feature are suitable for the reverse modeling method based on solid features. For some free-form surface parts, such as outer cladding, the surface fitting reverse modeling method based on surface features can be used. According to the structural characteristics and actual conditions of engineering equipment, the traditional method of machine measuring and drawing is actively used in reverse measurement to obtain some basic parameters of some parts like gears. The feature parameters extracted through advanced measurement and in the reverse modeling software are imported into the forward modeling software for editing, modification and solid modeling. The existing mature modeling technologies are made full use of by the organic combination of reverse modeling and forward design and cross multiple 3D modeling software platforms. They should be comprehensively applied, give full play to their modeling advantages, learn from each other, complement each other, and give full play to their respective advantages. Therefore, the hybrid reconstruction of engineering equipment 3D model not only adopts a variety of hybrid reverse modeling methods, but also adopts forward and reverse hybrid modeling. Its process is shown in figure 1.

Patch optimization can eliminate impurities by smoothing, reduce the surface roughness, so that the surface is more smooth. It can be optimized on the whole surface, but also on the local surface, according to the actual situation to improve the quality of the surface.

![Figure 1. Hybrid reconstruction process of 3D model.](image)

2.2. AXE-B11 Handheld Global 3D Scanner

This paper takes the two-stage bevel gear worm reducer as the research object. Two-stage reducer is shown in figure 2. The appearance of AXE-B11 scanner is shown in figure 3. Based on the decomposition and determination of basic parameters, AXE-B11 handheld global 3D scanner is selected to quickly scan the reducer to obtain the point cloud data of each part, and then carry out large-scale processing of point cloud data to restructure a regular and accurate model. The accuracy of
reconstructed solid model data is required to reach part level, and the key model accuracy is to the millimeter level. Considering the reuse of existing models, it supports the transformation of a variety of standardized model formats. After importing the virtual system, the shape, structure, proportion and texture of the parts are basically consistent with the actual ones.

Figure 2. Two-stage reducer.

Figure 3. 3D scanner.

The scanner obtains spatial three-dimensional point cloud by using binocular vision principle. The space position of the scanner and the measured object is obtained by scanning the mark point of the current frame and matching the mark point library. The laser is emitted by the laser transmitter and irradiated on the surface of the scanned workpiece. Then the reflected light is captured by two calibrated industrial cameras, and the shape data of the workpiece is obtained through calculation. The light source is 22 crossed blue laser lines (plus 1 blue laser line), the blue light reference distance is 450mm and the depth of field is 500mm. Deep hole scanning supports an accuracy of 0.020 mm, and it has the scanning rate of 1300000 times per second.

3. Reverse Reconstruction of Bevel Gear

3.1. Determination of Basic Parameters

The picture of bevel gear part is shown in figure 4. After measurement, the diameter of the reference circle at the big end of the bevel gear is 58.13mm and the number of teeth is 30, the calculated value of the module at the big end is 1.937mm, then the standard value is 2mm. See Table 1 for some parameters.

Table 1. Some parameters of bevel gear.

| Number of teeth | Module | Diameter of reference circle at the big end | Crossed axis angle | Outer cone distance | Addendum height | Root height | Apical gap | Root angle |
|-----------------|--------|--------------------------------------------|-------------------|--------------------|----------------|-------------|------------|------------|
| 30              | 2mm    | 60mm                                       | 90°               | 42.43mm            | 2mm            | 2.4mm       | 0.4mm      | 3.23°      |

3.2. Coordinate System Establishment and Model Alignment

Scanning picture and point cloud data are shown in figure 5. To import the scanned data to Geomagic Design X, coordinate alignment is required to make the model coordinates coincide with the system coordinates.

Figure 4. Bevel gear.

Figure 5. Scanning picture and point cloud data.
3.3. **Solid Model Construction Based on Maximum Outer Contour**

We can change the direction of the intercepted feature and adjust the view for inspection. As long as the intercepted range includes the tooth top, the maximum outer contour can be intercepted.

After the sketch is drawn (figure 6), the deviation of the line is analyzed. As shown in figure 7, the deviation is displayed in green within plus or minus 0.1mm and yellow within plus or minus 0.2mm. When the positive and negative deviation is close to or even more than 1mm, the line is red. Enlarge the figure, we observe and adjust the line to make it as green as possible to reduce the deviation.

![Figure 6. Patch sketch fitting.](image)

![Figure 7. Line deviation analysis.](image)

After checking the deviation, we select the separation end point and check whether the sketch is closed. If it is not closed, light green dots will appear, as shown in Figure 8. If it is not deleted, the entity creation operation cannot be realized.

3.4. **Creation of Cutting Surface**

3.4.1. **Basic Surface Creation Method**

- Select the field color block to create the base surface.

The region is an important basis for fitting patches. It uses different color blocks to split different surfaces according to the curvature changes of model surfaces, as shown in figure 9. The color block is attached to the STL triangle, which reflects the characteristics of the model, and is used to extract the shape and dimension information of the STL model. In the field color block of bevel gear, we select smooth color block to create cylindrical surface for the target field. The color block with complete smooth is helpful to the creation of our surface and reduce the deviation. The accuracy of regional division directly affects the accuracy of the fitting patch.

![Figure 8. Line separation point inspection.](image)

![Figure 9. Regional division.](image)

Firstly, the reverse parametric modeling method based on regional division is to divide the polygon model according to curvature, and express the features of the model through region groups. Then, the 2D section line and projection boundary contour are created according to the feature extraction of the region, and the parameter values are modified and the line constraint relationship is added to obtain more accurate 2D sketch. Then, stretch, rotate, scan the sketch, and create a parametric model. At the same time, surface fitting is carried out according to the region to create patches. Finally, the patch and parametric model are Boolean operation to get the accurate parametric model.
- Drawing UV curve.

UV curve provides a connection between the model surface and the texture image. UV curve is responsible for determining which vertex (pixel) on the texture image should be placed on the model surface, so that the whole texture can be covered on the model.

![Figure 10. Drawing UV curve.](image1)

![Figure 11. Fitting surfaces.](image2)

Select UV curve to loft to create a surface. Then, the remaining surface parts are obtained by cutting, and the groove parts of the two surfaces are fitted, as shown in figure 11.

### 3.4.2. Patch Fitting Method

- Select the fitting object and adjust fitting range.

Rotate the model to find the field color block with complete surface and good quality as the fitting object, as shown in figure 12. Adjustment of fitting range is shown in figure 13.

![Figure 12. Selection of fitting object.](image3)

![Figure 13. Adjustment of fitting range.](image4)

- Check patch fitting effect.

A patch is a series of points, edges and faces (usually triangles) that are digitized in 3d based on polyhedra. Surface triangulation is the process of connecting three points and constructing a surface. There may be some wrong triangles in the process of Triangulation, such as cross triangles and redundant triangles, which should be deleted to improve the quality of the surface. In addition, defects such as holes and bulges may appear in the initial piece, so it needs to be repaired. The missing hole is filled with the element surface according to the shape curvature of the local patch, and the convex part of the patch is removed and repaired. The fitting quality of tooth surface needs to be checked to make the deviation analysis of fitting tooth surface as green as possible, as shown in figure 14.

![Figure 14. Tooth surface checking.](image5)

The resulting surface arraying is shown in figure 15. After solid cutting and keyway creation, the whole bevel gear model is reconstructed. Through deviation analysis and parameter adjustment, we can obtain the model meeting the accuracy requirement, as shown in figure 16. The final model is shown in figure 17.
4. Evaluation of Reconstruction Model

Geomagic Control platform provides the ability to simplify almost every process, reduce human interaction in measurement and recording, reduce measurement time and significantly enhance “GD&T” results. Geometric tolerance, hard measurement and azimuth inspection can not only speed up the measurement speed and improve the accuracy of parts. After importing the exported STL file and STP file into Geomagic Control software, the patch file and the model file are best fitted. We can analyze multiple aspects, such as 3D comparison (figure 18), 2D comparison (figure 19), cross section through the object; 2D dimensioning (figure 20), etc. Finally, we can also create PDF evaluation reports.

![Figure 15. Surface array.](image1)

![Figure 16. Deviation analysis.](image2)

![Figure 17. Final model.](image3)

![Figure 18. 3D comparison results.](image4)

| ≥Min (mm) | <Max (mm) | Ni (Number of points) | R_i (%) |
|-----------|-----------|-----------------------|---------|
| -0.5000   | -0.3000   | 256                   | 0.40    |
| -0.3000   | -0.1000   | 13373                 | 20.99   |
| -0.1000   | 0.5000    | 50076                 | 78.60   |

\[ R_i = \frac{N_i}{(N_1 + N_2 + N_3)} \times 100\% \]
The Statistics for 3D comparison are shown in Table 2. The deviation between -0.1 and 0.5mm accounted for 78.61%. The result indicates that the reconstruction model of bevel gear fully meet the requirements which the accuracy needs to be in millimeter for virtual maintenance system.

5. Conclusion
In the process of hybrid reconstruction, different features can be better divided according to the curvature division region, and the same feature can be edited manually. It is more conducive to the expression of features by dividing several regions. Therefore, it is important to divide the regions reasonably and accurately to construct the precise reverse parametric model effectively. The hybrid reconstruction method saves time compared with the traditional surface fitting method.
In addition, after obtaining the design parameters of the existing model, the relevant parameters and models can be easily adjusted to meet the accuracy requirements of the final model. Therefore, this method can meet the requirements of different precision models such as virtual maintenance system, structural wall chart and atlas, multimedia and so on. And if we want to improve or innovate the design on this basis, it also has great freedom and flexibility.

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