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Reverse Engineering Techniques Used To Create Finished Products With Backflow Smoke Effects

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***Abstract*—The smoke backflow effect is currently widely used in home landscaping decorations. The main phenomenon is that after the Incense Tower is lit, in a windless indoor environment, the smoke does not float upward but flows downward. Through special landscaping to drainage, the white smoke will look like a small waterfall, which is very visually pleasing, so it is very popular among the general public. Therefore, this paper intends to use reverse engineering technology to scan and reconstruct a 3D model of a sculpture with a unique shape, and then use Rhinoceros modeling software to create a smoke guide aisle inside the model to complete an art work with a backflow smoke effects.**

***Keywords*—reverse engineering technology**

I. INTRODUCTION

Due to the rapid development of 3D scanning technology, digital model manufacturing has become a new trend in today's industry, in which reverse engineering technology plays an important role. In reverse engineering technology, the accuracy of obtaining point group data, the processing and superposition of point group data, and even the reconstruction of fitting surfaces are all important factors for the success of reverse engineering. Because today's measurement equipment is sophisticated, the point group data scanned are very large. For this problem, the average point method, magnification method, spacing method, chord length deviation method, interpolation method, average filtering, Gaussian filtering, etc. are used to reduce the number of data point groups to speed up data processing. As for the superposition of different point groups, the currently more commonly used methods and operating procedures will be introduced in detail later.

Methods for reconstructing surfaces in reverse engineering are roughly divided into two types: directly reconstructing the surface from point groups, or first constructing characteristic lines from point groups and then reconstructing the surface. Among them, the way to directly reconstruct the surface from the point group is to use the fitting method to create a surface attached to the point group data. The boundary of the fitted surface usually extends beyond the range covered by the point group data to facilitate subsequent surface trimming processing. The method of reconstructing a surface from point groups and characteristic lines is to first construct the boundary characteristic lines of each area of the surface through point groups, and then use these boundary characteristic lines as restrictions to constrain the point groups in the area. The fitted surface can be closer to the surface of the original object. It is also the most commonly used method for reverse engineering to reconstruct the surface. Many studies have been published in this part. For example, Huang [1] proposed two rules that uses point clouds to construct the characteristic surfaces and to modify the surface method. The first one includes point data preprocessing and characteristic surface joining rules. Point data pre-processing is to smooth the point data to reduce the offset error of the point data. The purpose of characteristic surface joining is to construct a characteristic surface with the minimum control points through those smoothed point data. As for the second rule, which includes feature control point sampling, feature control point segmentation and feature change, it mainly uses the differential characteristics of the B-Spline curve and uses the curvature changes to extract the control points of the feature boundary surface and isolate them. The control points inside each closed feature edge are movable control points when the feature changes, so that the purpose of local feature deformation can be achieved.

Choi [2] also proposed the influence of Ferguson, Bezier, B-Spline curves and surfaces, and their nodes and weighted values on curves and surfaces. And NURBS surfaces also have a detailed discussion on the mutual changes between control points and fitting points. Yao et al. [3] proposed using the method of curvature analysis to extract characteristic curves, complete the definition of surface boundaries, and then separate the point groups into different areas according to the geometric shape of the workpiece to make the arrangement of the data point groups more correct. And complete the fitting of the separated areas with NURBS surfaces. In this study, the ExScan software used with the EinScan-SE model scanning instrument of SHINING 3D Company was used as the output tool for scanning, repairing, and reconstructing surface and triangular mesh files.

II. BACKFLOW EFFECT

Backflow incense is a part of the traditional Chinese incense lighting culture. The main reason is that when the incense tower is made, a deep hole will be left inside the incense tower running through to the bottom. Therefore, when the incense tower burns to the hole, because The smoke itself contains more particles and is therefore heavier than air, so it is easier to float downward. At the same time, it avoids the rising hot air when burning at the top of the incense tower. Therefore, without the influence of other air flows, the smoke will flow down along the holes inside the incense tower. At this time, if it is combined with a backflow incense burner with a special shape, there will be good visual effects. This backflow effect is often associated with complex hydrodynamic phenomena that are not easily represented by simple mathematical formulas. Therefore, we will not discuss its principle here, but only use reverse engineering technology to produce products with this functional phenomenon [4].

III. POINT GROUP DATA REGISTRATION PRINCIPLE

In reverse engineering technology, point cloud registration is an important step, which is used to merge scanned data from different angles or positions into a complete 3D model. The steps are as follows;

Step 1: Coarse alignment: the purpose of coarse alignment is to roughly align different point cloud data sets for more accurate fine registration. Common methods are: [5]

(1) Manual Alignment: Use software tools to manually select 3 common feature points on the point cloud and roughly align the point cloud.

(2) Marker-Based Alignment: Place markers on the scanned object, capture these markers at the same time during scanning, and use these markers for point cloud alignment later.

(3) Global Feature-Based Alignment: Extract global features of the point cloud, such as surface normals, curvature, etc., and use these features for alignment.

Step 2: Precise alignment; mainly to further improve the alignment accuracy of point cloud data, usually after rough registration. The main methods are: ICP (Iterative Closest Point) rule and NDT (Normal Distributions Transform) rule. The precise alignment method in this article uses the ICP (Iterative Closest Point) rule, and the steps are as follows;

(1) Initialization: Set the source point set P, the target point set Q, and the transformation matrix T.

(2) Closest point pair matching: Use the proximity search rule to find each point Pi in the source point set P and the point Qi closest to them in the target point set Q.

(3) Calculate the spatial transformation matrix: Based on the closest point pair sets Pi and Qi found in the previous step, calculate the optimal spatial transformation matrix (rotation R and translation matrix T), so that the source point cloud P is transformed into the target point The distance between the corresponding point pairs of cloud Q is the shortest.

In this way, as long as the target point set Q is multiplied by the obtained spatial transformation matrix, it can be superimposed with the source point set P, and then the duplicate points can be deleted (within a certain error range) to obtain a new point.

IV. SURFACE FITTING PRINCIPLE

Surface fitting refers to deriving a continuous mathematical surface from discrete point cloud data, with the purpose of accurately describing the shape of the object represented by the point cloud data. The more commonly used surface fitting methods today are as follows: [6]

(1) Polynomial surface fitting

Polynomial surface fitting is a basic surface fitting method, suitable for fitting more regular surfaces. Common polynomial surface forms such as spheres, cones, cylinders, ellipsoids, paraboloids and hyperboloids, etc. In particular, spheres, cones and cylinders play an important role in the manufacture of mechanical parts. Generally speaking, parametric representation and geometric methods are usually used to express Polynomial surface mathematical expressions. The generalized Polynomial surface expression is:

$$\mathrm{Q(x,y,z)} = \mathrm{A}x^2 + By^2 + Cz^2 + Dxy + Eyz + Fxz + Gx + Hy + Iz + J$$

where *A, B, C, D, E, F, G, H, I, J* are all constants.

The basic principle of polynomial surface fitting is to use the least squares method to minimize the distance error from the point set data to the fitted surface and solve for the coefficients of the polynomial.

(2) B-Spline surface fitting

B-Spline surface is a fragment polynomial surface composed of B-Spline basis functions, which is suitable for fitting complex and irregular surfaces. The form of B-Spline surface is:

$$\mathrm{Q(u,w)} = \sum_{i=1}^{n+1} \sum_{j=1}^{m+1} B_{i,j} N_{i,k}(u) M_{j,l}(w)$$

where

$$N_{i,1}(u) = \begin{cases} 1 & if\ x_i \le u < x_{i+1} \\ 0 & otherwise \end{cases}$$

$$N_{i,k}(u) = \frac{(u - x_i) N_{i,k-1}(u)}{x_{i+k-1} - x_i} + \frac{(x_{i+k} - u) N_{i+1,k-1}(u)}{x_{i+k} - x_{i+1}}$$

$$M_{j,l}(w) = \begin{cases} 1 & if\ y_j \le w < y_{j+1} \\ 0 & otherwise \end{cases}$$

$$M_{j,l}(w) = \frac{(w - y_j) M_{j,l-1}(w)}{y_{j+l-1} - y_j} + \frac{(y_{j+l} - w) M_{j+1,l-1}(w)}{y_{j+l} - y_{j+1}}$$

The B-Spline surface has local control and high flexibility, so it can fit complex surface shapes.

(3) Non-Uniform Rational B-Spline surfaces fitting

NURBS surface is a generalization of B-Spline. It has stronger representation ability and can accurately represent arcs, conic surfaces, etc. The mathematical form of a NURBS surface is:

$$Q(u,w) = \sum_{i=1}^{n+1}\sum_{j=1}^{m+1} B_{i,j}^{h} N_{i,k}(u) M_{j,l}(w)$$

Among them, $B^{h}_{i,j}$ is a four-dimensional homogeneously defined polygon vertex, and $N_{i,k}(u)$ and $M_{j,l}(w)$ are the basis functions of B-Spline as in the previous section. NURBS surfaces have high precision and are therefore widely used in computer graphics.

V. Experimental equipment and operating procedures

Here we take a sculpture in the shape of a dragon as an example, as shown in Figure 1. The EinScan-SE model scanning instrument of SHINING 3D Company is used, as shown in Figure 2, to perform scanning, data registration and area reconstruction operations. Finally, it is loaded into the Rhino software to construct a smoke backflow channel.

Figure 1 Dragon-shaped sculptures

Figure 2 EinScan – SE model scanning instrument

(1) EinScan–SE model scanning instrument specifications [7]

- Scanning accuracy: Single frame scanning accuracy 0.1 mm.
- Minimum scanning object size: 30 * 30 * 30 mm.
- Maximum scanning range (turntable): 200 * 200 * 200 mm.
- Single frame scanning range: 200 * 150 mm.
- Point pitch: 0.17 ~ 0.2 mm.
- Camera resolution: 1.3 million pixels.

(2) Operation process

Because the size of the dragon-shaped sculpture this time was larger than the scanning range of the EinScan-SE model, it could only be scanned in batches and then merged.

(a) Scanning orientation 1 (the dragon’s head facing forward and upright)

First, scan with the dragon's head facing forward and upright, as shown in Figure 3.

Figure 3 Scanning orientation 1

Step 1: Extract data point groups from various angles

Because it is placed on a turntable, the data point group at each angle in this direction can be obtained by scanning every 45 degrees, as shown in Figure 4.

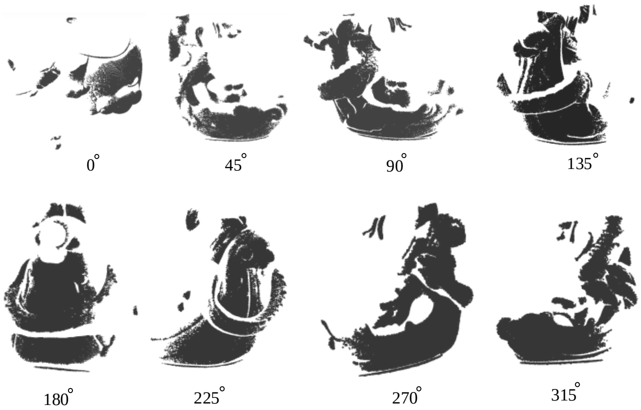

Figure 4 data point groups for various angles of orientation 1

Step 2: Integrate data point groups measured from various angles

Then gradually merge the data point groups from each angle, as shown in Figure 5. Figure 6 shows the merging results of point groups at each angle of this orientation.

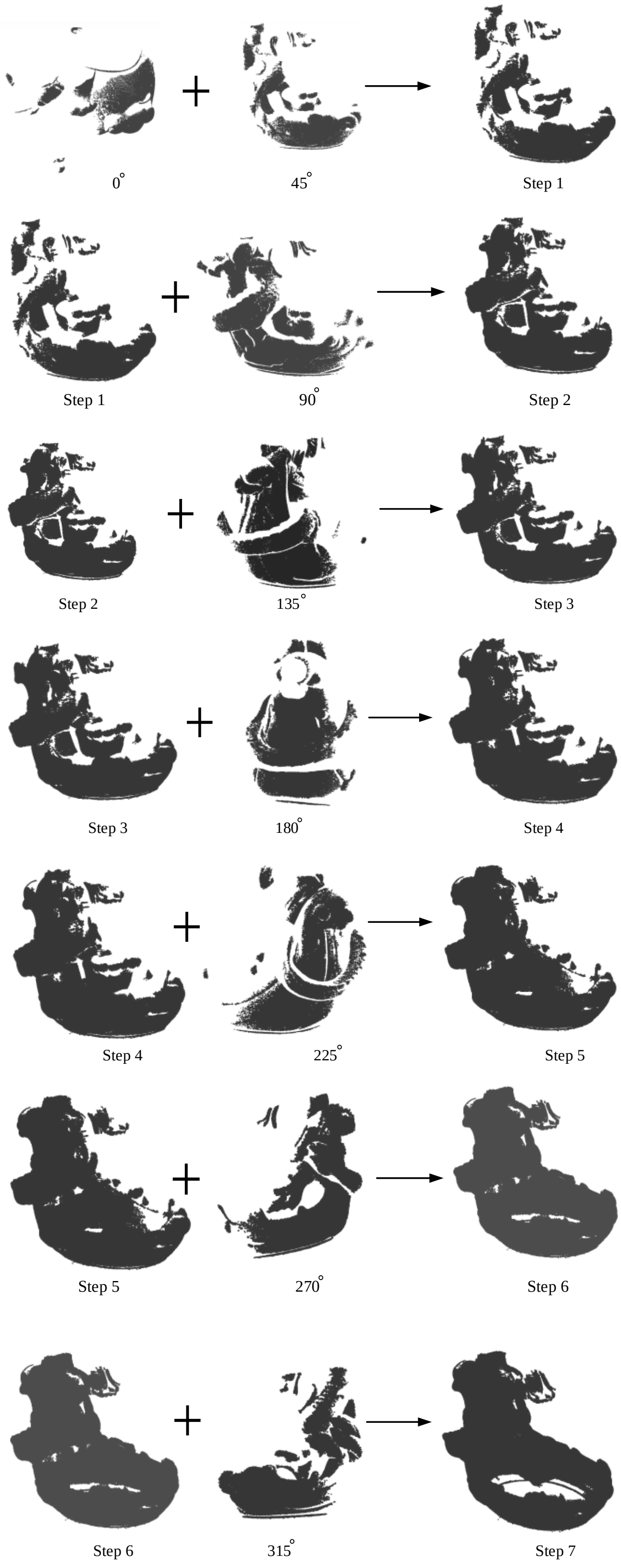

Figure 5 Merging process of point groups at various angles

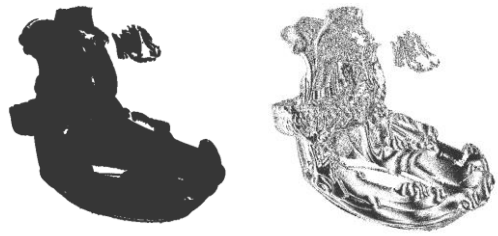

Figure 6 the merging results of point groups at each angle.

(b) Scanning orientation 2 (the dragon’s head is lying flat to the right)

Then scan with the dragon's head lying flat to the right, as shown in Figure 7.

Figure 7 Scanning orientation 2 (the dragon’s head is lying flat to the right)

Step 1: Extract data point groups from various angles

Because it is also placed on a turntable, it scans every 45 degrees to obtain the data point group at each angle in this orientation, as shown in Figure 8. Figure 9 shows the merging results of point groups at each angle of this orientation.

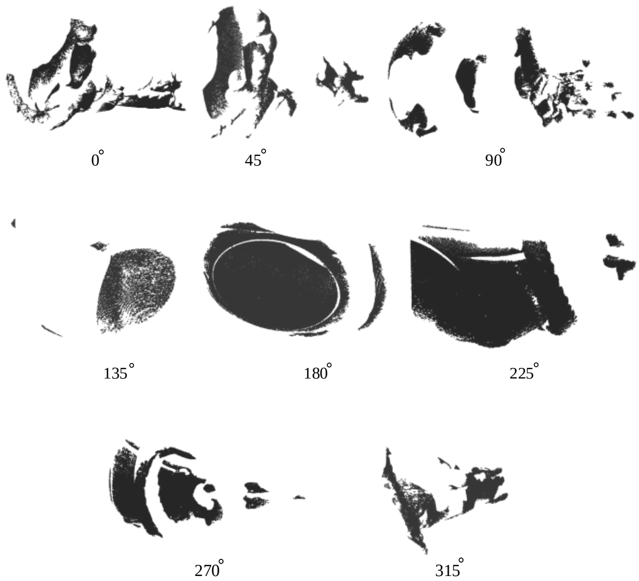

Figure 8 data point groups for various angles of orientation 2

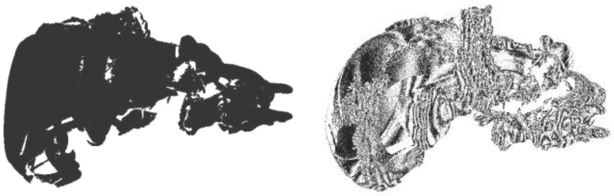

Figure 9 the merging results of point groups at each angle.

(c) Scanning orientation 3 (the dragon's head is lying flat to the left)

Then scan with the dragon's head lying flat to the right, as shown in Figure 10.

Figure 10 Scanning orientation 3 (the dragon's head is lying flat to the left)

Step 1: Extract data point groups from various angles

Because it is also placed on a turntable, it scans every 45 degrees to obtain the data point group at each angle in this orientation, as shown in Figure 11. Figure 12 shows the merging results of point groups at each angle of this orientation.

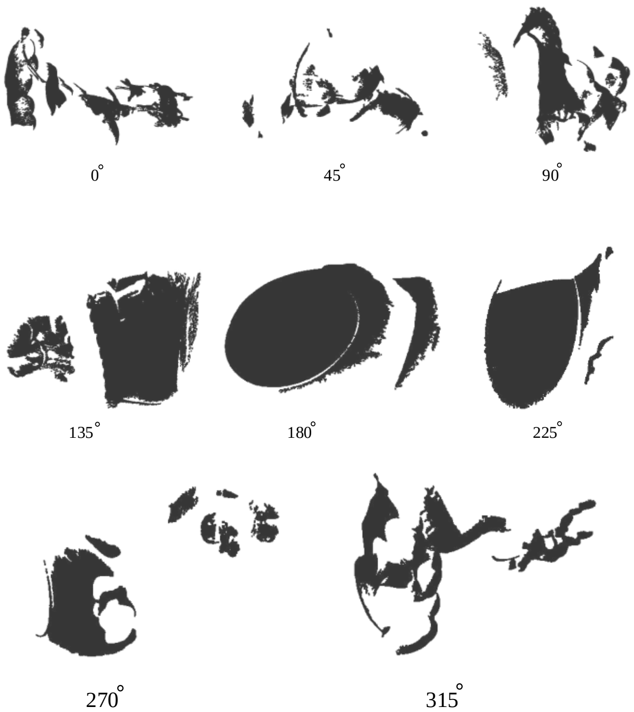

Figure 11 data point groups for various angles of orientation 3

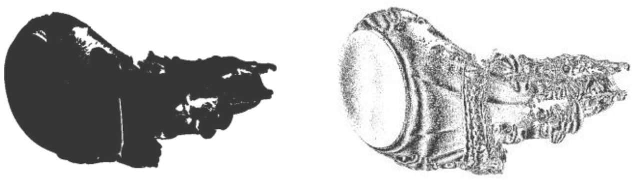

Figure 12 the merging results of point groups at each angle.

(d) Integrate point groups measured from 3 orientations

Then complete the merger of three orientation point groups, as shown in Figure 13.

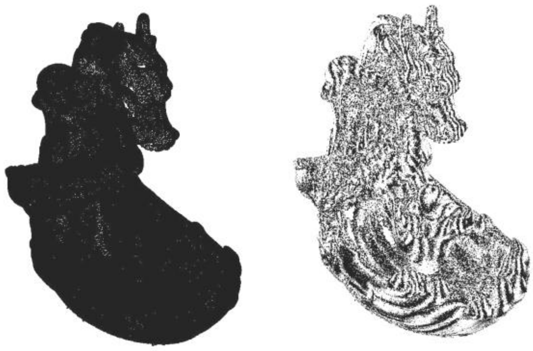

Figure 13 the merging results of point groups from 3 orientations

(e) Repair defects and convert triangular meshes

Then repair the defects and convert the complete point group into a triangle mesh format (*.stl) acceptable for 3D printing, as shown in Figure 14.

Figure 14 the triangle mesh file

(f) Construct the smoke guide aisle inside the model

Then import it into Rhinoceros modeling software to create a smoke guide aisle inside the model, as shown in Figure 15.

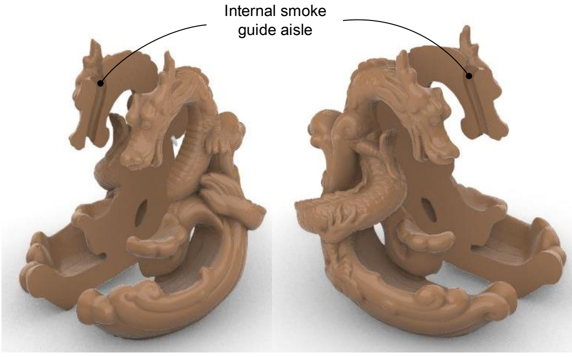

Figure 15 the smoke guide aisle

(g) Output finished products

Use 3D printer to print the product with smoke backflow effect, as shown in Figure 16.

Figure 16 finished product

VI. Conclusion

Backflow incense is a part of the traditional Chinese incense lighting culture. The main reason is that when the incense tower is made, a deep hole will be left inside the incense tower running through to the bottom. Therefore, when the incense tower burns to the hole, because The smoke itself contains more particles and is therefore heavier than air, so it is easier to float downward. At the same time, it avoids the rising hot air when burning at the top of the incense tower. Therefore, without the influence of other air flows, the smoke will flow down along the holes inside the incense tower. At this time, if it is combined with a backflow incense burner with a special shape, there will be good visual effects. this paper intends to use reverse engineering technology to scan and reconstruct a 3D model of a sculpture with a unique shape, and then use Rhinoceros modeling software to create a smoke guide aisle inside the model, successfully completing an art work with a backflow smoke effects.

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