The Evaluation and Correction of the Reconstructed NURBS Surface Smoothing and Accuracy

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Abstract: NURBS surface reconstruction is discussed from the two aspects of smooth surface and precision. Given the test whether surface is smooth. To the not smooth surface, by using modified point, section feature curve to improve the surface smoothness. Surface reconstruction accuracy does not meet the requirements of the situation, using the modified method of control vertices to correct surface reconstruction error. This paper provides a method for the reconstruction of surfaces effective assessment and correction.

Keywords: Surface reconstruction, Smoothing assessment, Accuracy correction, Reverse engineering.

1. Introduction

In the reverse engineering technology, the reverse process of surface needs to pass through the point cloud data acquisition, data processing, surface reconstruction and product manufacturing process [1]. The evaluation of the effectiveness and accuracy of the free-form surface, the commonly used method is to compare the surface and the origin of reverse cloud data. From the reverse process of the entire technology loop will produce errors, especially errors in the manufacturing process is very complex. Therefore, the reconstructed surface characteristic evaluation model is an important step in the reverse process before the production.

If the surface reconstruction is the most essential part of the words, then the quality evaluation of surface reconstruction in reverse engineering is the most key link. Surface quality mainly includes two aspects of smoothness and accuracy, Smoothing is a very subjective concept, which contact with human subjective feeling great. Smooth product appearance beautiful generous, beautiful shape, giving a pleasant feeling, and includes streamlined dynamic model of the surface, with good aerodynamic performance. Due to the subjective factors is relatively large, it is difficult to give a specific definition smoothing, resulting in a number of different evaluation criteria. As with the processing of the product, surface reconstruction has the accuracy of 3-D reconstruction, the 3D reconstruction accuracy, refers to meet the degree between the reconstructed surface and reverse prototype. If the surface reconstruction is not up to the given precision requirements, even if the surface is reconstructed, there is no actual application value. Accuracy assessment has increasingly become an important part of reverse engineering in the whole life cycle. In this paper, in order to reflect the real surface characteristics of point cloud data for evaluation basis, from two aspects of the curved surface smoothing and surface accuracy of the free-form surface reconstruction of...
performance assessment, and in view of the item does not meet the technical modification measures are put forward.

2. Smooth Surface Characteristics Evaluation and Correction Methods

Smooth surface characteristics evaluation is to assess whether the surface primarily aesthetic, whether with a fluent line and smooth surface, namely on the fairing of the assessment. Products of free-form surface generally require surface smoothing.

2.1. Criteria and Methods of Evaluation of Reconstructed Surface

Surface smoothing criteria is relatively complicated, it is according to the critical curve on the surface (such as: the parameters of the u and v direction line coordinate or surface and parallel to the plane of a series of plane cross section of the line, etc.) whether smoothing and surface curvature (main curvature and gauss curvature, mean curvature) whether changes evenly to judge. Surface smoothing criteria [2]:
1) The critical curve fairing;
2) Surface without extraneous inflection point (or points) and variable perturbation;
3) The principal curvature in the nodes of the curvature jump is small enough;
4) Gaussian curvature changes uniform.

Reconstruction surface due to the limitation of computer display, it is very difficult to directly determine the smoothness of the surface, so we must adopt the method of mathematical analysis. There are four kinds of surface fairing analysis method: the method based on curvature and reflection line algorithm, high brightness line method and isophotes method, each method has certain characteristics.

2.1.1. Curvature Based Method

Curvature based method is the curvature analysis to the surface, the surface having the same curvature point values together into a certain order of the curve, the contour of partial curvature can be obtained through the establishment of the equation [3-4]. Define a parametric surface M and a scalar function \( k \), which means that some kind of curvature has the following formula

\[
k(u,v) = k(M(u,v)) \quad (1)
\]

Using the above formula to create surfaces

\[
P(u,v) = P(u,v,k(u,v)) = P(u,v,k(M(u,v))) \quad (2)
\]

To calculate a group of planes of \( P \) surface obtained by lines of curvature. Curvature analysis is an important tool for surface analysis, often using color mapping and drawing curvature contour lines of curvature in two ways curvature of the surface analysis. Fig. 1 shows a freeform mean curvature color maps.

![Fig. 1. Mean curvature surfaces color map.](image1)

Drawing contour lines of curvature on the surface is to connect the dots with the same curvature into the line. Its method with the curvature of color mapping is the same in essence, only expressed in different ways. Fig. 2 is a freeform mean curvature contour curvature graph.

![Fig. 2. Surface contour curvature graph.](image2)

As shown in Fig. 3 by the distribution of curvature comb whether smooth uniform, can determine the surface smoothing of whether meet the requirements.

2.1.2. Reflection Line Algorithm

Reflection line refers to a set of rays on the surface obtained by projecting surface curve [5]. Given a set of parallel rays \( L(t) \), they pass through the same viewpoint \( A \) to the object irradiation, which
will produce a set of parallel rays reflected by the optical theorem physics that, the angle of reflection equal to the angle of incidence, by observing the reflection density of the yarn and deformation to determine surface smoothness. Reflection point $Q$ satisfies

$$\frac{[L-Q]}{[A-Q]} \cdot (A-Q) + (L-Q) = 2N(N, L-Q) \quad (3)$$

Fig. 4 (a) can be seen not only along the reflected ray and spacing are different, judging the surface is not smooth, Fig. 4 (b) for the modified surface, the reflected ray comparison rules, distribution is more uniform, smoothness improved significantly.

2.1.3. High Brightness Line Method

This is a special reflective line method, if there is no view; the reflected ray becomes a set of points on the surface. Then light lines $L(t)$ can be represented by the following formula:

$$L(t) = A + Bt \quad (4)$$

$A$ is the source point on the line, $B$ is the direction vector. For any point $Q$ on the surface, $N$ represents the surface normal vector in the direction of the point. The $N$ direction in a straight line through the point $Q$ is the Q-point surface normal vector of extension cord, which can be expressed as

$$E(s) = Q + Ns \quad (5)$$

Fig. 5 is a high-brightness line method to check the surface quality.

Fig. 3. Curvature comb.

Fig. 4 is the use of reflection line method for detecting surface.

Fig. 4 (a). Reflection line method.

Fig. 4 (b). Reflection line method.

Fig. 5. High brightness line method.
High brightness method associated with the vector method of curved surface, and to the direction of the vector change stick don't sensitive parameters for a given surface \( S(u,v) \), the method of one point vector \( u, v \) can be used in both directions of a derivative, namely tangent vector to define. If the first derivative is discrete, the highlighted line in which the showed irregular, so sensitive method of high brightness can be locally is not only suitable for testing surface. As shown in Fig. 5(a) that line is not smooth, you can determine the surface smoothness is poor, Fig. 5(b) flow smoothly and evenly spacing change, which means that surface smoothing good.

2.1.4. Isophote Method

The same definition with the curvature line, have the same illuminance point according to the order form of the curve is the isophote [6-8]. The isophotes can be defined by type

\[
(N(u,v), L) = c = \text{const}
\]

In the formula, \( X(u,v) \) is the parametric surface, \( L \) as the direction vector parallel light; \( N(u,v) \) represents the normal point of surface.

Smooth isophote represents a surface have good quality; irregular distorted isophotes display defects in one or two derivative surface; continuous and uniform distribution of the isophotes said surface smoothness high degree. From Fig. 6 we can see the isophote lines smooth, and space evenly, thereby determining the surfaces have good smoothness.

2.2. Not Smooth Surface Modification

There are many kinds of the correction method of curved surface shape characteristics; there are local modifications and overall correction. Overall correction effect is good, but computationally intensive and slow. Partial correction method is mainly through different means of inspection, found only on the surface along the section, and then uses some method to adjust some control surface vertices to achieve smooth surfaces. Correction method is usually caused by local surface shape characteristic evaluation method to decide what corrective action. In view of the commonly used evaluation method based on curvature and contour, the most simple and calculation of curved surface shape characteristics of the minimum amount of correction measures are characteristic curve using the modified cross-section the way to correct it.

Let the detected sequence of points \( P_i (i = 0,1,\ldots,n) \), \( P(t) \) is the interpolation curve of \( P_i \), \( k_i \) is the relative curvature at the point \( P_i \).

When \( k_i \cdot k_i < 0 \) and \( k_i \cdot k_{i+1} < 0 \), the point \( P_i \) is dead pixels. Make

\[
\Delta_i = \frac{\|P_iQ_i\|}{\|P_iQ_{i+1}\|}
\]

\[Q_i = (P_{i+1} + P_{i-1})/2\], the first amendment point is \( \max \{\Delta_i\} \), Let dead pixel is \( P_j = P(t_j) \).

With \( P_j \) of the adjacent point where \( P_j \) and \( P_{j+1} \) vector and the tangential vector information construct curve \( C(t) \), \( D_j = C_j - P_j \), when \( \|D_j\| < \varepsilon \) ( \( \varepsilon \) is the maximum number of modifications), Modify the \( P_j \) to the \( C_j \); Otherwise, modify the \( P_j \) to the \( P_j + \varepsilon \frac{D_j}{\|D_j\|} \).
Re-fitting the modified data points, get the new cross section characteristic curve, and then rebuild the surface, realize the correction on the curved surface shape characteristics.

3. Surface Accuracy Assessment and Correction

3.1. Surface Accuracy Assessment

In reverse engineering, the physical prototype has been digitized, high-density measurement point cloud contains a large amount of data, fully expressing the measured surface characteristics, it can be used the same as a real surface, therefore, the error between the physical prototype and model surface, can be expressed by the sampling error between the point and the model surface. Comparison of the model with the physical problem into a calculated point-to-surface distance, using accuracy of minimum distance from a point to surface to characterize the surface reconstruction model [9], and the finished surface models from point cloud data analysis which, if the minimum distance is in the error range you can assess the reconstruction model of qualified over the range of error, setting that surface accuracy is not qualified, as shown in Fig. 7 between the surface model and the original point cloud through distance analysis, this can be used to evaluate the model accuracy index.

Fig. 7. Point cloud to surface distance.

The key issue here is to calculate the sampling point to the surface of the shortest distance, set point $P$ is the nearest point to the surface $S(u,v)$ of point $Q$, and then the vector $(P-Q)$ must be the same as the surface normal at point $P$.

Therefore, the point to the surface of the problem can be transformed into calculation points in the parameter surface $S(u,v)$ of the projection, the projection direction of the surface normal vector, in general, spatial arbitrary point on the surface of projection can be expressed as

$$ Q - P = d \times \frac{S_u \times S_v}{|S_u \times S_v|} \quad (6) $$

where $P$ is the projection of $Q$ on the surface; $d$ is the shortest distance between $Q$ to the surface $S(u,v)$; $S_u = \frac{\partial S(u,v)}{\partial u}, S_v = \frac{\partial S(u,v)}{\partial v}$ is the partial derivative of parametric surfaces. For complex surfaces, the equation (6) is a high-order nonlinear equations, Newton's method can often be used to solve, but the Newton method for initial demanding at the boundaries may lead to divergence calculation; while Newton's method is time-consuming, practice in order to avoid solving linear equations, often using geometric segmentation method, the surface plane slices into a series of discrete polyhedra, and then point to calculate the distance to each flat piece, take the minimum value for the shortest distance.

3.2. Error Correction Measures

In practice, once the error exceeds the allowable value of the surface, the surface should be corrected. Correction method also has many, thereby increasing or decreasing the number of control points to improve, by modifying the surface with a method of control vertices. This paper used to modify the surface control vertices surface error correction method to improve the surface accuracy [10]. Let $h \times k$ times given point NURBS surfaces

$$ p = p(u,v), \quad u \in (u_i, u_{i+k}), \quad v \in (v_j, v_{j+k}) $$

Change the control vertices $d_{ij}$ to $d_{ij}'$, so that the surface point $p$ moves along the $c$ direction given distance $s$ to point $p'$. That is

$$ p' = p + acR_{i,j,k}(u,v), \quad (7) $$

where $R_{i,j,k}(u,v)$ is the rational basis function. Then

$$ a = \frac{s}{|c| R_{i,j,k}(u,v)} $$

Thus, you can get new control vertices are $d_{ij}' = d_{ij} + ac$, to reconstruct the surface with new control vertices, until it meets the accuracy requirement.

4. Conclusions

This paper summarizes the surface smoothing performance testing standards and methods, summarizes the various characteristics of curved
surface smoothing method and according to the surface phenomenon, and by amending section gives the characteristic curves for surface partial correction method to fix it, which can improve the surface smoothing performance very well. According to the precision of the reconstructed surface problem, to reconstruct surface intersects the measured point instead of the normal and the distance for error estimation based on surface, has realized the error of the reconstructed surface, to the surface accuracy can not meet the actual requirements, adopt the method of modified control vertex to error correction surface, effectively ensure the accuracy of the surface performance meet the requirements.

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References


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