The Design of Case Products’ Shape Form Information Database Based on NURBS Surface

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Abstract. In order to improve the computer design of product shape design, applying the Non-uniform Rational B-splines (NURBS) of curves and surfaces to the representation of the product shape helps designers to design the product effectively. On the basis of the typical product image contour extraction and using Pro/Engineer (Pro/E) to extract the geometric feature of scanning mold, in order to structure the information data base system of value point, control point and node vector parameter information, this paper put forward a unified expression method of using NURBS curves and surfaces to describe products’ geometric shape and using matrix laboratory (MATLAB) to simulate when products have the same or similar function. A case study of electric vehicle’s front cover illustrates the access process of geometric shape information of case product in this paper. This method can not only greatly reduce the capacity of information debate, but also improve the effectiveness of computer aided geometric innovation modeling.

1. Introduction

Since NURBS was proposed, its unique characteristics have been widely recognized and NURBS become the only standard for the Initial Graphics Exchange Specification (IGES) gradually, and so there are more and more correlation studies about NURBS curves and surfaces [1]. The application of NURBS surface reconstruction is extensive and it has a very wide range of application in the appearance of the products’ three-dimensional model [2] and reverse design [3]. At present, there are a number of independent research and development of NURBS surface modeling of the geometric characteristics of the relevant computer aided system [4], which can provide a theoretical reference for the development of complex surface modeling by using programming language. This paper, based on the analysis of the geometric feature information of the appearance of the product, proposes the unified expression of NURBS curves and surfaces and its simulation presentation methods for the products with the same or similar functions by using the typical image contour extraction software, Pro/E, MATLAB software. And According to the digital characteristics of NURBS curves and surfaces, the information database system is constructed.

2. Geometric shape feature extraction

2.1. Product morphological features and elements

An industrial product is a three-dimensional object with a certain geometry and product appearance modeling is based on certain technology and art to achieve. The shape of the product is composed of simple geometric shapes. Although the composition, structure and function of each product are...
different, the basic form of the appearance is the same. The morphological categories of industrial products has figurative form, analog form, symbolic form and abstract form. The geometric shape of the product is formed by different sets of points, lines and surfaces as a result of being decomposed. The line is not only the characteristic element, but also can influence the surface and body feature, so the line is the smallest factor that affects the geometric shape of the product.

2.2. Geometric feature line extraction of product modeling

The geometric shape of the appearance of the product is formed by connecting a plurality of shapes, so the feature line is the key to the shape and style of the product. The contour boundary line is the first characteristic line of the product. The following is an example of the front cover of electric vehicles, which shows that the process of product feature extraction. The geometric shape of the product is formed by different sets of points, lines and surfaces as a result of being decomposed. The line is not only the characteristic element, but also can influence the surface and body feature, so the line is the smallest factor that affects the geometric shape of the product.

By using image contour extraction software to extract feature line of electric vehicle front cover, figure 1 shows the characteristic line of the prototype which is vague but has less error. The point cloud model of the front shell of the electric vehicle is obtained through three-dimensional scanning, and the grid surface is shown in Figure 2. Then we import it in Pro/E by IGES data format. As shown in Figure 3, referring to figure 1 (b) to construct the cut plane, we extract feature lines in cut plane and reconstruct of spline curves based on extracted feature lines.

3. Unified expression of NURBS surface

The appearance of the product can reflect the internal structure to a certain extent. When the products have the same type of internal structure, they also have a similar appearance profile. In order to describe the contour of the product better, it’s necessary to summarize the product modeling, and describe the similar geometry in a unified way.

3.1 The inverse of the three NURBS interpolation curve

By using the type value points on the curve, the control process is: ① NURBS curve value point \( q_i \); ② using parametric method to calculate node \( u_i \); ③ compute node vector \( U_i \); ④ compute its basis function \( N_{i,3}(u) \); ⑤ compute linear equations of control point matrix; ⑥ get control points \( d_i \).

For the three NURBS interpolation curve, we use the method of accumulating chord length to obtain the corresponding parameter of value points.
points of the curves are given as known quantities and we take the same sequence as the determined. Then calculating

\[
N_{u_{i+3}} = N_{u_{i+2}} + \left| p_i - p_{i-1} \right| \sum_{i=1}^{n} \sqrt{p_i - p_{i-1}} \quad (i=1, 2, ..., n-1)
\]  

(1)

For the three NURBS open curve, the node is generally 4, and the starting and ending points are between 0 and 1. The spline basis is;

\[
N_{i,3}(u) = \frac{u_{i+4} - u}{u_{i+4} - u_{i+1}} \frac{u_{i+4} - u}{u_{i+4} - u_{i+3}}, \quad N_{i+1,3}(u) = \frac{u - u_{i+1}}{u_{i+4} - u_{i+1}} \frac{u_{i+4} - u}{u_{i+4} - u_{i+3}} + \frac{u_{i+5} - u}{u_{i+4} - u_{i+3}} \frac{u - u_{i+3}}{u_{i+5} - u_{i+3}},
\]

\[
N_{i+2,3}(u) = \frac{u - u_{i+2}}{u_{i+4} - u_{i+2}} \frac{u_{i+4} - u}{u_{i+4} - u_{i+3}} + \frac{u - u_{i+3}}{u_{i+5} - u_{i+3}} \frac{u - u_{i+3}}{u_{i+5} - u_{i+3}} \frac{u_{i+5} - u}{u_{i+5} - u_{i+3}},
\]

(2)

The solution of the closed curve control points is:

\[
a_i = \frac{(u_{i+3} - u_{i+2})^2}{u_{i+3} - u_i}, \quad b_i = \frac{(u_{i+3} - u_{i+2})(u_{i+2} - u_i)}{u_{i+3} - u_i} + \frac{(u_{i+2} - u_{i+1})(u_{i+4} - u_{i+2})}{u_{i+4} - u_{i+1}},
\]

\[
c_i = \frac{(u_{i+2} - u_{i+1})^2}{u_{i+4} - u_{i+1}}, \quad c_i = (u_{i+3} - u_{i+1})q_{i-1}
\]

(3)

The solution of open curve control points is:

\[
a_i = 1, \quad b_i = c_i = 0, \quad \tilde{q}_i = \tilde{q}_0 + \frac{\Delta \tilde{q}}{3} q_0
\]

(4)

3.2. NURBS surface inverse calculation

NURBS Surface expression is:

\[
p(u, v) = \sum_{i=0}^{n} \sum_{j=0}^{m} \omega_{i,j} d_{i,j} N_{i,k}(u) N_{j,l}(v)
\]

(5)

The inverse calculation of NURBS surface control points is the extension of the inverse of the curve control points, which are calculated in two directions, \( u \) and \( v \). Firstly, the control vertex of the NURBS surface and its power factor[5], the power of parameter \( u \) and \( v \), and the node vector \( U \) are determined. Then calculating \( u \) direction in the method of the inverse of the curve. Then, the control points of the curves are given as known quantities and we take the same sequence as the \( v \) value of the point of the curve sequence and simulate curve inversely. Finally, the control points of the surface are obtained.

3.3. The control points inverse calculation of modeling NURBS curve control points inverse calculation

As shown in Figure 4, we extract the feature points of the front shell of the electric vehicle by using Pro/E. The extracted feature points are regarded as the value points.
The algorithm of the three NURBS curve control points is illustrated by an example of characteristic line in Figure 4. The coordinates of the feature points on the feature line are 

\[
(7.5606, 11.4546), (8.2126, 11.5759), (8.8613, 11.6227), (9.9596, 11.5925), (10.0924, 10.4693), (12.04, 9.7446), (12.8427, 8.9772), (13.2756, 8.4897), (13.448, 7.8535), (13.117, 7.139), (12.4096, 6.787), (11.5628, 6.4084), (10.7712, 5.9399), (10.4282, 5.5006), (10.3743, 4.7424), (10.4042, 4.2318).
\]

And the coordinates of control points on other feature lines are obtained in like manner.

4. Structure the information database of geometric shape

Because the appearance of the product has a variety of geometric shapes for many cases, it is necessary to construct the relevant geometry information database, which can be used to store the information of the type value points, control points, node vectors and so on. We use Microsoft Office Access, MATLAB and other related software to construct the information database. The flow is:

1. extracting feature points in Pro/E;
2. recording feature point coordinates \((PX, PY, PZ)\);
3. inverse control point coordinates \((DX, DY, DZ)\);
4. recording control point coordinates \((DX, DY, DZ)\);
5. simulating information base management system;
6. using MATLAB software to simulate.

4.1. Designing the information bank for modeling parts’ feature lines

The geometry of the front cover of the electric vehicle is divided into 4 parts, each of which has the same number of points. The same table structure can be designed. Other parts of tables can be constructed and the like.

The numerical calculation of the characteristic line is carried out on the MATLAB software. We need to connect the database and MATLAB, and read the relevant information in the MATLAB to complete the calculation and store the results in the information bank. Table 1 shows the result.

4.2. Surface simulation based on information database
As shown in Table 1, the geometry information of the product modeling is stored in the repository. And then according to the MATLAB software, the surface simulation is carried out, and the surface or curve shape of the model is presented in the form of the effect diagram. As shown in Figure 5 is the front cover of the electric vehicle shell surface in the Pro/E software interception of a section of the characteristic line. By comparing the value of the type and the shape of the feature line, we can get the spline curve which can be used to accurately represent the original feature line of the model. The characteristic lines of the front cover of the whole electric vehicle are displayed in the same window, and the result is shown in Figure 6. Compared with Figure 3, the spline curves constructed by NURBS curve have high similarity. As shown in Figure 7, MATLAB software reproduces the shape of the surface by reading the corresponding data in the database. Compared with the original surface shown in Figure 8, it has high similarity.

Table 1. The value points of electric vehicle front shell type, control points and spline matrix

| Ta | PX  | PY  | PZ  | DX  | DY  | DZ  | N₁ | N₂ | N₃ | N₄ | N₅ | N₆ | N₇ | N₈ | N₉ | N₁₀ | N₁₁ |
|----|-----|-----|-----|-----|-----|-----|----|----|----|----|----|----|----|----|-----|-----|-----|
| 1  | 6.17| 9.87| 2.42| 6.17| 9.87| 2.42| 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0   | 0   |
| 2  | 7.05| 10.01| 2.42| 6.17| 9.87| 2.42| 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0   | 0   |
| 3  | 8.01| 10.0| 2.42| 7.215| 10.07| 2.42| 0 | 0.075 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.075 |
| 4  | 8.968| 9.713| 2.42| 7.979| 10.06| 2.42| 0  | 0.174 | 0.167 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.174 |
| 5  | 9.768| 9.118| 2.42| 9.003| 9.758| 2.42| 0  | 0  | 0.647 | 0.186 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6  | 10.06| 8.501| 2.42| 9.741| 9.249| 2.42| 0  | 0  | 0.103 | 0.643 | 0.257 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7  | 9.855| 7.869| 2.42| 10.15| 8.525| 2.42| 0  | 0 | 0.139 | 0.690 | 0.170 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8  | 9.271| 7.058| 2.42| 9.926| 7.789| 2.42| 0  | 0 | 0 | 0.172 | 0.667 | 0.160 | 0 | 0 | 0 | 0 | 0 |
| 9  | 8.651| 7.229| 2.42| 9.243| 7.498| 2.42| 0  | 0 | 0 | 0 | 0.166 | 0.683 | 0.150 | 0 | 0 | 0 | 0 |
| 10 | 7.808| 6.835| 2.42| 8.671| 7.241| 2.42| 0  | 0 | 0 | 0 | 0 | 0.238 | 0.587 | 0.178 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 7.808| 6.835| 2.42| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 12 | 0 | 0 | 0 | 7.808| 6.835| 2.42| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 |

5. Conclusion
The appearance of the products which have same function is similar, and it can be applied to NURBS curve and surface. A unified data table structure can be constructed according to the digital characteristics of NURBS curves and surfaces. Based on this, the information base system can be built up. The integration of MATLAB software, Access database, Pro/E software and image contour extraction software can effectively realize the geometric feature line and feature points extraction, storage and surface reconstruction. The information system which has a large number of
cases of product features of the geometric shape can effectively help designers innovate for product modeling.

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