The Study on Three-Dimensional Reconstruction Based on Hierarchical and Ordered Point Cloud Data

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Abstract. Aiming at a new kind of virtual slice 3D non-destructive measurement method, the quality of each slice can be acquired rapidly and accurately by measuring in X, Y and Z directions, and the mathematic model is established to calculate the ordered point cloud data. Based on the ordered point cloud data of physical slices, the reconstruction of points, lines and areas by means of NX secondary development technology and its reverse engineering technology was carried out by means of outlier extraction, feature boundary point extraction and least squares fitting. Dimensional model reconstruction based on hierarchical feature ordered point cloud in NX. The reconstruction of the model is based on the point cloud data measured by the mechanical parts. The experimental results show that the model can be reconstructed more quickly and accurately than the regular measured entities by the experimental verification and error analysis.

Keywords: Reverse engineering, Model reconstruction, Point cloud data, Fitting.

1. INTRODUCTION
The virtual slice nondestructive measurement device is a new 3D nondestructive testing device based on the lever balance principle. The nondestructive detection is indirectly realized by the force change in the lever balance system [1]. The principle of the measuring device is based on the relationship between the force and torque balance and the weight of the part in the lever balance system. This device moves slightly through the fulcrum in a certain direction to measure the force change part in the lever balance system. By means of intelligent calculation and combined with unit space
representation. It will be collected data into the measured entity of the three-dimensional point cloud data. Based on the three-dimensional non-destructive measuring device measured the order of point cloud data for reverse reconstruction, to achieve the object model. This method lays the foundation for the analysis of objects in the future.

The literature developed the function modules of point cloud extraction and feature line fitting in NX software. In the previous articles [2] using NX and Matlab software integration, through the NX/Open API development and application interface to achieve pre-processing functions. Zhou [3] using the secondary development tool of NX to write the “point cloud stratification” and “data projection”. However, most of them are scattered cloud, scanning line cloud and CT slice image, and the point cloud data is huge and time-consuming. At present, there is little research on the related reverse processing technology for the hierarchical feature ordered point clouds. By combining the inverse processing function of the NX software, the 3D reconstruction technology of the hierarchical feature point clouds can be done more accurately and quickly to achieve the reconstruction of objects.

2. PREPROCESSION OF POINT CLOUD DATA

It is known that the measurement process is equivalent to a process of equidistant slicing the measured object. This method can be used to solve the mathematical model to obtain the coordinates of unit of space. The number of spatial units on each slice can be viewed as a two-dimensional planar data set that is parallel to each other. As a result of measurement, some errors will be introduced in the process of model solving, which will lead to abnormal data in the data. It will be unfavorable to the subsequent fitting work. In this paper, the K-Nearest Neighbor Search method is used to collect the information of the neighboring regions [4]. The points of the distance between the seed points before and after the seeds are obtained by three coordinate axes. Finally, the K points closest to the seed points are retained. All the neighboring points can be obtained by setting the threshold. The minimum rectangular envelope of the object to be measured, starting from any point in the original point set: \( S = \{V_i\} (i = 1, 2, \ldots, n) \). The threshold of the search distance is set as the unit stroke of the measuring device, and the X, Y and Z directions of each point are the existence of adjacent points as a basis for judging the basis of points. At last, combined with the outliers and defects point in the rules of judgment, the exception can be quickly screened. As shown in Fig. 1(a) and (b), a patch of rectangular parallelepiped with a rectangular hole is repaired. By the neighborhood search method, it is clear that the missing point cloud boundary is repaired.
Based on the point cloud data measured by the previous three-dimensional nondestructive measuring device, combined with the NX software's API function. This paper completes the model reconstruction of the hierarchical feature ordered point cloud. As the API function can support multiple language development, multi-operating system support and with a good combination of different versions of NX so as to avoid the cumbersome development of the development environment. Excessive measurement of the number of point clouds will result in slower NX response. The cloud data preprocessing of point clouds is realized by Matlab software. The aim of this method is to implement the function algorithm of point cloud preprocessing quickly. After the data processing and output TXT format point cloud data files, so that the coordinates of each data point are stored in orderly TXT file.

3. THREE-DIMENSIONAL RECONSTRUCTION TECHNOLOGY

3.1 Curve Fitting

For this paper, the measurement object is mechanical parts, the general curve is composed of straight line, arc, spline curve, etc. In order to improve the accuracy of curve fitting, the method of segment fitting is used to curve fitting. In this paper, the method of curve fitting is presented in this paper. Firstly, the points on different contours of the same layer are grouped so that the point cloud between group and group does not interfere with each other. Then the group is used as the fitting object to divide each point into different groups. Contour points of the points to deal with, and then achieve the curve fitting. Bezier curve fitting through the control point position polygon curve is used to control the approximation of polygons, the lack of local modification ability. The least squares method is the most traditional and mature approximation theory [5], its expression is as follows:

\[
C(x) = \sum_{i=0}^{n} f_i(x)P_i \quad (x \in [0,1])
\]

In the formula (1), \(C(x)\) is the curve function; \(P_i\) is the control function; \(f_i\) is the base function; \(n\) is the curve order. The formula can be expanded formula (2):

\[
C(x) = f_0(x)P_0 + f_1(x)P_1 + \cdots + f_{n-1}(x)P_{n-1} + f_n(x)P_n
\]
Let \( W_j (j = 1, 2, \ldots, m) \) be the point cloud point, then the error value \( m_j \) is expressed as:

\[
m_j = W_j - \sum_{i=1}^{n} f_i(x)P_i \quad (j = 0, 1, \ldots, m)
\]  

(3)

In the formula (3), \( m_j \) is the error value. Let the objective function \( T \), \( W_0 = C(0), W_1 = C(1) \), according to the principle of least squares can get the following formula:

\[
T = \frac{m}{j=0} m_j^2 = \frac{m}{j=0} (W_j - \frac{m}{j=0} f_i(x)P_i)^2
\]  

(4)

Then \( \frac{dT}{dP_i} = 0 \) find the solution of the equation is the desired curve \( C(x) \).

As shown in Figure 2 is a direct curve fitting and segmentation fitting comparison, the figure can be seen better quality of sub-fitting curve, high precision, better highlight the curve characteristics.

(a) Direct fitting curve (b) Segment fitting curve

**FIGURE 2. Curve fitting.**

### 3.2 Surface Fitting and Reconstruction

#### 3.2.1 Surface Fitting

Surface fitting is based on the actual experimental test data, the function \( f(x, y) \) and the variable \( x, y \) with the analytic expression, so that the surface determined by or approximate through all the experimental test points. For point cloud data with hierarchical feature order, it can be used to fit the boundary points of the extracted feature points to establish the curve connection relation between the grouped point cloud points. After the curve structure is completed, by scanning, lofting and curve group fitting function Complete the surface modeling [6]. The surface expression is as follows:

\[
\phi(x, y) = a_0 + a_1x + a_2y + a_3x^2 + a_4xy + a_5x^3 + a_6x^2y + a_7xy^2 + a_8y^3
\]  

(5)

The curve equation in(5) can be expressed as: \( z = \phi(x, y) \) assume that \( h = (x, y) \), \( h \) as a set of surface coordinates of the \( (x, y), (i = 1, 2, \ldots, N) \) base function \( \{b^1(h), b^2(h), \ldots, b^r(h)\} \). For any \( h \), the linear function holds. The linear function is established as formula (6):
In the formula (6), \( b^j(l) = x^p y^q \), \( p \geq 0, q \geq 0, j = 1, 2, ..., n \)  
\( b^j(l) \) is a set of base polynomials of degree, \( a_0, a_1, ..., a_n \) is the vector of the obtained coefficient. The matrix expression is formula (7):

\[
BA = Z
\]  

\( B \) is a \( n \times N \) matrix, where:

\[
B = \begin{pmatrix}
   b_1^1 & b_1^2 & \cdots & b_1^n \\
   b_2^1 & b_2^2 & \cdots & b_2^n \\
   \vdots & \vdots & \ddots & \vdots \\
   b_n^1 & b_n^2 & \cdots & b_n^n 
\end{pmatrix}
\]

\( A^T = (a_0, a_1, ..., a_n), Z^T = A(z_1, z_2, ..., z_n) \)

\( Z \) and \( A \) are three-dimensional column vectors. In the surface fitting, the least squares method is used to make the error between the point cloud data and the real value reach the sum of the square and the minimum error expression:

\[
E(\phi) = \sum_{i=1}^N (\phi(l_i) - z_i)^2 = \sum_{i=1}^N \left( \sum_{j=1}^n a_j b_j^i(l_i) - z_i \right)^2
\]  

(8)

To minimize \( E(\phi) \), the formula (8) needs to satisfy: \( \frac{\partial E}{\partial a_i} = 0 \)

This method can achieve the surface reconstruction of the layered point cloud well and can guarantee a certain precision quality. In order to ensure the appearance of the shape of the object, to smooth the surface to do the determination and treatment. NX software to reflect the ray method to observe the surface curvature changes to assess the surface quality. At the same time, the accuracy of the fitting was evaluated according to the "Deviation Measurement" function in NX software. The function of Deviation Gauge Builder was used to transplant this function into the point cloud reverse modeling system. The surface and point cloud were selected to get the fitting surface error Analysis of the surface to determine the accuracy. Fig.3 shows the surface fitting effect, we can see that the surface fitting accuracy is higher, for better 3D reconstruction laid the foundation.

**FIGURE 3.** Surface fitting.
3.2.2 Model Reconstruction
Mechanical parts of the physical structure are generally rectangular, cylindrical, cone, etc. by stacking and cutting combination of composition. So the surface is mainly composed of plane and analytic surface composition. The three-dimensional reconstruction of the model is realized by taking the hierarchical ordered point cloud data of bearing housings as an example. Fig. 4(a) shows the three-dimensional point cloud data bearing. For this figure, the model is a rectangular base, ribs, columns formed by the split. The feature boundary point is extracted firstly, then the curve fitting is carried out on the special boundary point by using the fitting function, and then the curve is used to fit the surface. Finally, using NX's drawing, drawing and stitching functions, Finally, the three-dimensional reconstruction model of the bearing housing is obtained as shown in Fig. 4(b), and the results of error analysis are obtained.

(a) Three-dimensional modeling          (b) Model reconstruction

FIGURE 4. Model.

4. EXPERIMENTAL VERIFICATION
In this experiment, a hard aluminum alloy homogeneous solid part with a minimum rectangular envelope of 60mm*60mm*17mm was used as the measurement object. As shown in Fig.5, the mechanical part was measured with a virtual section nondestructive measuring device. The measuring device, including the experimental platform, is based on mechanical balance and the overall effect of data acquisition. The device measures the lever in three directions of X, Y and Z by rotating the angle of the tested entity by setting the unit step distance of 0.5mm, stroke of 65mm and speed of 0.12cm/min by slightly shifting the fulcrum in a certain direction. The weight of each part of the system is balanced to calculate the mass of each part and the barycentric coordinates of the corresponding slice. Finally, the point cloud data are calculated by the intelligent calculation.
First of all, the collected point cloud data preprocessed. Fig. 7a shows the results of point clouds, the number of imported point clouds is 427241. In order to facilitate the observation data, the slice cloud of Z= -6mm is chosen as the analysis object. B. Then the removal of abnormal points and repair processing, the results shown in Fig. c. We can see that the pretreatment effect is good. As shown in Fig. d, the effect of extracting the boundary points, after pretreatment to reduce the number of point clouds to 23,600, to achieve the effect of streamlining. Finally, the point cloud data is output as a TXT format file. In order to prepare the point cloud data model reconstruction. Through the observation of the model of the measured entity consists of two parts, and are obtained through the stretching function of the entity. As long as the two parts of the feature boundary points can be extracted quickly to achieve three-dimensional model reconstruction. As shown in Fig. 8(a), the point clouds are grouped and updated in the tree list to obtain feature boundary points. The curve is fitted by special boundary points, then the fitting curve is smoothed to obtain the better curved surface. Finally, the three-dimensional model of the mechanical parts is obtained by stretching commands. So as to reconstruct the three-dimensional model of point cloud data. After the model is reconstructed, the accuracy of the model reconstruction is verified by the error analysis, as shown in Fig. 8(b). The errors are mainly concentrated in the arc surface and non-vertical plane in the X, Y and Z directions.

5. CONCLUSION AND OUTLOOK
Aiming at the characteristics of ordered point clouds, the paper proposes a set of reverse processing solution based on curve-based model reconfiguration. In
this method, a set of solution is put forward to solve the complicated process of reverse operation in NX software. This method improves the efficiency of reserve processing.

Curve fitting can be used to quickly and accurately fit the curve of the point cloud. It is also possible to pick the feature boundary points to quickly identify the shape of the model. But it can not identify the larger density point cloud error area, need to be dealt with manually to solve.

For the more complex curve, the curve segmentation processing using manual grouping function to achieve the lack of automation and intelligence to affecting the processing efficiency. It can replaced manual grouping by the corresponding algorithm. In this paper, the idea of reverse processing can provide a reference for the reverse processing of the hierarchical feature ordered point cloud.

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7. REFERENCES
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