Reverse Forming Parts of Characteristics Analysis and Optimization

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Abstract—The non-contact 3D surface measurement theory and CAD technology integration, the reverse engineering means can be three-dimensional entity model accurately obtain irregular products. Application of reverse engineering method to establish CAD model and suitable to finite element analysis, the shape and size of surface reconstruction of entity can be guaranteed, through the component structure design and optimization, the realization of rapid prototyping and quality testing of new products. The point cloud data acquisition products surface using 3D laser scanner, the scanner itself, the measurement process vulnerable to the external environment and the surrounding objects of interference noise, therefore, the research take the suitable method of point cloud data denoising. The key research based on the mathematical model of NURBS curve and surface, revealing the control principle of curve and surface, the shape is easier to achieve the best effect, the completion of surface reconstruction and materialization process in CAD software. The final will be imported into the finite element software reverse molding analysis and optimization of the characteristics of the local, through the analysis of cloud drop test, stress generation, to provide a theoretical basis for the optimization design of structure.

Keywords-reverse engineering; CAD; finite element analysis; quality detection; 3D entity model

I. INTRODUCTION

During the development, design and manufacturing of the product, the technical data which the engineering and technical personnel get is not completely, much is from upstream manufacturers directly by physical model of the product, Therefore, designers need to make these physical information into CAD model by some way, which is applied to the reverse engineering technology. Reverse engineering is a common design strategy in industry. It is a term that has come to encompass a large array of engineering and design activities in the literature; however, in its basic form, reverse engineering is simply the process of extracting information about a product from the product itself. It also can be as conventional as competitive benchmarking or as benign as the dissection of a popular product by a curious consumer [1]. Reverse engineering in the physical environment with the goal of producing highly accurate digital models in the virtual environment that can be further used by CAD/CAM/CAE applications. Reverse engineering software extracts geometrical and topological information from the digitized point cloud and describes it to the user [2]. It is an object of advanced products, samples, software or image as the research object, the application of modern design methodology, manufacturing engineering, materials science, and relevant professional knowledge to carry on the system analysis and the key technology research, and then to develops a kind of more advanced product technology, which is aimed at digesting and absorbing advanced technology by adopting a series of analysis methods and the applied technology. Reverse engineering is not simply to restore the original object, but also to proceed secondary innovation on the basis of the prototype, so it as a new innovation technology is now widely used in industrial fields and achieved significant in economic and social benefits.

The finite element analysis method is the combination of the mechanical analysis and calculative method and the computer technology, it is a powerful numerical tool to solve engineering problems, and it also has its own theoretical basis and methods. Finite element analysis method is a method that divides the continuum into a finite number of units artificially, that is it regards the structure as an overall unit which is consists of several connected nodes, and then through the unit analysis, it puts these units together on behalf of the original structure. The method that pieces first, product zero for the whole again is called finite element method. It not only guarantees the theoretical integrity, purity, specifications, precision and convergence performance, and also has more widely applicable than other numerical methods due to it can make applicable unit structure according to the nature of

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the problem. With the development of computer technology, it has become an indispensable tool for mechanics scientific research and engineering technology.

This paper used reverse engineering method to establish the suitable CAD model and carry on the finite element analysis, which could ensure the reconstruction of curved surface shape and the size of the entity, through the structural design and optimization to ensure product performance and fuel economy. Combining reverse engineering and finite element technology has become indispensable in the development process. Use of reverse engineering technology can quickly get accurate product CAD model; Finite element technology can proceed the structure performance of analysis and improvements, so as to shorten the product development cycle, save development costs. The research achievements of this paper can be applied to real achieve good economic and social benefits; it also can provide reference for the design and manufacture other products.

II. REVERSE ENGINEERING PROCESS

A. The Point Cloud Data Acquisition

Data acquisition is the use of coordinate measuring to get modeling data, coordinate measuring technology and many subjects are closely related, its application field is very wide, it is also realized the basis of reverse engineering. Overall, coordinate measuring equipment is divided into nondestructive measurement equipment and destructive measurement equipment two big kinds. Each data acquisition method is different, each have each advantage. According to the shape of the object and the precision requirement, data collection methods should be ensured. Contact measurement technology has been relatively mature, measurement precision is high, but it isn't suitable for soft, fragile, easy deformation and ultrathin sample. Non-contact measuring has high level automation, faster measurement speed and less vulnerable to thickness influence, it can avoid causing the error of measurement because the contact pressure and friction cause model deformation. Recent advances in non-contact technologies, which are capable of collecting a large number of data points quickly, have provided a potential solution to reverse engineering [3].

When modeling requirement is not high, non-contact measurement has the outstanding. The traditional method can only obtain a finite number of sample points in some area, so the modeling precision is relatively low. But at this moment if we use the non-contact measurement can quickly get a large number of points and achieve precise reconstruction model. This article mainly studied the non-contact measurement of point cloud data processing and reverse engineering theory.

B. Point Cloud Data Processing

Data processing is an important technology link of reverse engineering; it can directly affect the result of late model reconstruction speed and quality. Data processing main content includes: eliminating yawp, data smoothing and filtering, data compacting, data segmentation, data positioning alignment etc, through the processing to enhance the data rationality and completeness.

Non-contact optical scanner is due to its own characteristics, the process of measuring pronely engender noise point by external environment and the surrounding objects. Noise points exists interfere with subsequent surface reconstruction, at the same time, a lot of noise points are also affect the subsequent processing efficiency. Therefore noise points must be removed. Noise removal methods include: Direct observational method, Least square method, Chord height difference method.

Direct observational method: One of the simplest point cloud denoising method, it's using reverse engineering software to open the point cloud data, which can be intuitive to judge some noise points that are often bulky error. These noise points are manually removed. This way often is used for initial processing noise points.

Least square method: Using the least squares principle to fit all the data points on the line, this can get a spline curve. Then, Calculate each point to the spline of Euler distance $\|e\|$, $[\varepsilon]$ is a given maximum threshold in advance, if $\|e\| \geq [\varepsilon]$ can be concluded this point is the noise points should be removed.

Chord height difference method: Select a detected scan line, first we can intuitive tell bulky error points by human-computer interactive method, and then make curve of a chord by through these points two side ,calculate the these points to chord distance h_i , by comparing h_i with the given threshold e_i , according to certain criteria, to determine whether this point for the noise points.

The h_i calculation formula is as (1):

$$h_i = \frac{|k_i x_i + b_i - y_i|}{\sqrt{1+k_i^2}}, \quad i = 1,2,\mathrm{L}\ ,n \qquad (1)$$

Various main parameters:

$$k_i = \frac{y_{i+1} - y_{i-1}}{x_{i+1} - x_{i-1}} \qquad b_i = \frac{x_{i+1}y_{i-1} - x_{i-1}y_{i+1}}{x_{i+1} - x_{i-1}}$$

$$e_i = 1.1 \times \max(h_i)$$

This article selected phone shell as research object, through the non-contact scanners to obtain phones shell of point cloud data, through the direct observational method, chord height difference methods to deal with the noise points, the results are shown in Fig .1.

Figure 1. After denoising point cloud data

To improve the quality of the resulting CAD model, the range images are often acquired at a very high resolution to accommodate this need for detail. However, the full complexity of such models is not always required, and the required level of detail may actually vary

significantly according to the application. The increasing complexity of the models makes them expensive to store, transmit, and render. So many simplification algorithms have been developed [4]. Its main methods are: Maximum allowable deviation compaction, uniform grid method and Non-uniform grid method. Among them, maximum allowable deviation compaction is given by two thresholds: Angle error limitation and string high error limitation. String high for *d*, Angle for α , through the experiment to verify $\Delta\alpha$, the smaller the $\Delta\alpha$ value, the higher the accuracy of reverse. For Δd value can be calculated according to the type: $\Delta d = \mu \frac{N_b}{N_a} \sin \Delta\alpha$, among them: the value of μ is normal distribution of the distance between adjacent points on average; the number of N_b is streamlined data points before; the number of N_a is expected to simplify the point. In this paper, through the uniform grid method to streamline point with data, reduced as shown in figure 2. To display characteristics more intuitive and clear observation point cloud should set to point cloud data polygonization, result as shown in Fig .3.

Figure 2. After data simplification

Figure 3. Point cloud polygonization

C. Curve Surface Construction

Measurement data model reconstruction according to different curved surface can be roughly divided into two categories: one is many small triangle planar composed of triangular mesh surface model; another kind is established the square field surface model, such as Coons surface, the Bezier curve, B spline surface, NURBS surface, etc. The characteristics of the triangular mesh model has flexible construct and good adaptability border, especially suitable for the scattered data. But this method is not compatible with general CAD/CAM system. In order to produce digital models consistent with the common CAD system, so that the reconstruction model can proceed to interact modification and write CNC program like regular CAD model, as well as, meet demand of continuity, fairing, therefore NURBS or B-spline surface model is often researched in the field of engineering design. NURBS surface is the standard form in a general CAD system; it has the irreplaceable important position in the field. At present, market-oriented professional reverse engineering software has as many as a dozen, these software are based on NURBS surface to construct the mathematical model.

Fitting of NURBS curves and surfaces is most often undertaken in order to reconstruct the shape of a digitized object from measured data and to represent the geometry in a form suitable for CAD, or when an existing CAD model needs to be modified using measured data so that it reflects the actual shape of the manufactured object [5]. NURBS curve equation of the rational function notation is (2):

$$p(t) = \frac{\sum_{i=0}^{n} N_{i,m}(t) w_i P_i}{\sum_{i-0}^{n} N_{i,m}(t) w_i} = \sum_{i=0}^{n} R_{i,m}(t) P_i \quad (w_i > 0) \qquad (2)$$

P_i for the control point; w_i for all the factor; *t* for the parameter value; m for B-spline order: $N_{i,m}(t)$ for *m* order B-spline of primary function; $R_{i,m}(t)$ as the rational basis functions.

$R_{i,m}(t)$ has some important properties: universality, not negative, the standardization, locality and differentiability. Besides it has the same properties like B-spline basis function, also increases the impact on weighted value, which makes the control vertex have the different influence proportion to the curve shape. In this way, the curve has more flexible space, so that the curve shape is more likely to achieve the best effect.

The mathematical description of NURBS surface is (3):

$$P(u,v) = \frac{\sum_{i=0}^{n_1}\sum_{j=0}^{n_2} w_{i,j} P_{i,j} B_{i,m_1}(u) B_{j,m_2}(v)}{\sum_{i=0}^{n_1}\sum_{j=0}^{n_2} w_{i,j} B_{i,j}(u) B_{j,m_2}(v)} \qquad (3)$$

Control point $P_{i,j}$, $i = 0,1,\mathrm{L}\ ,m$, $j = 0,1,\mathrm{L}\ ,n$, topological rectangular array form a grid control. $w_{i,j}$ with Control piont $P_{i,j}$, Regulate four vertices use positive weight factor: $w_{0,0} > 0$, $w_{m,0} > 0$, $w_{0,n} > 0$, $w_{m,n} > 0$, the others $w_{i,j} \geq 0$. $N_{i,k}(u)$, $i = 0,1,\mathrm{L}\ ,m$ and $N_{j,1}(v)$, $j = 0,1,\mathrm{L}\ ,n$ respect *u* direction *k* order and *v* direction 1 order for specification B-spline base. They are respectively decided by *u* and *v* nodes vectors $U = [u_0, u_1, \mathrm{L}\ , u_{m+k+1}]$. And $V = [v_0, v_1, \mathrm{L}\ , v_{n+j+1}]$. In the following the phone shell production process, through adjust various parameters and control points to realize the flexible production and precise control, result as shown in Fig .4.

In surface reconstruction process, first point cloud pass the ring set point to partition area, then respectively structure surface, and then pass the bridge, transition, cutting and other detailed characteristic operation to form the final surface. Surface can be directly generated surface by the point cloud. It also can first separate out point cloud, then fit a curve, and then use the boundary surface, two-

way lofting, through the loft curve method to generate surface, the result as shown in Fig .5. Surface analysis is a critical technology can be used to check the continuity of surface, deviation or surface reflection line curved to point cloud to test the quality of the reconstructed surface patches, the deviation of the results by examining the surfaces to the point cloud in Fig .6 shown, the maximum deviation is 0.5 mm, and basically meet the requirements.

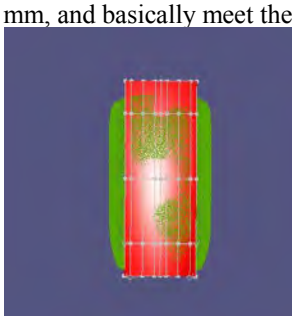

Figure 4. Surface control and regulation

Figure 5. surface reconstruction

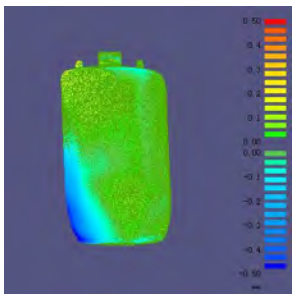

Figure 6. Deviation Analysis

III. FINITE-ELEMENT ANALYSIS

Use reverse engineering technology to obtain the product entity, import it in the finite element analysis software can be finished characteristics analysis, realize the related product problems' inspection. On the basis of the finite element static analysis for object dynamic equation is: $[M]\{X''\}+[C]\{X'\}+[K]\{X\}=\{F(t)\}$, $[M]$ is mass matrix; $[C]$ is damping matrix; $[K]$ is stiffness matrix; $\{F(t)\}$ is force vector; $\{X\}$ is displacement vector.

The basic idea of FEA is to find a numerical, approximate solution for a complex construction. The continuum of the construction is idealized and discretized with small, regular 3D solids that are called finite elements. Finite elements are bonded one to another over mutual nodes and the number of nodes is in direct proportion with the density of finite elements in the continuum and the size of the finite elements [6]. The change of influencing parameters within finite elements is described with simple approximation functions. Using the discrete elastic continuum to establish approximate mechanical model, calculate the numerical model, and then establish the relationship between the displacement and internal force, by means of variation principle, change the differential equations into algebraic equation, and then reassemble into unit structure, form the integral structure stiffness equation:

$$KU = Q$$

Type: K is the structure of global stiffness matrix; U is nodal displacement; Q is nodal load.

A. Import the Entity and Meshing

ANSYS Workbench is the new generation of collaborative simulation working platform, ANSYS Workbench integrates multiple ANSYS multiple solvers, and also inherits ANSYS software of powerful simulation analysis function.

ANSYS software mainly includes three parts: Pretreatment module, Calculation module and Post-processing module. Pretreatment module provides powerful entity modeling and meshing tool, users can easily construct finite element model. It has very good two-way correlation with CAD software, to realize seamless connection with CAD software, good to solve data loss problem between CAD and CAE mutual transmission. Can also through the optimization function to save the manufacturing cost, which is under without loss of performance the premise of to optimize construction and reduce the materials [7]. 3D entity model was obtained by reverse forming, as shown in Fig .7.

In order to avoid the situation "efficiency without accuracy" or "accuracy without efficiency" appearing, and model transformation failing because of too many detail in the conversion process, the 3D model shall be simplified properly, the geometrical characteristics (such as round angle and chamfer angle) which have little effect on finite element analysis shall be deleted, and matrix part shall be kept for reducing the difficulty and complexity of the mesh of finite element model, so as to speed up the analysis [8]. Meshing the results as shown in Fig .8.

Figure 7. 3D entity

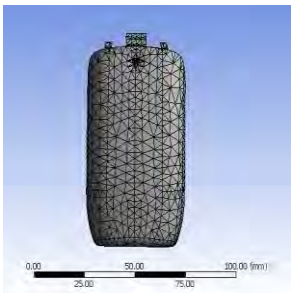

Figure 8. Meshing

B. *Analysis And Optimize*

This article selected the phone shell material is ABS plastic, density is 1.05 g.cm^3, modulus of elasticity is 0.2 GPa, poisson's ratio is 0.4. According to the national standard to test product quality, we can undertake the drop test. Assume phone weight is 100 g, drop height is 1.25 m, touch time is 0.1 s, stress area is 10-6 m^2, so we could calculate the pressure is 2.5 MPa. Assume the mobile shell side surface as the thrust face. Based on the Post-processing functions of the software, you can get the distribution of the stress [9]. As shown in the following figure, Fig .9 is the stress analysis nephogram, The figure shows that phone shell's maximum stress is 6.2 MPa, the data show that the ABS plastic allowable stress of 8.5 MPa, although the product maximum stress is less than allowable stress, but the products is also a lot of elastic deformation on the brink of destruction.

Under the premise of not affecting the phone internal space, product structure should be improved [10]. So we could join a stiffener into the product maximize stress. The product weight increase was very small, it didn't affect produit light and beauty. The Internal structure is shown in Fig .10. Stress analysis was shown in Fig .11. The maximum stress reduced to 3.8 MPa, and the deformation had been obviously reduced. It had obvious less than the plastic allowable stress, and more durable than the prototype.

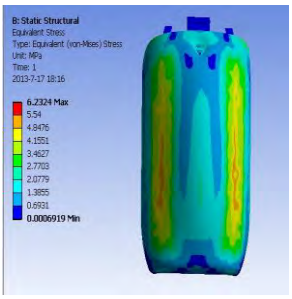

Figure 9. Stress analysis nephogram

Figure 10. model optimization

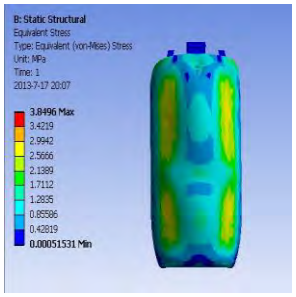

Figure 11. Optimized stress analysis nephogram

IV. CONCLUSIONS

(1) In this paper, Contact type and non-contact basic technical characteristics were introduced, the two methods were compared to expound both of the advantages and disadvantages. Introduced the point cloud denoising processing and methods. Focused on the mathematical model of the NURBS curve and surface, fundamentally revealed the control curve and curved surface principle, made the shape more easily achieve the best results.

(2) Studied the finite element method's principle and the basic analysis steps. Reverse engineering obtained Entities which could import in the Ansys Workbench to undertake the drop test. Generated Stress analysis nephogram to provide a theoretical basis for the structure optimum design.

(3) Finished the phone shell structure optimization design. The basic processing can be referenced for other similar problems, which have guiding significance and also prove this reverse design method's practical value.

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REFERENCES

[1] Shane K, Curtis, Stephen P, "The Fundamentals of Barriers to Reverse Engineering and Their Implementation into Mechanical Components," Res. Eng. Design, vol. 22, 2011, pp. 245-247.

[2] Kunal Soni, Daniel Chen, Terence Lerch, "Parameterization of Prismatic Shapes and Reconstruction of Free-form Shapes in Reverse Engineering," Int. J. Adv. Manuf. Technol., vol. 41, 2009, pp. 948-949.

[3] Chow J, T. Xu, and S. M. Lee, "Development of an Integrated Laser-Based Reverse Engineering and Machining System," Advanced Manufacturing Technology, vol. 19, 2002, pp. 186.

[4] Minho Chang, Sang C, "Range Data Simplification for Reverse Engineering," Int. J. Adv. Manuf. Technol., vol. 41, 2009, pp. 86-89.

[5] Djordje Brujic, Iain Ainsworth, Mihailo Ristic, "Fast and Accurate NURBS Fitting for Reverse Engineering," Int. J. Adv. Manuf. Technol., vol. 54, 2011, pp. 691-692.

[6] Dragoljub S, Dragan S, Milan S, "The Rmomechanical Finite Element Analysis of Hot Water Boiler Structure," Thermal Science, vol. 16, No. 2, 2012, pp. 388.

[7] Sanchez-Caballero S, Pla R, Seguí J, "A Way to Reduce Material and Manufacturing Cost," Finite Elements Analysis and Multiobjective Optimization, 2012, pp. 719-724.

[8] Fan Jun, Wang Leigang, "Precision Analysis and Control of Rapid Development Based on Reverse Engineering," Machinery Design & Manufacture, No. 1, 2013, pp. 182-184.

[9] Zhao Weiguo, Gou He, and Wang Yan, "Research the Building Model Based on Revers Engineering and Technology of Surface Modeling," Modern Manufacturing Engineering, No. 8, 2014, pp. 78-82.

[10] Meng Xiaoping, Wang Zuowen, QiuYaling, "Reverse Engineering Innovative Experiment Teaching Research Based on 3d Laser Scanning," Experiment Science and Technology, vol. 12, No. 3, 2014, pp. 65-67.