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Self-replication and Redesign of Copper Artworks Based on Reverse Technology

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Abstract:

In view of the complex morphology and difficult modeling of copper artworks, reverse engineering is combined with 3D printing technology to collect the three-dimensional Buddha face modeling data using industrial-grade optical scanning equipment (MetraScan3D), with the modeling of a cooper Buddha artwork as an example. Preprocessing of point cloud model was performed in Geomagic environment, including stitching, noise reduction, repair, encapsulation, quality analysis and NURBS surface construction, etc. The Buddha face was redesigned using ZBrush sculpture software, and the three-dimensional parts of the Buddha face were rapidly formed with the help of FDM 3D printer, thus basically completing glass steel tapping and copper artwork production. The basic process for self-replication and redesign of complex copper artwork was proposed and verified to provide an important reference for technological innovation in the field of copper artwork production.

Keywords*: reverse engineering; 3D printing; copper artwork; redesign; modeling; Geomagic; Z-Brush*

I. INTRODUCTION

Copper artworks come in various forms and types, enjoying extensive application in practice, such as the reproduction of bronze artifacts, bronze reliefs, urban themed sculptures, tourist souvenirs and religious Buddha sculptures, etc. [1]. In traditional copper artwork production, clay sculpture is first used for modeling design, and then a reference object is established by melting wax casting or duplication of the glass fiber reinforced plastic model [2]. On this basis, the manual tapping and subsequent processing of the copper artwork are completed. However, for some copper artworks with complex curved surfaces and huge volumes, traditional manufacturing methods face great limitations in terms of craftsmanship, so rapid mass production of copper artworks is impossible.

This paper combines reverse technology with copper artwork design and production to explore and verify the implementation process of self-replication and innovative design of complex copper artworks using industrial-grade 3D optical measuring instruments, 3D rapid prototyping machines and mainstream reverse design tools, which will provide strong support for production and redesign of copper artworks.

II.REVERSE ENGINEERING TECHNOLOGY

"Reverse Engineering (RE)" is an advanced manufacturing technology of using data measurement to achieve geometric model reconstruction of the item, digital management and innovative design [3].

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Different from the traditional forward design mode, reverse technology integrates multidisciplinary theories such as computer graphics, differential geometry, numerical analysis, mathematical statistics, image processing and software engineering, etc. Through reverse engineering, fast reverse design and model repair of products is possible, which facilitates the digital design, manufacturing, management and technical services of products, thus greatly increasing the engineering research and development efficiency and informatization level of products.

With the rapid development of computer technology and modern CAD/CAM systems, reverse technology enjoys increasingly mature development and industrial applications. With profound impact on the traditional industrial production mode [4], so far, it has been widely used in many engineering fields, including aerospace, automobile manufacturing, 3D printing, cultural relic restoration, biomedicine, etc.

III. REDESIGN IDEAS

Compared with the traditional manual clay sculpture method, redesign of complex copper artworks through reverse technology and 3D printing can not only effectively increase the model accuracy and surface quality, but also reduce the technological difficulty and comprehensive cost in copper artwork production [4]. The basic process of redesigning copper artworks is illustrated in Figure 1. First, select the existing copper artworks for structural analysis to determine the measurement site and scope. Generally, complex special-shaped surfaces are taken as the main measurement area. Then, the surface data of copper artwork is measured using 3D scanning equipment, and the collected data is preprocessed in the software environment for denoising, hole filling and repair.

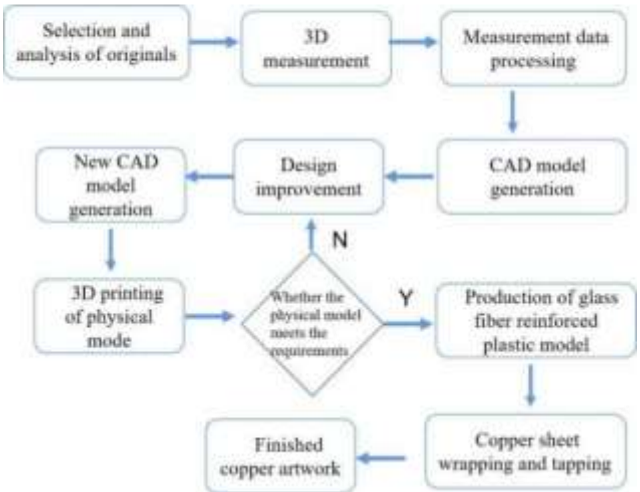

Fig 1: Basic redesign flow based on reverse technology

According to the processed point cloud data, a three-dimensional CAD geometric model of copper artwork is constructed and redesigned by means of computer-aided design, including local correction, improvement or surface reconstruction. Then, 3D printing equipment is used to make 3D parts of new products. Meanwhile, modeling analysis or morphological verification is performed on the 3D printing model. If the design requirements are not met, go back to the redesign process to modify or improve the

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digital model [5]. If design requirements are met, glass fiber reinforced plastic model of copper artwork can be made. Finally, the glass fiber reinforced plastic model is wrapped with copper sheet and tapped to build a new finished copper artwork model.

Fig 2: Original modeling of the Buddha statue

IV APPLICATION EXAMPLES

4.1 Original copper artwork

There are diverse Buddha statues in religious activities, and custom production of Buddha statues or Buddhist ritual instruments is often needed in the commercial copper artwork market [2]. Here, modeling of a Tibetan Buddha statue as shown in Figure 2 is taken as a research example, which is the original modeling of a sitting Buddha statue with a broken arm and missing ears. Considering the difficulty and complexity of copper artwork production, we temporarily select the facial contour of the Buddha statue as a reference for reverse innovation design, and on this basis, research and explore how to perform reverse replication and redesign of the overall modeling of the Buddha statue.

4.2 Data measurement and processing

4.2.1 Scanning Device

The original Buddha statue was optically measured by the MetraScan3D industrial-grade three-coordinate three-dimensional scanner from Creaform Company, Canada. As shown in Figure 3, MetraSCAN3D is a high-precision armless handheld optical scanning device. Rapid and continuous high-precision scanning is performed through optical reflection targets. The data acquisition is supported by a C-Track dual camera sensor, with oversampling rate at 24,000 3D points, the scanning accuracy up to 85μm, and the measurement volume in the range of 3.8~14.8m^3.

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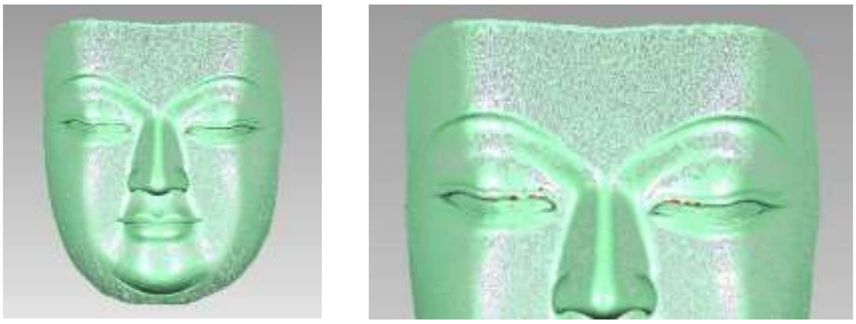
Fig 3: Experimental equipment for reverse design

Compared to other arm measurement 3D scanners, the MetraScan3D optical 3D scanner has higher reliability and sampling rate to guarantee generation of the most accurate measurement data in the laboratory and the workplace. In addition, MetraScan3D is also equipped with dedicated integrated 3D data acquisition software VXelements. By integrating all the basic elements and tools of measurement into a unified working environment, the software not only has friendly interface and easy operation, but also supports data sharing with third-party reverse design software, thus providing strong support for 3D data scanning and processing of the product.

4.2.2 Data acquisition and processing

3D data acquisition is one crucial link in the reverse design process. Before data measurement, the scanning instrument should be preprocessed to adjust C-Track camera distance, oversampling rate, reflection target setting and measurement range, etc. At the same time, VXelements software is initialized to prepare for data acquisition and processing. In order to collect high-quality 3D facial data of the Buddha statue, repeated scanning and measurement of dead zone should be avoided as much as possible. As the Buddha face will produce certain reflection in the scanning environment, a little developer is sprayed on the reflective area to achieve the best measurement effect.



(a) Model of point cloud data (b) Processing of isolated points in vitro

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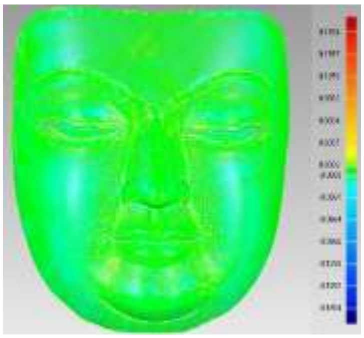

(c) Noise reduction deviation cloud map

(d) Encapsulation model

Fig 4: Facial data collection and processing of the Buddha statue

The sample point cloud data collected by scanning is imported into the reverse design software Geomagic Studio for post-processing mainly including isolated point removal, data noise reduction, hole filling repair, curvature sampling and model encapsulation, etc. [4] to finally form a complete and smooth face surface model of Buddha statue. The data is denoised using the simple averaging method. Informula shown in (1), N determines the average number of points. When N=1, it involves average of three points, and when N=2, it involves average of five points. [7]

$$P = \frac{1}{2N+1\sum_{n=-N}^{N} h(n)p(i-n)} \tag{1}$$

(1) is considered as a filtering formula, then the filtering factor is:

$$\begin{aligned} h(i) &= [h(-N),...,h(0),...h(N)] \\ &= \left(\frac{1}{2N+1},...\frac{1}{2N+1},...\frac{1}{2N+1}\right) \\ &= \frac{1}{2N+1}(1,...1,...1) \end{aligned} \tag{2}$$

As shown in Figure 4, the point cloud data is first preprocessed to delete the non-connected items far away from the main point cloud and isolated points in vitro. Then, the data is denoised based on the above formula, with attention given to avoid model distortion or deformation owing to excessive noise elimination. According to the noise reduction deviation cloud map shown in Figure 4(c), there is small difference in the point cloud data before and after noise reduction, with the deviation in the range of 6.9~185.4μm, indicating that the point cloud model of the Buddha face has good acquisition accuracy and quality.

In the point cloud data processing, as much point data as possible should be retained for parts with great curvature changes. In view of this, big cloud data can be optimized by curvature-based sampling to reduce redundant and unnecessary point cloud data [5]. This Buddha statue has a Tibetan Buddha modeling, with clear and tough facial contour. Hence, when encapsulating the point cloud data, the lips, nose and eye contour lines of the Buddha face need to be specially sharpened to finally form the Buddha face surface model based on polygonal stitching, as shown in Figure 4(d).

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4.2.3 Refined surface

In order to enable more realistic and vivid facial modeling of the Buddha statue, the encapsulation model was subject to surface refining using surface modeling technology Geomagic Studio, thus building a high-precision NURBS (Non-Uniform Rational B-Splines) surface model. NURBS surface mathematical model is constructed through functional methods to better characterize the curve degree of complex surfaces and special-shaped surfaces [6]. Compared with general surface models constructed from polygons, NURBS surface has higher accuracy and quality attribute. In this process, the curve is usually drawn by interpolation or approximation of point cloud data. Both interpolation and approximation demand polynomials in construction. When constructing curves with polynomial functions, parameter splitting of the data is needed first. The correspondence between the data points on the interpolation curve and the parameter domain is determined by nodes and breakpoints. It is hypothesized that the curve is composed of p_i points, each node or breakpoint forms a strict sequence: $\Delta u: u_0 < u_1 < \Lambda u_n$. u_n means segmentation of the parameters, and the following methods are taken to parameterize the data points. [8]

(1) Cumulative chord length arameterization method.

$$\left.\begin{aligned} & u_0 = 0 \\ & u_i = u_{i-1} + |\Delta p_{i-1}| \; i = 1,2,\Lambda n \end{aligned}\right\} \tag{3}$$

Where, Δp_k is the forward difference vector, $\Delta p_k = p_{k+1} - p_k$, namely, the chord vector. This method removes the double point problem in the isometric parameterization method, which can correctly reflect the distribution of data points based on chord length.

(2) Centripetal parameterization method

$$\left.\begin{aligned} & u_0 = 0 \\ & u_i = u_{i-1} + |\Delta p_{i-1}|^{1/2} \; i = 1,2,\Lambda n \end{aligned}\right\} \tag{4}$$

The cumulative chord length method can effectively solve the problem of uniform parameterization, but it cannot guarantee smoothness of the derived curve. The centripetal parameterization method effectively modifies the cumulative chord length method, but it cannot reflect inflection in adjacent side boundary of data points.

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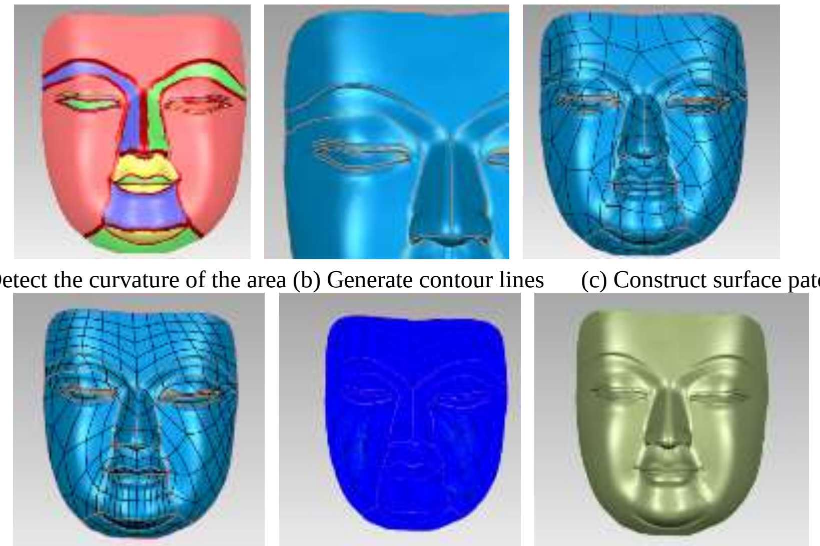

(a) Detect the curvature of the area (b) Generate contour lines (c) Construct surface patches

(d) Regularize surface patch (e) Build grid (f) Generate NURBS surface

Fig 5: Construct NURBS surface

The NURBS surface construction process in Geomagic Studio environment is explained in Figure 5. First, curvature detection and area division are performed for the Buddha facial encapsulation model to generate the facial area contour line. On this basis, the surface patch is constructed and regularized. Next, the surface patch is rasterized to finally build the NURBS surface model of the Buddha face. Through the NURBS surface, the Buddha face model can be more accurately represented to provide an important basis for the subsequent design improvement and copper artwork production.

4.3 Redesign of copper artwork

4.3.1 Buddha Face Improvement

The Buddha face in the experiment needs to be adjoined with another sitting Buddha body. In order to match it with the size of the Buddha body, the digital model of the Buddha face needs to be scaled. According to the NURBS surface model of the Tibetan Buddha face shown in Figure 5(f), the top of the hairline and the bottom of the mandible are used as references to measure the distance between the two reference points in Geomagic Studio. Based on the original face size and the corresponding reference point of the sitting Buddha, it is calculated that the Buddha face can be matched with the seating Buddha's body after enlargement by 1.7 times.

In order to reduce the error in the Buddha face, 3D comparison was made between the enlarged digital model and the original face of the sitting Buddha in the Geomagic Qualify environment. The two Buddha statues basically match in face size, but there are big errors due to different facial features in some areas such as eyebrows, nose bridge, etc. In this case, the Buddha face design needs fine-tune and improvement to render better expression and modeling effect of the Buddha as a whole.

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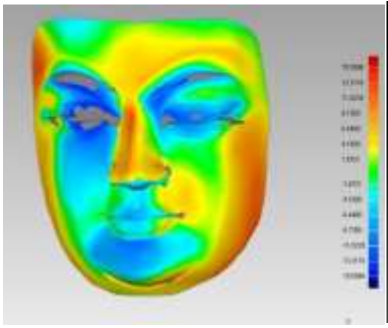

Fig 6: 3D comparison of Buddha face   Fig 7: Z-Brush model improvement

The 1.7 times-enlarged Buddha face model is converted into ".obj" format, and imported into Z-Brush sculpture software to locally correct and improve the facial details, as shown in Figure 7. According to the 3D data comparison results, rich and powerful brush function of Z -Brush is utilized to adjust the Buddha face area, with focus on redefining and redesign of eyebrows, eyes, nose bridges, etc. until satisfactory effect is achieved.

4.3.2 3D printing of solid model

The surface model of the improved design is solidly thickened, and the 3D CAD model is converted into ".STL" format and output to slice software for hierarchical processing, so that 3D printing of Buddha face solid model is possible. Rapid product redesign is possible through reverse engineering and 3D printing, with specific process shown in Figure 8. The process of making a 3D solid model of Buddha face involves data communication and format conversion of multiple software and hardware devices, such as MetraSCAN3D scanner, VXelements data acquisition software, Geomagic Studio/Qualify reverse software, Z-Brush sculpture software, 3D printing slice software and equipment, etc.

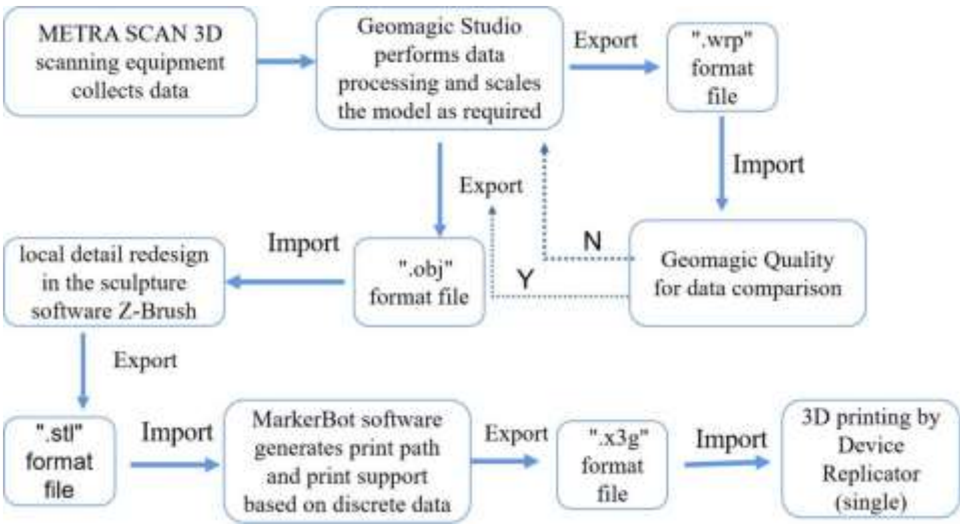

Fig 8: 3D printing implementation process based on reverse technology

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The SCAN desktop 3D printer is used for 3D rapid prototyping of the Buddha face. The equipment adopts the FDM fused deposition molding process, using PLA coil with hot melting temperature at about 230℃as printing material. The limited range of the 3D printer makes it impossible to print Buddha face at one time, so the CAD model is first divided into regions, and then each region is transferred to the ".STL" format and imported into the MakerBot software for slicing processing. As shown in Figure 9, 3D printing related process parameters are set, including support form, nozzle temperature, slice thickness and printing path, etc.

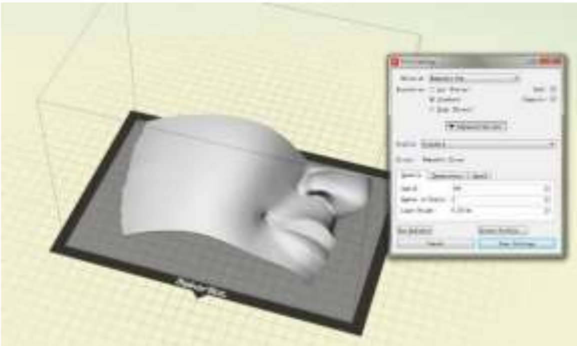

Fig 9: 3D printing process processing   Fig 10: 3D printing model

The preprocessed data file is converted into ".x3g" format and placed in the 3D printer to make a solid model of the Buddha face, followed by support material removal and burrs polishing. On this basis, the printed face areas are spliced, so that the overall three-dimensional part of the Buddha face is finally formed, as shown in Figure 10. At this stage, analysis, assessment and verification are needed for the 3D facial model of the Buddha statue. If accuracy and quality requirements are not met, return to the design improvement stage to redesign the Buddha face model.

4.3.3 Subsequent production

Based on the 3D printing solid model of the Buddha face, the FRP liquid resin material is coated on the model surface, and appropriate curing agent is added at the same time. The glass fiber reinforced plastic model of the Buddha face is built after solidification of the liquid resin. On this basis, the copper artwork of Buddha head is prepared according to the traditional method. Namely, by referring to the glass fiber reinforced plastic model of Buddha head, the copper sheet is first placed on the pad to make a rough model, and then wrapped on the tempered glass model to refine the details. During the copper sheet tapping, the Buddha head model can be re-created as needed. Finally, the copper Buddha face and Buddha body components are welded and polished to make the finished copper artwork as shown in Figure 11.

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Fig 11: Finished copper artwork of Buddha statue

V CONCLUSION

The production of complex copper artworks under traditional methods is not only time-consuming and labor-intensive, but also faces difficulty in precisely controlling the precision and quality of copper artworks, often resulting in unsatisfactory finished products. The combination of reverse technology and 3D printing not only supports rapid redesign and model making of complex copper artworks, but also effectively reduces the difficulty and comprehensive cost in previous copper artwork production, so that design of copper artworks is more flexible, which greatly improves the design efficiency and quality of finished products, and provides new ideas and technical references for the production of complex copper artworks.

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