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REVERSE MEASUREMENT AND MODELING OF MUDGUARD PROFILE BASED ON LASER SCANNING

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Abstract: Through studying the cultivation of high-skilled talents and the inheritance of craftsmanship spirit in vocational education, this research analyzes the vertical and horizontal transmission processes of craftsmanship spirit inheritance from a sociological perspective. The objective is to integrate and promote knowledge transmission, ability cultivation, and value shaping. By utilizing the "four factors", the craftsmanship spirit is coupled and internalized in the process of cultivating high-skilled talents. Through the "three transformations" of the craftsmanship spirit, the problem of precise matching between the "three embeddings" of the spirit of craftsmanship and the "three integrations" of skill cultivation has been solved. Relying on four key areas, the difficulties in skill cultivation and the inheritance of the spirit of craftsmanship have been addressed, gradually forming a "composite four-factor resonance, three-in-one" ecological model for the cultivation of high-skilled talents. This provides a theoretical basis and typical examples for the cultivation of high-skilled talents and the inheritance of the spirit of craftsmanship.
Keywords: 3D detection; Reverse design; 3D Scanning

1 INTRODUCTION

A mudguard is a plate-shaped object fixed to the rear frame of a car wheel, typically crafted from high-quality rubber or high-strength plastic. Mudguards are commonly installed behind the wheels of vehicles, with materials commonly being plastic or rubber. The primary function of a mudguard is to prevent dust and dirt thrown up by the wheels from splashing onto the vehicle or the driver, which can detract from the vehicle's appearance and protect related car parts from being affected or rusting. Additionally, mudguards can prevent stones and other objects carried in the wheels from being thrown onto the vehicle or the driver, thus avoiding damage to the paint or injury to the driver[1]. The mudguard structure features a complex curved shape. For forward design, designers must create a model from scratch, which not only prolongs the production cycle but also increases the corresponding production cost. Therefore, the challenge lies in finding technical solutions that can facilitate the creation of a precise 3D model for subsequent shape inspection, defect repair, or innovative modifications to the mudguard, which has become a significant hurdle nowadays.

In recent years, computer science and technology have rapidly advanced, with reverse design emerging as a standout practice in the industry and garnering significant attention. Reverse technology has the capability to transform existing parts into three-dimensional digital models, thereby not only enhancing design efficiency but also significantly cutting down production costs, addressing issues inherent in forward design[2]. Utilizing reverse design technology, we can swiftly acquire three-dimensional digital models of intricately structured parts, offering a precise solution for subsequent innovative modifications and precision testing of these parts.

This paper utilizes a 3D laser scanner to scan the mudguard, acquiring 3D point cloud data. This data is then modeled using reverse engineering software, resulting in a 3D digital model of the mudguard. Subsequently, a precision comparison analysis is conducted between the 3D digital model obtained from reverse design and the point cloud data obtained from 3D scanning, to assess whether the 3D digital model meets the design requirements. This provides precise and effective data for future secondary innovation and repair of mudguards.

2 PRINCIPLE OF LASER 3D SCANNING

The acquisition of 3D point cloud data marks the initial step in reverse engineering. Point cloud data acquisition devices are categorized into contact and non-contact types. Commonly used contact devices include coordinate measuring devices manufactured by companies like Zeiss, ZK, and DEA[3]. Non-contact devices primarily consist of optical measurement devices, which prove to be more convenient when acquiring data from complex curved parts. The most frequently used non-contact devices are 3D scanners produced by companies such as Creaform, GOM, and SCANTECH.

n this chapter, the PRINCE775 handheld laser scanner provided by Sihua Technology (Hangzhou) Co., Ltd. is utilized to gather point cloud data of mudguards. Figure 1 depicts the PRINCE775 handheld laser 3D scanner. Its core technology lies in the 3D laser measurement method. The scanner primarily consists of two cameras and a set of laser emitters. It employs the binocular vision principle to acquire three-dimensional point clouds in space. During operation, it utilizes reflective markers affixed to the surface of the part to be scanned for positioning. The laser emitter emits light to illuminate the surface of the component, while two manufacturer-calibrated cameras capture the reflected light. Part shape data is then obtained through calculation.

Figure 1 PRINCE775 Handheld Laser 3d Scanner

The principle of binocular vision is a crucial form of visual recognition, primarily utilizing multiple images to compute geometric information and derive corresponding positional data [4]. This principle typically involves two cameras capturing images simultaneously from different angles, resulting in two images. Using the disparity principle, the three-dimensional geometric information of the measured point is calculated, ultimately presenting a comprehensive set of three-dimensional data. Figure 2 illustrates a relatively simple schematic diagram of binocular vision imaging, featuring cameras A and B. B represents the distance between the center points of the projection directions of the two cameras, known as the baseline distance.

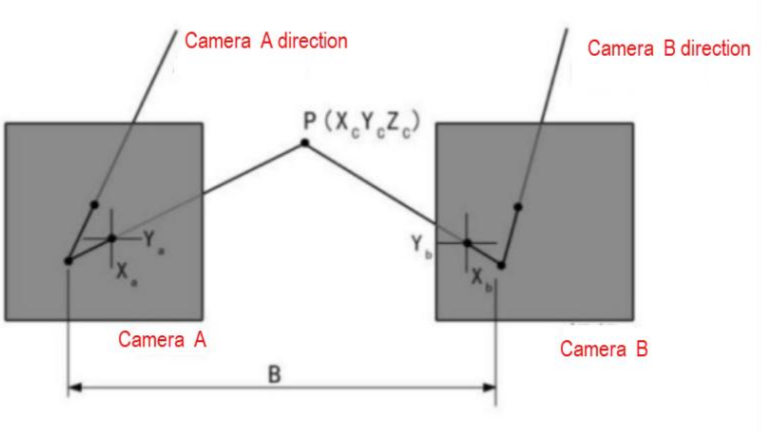

Figure 2 Schematic Diagram of Binocular Vision

As shown in the figure, assuming point P is the measured point, the imaging point coordinates of camera A are Pa=(Xa, Yb), and those of camera B are Pb=(Xb, Yb). If the two cameras are on the same plane, the coordinates of point P in the Y direction will be the same, that is, Ya=Yb=Y. According to the principles of trigonometry, it can be concluded that:

$$\begin{cases} \mathrm{X_a} = f\dfrac{\mathrm{X_c}}{\mathrm{X_c}} \\ \mathrm{X_b} = f\dfrac{(\mathrm{X_c} - \mathrm{B})}{\mathrm{Z_c}} \\ \mathrm{Y} = f\dfrac{\mathrm{Y_c}}{\mathrm{Z_c}} \end{cases}$$

Parallax is defined as the deviation of the same point in the X direction of the left and right cameras, denoted as Disparity = Xa - Xb. Therefore, the position of point P in the left camera coordinate system can be represented as [5]:

$$\begin{cases} \mathrm{X_c} = \dfrac{\mathrm{B} \cdot \mathrm{X_a}}{\mathrm{Disparity}} \\ \mathrm{Y_c} = \dfrac{\mathrm{B} \cdot \mathrm{Y}}{\mathrm{Disparity}} \\ \mathrm{Z_c} = \dfrac{\mathrm{B} \cdot f}{\mathrm{Disparity}} \end{cases}$$

Laser-based 3D scanners are easy to operate, feature fast acquisition speeds, and deliver high data accuracy. They can output files in formats such as STL, ASC, and OBJ, and can also be directly opened and edited in other reverse engineering software. As a new type of fast and convenient measuring device, handheld laser 3D scanners are widely used in practical production, mold inspection, aerospace, and medical and healthcare fields. Table 1 presents the main technical parameters of the PRINCE775 handheld laser 3D scanner.

Table 1 Technical Parameters of PRINCE775 Handheld Laser 3D Scanner

Model	PRINCE775	
Scanning Mode	R Standard Scanning Mode	B-Ultrasound Fine Scanning Mode
Laser form	14+1	5
Accuracy	0.030mm	
Scanning rate	480000 measurements per second	320000 measurements per second
Camera frame rate	60fps	120fps
Maximum scanning surface width	275mm×250mm	200mm×200mm
Resolution	0.050mm	0.020mm
Volume accuracy	0.020mm+0.060mm/m	0.010mm+0.060mm/m
Reference distance	300mm	150mm
Depth of Field	250mm	100mm
Output formats include	.stl,.ply,.obj,.igs,.wrl,.xyz,.dae,.fbx,.asc, etc	

3 PREPARATORY WORK FOR DATA COLLECTION

To obtain high-quality 3D point cloud data, some preparatory work must be carried out prior to scanning. Paste marking points: Given that the mudguard's shape primarily consists of curved surfaces and there are no scanning blind spots, 3D scanning of the mudguard is relatively straightforward. To facilitate automatic stitching of the mudguard point cloud data during the acquisition process by the 3D scanner, it is necessary to paste an appropriate number of marking points on the mudguard surface. This enables the scanning device to swiftly and accurately stitch the point cloud data during the acquisition process. Marking points serve as crucial reference objects for assisting the 3D scanner in stitching. Improper pasting can prevent the scanned data from accurately representing the true shape and may also result in the loss of important features. Therefore, during the process of pasting marking points, the following points should be noted: Marking points should be pasted on a relatively flat surface of the object and should avoid the boundary of the zero point. Marking points cannot be pasted in a straight line, and the pasting effect should not be symmetrical.The number of transitional marker points should be at least three, but due to the shape and scanning angle of the marker points, there are a few that cannot be recognized. Therefore, it is recommended to increase the number of marker points pasted as much as possible, usually at least five [6]. The pasted marking points should ensure a smooth transition during the scanning process to complete scanning from various angles, and should be evenly pasted in all directions. As shown in Figure 3, the mudguard model is pasted with complete marking points.

Figure 3 Model of Mudguard with Complete Marked Points Pasted

Scanner calibration: Laser 3D scanners, as high-precision measuring devices, necessitate precision calibration, also termed as calibration, prior to use to enhance the performance of 3D scanning operations. Calibration of the 3D scanner is imperative in the following scenarios: 1. After long-distance transportation or changes in the scanning environment. When the scanning quality is subpar. When the scanning data cannot be stitched together. The handheld laser 3D scanner utilized in this article comes equipped with a corresponding calibration board provided by the manufacturer. Following the computer's prompts, calibration can be accomplished within half a minute after proficient use.

Scanning parameter settings: During the 3D scanning process, there are two parameters that directly affect the scanning speed and quality, namely "resolution" and "exposure value". Resolution will affect the level of detail presented in scanning. Taking mudguards as an example, there are no small features on the surface of mudguards, and the minimum rounded corner is around 1mm. Therefore, the resolution can be set at around 0.5, but the smaller the parameter set, the slower the scanning speed. Therefore, the resolution is set to 0.7mm. The exposure value affects the brightness of the projected laser, which depends on the color and reflectivity of the scanned part surface. Taking the mudguard as an example, it is made of white plastic injection molded with a moderate smoothness and no obvious reflectivity. Therefore, the exposure value can be set to "2".

4 THREE DIMENSIONAL DATA ACQUISITION

The collection of 3D point cloud data serves as the initial step in reverse engineering, with the quality of the point cloud obtained from 3D scanning directly impacting the quality of subsequent reverse modeling and accuracy inspection. This paper employs a handheld laser scanner to gather data on the outer surface of mudguards. During the 3D scanning process, the scanner locates marker points affixed to the object's surface, completes the stitching between frames, and thereby acquires comprehensive 3D point cloud data of the mudguard. Points to consider during the 3D scanning operation include: the scanning environment should not be excessively bright, as this could interfere with the generation of point clouds in high-light areas on the object's surface, potentially resulting in the formation of holes; During the scanning process, the 3D scanner must move at a steady and slow pace to prevent shaking, as this can introduce noise and affect the scanning outcome, thereby increasing the workload of post-processing; If the computer fails to adjust to the corresponding angle when the scanner is moved during the scanning process, it is necessary to consider whether the placement of marker points is improper or whether the scanner requires recalibration. Figure 4 displays the final 3D point cloud data of the mudguard. The scanned data can be optimized in scanning software, including hole filling, noise reduction, and smoothing. Ultimately, the point cloud data is encapsulated to produce a triangular surface model. This software supports the generation of STL format files, thus the scanned 3D data is saved in STL format to prepare for future reverse modeling.

5 POINT CLOUD DATA PROCESSING

Laser scanners, as optical devices, can scan larger objects to obtain a large number of data points in a shorter time, up to tens of thousands per second, and can generate more precise digital information of the scanned parts. However, the data scale of laser 3D scanning point cloud data is relatively large, and it may be interfered by some similar features during the 3D scanning process, resulting in an increase in the number of scanned point clouds and an increase in computer computation [7]. Therefore, it is necessary to simplify and optimize the point cloud while ensuring its accuracy. Because laser scanners are optical devices, they are affected by environmental light, scanner operating distance, and the degree of reflection on the surface of the object being measured during operation, which can reduce the quality of 3D point cloud data. Sharp spikes or floating points on their surface can also form voids on the surface of the point cloud data. In some features with deep holes or subtle gaps, laser cannot penetrate them or cannot recognize the reflected light, resulting in holes caused by data loss. To achieve high-quality and efficient reverse modeling, it is necessary to optimize the 3D point cloud data and ultimately generate a complete and flawless triangular mesh model. Therefore, it is necessary to optimize the 3D point cloud data to achieve the requirements of removing redundant features, filling holes, and smoothing surfaces. Data processing mainly includes point cloud smoothing, hole filling, point cloud simplification, and coordinate alignment [8].Due to the large amount of data generated by 3D laser scanners during data acquisition, some unnecessary noise points may be generated. It is necessary to improve the quality of point clouds by using methods such as smoothing point clouds and reducing noise. Mainly using computers to filter out noise points, all point clouds are filtered and ultimately optimized shown in Figure 4,. The commonly used filtering methods include standard Gaussian filtering, median filtering, and average filtering. Gaussian filtering can ensure the shape of the original data as much as possible, with minimal impact on its shape. Median filtering can remove features that resemble spikes generated. The average filtering takes the average value between the two methods.

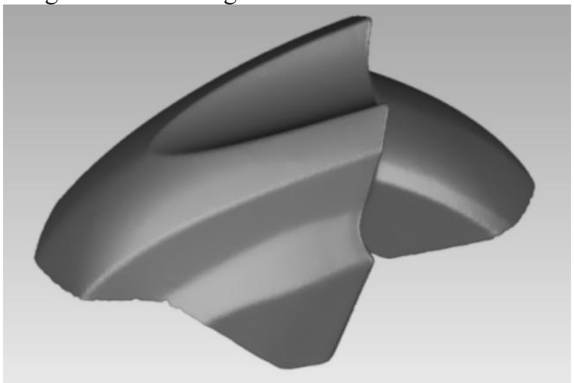

Figure 4 Mudguard Scanning Data

6 SURFACE RECONSTRUCTION OF MUDGUARD

6.1 Import Data

Drag and drop the model data directly into the Geomagic Design X window to open the model.

6.2 Coordinate Alignment

Since the mudguard is symmetrical, the symmetrical plane can be used as one direction of the coordinate system. Create a plane that approximates the mirror plane, and automatically calculate a more precise mirror plane using the mirror method within the additional plane method. Extract the contour lines of the data on this plane, select one line as the other direction of the coordinate system. With a plane and a line segment satisfying the alignment requirements, the coordinate alignment is completed.

6.3 Domain Segmentation

Firstly, it is essential to establish the reverse modeling approach. Given the numerous mudguard surfaces, we primarily utilize surface fitting and lofting guides to manually segment the model into distinct domains based on varying curvatures. The segmentation results are illustrated in Figure 5.

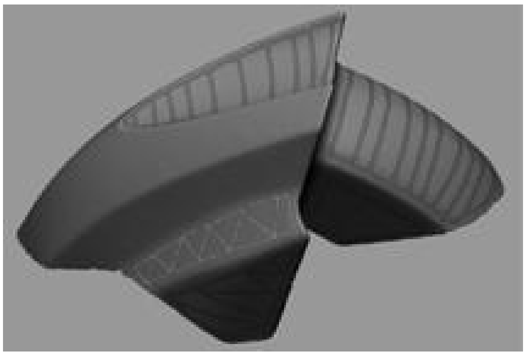

Figure 5 Fender Domain Segmentation

6.4 Surface Creation

Curves serve as the foundation for surface construction. In reverse engineering, splines are typically adjusted via interpolation or approximation, followed by the generation of surfaces through scanning, stretching, sampling, and other techniques. Curves determined by interpolation must pass through all measured data points, ensuring zero error between the curve and the data points. However, with a large amount of data and noise points, there may be too many curve control points, making the interpolation results uncertain. The approximation method tolerates some errors and permits the adjustment of the number of control points. The distance between the curve and the data points is calculated using the least squares method, and the control points are adjusted to meet the error requirements. Since the parts are laser scanned, and the volume of point cloud data is substantial, the contour curve of the machined assembly surface is adjusted through interpolation, while the surface contour curve is approximately adjusted. Set and limit the shape, size, and position of key curves, and modify other curves accordingly.

The front section of the mudguard is completed using the layout command. Firstly, 10 planes corresponding to the normal direction are created according to the surface shape. The corresponding contour lines are extracted from each plane, and a contour line sketch is established. The 10 contour lines are surveyed using the surface layout command to obtain the surface shape. Then, the domain surface is created using the layout guide, patch fitting, and other commands. The surface creation result is shown in Figure 6.

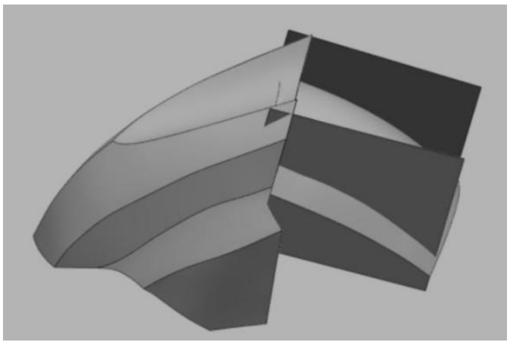

Figure 6 Surface Fitting Results

6.5 Detail Processing

Crop the existing surface shapes together, use the mirror command to copy the surface shape on the other side, and complete the creation of all surfaces.Using the thickness command, assign thickness to the surfaces, transforming the model into a solid state. Finally, round the edges to complete the reverse modeling. The final effect is shown in Figure 7.

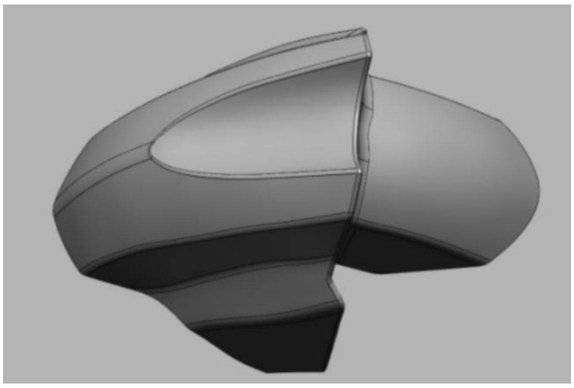

Figure 7 Reverse Design Result

7 ACCURACY ANALYSIS OF MUDGUARD SURFACE

Utilize Geomagic Control X software to compare and analyze the CAD model obtained from reverse modeling with the point cloud data acquired from 3D scanning. Initially, coordinate alignment is conducted. Since both datasets are exported from the same coordinates within Geomagic Design X software, they are already aligned upon import, eliminating the need for further manipulation. Subsequently, a 3D comparison is carried out, resulting in a 3D comparative chromatogram that facilitates precise accuracy identification through the colors displayed on the model. Employ 2D comparison, comparison points, and other pertinent functions to produce detailed data. Ultimately, a comprehensive comparative report is generated. According to the report, the maximum error between the reverse CAD model and the 3D point cloud data stands at 0.12mm, while the minimum error is 0.01mm. The comprehensive comparative chromatogram is illustrated in Figure 8. The overall reverse modeling accuracy of the mudguard is high, and the quality of the parting line and surface is reasonable and reliable, albeit with significant deviations at certain sharp corners or grooves.

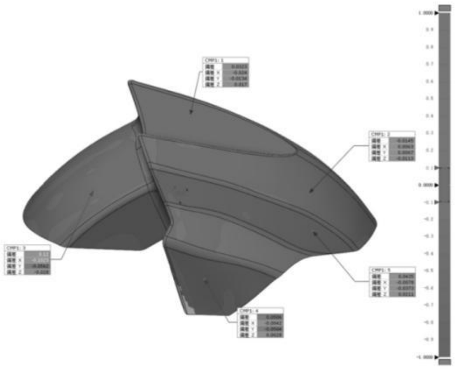

Figure 8 Comparison Chromatogram of Accuracy

Typically, the critical dimensions of laser scanning point cloud data models and coordinate measurement inverse models are rounded off based on the measurement results. Since most crucial design geometric parameters are integers, the rounding process aims to preserve the original dimensions and design concept while minimizing errors in the reverse modeling results. However, due to measurement errors from both measurement methods and discrepancies in geometric dimensions when modeling non-significant areas, the maximum local deviation reaches 0.12mm. After undergoing comprehensive verification and iterative testing, it has been confirmed that the accuracy of the reconstructed model meets the precision requirements for mudguard design.

8 CONCLUSION

By utilizing a handheld laser 3D scanner to gather 3D data of the mudguard, and subsequently employing reverse modeling software to conduct feature domain segmentation, extract spline curves, loft surfaces, trim surfaces, and assign thickness to the 3D point cloud data, we have successfully reverse-modeled the mudguard and derived a CAD model. We then compared and analyzed the CAD model obtained from reverse design with the 3D point cloud data gathered from scanning, completing accuracy testing. Ultimately, we determined that the maximum deviation was 0.12mm, satisfying the design requirements. This experiment underscores that the 3D data acquisition and reverse reconstruction modeling approach utilizing handheld laser 3D scanners offers a highly efficient and precise reverse design method for curved components. This method facilitates innovative design, repair, and enhancement of products in subsequent stages, significantly reducing the research and development cycle.

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COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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