

# The optical scanning measurement and rapid prototyping technology of complex surface part

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According to the combined application of the reverse technology and the rapid prototyping, which is necessary for the complex design and the concept design of part surface, the text firstly introduce the method of gathering reverse data by ATOS laser scanning measurement system and the technology of blending triangular Bezier surface . Second, it analyses the optimized disposition of method of measurement data which is related to the technology of rapid prototyping. Third, the trial has been done about the interface files generated and linked the device of rapid prototyping and model processing experiment.

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## 1. Introduction

Rapid Prototyping Manufacturing (RPM), considered as an important branch of agile manufacturing technology together with reverse engineering (RE), play an important role in achieving product conceptual design and the complex surface design [1]. Reverse Engineering is a very powerful tool in data extraction of part models, and artworks, and historical relics with very irregular surface shapes which are difficultly designed with CAD. Rapid prototyping can quickly recovery the measuring data model into a practicality model without limitation of the model geometry. Therefore, the combination of RE and RP technologies can rapidly achieve reproduction of three-dimensional parts [2-3].

Using ATOS measurement system, the three-dimensional digital measurement and surface reconstruction with triangle plane parameters of the tap are performed in this paper. The optimized method for collecting data, whether meets requirements of STL interface file in RP technology, is analyzed by Combining with rapid prototyping technology. The application and development prospects of the two combination techniques are presented with application example for the measurement and forming of water tap.

## 2. Measurement and reverse engineering

### 2.1 Data acquisition technology-digital measurement of physical model

A new measurement method, being fit for the reverse engineering, is introduced to obtain the raw data, namely ATOS optical non-contact photo measurement systems.

ATOS measurement system, needing not contact with the part surface, can perform the continuous measurement of points on the surface of three-dimensional physical body using optical systems with fast measurement speed and high scanning resolution. The system, possessing intensive collection of data points and high scanning accuracy, is very suitable to measure the external surfaces of complex parts model.

ATOS triangulation system composed of projection light source, CCD camera, image acquisition card, and microcomputer, can reduce the measurement dead zone and improve the measurement accuracy owing to using two CCD cameras which are symmetrically placed with the same parameters. Triangulation method uses the relationship among base level, image points, objects distance and image distance and so on to calculate Z coordinate values of objects. It is shown in Fig. 1.

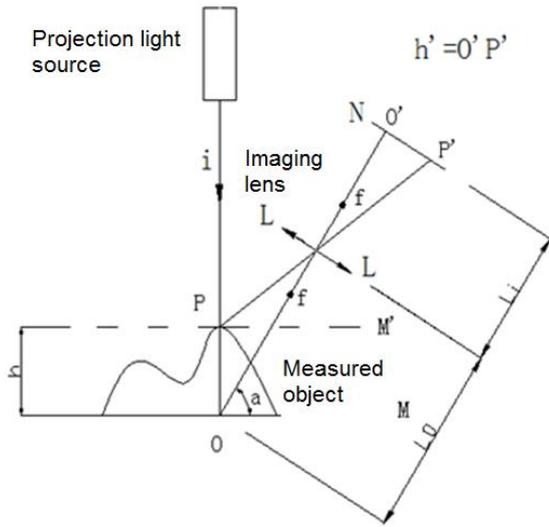


Fig. 1. The schematic diagram of ATOS measurement optical theory. *i*: the incident light; *L*: imaging lens; *N*: imaging screen; *f*: focal length of imaging lens; *L*<sub>0</sub>: object distance of imaging lens *L*; *L*<sub>*i*</sub>: the image distance of imaging lens *L*; *O*: intersection point of *L* axis with the incident light *i*; *P*: light points on the object plane; *P'*: image point of *P*; *O'*: image point of *O*; *h*: the height that light points on the object plane relative to the base level *M*; *α*: incident angle of diffuse light; *M'*: target plane; *M*: participation plane.

According to the principle of geometrical optics:

$$\frac{1}{-L_0} + \frac{1}{L_i} = \frac{1}{f} \tag{1}$$

$$\frac{h \cos \alpha}{h'} = \frac{L_0 - h \sin \alpha}{L_i} \tag{2}$$

Obtained from equation 1.2:

$$h = \frac{L_0 \times h'}{\cos \alpha \times L_i + h' \times \sin \alpha} \tag{3}$$

Where *L*<sub>0</sub>, *L*<sub>*i*</sub>, *α* is the system parameters that are fixed values. Thus, the *h* value can be calculated from *h'*. Fig. 2 shows the data point cloud of the tap surface obtained by the ATOS system.

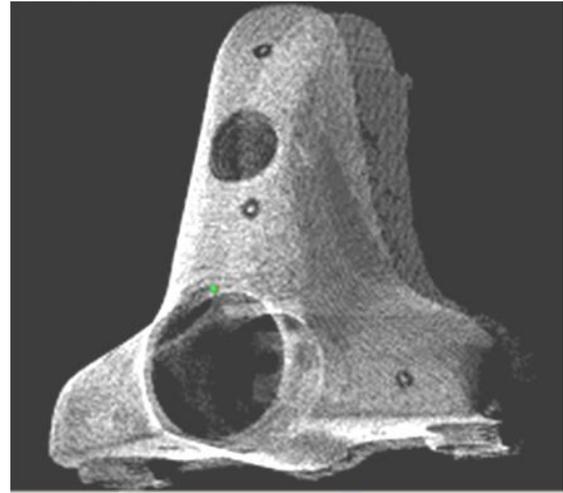


Fig. 2. The data point cloud of tap surface.

### 2.2 Free surface model reconstruction technology

As can be seen from Fig. 2, the original point cloud data collected from measurement, disorderly scattered, is very large. And it contains a large number of redundant and noise points [4]. Therefore, Point cloud needs be pre-processed as follow:

- Polygon mesh of point cloud, and establishing topological relations between points.
- Alignment and registration of multi-view of point cloud.
- Point cloud smoothing, removing or amending the noise points in the point cloud.
- Simplify point cloud, remove the redundant points, decrease the size of the point cloud to reduce the amount of the calculation of subsequent surface fitting [5].

Fig. 3 shows the points cloud of the tap surface after deleting the noise points with the gauss method. The points cloud of the tap surface after streamlining and simplifying with the bi-directional non-uniform grid method are shown in Fig. 4.

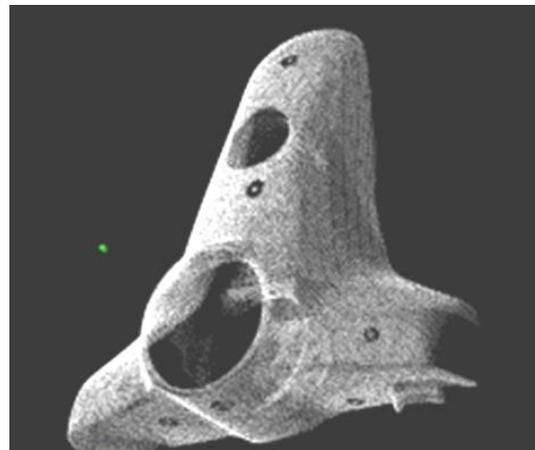


Fig. 3. Points cloud of the tap surface after deleting the noise points.

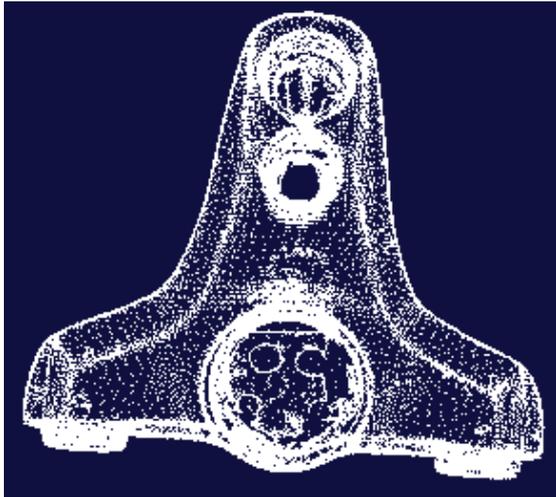


Fig. 4. Points cloud of the tap surface after simplifying.

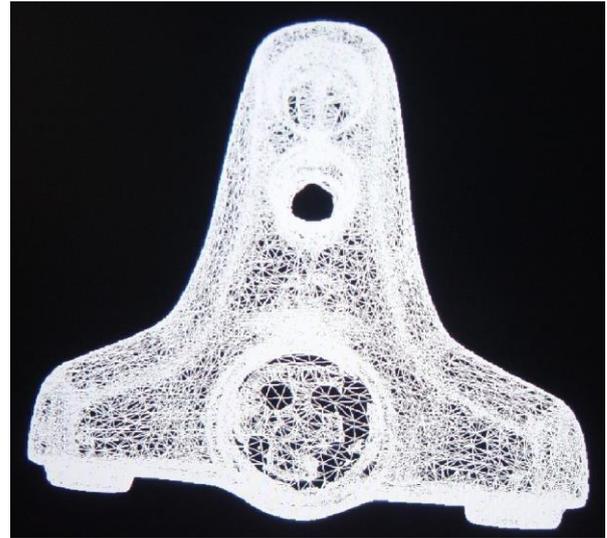


Fig. 5. Triangulation mesh of tap surface.

In modeling with measurement data, the research results of Hoppe [6-8] are most representative for reconstructing the surface of large-scale measured data, which is divided into three main steps:

#### First step: Initial surface

Using function method construct a surface interpolated the measure points, then define a function  $f: (\mathbb{R}^3 \rightarrow \mathbb{R})$  to estimate the distance between measurement points and the surface, finally uses a contour extraction algorithm (March Cub) to extract surface of  $f=0$ , and get  $Z(f) = \{P \in \mathbb{R}^3: f(P) = 0\}$ .

#### Second step: Mesh optimization

Use the grid in the first step as a starting point. The step aims at reducing the number of triangles and improving the approximation accuracy of surface, which is accomplished with energy method. Firstly define an energy function, and then optimize this function, which makes the grid nodes meeting the precision conditions least.

#### Third step: Piecewise smooth surface patches

Using a segmentation refinement method constructs corner feature of the surface to improve the approximation accuracy of surface.

Fig. 5 shows the water tap model obtained by triangulation surface fitting. The compared result between the reconstructed surface model and the initial point cloud data model is shown in Fig. 6. Obviously, the dimension error is much lower. Therefore, the modeling outcome with triangulation surface fitting is more ideal.

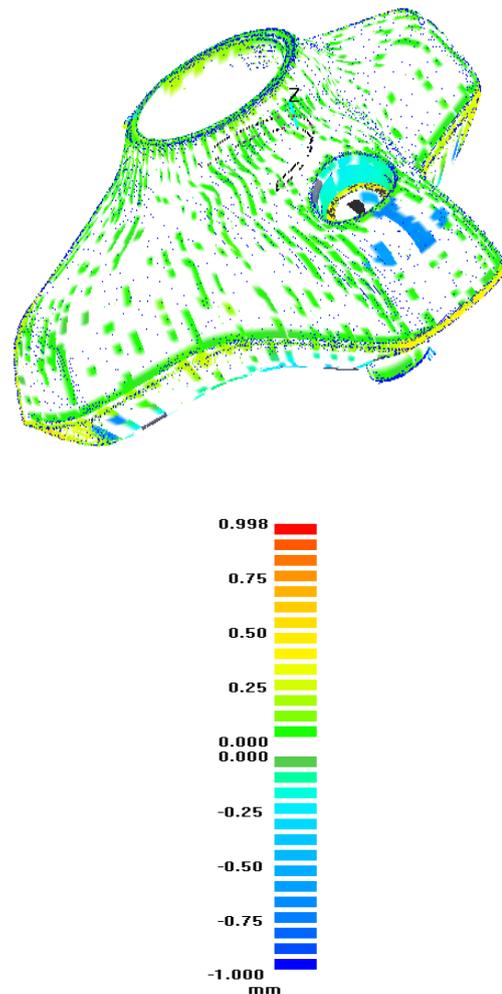


Fig. 6. Matching result of the restructured surface model and point cloud data model.

### 3. Data processing in rapid prototyping technology

Measurement data obtained by variety of numerical methods must be converted to the data format that can be accepted by RP equipment [9]. The data can be recovered into a solid model by using the rapid prototyping method. Now STL file is common data format accepted by the RP devices. There are usually two optimized methods processing measurement data to obtain the STL file: indirect and direct method. According to

the scan and forming requirements of the water tap, the indirect method is used in the forming experiment [10].

Indirect method is to recover the measured data into a CAD model by reconstructing. Then, the CAD model is modified and converted into STL format file. Finally, the STL file is entered into rapid prototyping system. And the contours curve data of all slice layers in STL file, obtained by slicing the data model with the slicing software, can be used to make a copy of the prototype in RP devices. The process can be described as shown in Fig. 7.

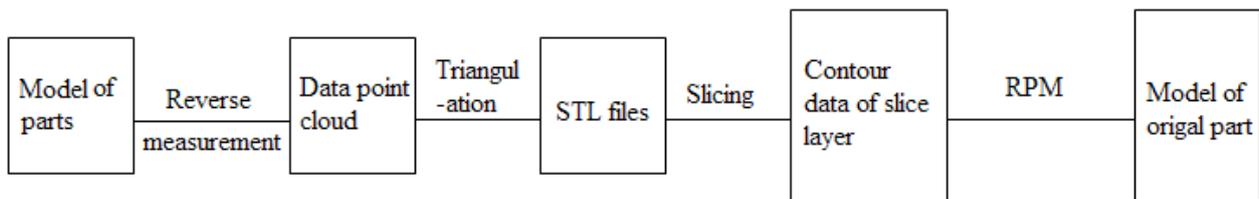


Fig. 7. Indirect data processing method.

In the physical rapid prototyping test of tap, it was found that STL file is too large and contains a lot of errors. Nearly half of the slice layer data have defects and can not form closed data loops which are independent each other. According to their characteristics, the defects can be divided into the following categories:

- (1) The gap error: Some small of the triangular piece is missed and caused the gap in meshing the solid model.
- (2) The isolated surface error: The portion which should be empty in the mesh model emerges the isolated surface composed of one or more of the triangle pieces, which will lead to Ambiguity in the manufacture.
- (3) Overlapping surface: Slices layer appears the overlapping scan lines, which causes no material accumulation in this cross-layer. It is greatly affected the internal quality of the part.
- (4) Intersect error: Including the intersection in space and the self-intersection of different surface. It is a more serious error certainly causing manufacturing ambiguity.

Taking the above slice data defect into account, we do not simply and insolently remedy defects, but systematically study the relationship between each slice parameters, the outline of the shape, support structure and the model material in the forming processes [11]. Through optimization simulation of the spraying path as well as optimization adjustment of the relevant parameters, which makes it possible that each slice layer is an independent closed loop, the above defects were mostly eliminated [12]. Fig. 8 shows the gap repair for STL slice of the water tap with the optimized spray path. The overlap repair for STL slice of the water tap can be observed in Fig. 9. The defect repair of the folding inflection point is shown in Fig. 10. Fig. 11 shows the defect repair of the isolated surface in STL slice of the water tap. Fig. 12 shows a tap part

manufactured at the rapid prototyping machine of the fused deposition modeling (FDM) with the optimized process obtained by the above methods

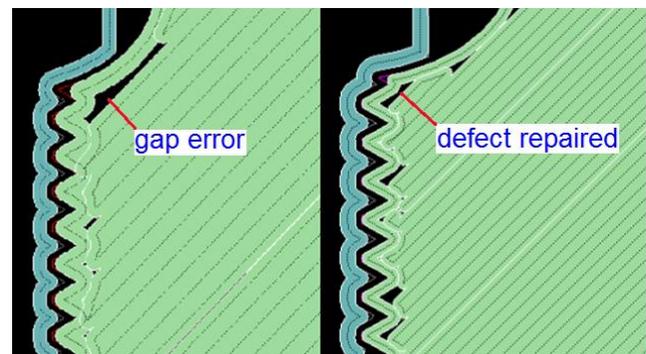


Fig. 8. The gap repair for STL slice of the water tap.

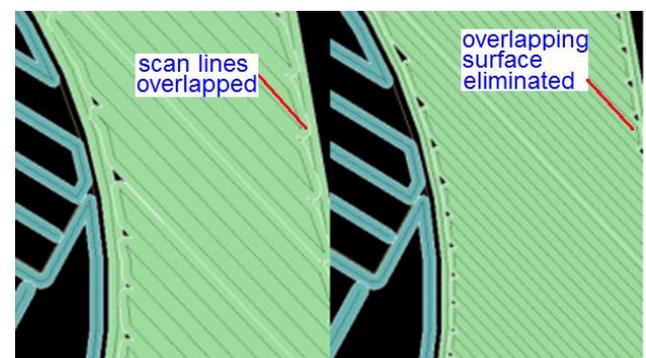


Fig. 9. The overlap repair for STL slice of the water tap.

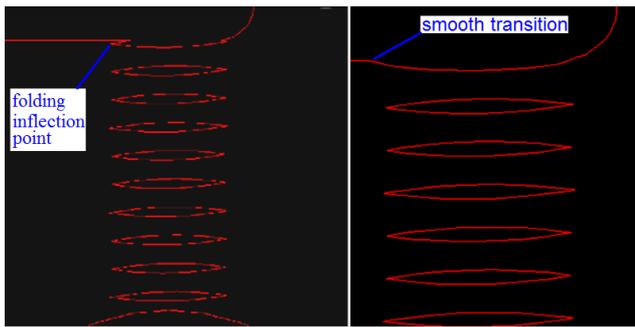


Fig. 10. The defect repair of the folding inflection point.

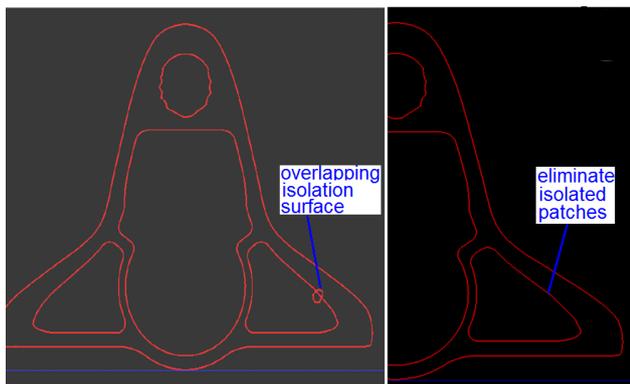


Fig. 11. The defect repair of the isolated surface in STL slice of the water tap.



Fig. 12. The tap part formed at the rapid prototyping machine of the fused deposition modeling (FDM).

#### 4. Conclusion

A method to produce high-accuracy parts, using optical scanning measurement and rapid prototyping technology, has been developed. Then, the forming process parameters of a water tap part are optimized with the simulation method. The present work constructed a CAD model of tap, and manufacturing a tap part.

Based on this study, the following conclusions can be drawn:

1) It has been confirmed that the measured data processing

method and the smooth surface construction technology of the triangular mesh is in line with features of STL file in RP technology by experiment, which has been successfully applied in manufacturing of one water tap part.

- 2) Digital measurement is a very beneficial tool to duplicate parts with complex shapes. Combining reverse engineering with rapid prototyping technology, and using appropriate measurement and data processing methods will produce great application value in modifying product design and copying the physical model.
- 3) The forming defect repair methods have been determined by simulation-optimization to be capable of providing optimum process parameters for rapid prototyping of parts.
- 4) The manufacturing results show that the combined method of the measurement technology and rapid prototyping is reasonable and effective. It can be taken as a new approach for rapid product development and product imitating.

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