Research of three dimensional laser scanning coordinate measuring machine

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Abstract. Three dimensional laser scanning coordinate measuring machine is suitable for the measurement of 3D printing products, and its measuring range depends on the three coordinate measuring machine. It is the main 3D printing product measuring instrument [1]. In this paper, the principle of laser scanning three coordinate measuring machine is analyzed. The accuracy and reliability of the calibration system for 3D printing products are verified. According to the newly revised JJF 1064 *Calibration specification for coordinate measuring machines*[3], it is calibrated.

1 Introduction

With the development of modern coordinate measurement technology and photoelectric technology, 3D non-contact laser scanning measurement technology based on optical principle and computer image processing has been developed rapidly. 3D laser scanning coordinate measuring machine by laser scanning measuring a beam of laser light hair, light irradiation to the measured object and according to the actual shape of the measured object, moving or rotating the probe, can capture the actual shape of objects. The laser scanning probe is equipped with the traditional three coordinate measuring machine and Geometry point cloud measuring software, which can realize the measurement of 3D printing products.

China's manufacturing industry has gradually entered the era of Industry 4.0, and the improvement of precision measurement is also the only way. The combination of the traditional three coordinate measuring machine and the 3D laser scanning system perfectly presents the measuring field.

With the development of computer machine vision, it has become a trend to use non-contact laser scanning to rapidly measure the 3D shape of the surface. It has non-contact, no damage, high precision, high speed. Besides,

It is easy to implement automatic measurement under the computer control and a series of features. It has become an important approach and development direction of modern 3D surface shape measurement. The non-contact laser scanning measurement not only avoids the trouble caused by the compensation of the radius of the probe in the measurement of contact, but also realizes the high-speed three-dimensional scanning of various surfaces. The 3D laser scanner can reach 5000-10000 points / sec speed.

Non contact measurement methods are divided into several sub categories due to the application of different technologies, including microwave technology, lightwave technology and ultrasonic technology, three dimensional laser scanning measurement is one of the light wave techniques is seen in Fig. 1.

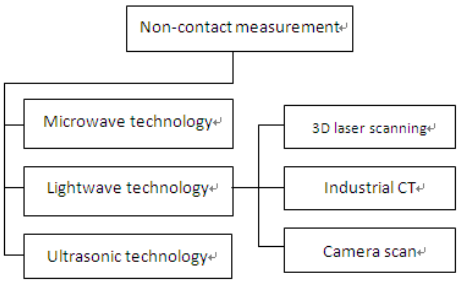

Figure 1. Classification of noncontact measuring techniques.

This paper mainly analyzes the measuring principle of 3D laser scanning coordinate measuring machine, and provides the basis for the research of the traceability of 3D printing value.

2 The principle analysis of three dimensional laser scanning coordinate measuring machine

2.1 Optical triangle principle

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The optical triangle principle [2]is shown in figure 2. The light emitted by the laser is projected onto the

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surface of the object after focusing the lens to form a diffuse reflection spot. As a sensing signal, the reflected light is collected on the focal plane of the imaging lens using the imaging principle of the lens. A photoelectric receiver is placed here, and when the diffuse light spot rises with the surface of the object to be measured, the imaging light spot moves correspondingly on the photoelectric receiver. The position of the surface of the object to be measured can be determined according to the size of the image shift distance and the structure parameters of the sensor, and the position of the measuring point of the surface to be measured can be determined.

See Fig.2, i -incident light, N -Imaging screen, u -Object distance of lens, v -Image distance of lens, O -Intersection point of optical axis and incident light, A -Spots on an object surface, A , O is Respectively A , O the image points, h -The relative height M of the spot on the object relative to the base plane, α -The angle between the incident light and the optical axis, M' -Target plane, M -Reference plane.

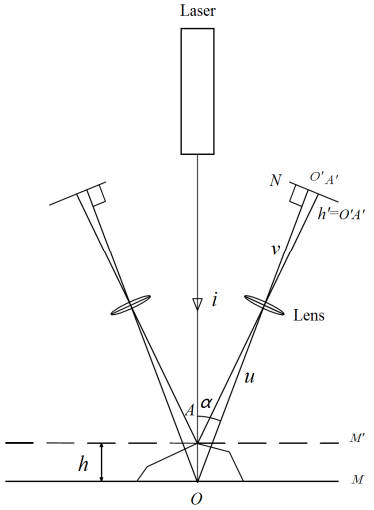

Figure 2. Schematic diagram of optical triangle.
Geometric optics principle available formula 1

$$h = \frac{u \cdot h'}{v \cdot \sin\alpha + h' \cdot \cos\alpha} \quad (1)$$

Type u 、 v 、 α are system parameters, they are all fixed values, h' is the A 、 O Distance between the image points.

When the light spot projected by the light source expands into an optical stripe, the light cutting method is formed. A method of fringe projection is used when multiple identical light bars are projected simultaneously. When a projected light bar is encoded in time or space, a coded image projection method is formed.

In the fringe projection, the triangle principle is used to calculate the contour height. The key point is to find the fringe center to the fringe center precisely by analyzing the law of light intensity distribution. But its nonlinear error is large, and it is seriously affected by the inclination and characteristics of the measured surface. The measurement accuracy decreases with the increase of the incident angle (the angle between the laser beam and the normal vector of the measured point). When the incident angle exceeds a certain angle, the blind spot will appear, which makes the measurement invalid. Generally, the inclination angle of the measured surface shall not be greater than 45 degrees. Therefore, the optical triangulation principle is usually combined with other methods to obtain high data acquisition accuracy and stability.

2.2 Composition structure of 3D laser scanning coordinate measuring machine

The 3D laser scanning coordinate measuring machine consists of a mechanical host, a displacement sensor, a laser scanning system, a control section and a measuring software. The basic principle is to place the measured parts into the measuring space of the coordinate measuring machine. The point data set of the surface of the product is also measured, also called point cloud, and a point cloud can be obtained by using three-dimensional laser scanning. We should find the rotation and translation matrix between two points (rigid transform or Euclidean transform), then transform the source cloud into the same coordinate system of the target cloud. The pattern of fine registration has basically been fixed using the ICP algorithm and its various variants, including:

1) Minimize an objective function,
2) Finding corresponding points,
3) Rotating R and translation T optimization,
4) Iteration.

Through 3D point cloud registration and Geometry++ geometry library, the shape of 3D printing product can be reproduced accurately.

2.3 Measurement process error analysis

There are many kinds of errors in the measurement, including the errors of the measuring instrument itself, the errors of measuring auxiliary equipment, measuring methods, external environment and operation technique. Now it is divided into two parts: the error caused by the machine itself and the error caused by the external factors. Errors caused by the machine itself:

1) System hardware error: The errors in the hardware system are mainly caused by the quality of the grating, the non-uniformity of the lens and the inaccuracy of the surface conditions, and the defocus will cause aberrations, the intensity of the light source and the error caused by illumination uniformity.

2) Software induced error: The error caused by software mainly refers to data preprocessing error and modeling error. Data preprocessing refers to smoothing and transformation of measurement data. It is mainly used for the relocation of multi view data, the selection of datum mark and the measurement error of datum mark can lead to the error of data transformation. The modeling error is mainly the solid modeling error of CAD modeling software and the fitting error of curve and surface. In the software, the least square approximation is

used for spline curve and surface fitting, and there exists a tolerance problem or fitting accuracy control problem.

Work process and data processing:

According to the working process and principle analysis of the laser scanning coordinate measuring machine, the data processing process of the measurement system is shown in Fig.3.

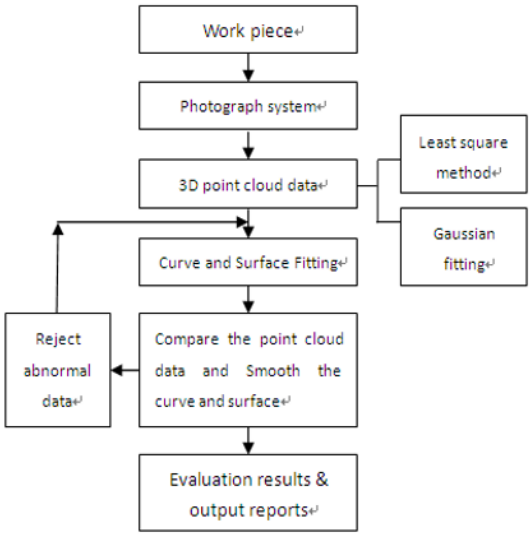

Figure3. data processing process of 3D laser scanning measurement system.

Error caused by external factors and improvement measures:

1) Environmental error: Environmental errors include fluctuations in temperature, humidity, air pressure, dust, electromagnetic fields, etc. In order to reduce the error caused by environmental factors, a special measurement room established by the enterprise and the metering Institute has optimized the environment.

2) The error caused by the object being measured: The instability of parts and components, the deformation of parts and components, uneven surface film, friction and so on. In the part clamping, should follow certain principles, and strive to make the parts deformation minimum. In the measurement of thin-walled parts, should be as much as possible with rubber mud or glue gun temporary bonding fixed, avoid using metal clamps, prevent parts deformation.

3 Measurement uncertainty analysis of 3D laser scanning coordinate measuring machine

Three dimensional laser scanning coordinate measuring machine is based on the traditional three coordinate measuring machine [3], and uses 3D laser scanning probe to replace the contact probe. The basic errors consist of three dimensional laser scanning detecting error and three coordinate measuring machine's measurement uncertainty [4].

3.1 The basic error of 3D laser scanning

From Figure 2, we can see that the basic angle of laser triangulation α and vertical magnification of imaging system ζ are design parameters. The pixel size of the linear array CCD sensor is 10 μm, and the standard deviation of the centroid stability of laser spot is less than 0.03 pixels, and the peak peak value is not more than 0.1 pixels, and the error of the image surface of the linear array CCD sensor is as follow formula 2.

$$\partial h' = 0.1 \times 10 \mu m = 1 \mu m \quad (2)$$

Table 1. performance parameter list of laser sensor

Laser wavelength	0.66 μm
Basic angle of laser triangulation α	18°
Vertical magnification of imaging system ζ	0.245
Image plane error of linear array CCD sensor $\partial h'$	1 μm

Fig.2 shows the vertical magnification of the sensor imaging system ζ as follow formula 3.

$$\zeta = \frac{\partial h'}{\partial h \times \sin(\alpha)} \quad (3)$$

Data is substituted by table 1, Height measurement error is as follow formula 4.

$$\partial h = \frac{\partial h'}{\zeta \times \sin(\alpha)} = 13.2 \mu m \quad (4)$$

3.2 Measurement uncertainty analysis of three dimensional laser scanning coordinate measuring machine

Taking the common type three coordinate measuring machine in Shanghai Institute of Metrology and measurement technology as an example, the uncertainty of measurement is $U = 3\mu m + 4 \times 10^{-6} L, (k = 2)$. Instead of a laser three-dimensional scanning probe, the uncertainty of measurement is $U = 14\mu m + 4 \times 10^{-6} L, (k = 2)$.

4 Conclusion

3D laser scanning coordinate measuring machine is the main instrument of 3D printing products, carry out a variety of calibration of 3D laser scanning coordinate measuring machine to measure a measuring mechanism of strength, Shanghai Institute of measurement and testing technology undertakes calibration of 3D laser scanning coordinate measuring machine.

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