Design of optical emission system in 3D shape detection with oblique laser triangulation probe

Qinghua Yao\(^1\) Miao Cao\(^2\)
\(^1\)Changchun University of Technology, Jilin Changchun, China
\(^2\)Changchun University of Science and Technology, Jilin Changchun, China

Corresponding author and e-mail: Qinghua Yao, yaoqinghua@ccut.edu.cn

Abstract. In 3D laser scanning measurement system, the measurement accuracy of the whole system is determined by the optical system of the laser triangulation probe. This paper studies the optical transmitting system of oblique laser probe to solve this problem in 3D shape detection, based on the analysis of the principle of oblique laser triangulation. In order to reduce the influence of stray light and reduce the geometric distortion of 3D laser scanning measurement system, this paper selected a laser with a wavelength of 650nm as the light source to improve the distribution uniformity of image plane illumination. The design of optical transmitting system of the laser probe applies the beam splitter and normal coaxial layout under the premise of reducing the number of lenses and ensuring imaging quality. Finally, the results are analysed for radial transfer function curve, spot diagram and relative distortion.

1. Introduction
Laser triangulation is a non-contact detection method, which has a long history. Due to the development of the new photoelectric scanning technology and the array type photoelectric detector, the traditional method has many new progress and application with the aid of the computer control and data processing. The laser triangulation system is to emit a beam of light from the light source to the surface of the measured object, image on the optical detector after diffuse reflection. When the position of the object surface is changed, the corresponding displacement of the image on the detector is also changed, according to the relationship between image motion and actual displacement, and real object displacement can be obtained by the detection and calculation of image motion [1-3]. The projection axis, axis imaging and photoelectric detector baseline constitute a triangle, so this method is called triangulation. At present, the laser triangulation with its non-contact, high precision, fast response and strong anti-interference ability, wide working range, easy to measure various materials, simple structure and so on, has attracted wide attention, and the main instrument used in the laser triangulation is the laser triangulation probe. Dynamic detection can greatly improve the efficiency of product detection and enhance the automation of production line. The distance sensor based on laser triangulation principle can realize the accurate measurement of micro parts, and the measurement accuracy can reach 5 μ m in the dynamic moving process.

2. The principle of laser triangulation displacement measurement
According to the relationship between the incident light and the surface normal of the measured work piece, laser triangulation measurement can be divided into direct and oblique, oblique triangle method with higher resolution than the direct type triangulation [4-7].

Oblique laser triangulation as shown in figure 1. Laser beam which emitted by a laser and formed a certain angle with normal of measured object surface is incident on the surface of the measured object. At this time, it must meet the Scheimpflug condition as follow:

\[ \tan(\alpha_1 + \beta) = \lambda \tan \beta \] (1)

On the sensitive surface of the detector, if the displacement of image of light spot is \( x \), the moving distance of the object surface along the normal direction is:

\[ h = \frac{lx \sin \beta \cos \alpha_1}{l' \sin(\alpha_1 + \alpha_2) \pm x \sin(\alpha_1 + \alpha_2 + \beta)} \] (2)

**Figure 1.** Principle diagram of oblique laser triangulation measurement system.

In the Figure 1, \( \alpha_1 \) is the included angle between the laser beam axis and the normal of the measured object surface; \( \alpha_2 \) is the angle between the receiving lens optical axis and the normal of the measured object surface; \( \beta \) is the angle between the optical axis of the detector and the optical axis of the receiving lens. (When the measured object located above the reference plane is plus, located below the reference surface is minus.)

3. **The design of the emission and focus optical system**

3.1. **Beam characteristics of semiconductor laser beam**

According to the principle of laser triangulation measurement, it is known that the laser beam is irradiated to the surface of the measured object and get as little light as possible to improve the precision of the measurement in the measuring range. Because the geometric deflection of stable cavity has very low loss, in most cases, small power laser device uses stable cavity, the laser generated by the laser with stable cavity will spread in the form of Gauss beam in space. Therefore, it is significant to study the focusing properties of Gauss beam [8-9].

The laser beam generated in a stable laser cavity is not a uniform plane wave, nor a uniform spherical wave, but a Gauss spherical wave. When the fundamental-mode Gaussian beam along \( Z \), its electric field can be expressed as:
\[ E(x, y, z) = \frac{A_0}{\omega_z} \exp\left(-\frac{x^2 + y^2}{\omega_z^2}\right) \exp\left[-i \frac{2\pi}{\lambda} \left(\frac{x^2 + y^2}{2R_z} + Z\right) + i \varphi_z\right] \]  

(3)

Where, \( E(x, y, z) \) is electric vector of \( x, y, z \) points; \( \frac{A_0}{\omega_z} \exp\left(-\frac{x^2 + y^2}{\omega_z^2}\right) \) is amplitude; \( \exp\left[-i \frac{2\pi}{\lambda} \left(\frac{x^2 + y^2}{2R_z} + Z\right) + i \varphi_z\right] \) is phase.

From (3) it can be very intuitive to see the overall shape of the Gauss beam, and its propagation characteristics. The characteristics of Gauss beam are described below.

3.2. Parameter optimization of the launch-focus optical system

Using the semiconductor laser as the light source, the light beam can be regarded as quasi Gauss beam. When the focusing position is Gauss beam waist, it can get the best of the focusing effect. By the nature of the Gauss beam it is known that the Gauss beam can be considered to be parallel in the Rayleigh length range.

With a single transverse mode laser as the light source, in the single lens, the variation of the beam properties is expressed. By Gauss beam knowledge from the last section. When the beam waist of the outgoing beam behind the back focus of lens, it is positive, otherwise it is negative.

4. Detection hardware composition

The platform is equipped with motion control system and position feedback system, so that the positioning and motion accuracy can meet the demand accuracy and meet the acquisition speed and range. The laser scanning probe is installed on the measuring platform, and the three-dimensional laser scanning is carried out on the surface of the cylinder block by using the laser triangulation method. The displacement information of the two platforms is combined to obtain the spatial coordinate data. Based on the comprehensive consideration of inspection quality and speed, the inspection characteristics, regions of interest and laws of cylinder parts are analyzed, and the number and distribution of cylinder sample points are optimized, which can reduce the detection cost and improve the detection efficiency. And finally a complete 3D surface data information of cylinder block is formed, which is compared with the original design data, and the detection results are obtained.
5. Conclusions
Try to reduce the number of lenses when designing system. In order to ensure the imaging quality, the first surface of the lens uses even aspheric surface. In terms of imaging quality, transfer function (MTF) in the cutoff frequency range is close to the diffraction limit, meridian transfer function curves in the entire field of view are very good. It can meet the high accuracy requirements of laser triangulation. With the progress of modern industrial technology, digital measurement and 3D reconstruction technology provides an effective means for product development and production. It mainly includes two levels, one is digital measurement; the other is 3D reconstruction, which refers to processing the data obtained by digital measurement and surface fitting, and finally obtaining the three-dimensional digital of the part. Finally, complete 3D surface data information of cylinder block is formed, and the test results are obtained by comparing and analyzing the original design data.
References

[1] Li S Z Adaptive sampling and mesh generation[J].Computer-Aided Design.1995, 27(3): 235-240.

[2] Meng Chia Hsing. Automated Precision Measurement of Surface Profile in CAD Directed Inspection. IEEE transactions on Robotics and Automation.1992, 8(2): 268-278.

[3] USB Implementer’s Forum. Universal Serial Bus Device Class Definition for Human Interface Device 1.1.2001. 6. 27.

[4] Martin Oakham. Demystifying DMIS. Metal Working Production, April 2007.

[5] International Metrology System Ltd. Machinery and Production engineering. Virtual-DMIS, 2010.

[6] Surendra Kumar Pandey. The optical emission induced by interacting excitonic states in quantum well systems[J]. Indian Journal of Physics, 2012, Vol.86 (8), pp.739-742

[7] BORST.S. User-level Performance of channel-aware scheduling algorithm in wireless data networks [C]. Proceeding of Information Communication, US:IEEE,2003:321-331.

[8] Jiang Yan-shu, Research on Application of Analog-probe for Measuring Center, Harbin University of Science and Technology[J], Vol.14 No.4 Aug.2009,121-124.

[9] BAI Ting-ting Image Edge Detection Based on Wavelet Transform and Canny Operator, Harbin University of Science and Technology[J], Vol.15 No.1 Feb. 2010.