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Normal Vector of Scanned Surfacer's Influence on the Laser Scanning Error

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***Abstract*—In the 3D laser line scanning system, the CCD camera is used to collected the reflection image of laser scan line on the object surface. Due to the effects of normal vector of object surface, there has deviation between energy center of light stripe and geometric center of light plane, and this deviation result in a max num error value of about 0.1mm In this paper, We use the standard high-precision sphere as a sampling, use left and right CCD camera to scan spherical surface, then the deviation of scanning data of left and right CCD camera can be calculated. The orthogonal test method was used to analyze the relationship between the deviation of true measurement and the normal vector of object surface, and give a reasonable error compensation on the actual measurement data, This makes the value of measurement accuracy ± 0.02mm.**

***Keywords*—Laser scanning; Error analysis; Orthogonal test method; Light reflex**

I. INTRODUCTION

The laser scan measurement has the advantages of high speed, high resolution, and non-contact sensing. and it is an important technique in digital design and manufacturing, And it has been widely used in industry, Such as cars, motorcycles, home appliances, sports equipment, toys, furniture, anthropometry, the design of shoes and clothing and hats, antique, head portrait, chinaware, crafts, three-dimensional animation, games, virtual environment , Medical rehabilitation, Forensic Identification, E-commerce etc since 20th century 90s. Which the error of 3D laser scanning system limited the application of the laser scanner in the precision dimensional inspection of manufactured components, Research indicate that the impact of 3-D laser scanning measurement accuracy has many factors, Such as CCD camera resolution, an error of calibration technique, the properties of the scanned surface etc[1]-[4], and the effects of deviation of energy center of light stripe and geometric center of light plane is mainly influence in measurement error. Analyzing the relationship between the deviation of true measurement and the normal vector of object surface, then we can give a reasonable error compensation on the actual measurement data, and improvement on laser scan measurement accuracy.

II. ENERGY DISTRIBUTION OF LASER SCAN LINE IMAGE

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Fig 1 is a double CCD camera laser line scanning diagram, laser diode directs a laser line onto the scanned surface, CCD camera distribute on the both sides of light plane and capture the scan line image. Due to the lasers have a certain divergence angle, so light stripe which on the scanned surface have some width, and the width of scan line image changing with the scanned surface shape's changing, which usually between 5 to 15 pixels. Mintron monochrome CCD camera converted the energy of light stripe to gray values when it captures images, Fig 2 is light stripe images and its gray distribution captured by CCD camera.

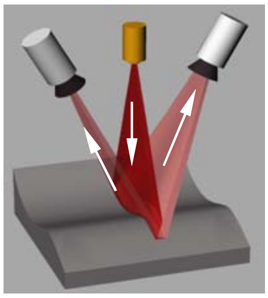
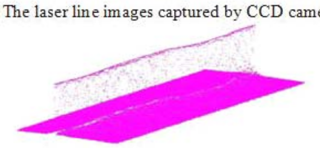


Fig.1. Laser line scan Diagram

(a) The laser line images captured by CCD camera



(b) Gray distribution of laser line images

Fig.2. Laser line images and its gray distribution

Based on object-image correspondence relationship, when conversion from the image coordinate to spatial coordinates should be extracted the gray center of light stripe, that is the energy center of light stripe. As shown in Fig3, Due to a deviation between the energy center of light stripe and the geometric center of light plane, the deviation $_1$ and $_2$ exist between measurement data of left and right CCD camera and the shape of real objects, and has a max num value of about 0.1mm[1]. As a result of the installation error, left and right CCD camera will not be strictly symmetric of light plane, and the image acquisition parameters such as focal length of left and right CCD camera and aperture is not exactly the same difference, $_1$ and $_2$ can not mutual cancellation, and when one CCD camera has been blocked by the scanned surface, only one CCD collecting light stripe image, the two CCD cameras can not compensate each other, and only revealing the relationship between measurement error and light stripe energy center and the geometric center of light plane, we can be done reasonable compensation on actual measurement data.

Fig 4 is a model of light reflection, the light reflection of surface of measured include diffuse reflection, specular reflection and scattering. When actual measurements, light stripe has a certain width, Fig 5 is a reflection section of light stripe which projection at the scanned surface, in all directions light energy unbalanced distribution, light energy near the direction of specular reflection more strong, the spatial coordinates which was calculated by left and right CCD cameras based on light energy, and point M which is the geometric center of light plane has been deviation, normal vector of scanned surface is the main factors.

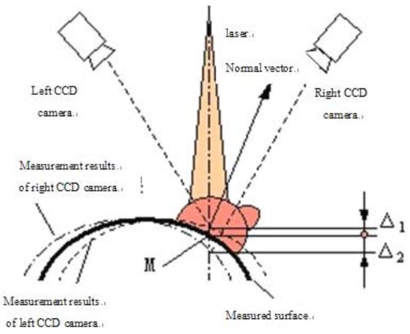


Fig.3. The Diagram of Measurement Error

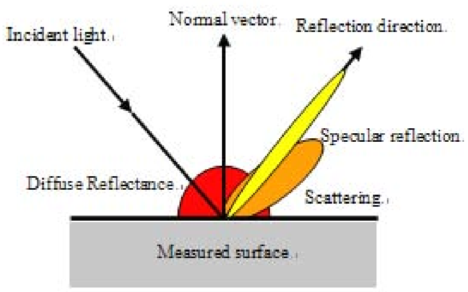


Fig.4.The Diagram of Reflection

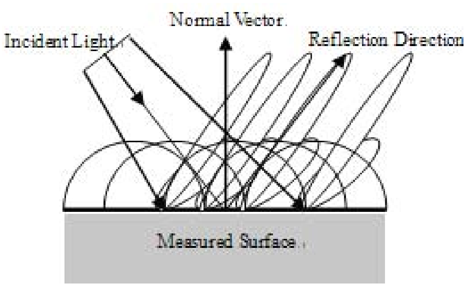


Fig.5. The Diagram Of Light Stripe

III. Normal Vector of Scanned Surfacer's Influence on The Laser Scanning Error

As shown in Fig 3, it is a schematic diagram of actual measurement error, as show in the figure double CCD cameras were installed on the both sides of light plane, the width of the light beam which from the light plane onto the optical surface were changed with the surface tilt. When the angle of the vector of the object surface and light plane is increased, the width of the light beam is increased too, extraction error of light beam center also increases too. Point M at the surface of measured is the center of geometric center of light plane, if it haven't compensation, What is more important is that energy of light reflection is an imbalance, so that the results of left and right CCD camera measurement between the true surface of measurement have a deviation. By expressed the $_1$, $_2$ as the deviation of measured data between left and right CCD camera measurement with the true surface of measurement, this deviation of the $_1$ and $_2$ does not asymmetric, simple average is very difficult to satisfy with actual shape of measurement. Point M is the real point of the object's surface corresponding to the optical geometry center light plane, using $_1$, $_2$ denote respectively the deviation of measured data which measured separately by left and right CCD camera between the scanned surface. Due to this deviation $_1$ and $_2$ isn't asymmetric, simple average is very difficult to satisfy with actual shape of measurement. In order to analyse the relationship between $_1$, $_2$ and normal vector of scanned surface, We choose a standard sphere sample (ø 50mm) which was processed by numerical controlled machine as a sampling, the results of the scan from the standard high-precision sphere which as the sample measured, you can ensure a higher degree of measurement accuracy, and it can reality reflection the impact of the normal vector of scanned surface on scan data, at the process of scanning the sampling data which was got by left and right CCD camera at the same time were saved, we selected a group of experimental data from the many random scanning in the measurement, the scope of the scan data for the X-axis 27mm, Y-axis direction for the 20mm, Z-axis direction for the 6.29mm, Scanning space of data 0.5 mm, the sampling points 2240.

Fig 6 is a measurement data of color-overlap display originated from the left and right CCD cameras scanning a standard sphere of high precision machining; on the right, the measurement data of left CCD camera(deep color) larger than right CCD camera measurement data (light color); on the left, the measurement data of right CCD camera (light color) larger than left CCD camera measurement data (deep color). Fig 7 is a row scan data comparison with Fig 6. Table 1 lists part of deviation from the sampled data in Fig 7 and its corresponding angle α (see Fig 7), the measurement error in this scanning range is about ± 0.05mm. It has been seen in Table Ⅰ, that the deviation of the measurement data between the left and right CCD camera and the real shape increases when α increases, Linear monotone increasing about the deviation of the measurement data. Angle α is the angle between the normal vector of scanned surface and Y-axis, we use the line between spherical center and average points of left and right CCD camera measurement data approximate calculation the normal vector of scanned surface, as $_1$, $_2$ standard is far less than the radius of the standard sphere, Therefore, the calculation error of angle α very small.

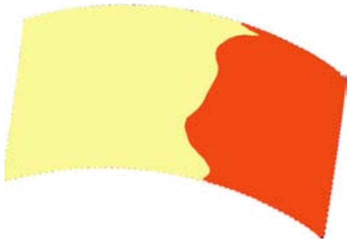


Fig .6. The measurement data measured by left camera and right camera

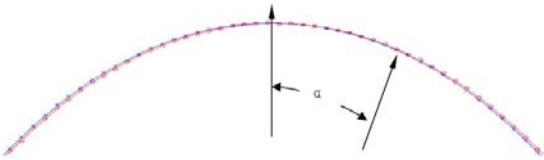


Fig 7. A raw data in Fig 6

TABLE Ⅰ. DEVIATION OF SAMPLING POINT AND ANGLE α

α (degree)	-29.846	-20.079	-15.434	-10.008	-5.304	0.249	5.192	10.495	15.933	20.023	30.652
Δ1-Δ2(mm)	-0.066	-0.063	-0.055	-0.048	-0.032	0.001	0.023	0.040	0.050	0.055	0.059

The actual measurement data show that the deviation between left and right CCD camera scanned data and actual shape, and angle α have a linear relationship. Lex the relationship between $_1$, $_2$ and angle α are f (α) and g(α):

$$f(\alpha)=a_1\alpha+b_1 \quad (1)$$

$$g(\alpha)=a_2\alpha+b_2 \quad (2)$$

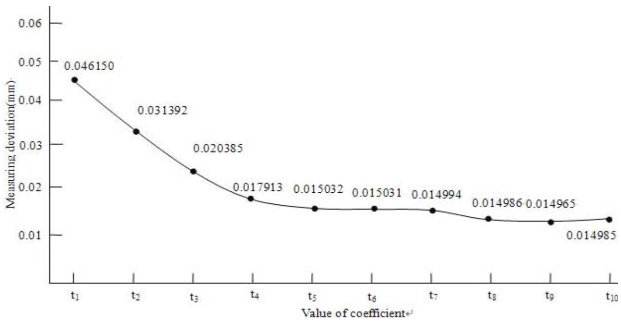
Because we do not know the actual shape of measurement objects beforehand， and just only know that the deviation of measured data between left and right CCD camera ($_1$+ $_2$), and we do not know the specific size of $_1$ and $_2$, so that in order to study the relationship between angle α which was the angle between body surface normal vector and light plane with $_1$, $_2$, and that is the measurement error of relationship about f(α) and g(α). If we obtained the coefficients of f(α) and g(α), and we can given a reasonable error compensation.

We using the orthogonal test method in statistics. In accordance with known $_1$+ $_2$, and finding which is the main factors impact of f(α) and g(α). Then we get preliminary conclusion through comparison of the orthogonal table, and we can providing a basis for error correction, chosing the measuring deviation of left and right CCD camera as the indicators of orthogonal test, the coefficients of f(α) and g(α) a_1, b_1, a_2, b_2 as the factors of orthogonal test, the different coefficients of f(α) and g(α) a_1, b_1, a_2, b_2 as the level of orthogonal test. Based on analysis of the data in Table Ⅰ, the level of each factor was determined 7, Initially the factor and levels as fellows:

TABLE. Ⅱ FACTOR AND LEVELS

factors	1 level	2 level	3 level	4 level	5 level	6 level	7 level
a_1	0.02	0.03	0.04	0.05	0.06	0.07	0.08
a_2	-0.02	-0.03	-0.04	-0.05	-0.06	-0.07	-0.08
b_1	-0.06	-0.04	-0.02	0.0	0.02	0.04	0.06
b_2	-0.06	-0.04	-0.02	0.0	0.02	0.04	0.06

According to the above analysis, we can know that this is a test of four factors and seven levels, and there is no interaction between the four factors, Therefore, $L_{49}(7^8)$ orthogonal table was selected for the experiment. Every row measurement data on the Fig.6 one by one as the experimental conditions of orthogonal test, after the group of orthogonal test have been completed, We are subdivision the value of factor level table basis on the best a_1, b_1, a_2, b_2 again, and then the orthogonal table was re-assignment by the value of subdivision coefficients, and the next round of orthogonal test was to be done, which is equivalent to recursive orthogonal test, recursive test was in order to further reduce the measurement deviation, until get the reasonable error compensation.



	a_1	b_1	a_2	b_2
t_1	0.040	0.020	-0.050	0.040
t_2	0.040	0.029	-0.056	0.043
t_3	0.046	0.023	-0.056	0.045
t_4	0.050	0.026	-0.057	0.043
t_5	0.053	0.023	-0.057	0.044
t_6	0.053	0.0245	-0.057	0.0415
t_7	0.054	0.0243	-0.0600	0.0416
t_8	0.053	0.0245	-0.0605	0.0415
t_9	0.053	0.0231	-0.0592	0.0403
t_{10}	0.053	0.024	-0.0573	0.043

Fig.8. Measuring deviation and coefficient value

TABLE Ⅲ. DEVIATION OF SAMPLING POINT AND ANGLE A (AFTER ERROR COMPENSATION)

α(degree)	-29.846	-20.079	-15.434	-10.008	-5.304	0.249	5.192	10.495	15.933	20.023	30.652
Δ_1-Δ_2(mm)	-0.0186	-0.0155	-0.0112	-0.0117	-0.004	0.001	0.007	0.0100	0.0133	0.0146	0.0149

Fig 8 is the relationship of measuring deviation and coefficient value after error compensation, Seen from the experimental results, with the increase of recursive test, when the coefficient of f(α) and g(α) a_1, b_1, a_2, b_2 were calculated from the first orthogonal, combination of the coefficients of f(α) and g(α) a_1, b_1, a_2, b_2 have been re-optimized by each orthogonal test. measuring deviation will be a gradual decrease from the original ± 0.05, after the fourth experiment, measuring deviation which in the each experiment are the horizontal linear and changing between ± 0.015, then we get the reasonable coefficient of f(α) and g(α) a_1=0.053, b_1= 0.024, a_2=-0.057, b_2=0.043, that is f(α) =0.053α +0.024, g(α)=-0.057α +0.043. Table Ⅲ shows the deviation of sampling point and angle α after error correction about Table Ⅰ, one can see that measuring deviation of left and right CCD camera has been down to ± 0.015 after the error compensation, we have been get a better error compensation effect.

Ⅳ. Conclusion

The imbalance of light reflection, which is due to the inconsistency of light center and geometric center , it is easy to produce error in the triangle measuring method which is based on geometrical optics center. We only determine the coefficient of f(α) and g(α), then we could give a reasonable error compensation. This paper based on the orthogonal experiment design method, using coefficients of f(α) and g(α) as factors, according to $_1+\ _2$, setting the different coefficients of f(α) and g(α) as levels, With the error of different values of coefficients between the left and right CCD camera as indicator. By comparing orthogonal table we get the relationship f(α) = 0.053α+0.024, which is the deviation of measurements data between left CCD camera and the true shape; And the relationship g(α)=-0.057α+0.043, which is the deviation of measurements data between right CCD camera and the true shape.

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