3D shape measurement system for various refractive indexes using optical projection method

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Abstract

We propose the 3D shape measurement system for various refractive indexes. This system using the optical projection method is a system that projects a line pattern or a stripe array pattern from the light source to the object surface, captures the object surface image by the digital camera, processes the acquired image information with the computer by the principle of the triangulation. This system measures spatial large amount data of the object surface without any contact in short time. Transformation equation has been proposed using Snell's law for various refractive indexes. In this case, we have to consider two or more refractive indexes because incident and reflect light beams travel through two or more mediums. In present system, basic experimental conditions are 640 x 480 pixel camera and n_1=1.000, n_2=1.0 (in air) and 1.333 (in water). Measurement area is X=305 mm and Y=230 mm at Z=0 mm. Experimental results show that the 3D shape can be reconstructed correctly by choosing the proper refractive indexes. Experimental results also indicated that the standard deviations for X, Y and Z are 0.21, 0.08 and 0.27 mm, respectively.

1 Introduction

3D shape measurement system has a wide industrial application for engineering from the micro-nano precision measurement to the wide area measurement. Until now, various 3D surface shape measurement systems have been proposed and commercialised [1, 2]. However, most of them can only measure the object in air.

In this paper, we propose the 3D shape measurement system for various refractive indexes. This system was measured the object surface without any contact in short time using the optical projection method. Since our target object at the moment is relatively large, we selected simple projection pattern method instead of moiré method. We evaluated the accuracy of the system for different refractive indexes.

This sytem has many applications such as realtime measurement for microfabricated device, external wall inspection device for outside space station and sensor of rescue robot in air, water and other transmissive medium.

2 Measurement system

2.1 Measurement principle

The schematic diagram of the 3D shape measurement system is shown in Fig.1. The system consists of a semiconductor laser, a rotating mirror, a CCD camera, a computer and a display. A line pattern from the laser is projected on a surface of an object. The incidence angle is defined by the rotating mirror angle which is controlled by the computer. The deformed patterns are captured by the camera, which is set perpendicular to the line pattern direction. We used difference image to improve an accuracy of the image processing. The acquired image information is processed with the computer by the principle of the triangulation, and records and shows the shape of the object surface. The object, the laser with the mirror, and the camera form an optical triangulation system. Therefore, the 3D physical spatial coordinates can converted from the 2D observation coordinates. The object is located in the various refractive indexes such as air and water. In this case, the incident and the reflect light beams travel through two or more mediums. Thus, transformation equation is applyed using Snell's law for various refractive indexes.

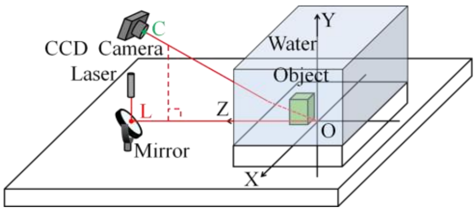


Figure 1: Schematic of measurement system

2.2 Coordinate calculation

Figure 2 shows the relationship of physical spatial coordinate of the object and the laser with mirror and measurement coordinate of the camera which can be used in 3D shape coordinate transformation by triangulation. The object coordinate system is an orthogonal physical spatial coordinate system with axes X-Y-Z and origin O(0, 0, 0), and the measurement coordinate system is a rectangular observation coordinate system with axes X'-Y' and origin O'(0, w+t, b+e). The laser with mirror and the camera are set to the principal point L(0, v, a) of the mirror and the incidence angle of α, the principal point C(0, w, b) of the camera lens, respectively. The boundary between n_1 and n_2 on the Z axis is B(0,0,c). β, γ,θ, φ, μ, ν are angles of the laser beam for Z axis at each position. n_1 and n_2 are the refractive indexes for each medium. The object surface point P(X, Y, Z) of the 3D coordinate system is captured at the camera pixel position P'(X', Y') of the 2D coordinate system which is corresponding to P'(m, w+t+u, b+e-f) of the 3D. Therefore, the 3D coordinates P(X, Y, Z) of the object is calculated by following equations.

$$X = -\left(\tan\nu \times \frac{AL-SI}{T}\right) + \left(\tan\mu \times (b-c)\right)$$

$$Y = AL + \left(\frac{SI\text{-}AL}{T} \times \tan\beta\right)$$

$$Z = c - \left(\frac{(SI - AL)}{T}\right)$$

$$T = \tan\beta + \tan\varphi$$

$$AL = v + (a - c) \times \tan\alpha$$

$$SI = w - (b - c) \times \tan\theta$$

$$\frac{\sin\alpha}{\sin\beta} = \frac{n_2}{n_1}$$

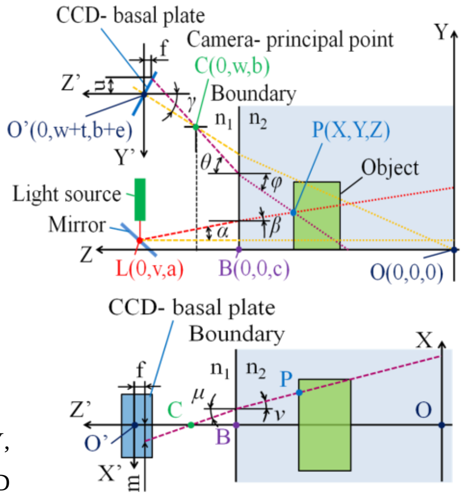


Figure 2: Measurement system spatial relationships for Y-Z plane and X-Z

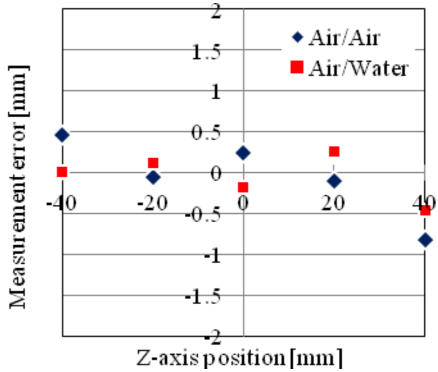
Thereby, the 3D coordinates P (X, Y, Z) can be calculated from the 2D coordinates of the image using the determined parameters.

In this system, there are various error causes such as the camera position error, the distortion of lens aberration and the error of the initial incidence angle, etc. To calibrate the system, the known reference object is pre-measured at five reference points and camera unknown parameters are identified. The dispersion of incidence angle 0.015° is measured experimentally. These experimental results also used to determine systematic errors.

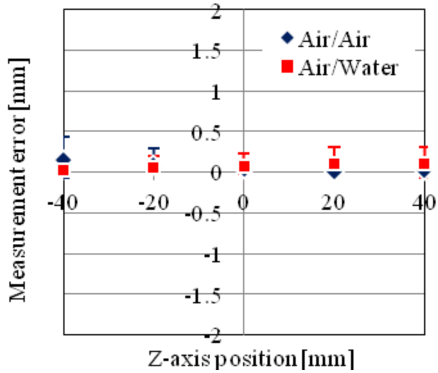
3 Result and discussion

In present system, basic experimental conditions are 640 x 480 pixel camera, C(0,220,275), L(0,0,335), α=1.182k^{o} (k is integer) and n_1=1.000 (in air). Measurement area is X=305 mm and Y=230 mm at Z=0 mm. Calculated resolution of the camera for X, Y and Z are 0.48, 0.48 and 0.67 mm, respectively. A cubic object which is 50.5 mm on a side and white is selected as a smple. To evaluate the effect of the refractive index, n_2=1.000 (in air) and 1.333 (in water) at 20^{o}C are selected.

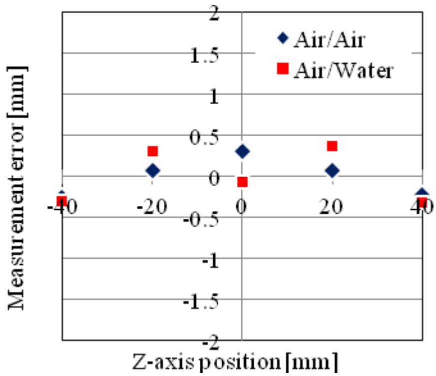
Figure 3 shows the measurement error as a function of the position of Z axis for X, Y and Z axes. Experimental results show that the 3D shape can be reconstructed correctly by choosing the proper refractive indexes. Experimental results also indicated that the standard deviations for X, Y and Z are 0.34, 0.07 and 0.18 mm (in air) and 0.21,0.08 and 0.27mm (in water), respectively. These values are under resolution of camera in present system.



(a) X-axis measurement error



(b) Y-axis measurement error



(c) Z-axis measurement error

4 Concluding Remarks

In this paper, we propose the 3D shape measurement system for various refractive indexes. Since it is possible to operate in various refractive indexes and there is no complex system, the proposed 3D measurement system is proved useful for industrial applications.

References:

[1] K.Tsujioka, et al., Proc. SPIE, 7156, Figure 3: Measurement error, CD-ROM, 1-6 (2008).

[2] R. Menon and H.Smith, J. Opt. Soc. Am. A 23(9) 2290-2294 (2006).