Three-dimensional Measurement Using Laser Pattern And Its Application to Underwater Scanner

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Abstract

In order to measure an accurate volume of the resources, the authors developed a new three-dimensional instrument consisting of a laser projector and a camera. The laser projector irradiates a sharp two-dimensional laser pattern independent the distance to the target object. Our instrument was able to measure three-dimensional shape of the target object with maximum error of 5% in the water, at one scan

Keywords: Three-dimensional measurement, structured light, Underwater instrument, Resource investigation

1. Introduction

Japan's exclusive economic zone is in rich in resources including mineral such as hydrothermal deposit, energy such as methane hydrate and biological resources [1]. For measurement of accurate volume of those resources, many institutes and have researched underwater instrument which is able to measure three-dimensional shape of target objects. A sonar such as synthetic aperture and multi-beams sonar measure sea bottom topographical of wide area with the resolution of a several meters, and is suited for survey of large resources [2]. An optical instrument using underwater camera measures object shape with high resolution, and its swath width is the smaller than the sonar. Light cutting method using a camera and a sheet laser [3], and stereo vision using two cameras [4], are able to measure three-dimensional shape of millimeter order. Because measurement accuracy of two methods depend on accuracy of self-localization of underwater vehicle with instrument, those are not suited for measurement of moving objects such as fish.

In order to measure actual volume biological resources, this research developed a new underwater optical instrument consisting of a laser projector and a camera. The laser projector irradiates a sharp laser pattern independent the distance to the target object. The instrument can measure three-dimensional shape of the target object using the laser pattern of several color beam at one scan. Thus, measurement accuracy of the instrument doesn't depend on position accuracy of mounted vehicle. This paper explains the principle of three-dimensional measurement of the instrument, and shows the results of its experiment for evaluating accuracy.

2. Principle of three-dimensional measurement

2.1. *Measurement model*

Our three-dimensional consist a laser projector inside a PC hull and a network camera inside a camera hull, and the position of the place where the laser beam hits is measured in camera coordinate. Although basic principle is the similar to general light cutting method, measurement area of the instrument is larger than the general by multi colors laser beam from the projector. Camera model in the instrument is shown in Fig.1, and Z axis direction of the camera coordinate which is located on the optical center inside the camera is same as the camera direction. The projector which is located y axis in the camera coordinate be inclined to pitch direction of φ_p

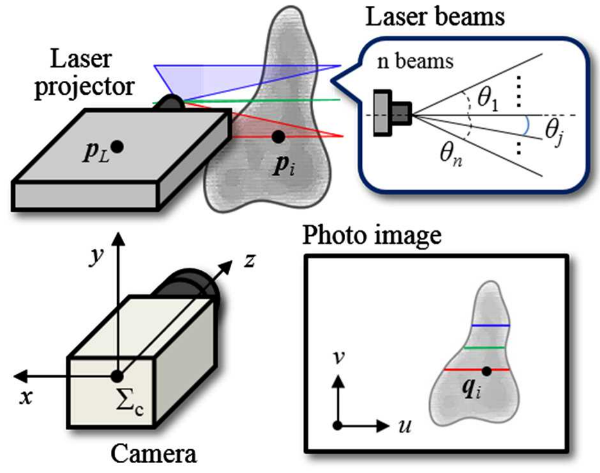

Fig. 1. Measurement model in our instrument

degrees, and n color beams be irradiated from the projector. The position $\boldsymbol{q}_i = [u_i\ v_i]^T$ in image coordinate denotes the position $\boldsymbol{p}_i = [x_i\ y_i\ z_i]^T$ where laser beam inclined at θ_j degree hits on the target object. Let the target object and its photo image be related by pinhole camera model. x_i and y_i in $\boldsymbol{p}_i$ are expressed by following equation:

$$x_i = \frac{su_i}{f} z_i \tag{1}$$

$$y_i = \frac{sv_i}{f} z_i \tag{2}$$

where f is focal length, and s denote the size per one pixel in image coordinate respectively. z_i is geometrically calculated using the projector position and beam angle.

$$z_i = \frac{y_L - y_i}{\tan(\varphi + \theta_j)} \tag{3}$$

y_L denotes the position of y axis of the projector. Then, equation (1) is substituted for equation (3), and z_i is represented by following equation.

$$z_i = \frac{f y_L}{f \tan(\varphi + \theta_j) + s v_i} \tag{4}$$

The camera capture photo image of laser reflection, and the position of each laser reflection in image coordinate is detected by binarization of HSV model. The shape of the target object can be measured by applying equation (1), (2) and (4) to all the pixels of the detected laser reflection.

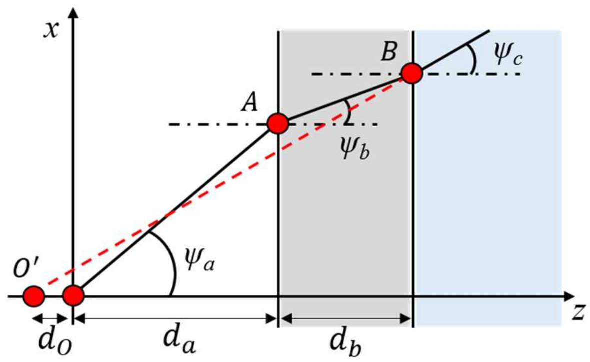

Fig.2 Schematic diagram of light path

2.2. *Water influence*

In our three-dimensional instrument, the network camera is installed inside acrylic housing for water proof, and it take underwater image from in air. Light refracts based on Snell's law when the medium though which light passes changes. In our instrument, light goes from air to acrylic, from acrylic to water, shown in Fig.2. Based on Snell's law, the view angle of the camera in air and water is related as following equation.

$$\frac{\sin \Psi_a}{\sin \Psi_c} = \frac{v_a}{v_b}\frac{v_b}{v_c} = \frac{v_a}{v_c} \tag{5}$$

ψ_a, ψ_b and ψ_c denote the view angel in air, acrylic and water, and v_a, v_b and v_c are light velocity in air, acrylic and water. The angle in water is obtained by solving equation (6) for ψ_c.

$$\psi_c = \sin^{-1}\left(\frac{v_c}{v_a} \sin \psi_a\right) \tag{6}$$

Because v_a and v_c are a parameter determined by physical property values, ψ_c is obtained from ψ_a by using equation (6).

Not only the view angle, but optical center also is affected by water. Using the distance d_a between optical center and acrylic and acrylic thickness d_b, the offset d_o of z axis of optical center is expressed by following equation.

$$d_0 = d_a + d_b - \left(\frac{d_a \tan \Psi a + d_b \tan \Psi b}{\tan \Psi c}\right) \tag{6}$$

ψ_b in equation (6) is obtained in the same way as ψ_c.

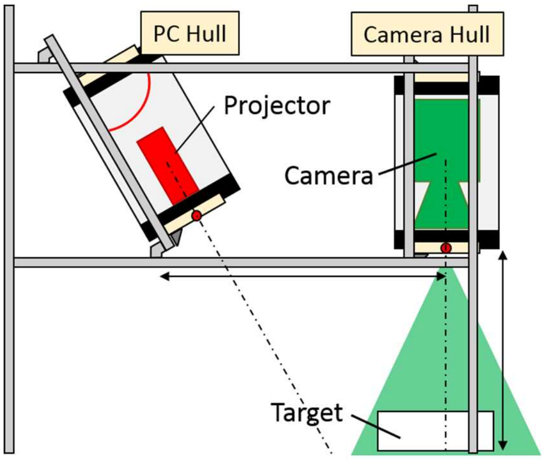

Fig.3 Experimental setup

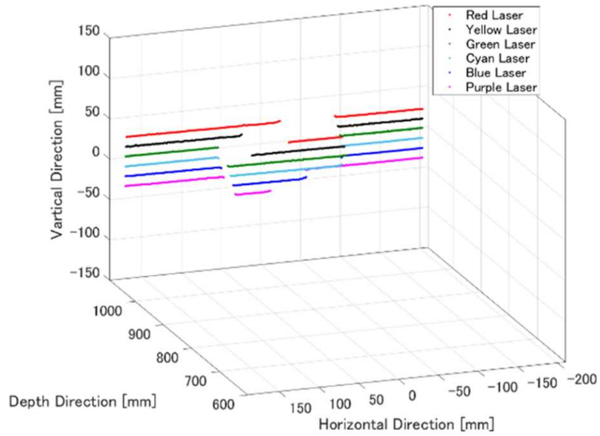

Fig.4 The position of laser reflection

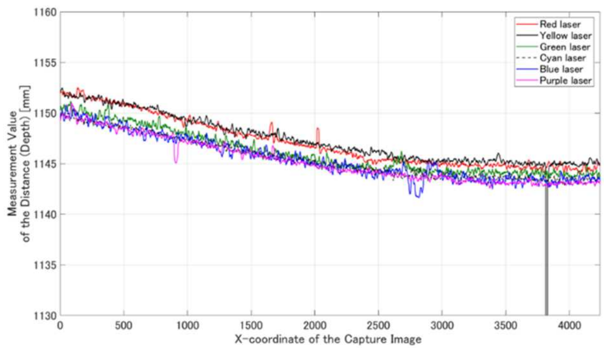

Fig.5 The distance measured with each laser beams

3. Experiment and evaluation

3.1. *Dry test*

To evaluate the performance of our three-dimensional instrument, the shape of a box which 55.4 mm wide, 150.6 mm length and 30.8 mm height was measured using setup shown in Fig.3. The box was putted on the bottom which 1,137 mm distance from the optical center of the center, and the projector inclined at 60 degrees is located at 600 mm distance from the camera. The projector irradiated 6 color beams including red, yellow, green, light blue, blue and purple to target object for measurement. Figure 4 shows the position of laser reflection calculated using equations in chapter 2.1. The instrument measured the distance to the bottom less than 5% error rate. As the box dimension was estimated based on measurement results, error rate of wide, length and height were 7%, 5% and 5% respectively.

3.2. *Wet test*

The distance to the bottom was measured in water by the setup same as Fig.3, and equations considering water influence shown in chapter 2.2 were used. Then, actual distance between the optical center and the bottom was 1,096 mm. Figure 5 shows measurement results with each laser beams. The instrument measured the distance in water with less than 5% error rate in each laser beam. Even though parameters and lens distortion had was calibrated before wet test, measurement results depended on the position of x axis. This cause is considered that the distortion of the projector lens was not calibrated.

4. Conclusions

We developed new three-dimensional instrument that can measure the shape of target located in 1,000m away with less than 5% error rate, in air. The instrument measured the distance to target with high accuracy.

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