Underwater 3D Scanner using RGB Laser pattern

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***Abstract*— For efficiency surveying fishery resource, the authors developed the scanner which measure the target shape at once time. The scanner based on the structured light method irradiated the laser patter coded on De Bruijn for high resolution the measurement under water. The evaluation experiment results showed that the scanner can measure the target shape less than 1.4 % error for the measurement range.**

I. Introduction

As the global fish population declines, TAC (Total allowable catch) that is capable amount for fishery resource has been introduce all over the word. To keep TAC and manage fishery resources appropriately, it is necessary to regular survey those biomass and growing conditions. The troll net which is commonly used for fishery resource survey can efficiently conduct a wide area of surveys. However, the method has a risk that roughs the habitat of the fishery resource and can be not operated at undulating seafloor. Recently, the AUVs (Autonomous Underwater Vehicles) equipped with a camera system is used for fishery resources survey [1-3]. Laser scanner for light cutting method [4-5] and stereo vision system [6] generates 3D reconstruction image based on vehicle navigation data, photo images, and measurement results, and its image show shows the population and distribution of the resource. However, the light cutting method is not suitable for moving object because its footprint at one time is narrow, and measurement resolution of the stereo vision is not enough for management of fishery resource.

For efficiency surveying fishery resource, the authors have working on underwater 3D scanner which can measure target shape with high resolution at once time [7]. Our 3D scanner which consists of a laser projector and a camera can measure the shape of target object located in 1,000 mm away with less than 5% error using six color lasers based on structured light method [8]. This paper explains new scanner that can measure the target shape with higher measurement resolution than previous by high frequency RGB laser pattern, experimental results using the scanner is shown.

II. Measurement Principle

A. Measurement model

Although basic principle is the similar to general light cutting method, measurement points of our scanner is more than the general scanner because of using laser pattern that consist of multi colors beams. Measurement model in our scanner equipped a camera and laser projector is shown in Fig.1. In the figure, the projector tilted φ on the y axis in the camera coordinate irradiates n sheet laser beams which consists multiple colors to target object, and the camera capture the reflection image of those beams. Let the target object and

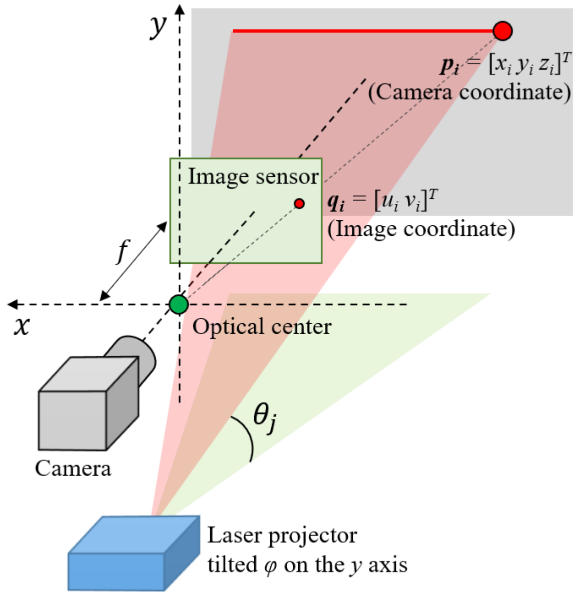

Fig. 1. Measurement model in our scanner

captured image be related by pinhole camera. Then, the position $\boldsymbol{p}_i = [x_i\ y_i\ z_i]^T$ where the laser beam inclined at θ_j degrees hits on the target object is expressed using $\boldsymbol{q}_i = [u_i\ v_i]^T$ in image coordinate by following equation:

$$x_i = \frac{s u_i}{f} z_i \tag{1}$$

$$y_i = \frac{s v_i}{f} z_i \tag{2}$$

where f is focal length, and s denotes the size per one pixel in image sensor. z_i in above equations geometrically calculated using the projector position $\boldsymbol{p}_p = [0\ y_L\ 0]^T$ and the beam angle.

$$z_i = \frac{f y_L}{f\tan(\varphi+\theta_j)+s v_i} \tag{3}$$

If laser beams in the captured image are detected by image processing, the position of the laser reflection points in the target is calculated by using equation (1), (2) and (3).

Because the camera in the scanner is installed inside acrylic housing for waterproof, photo images is affected by light refraction when the scanner is used underwater. View angle ψ_w of the camera underwater is expressed using view angle ψ_a in the air as following equation based on Snell's law.

$$\psi_w = \sin^{-1}\left(\frac{v_w}{v_a}\sin\psi_a\right) \tag{4}$$

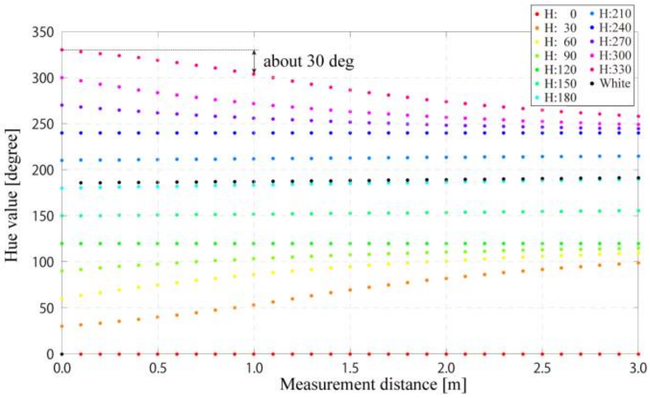

Fig.2 Simulation result of light attenuation

where v_a and v_w denote the light velocity in air and water, respectively. The view angle changed by the light refraction means that focal length f_w in the pinhole model under water is different from f in the air. f_w is represented by using ψ_w as follows.

$$f_w = \frac{l}{2\tan\psi_w} \tag{5}$$

where l denotes image sensor size in the direction relative to ψ_w. When the scanner operates underwater, equation (5) is used for measurement of target shape.

B. *Laser pattern*

In a structured light method using color lasers, the more laser colors are used for measurement, the higher the measurement resolution. However, underwater optical attenuation rate is higher than in the air, and especially red light has more attenuation than other color lights in seawater. If many colors are used under water for the structured light method, those colors cannot be correctly identified by image processing, resulting in many false measurements. For that the scanner based on structured light method has highest resolution as possible, laser colors are needed to use for its laser pattern considering the underwater optical attenuation rate of each colors. Light intensity I after passing a distance d through a medium is expressed as follows based on the Lambert-Beer's law.

$$I = I_0 e^{-\beta d} \tag{6}$$

where I_0 denotes the intensity of illuminated light. In equation (6), β denotes the absorbance in the medium and includes attenuation and diffusion rate. Figure 2 shows laser colors change associated with movement in seawater based on the absorbance of general seawater. Vertical axis in Fig.2 denotes hue value from 0 to 360 degrees, the figure includes the results of laser simulation of 13 hue values. As the figure illustrates, the lasers with a hue value close to red have a large change color more than other lasers, and hue value changes up to about 30 degrees when laser beam passes a distance 1.0 m through seawater.

Because this research will measure the shape of the fishery resource located from 1.0 m to 1.5 m away using the scanner, the laser pattern consists 6 colors that hue is more than 60 degrees apart for safety detection of laser reflection in the photo images. Because simple laser pattern with 6 colors cannot measure the target shape with high resolution, this research uses De Bruijn sequence [9-10] for coding. When the hues of neighboring colors are 120 degrees apart and the laser pattern is coded with 3 sequences and 6 colors based on the De Bruijn sequence, 54 codes are obtained as shown in Table 1. This research uses the laser pattern that the codes for 2 cycles are used and adjacent codes share two colors as shown in Fig.3, for the laser scanner. To improve the lase detection accuracy, a gap of several pixel in the laser projector is provided between each laser.

Table 1 Code table for laser pattern

ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Angle	-5.4	-5.2	-5.1	-4.9	-4.7	-4.6	-4.4	-4.2	-4.1	-3.9	-3.7	-3.5	-3.4	-3.2	-3.0	-2.9	-2.7	-2.5
Code	1	3	1	4	2	5	2	6	3	5	3	5	2	5	1	4	6	3
	3	1	4	2	5	2	6	3	5	3	5	2	5	1	4	6	3	1
	1	4	2	5	2	6	3	5	3	5	2	5	1	4	6	3	1	5
ID	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Angle	-2.4	-2.2	-2.0	-1.9	-1.7	-1.5	-1.4	-1.2	-1.0	-0.8	-0.7	-0.5	-0.3	-0.2	0.0	0.2	0.3	0.5
Code	1	5	2	4	2	6	4	6	4	2	4	1	5	3	6	4	1	4
	5	2	4	2	6	4	6	4	2	4	1	5	3	6	4	1	4	1
	2	4	2	6	4	6	4	2	4	1	5	3	6	4	1	4	1	3
ID	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Angle	0.7	0.8	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.2	2.4	2.5	2.7	2.9	3.0	3.2	3.4	3.5
Code	1	3	5	1	5	1	3	6	3	6	2	6	2	4	6	2	5	3
	3	5	1	5	1	3	6	3	6	2	6	2	4	6	2	5	3	1
	5	1	5	1	3	6	3	6	2	6	2	4	6	2	5	3	1	3

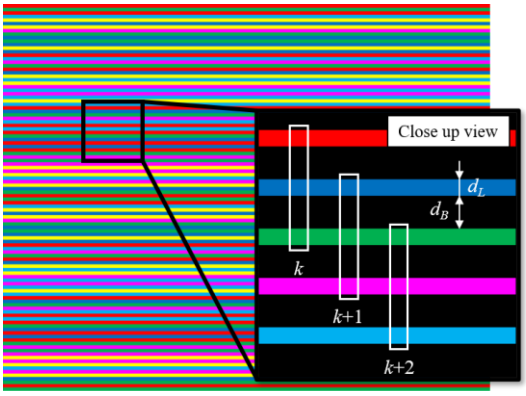

Fig. 3. Laser patten based on De Bruijn sequence

III. Data Processing for 3D Reconstruction

A. *Image processing*

To measure the target shape at once time needs to capture the reflection of the laser pattern shown irradiated from the laser projector, and the position of 6 color laser is detected from the captured image. However, if the surface color of the target closes to the color of each laser, image processing has a risk of false detection of the laser position from the reflection image. For improve laser detection accuracy, high pass fileted image is used for laser detection. The filtered image is made by taking a difference between the reflection image and its image smoothed by the gaussian filter. Figure 4 shows, the reflection image when the projector irradiates the laser pattern to the stone tiles of light red, and its high pass filtered image. Figure 5 shows 6 color lasers detected by that the filtered image is binarized by thresholds in HSV coordinate. As the figure illustrates, background component is removed from the

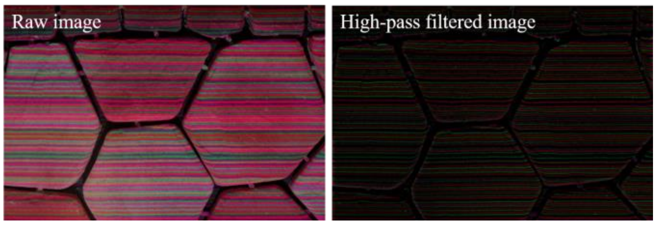

Fig.4 Raw image and its high pass filtered image

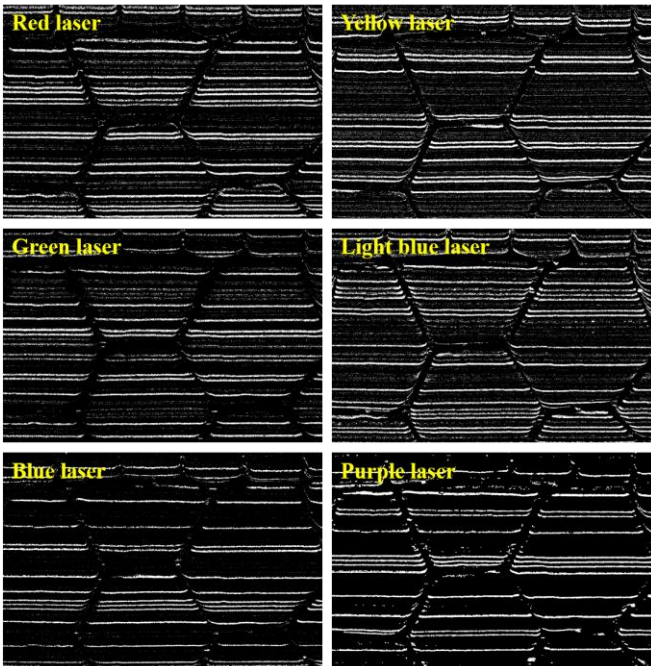

Fig. 5. Laser detection results

reflection image by high pass filtering, the lasers in the reflection image are detected with few errors.

B. Decoding

The irradiation angle is necessary for that the position in the camera coordinate is calculated from detected laser position in the image. The angle can be obtained by decoding the laser pattern based on the code table from laser detection results. Even if there are the few errors in the laser detection results, the wrong irradiation angle may be decoded by the errors and the scanner has a risk its accuracy is significantly reduced by it. Figure 6 shows decoding results including incorrect. When the scanner measures the object that the shape changes continuously, the irradiation angle obtained by decoding changes slowly with respect to the position in the image coordinate. And the obtained angle never decreases with respect to the *v* position unless the scanner measures a small floating object. Thus, there is a possibility of miscoding where the irradiation angle is changing rapidly or where the angle is decreasing. In this research, those angles with large deviation from moving average are removed as miscoding from coding results as shown in Fig.7, and the position in the camera coordinate is calculated using them.

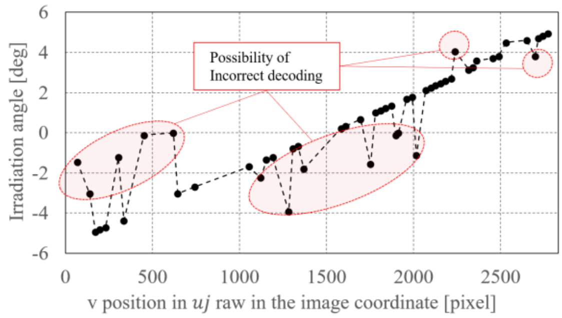

Fig.6 Decoding results including incorrect

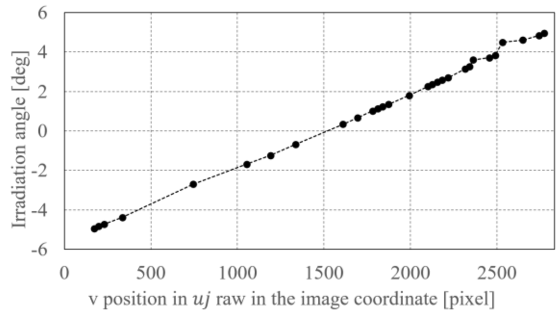

Fig.7. Decoding results with error handling

IV. EVALUATION EXPERIMENT

The experimental instrument shown in Fig.8 is used for evaluating the performance of the scanner with the laser pattern based on De Bruijn sequence and the data processing for 3D reconstruction. The camera and laser projector are placed in separate waterproof cylinders which have 40 m depth pressure resistance, the cylinders are connected by underwater ethernet cable with the cable for power supply. An embedded CPU board located in the cylinder same as the projector is used for control of the camera and the projector. The white block on the white board is used to evaluate the measurement accuracy of the scanner, the performances of the laser patter and data processing are evaluated using 5 color blocks on the gray board, and all blocks is located in about 1,000 mm away from the camera cylinder. Because the 4 colors in the blocks are the same as the laser beams and the black is the color that reflects the least light, measuring their shape is exceedingly difficult for the scanner based on the structured light. All experiments were conducted in a shaded container with a fresh water assuming measurement in the deep sea.

Table 2 shows measurement results of all blocks, and point cloud data obtained by that the scanner measures 5 color blocks is shown in Fig.9. The dimensions of the target blocks are estimated based on each point cloud data obtained by measurement. In the measurement of the white block, the measurement accuracy in the direction (length) orthogonal to the laser line is 1.0 % for the range, and the scanner can measure the target shape in other direction less than 0.1 % error. In the color blocks other black, although the measurement accuracy of the length is less than other directions, the scanner can measure the target shape less than 1.4 % error for the range. Reasons for poor the measurement accuracy of the length is that the edges of the blocks in the same direction as the laser line were detected as the laser reflections. Decoding around the

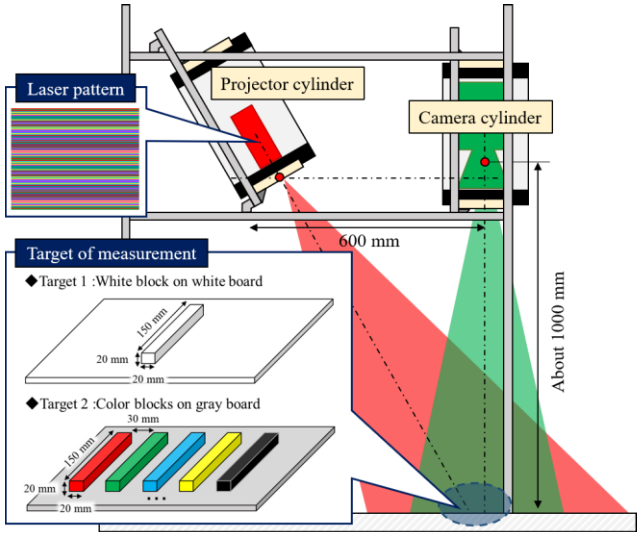

Fig. 8 Experimental instrument

edges does not work by the misdetection of the laser, and the measurement accuracy of the length has dropped because enough measurement points related the length are not obtained. Measurement points in the red, green blue and yellow blocks are less than the white block, and the scanner could hardly measure especially the shape of the black block. Because the brightness of the laser projector was not enough for the measurement range, the camera could not capture the enough intensity of the laser reflection in the color blocks for the laser detection.

V. Conclusion

To preserve and manage fishery resources, the authors developed the scanner based on the structured light method that efficiently measures the target shape at once time. The scanner irradiates the laser pattern that consists of the 6 color lasers and is coded in the De Bruijn sequence to measure the target even in water where light is easily attenuated. Data processing method including image processing and decoding for the reflection image captured by the scanner were proposed in this paper. The evaluation experiment results showed that the scanner can measure the color blocks other than black located in 1,000 mm away, less than 1.4 % error for the measurement range.

Acknowledgment

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Table 2 Measurement results

	White block	Red block	Green block	Blue block	Yellow block	Black block
Measuring point	14166	1799	2391	3171	1480	9
Target length [mm]	140.5	136.9	139.8	140.2	140.4	51.2
Target width [mm]	19.9	23.5	21.2	24.0	20.4	21.52
Target depth [mm]	20.9	21.2	20.7	20.5	21.0	19.7
Distance to the bard	989.0	991.3				

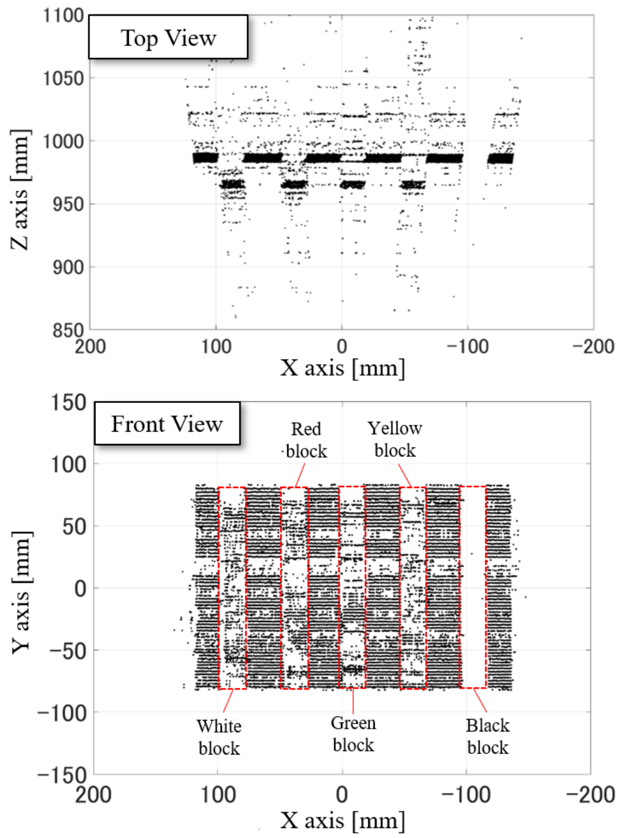

Fig. 9 Point cloud data of 5 color blocks on the gray bard

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