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Online Measurement of Compact Range Image Sensor Using Image Blur of Multi-Slit Laser *

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***Abstract*—This paper proposes a compact range image sensor with a multi-slit laser projector and a small camera. Distance is measured using image blur of the multi-slit laser lights. By determining the relationship between blur and distance per pixel in advance, 5.6 fps online measurement of range images is achieved. The effectiveness of the proposed sensor is verified by experiments of range image measurement.**

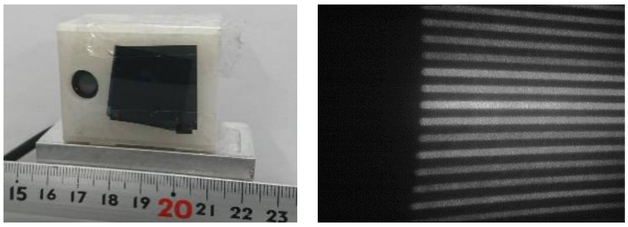
I. Introduction

In recent years, 3D measurement using images is widely used in both industrial and consumer applications. In particular, advances in technology and concepts such as IoT and AI have further increased the demand for this technology.

To realize small range image sensors, a number of methods based on active stereo, in which a light pattern is projected, captured by a camera and distance is estimated by measuring the disparity, have been studied [1], [2]. Iwasaki et al. constructed a compact range image sensor using a multi-slit laser projector [1]. Its measuring range is from 100 mm to 300 mm and it is reported that the slit image is blurred and the measurement accuracy deteriorates significantly at closer distances. Feng et al. proposed a method of distance estimation by measuring the size of the blur in short distance measurement by using the blur [3]. In this study, we adopt the Feng's method and aim to improve the measurement accuracy and achieve online measurement.

II. Structure of the Sensor

In this study, we construct a new sensor with a multi-slit projector and a small camera. The sensor is shown in Fig. 1(a), and the image of a white plate taken by the camera of the sensor at a distance of 50 mm is shown in Fig. 1(b). The laser projector is Coherent MINI-715L whose laser diode (LD) is replaced to Mitsubishi ML101J25. The laser wavelength is 780 nm and the maximum power is 100 mW. A simple constant-current power supply circuit is used to reduce the LD output to about 15 mW. The camera is UVCZBS-002 (CMOS type) with 1280×720 pixels, and an optical low-pass filter (Fujifilm SC-64) and a ND filter (Fujifilm ND-1) are attached in front of it. The dimensions are 48 mm × 31 mm × 37 mm, and the weight is 50 g.



(a)sensor (b)camera image

Fig. 1 Constructed range image sensor and its camera of a white plane at 50 mm.

III. Distance Measurement Method Using Blur

Blur in this study is defined by the distribution of intensity values of slit images taken with a camera and the amount of blur is expressed by standard deviation σ. Fig. 2 shows the pixel values between (640,0) and (640,719) in the image shown in Fig. 1(b). By extracting the peak of each slit and approximating the intensity value y to Gaussian distribution, we obtain.

$$y = k \cdot \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right) \tag{1}$$

where x is the coordinates of the image, k is a constant, and μ is the mean of x, i.e., the center of the slit. By taking the natural logarithm of both sides of (1),

$$\ln y = -\frac{1}{2\sigma^2}x^2 + \frac{\mu}{\sigma^2}x - \frac{\mu^2}{2\sigma^2} + \ln k. \tag{2}$$

From (2), σ can be calculated by fitting a quadratic curve to the logarithm of the intensity values using the linear least squares method. Fig. 3 shows the relationship between the distance and σ of the fifth slit in the 640^{th} column from the top of the image. As shown in this figure, σ is large at close distances and tends to converge to a constant value as the distance increases. The relationship between σ and the distance must be determined in advance. Fig. 4(a) shows the flow to obtain the relationship.

In this study, this relationship is used to estimate the distance value from the amount of blur σ. As shown in Fig. 3, there is a large amount of noise, so we apply a low-pass filter (LPF) to the image and the estimation results to reduce the error. A 5×5 averaging filter is used as the LPF.

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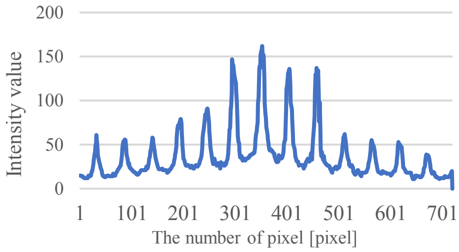


Fig. 2 Intensity value of the slit.

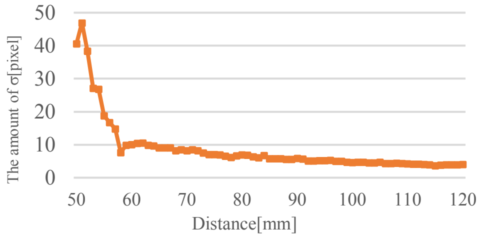
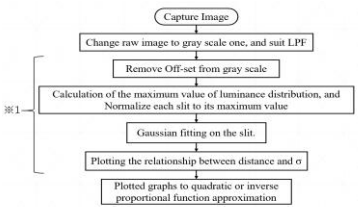
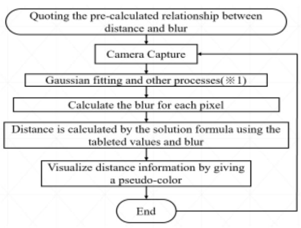


Fig. 3 Relationship between distance and the amount of blur.



(a)Derivation of the relationship between distance and blur.



(b) Online Measurement

Fig. 4 Flowchart of distance measurement.

The flowchart in Fig. 4(a) is the process of deriving the approximate function from the graph in Fig. 3, and the online measurement is performed in the order shown in Fig. 4(b). In this paper, we approximate the relationship between distance and blur to a quadratic function as follows.

$$\sigma = aX^2 + bX + c \qquad (3)$$

where X is the distance. We calculate a, b, and c in advance and then calculate the distance online using the blur obtained from (3).

IV. Distance Measurement Experiment

The constructed sensor was set in front of the measurement object, and range images were acquired as shown in Fig. 5. The results at distance of 100 mm are shown in Fig. 6(a), and the results for a slope (50 mm on the left and 100 mm on the right) are shown in Fig. 6(b). Table 1 shows the experimental results of the online distance measurement after removing the outlier. This shows that the distance to the object can be estimated with the proposed method. The processing speed is about 5.6 fps. However, the measurement error increases as the distance increases. In Fig. 3, the change of the amount of blur is small at the distance longer than 90 mm. In the proposed method, the blur amount is calculated from the width of the laser slit. It is considered that the slit width does not become uniform due to speckle noises, etc., which causes the measurement errors. And the measurement accuracy changes depending on the shape and the material of the measured surface like rough surface.


(a) Perspective from above

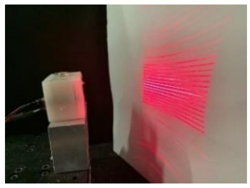
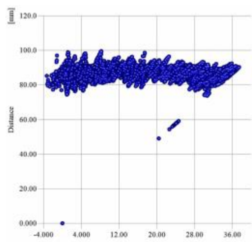

(b) Perspective from side

Fig.5 Range image measurement experiment: slope

TABLE I. RESULTS OF ONLINE DISTANCE MEASUREMENT EXPERIMENTS (UNIT: [MM])

Distance (true value)	Average (about 6000 points)	Min. /Max.	Standard deviation
50.0	56 .3	34 .8/112 .9	4 .4
75.0	75 .2	60 .6/104 .9	2 .5
100.0	93 .9	64 .6/117 .4	5 .4
125.0	95 .6	55 .7/116 .2	6 .1


(a) Distance (100 mm)

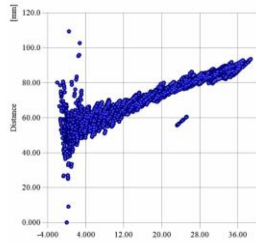

(b)Slope

Fig. 6 Results of range image measurement

V. Conclusion

In this paper, it is shown that on-line range image measurement by using a multi-slit laser and a camera is possible by using image blur. The processing speed about 5.6 fps was achieved. The future challenge is to improve the accuracy of distance measurement at long distances.

References

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