Development of Compact Range Image Sensor with Multi-Slit Laser Projector that Uses Disparity and Blur

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Abstract

In this paper, development of a compact and light weight range image sensor is presented. The sensor is designed for installing on a robot hand to help it sense the target or avoid the obstacle. The sensor we present can obtain 3D distance information at a range of 50mm – 300mm, which is simply made by a USB video device class camera and a multi-slit laser projector. The improvement over the previous sensor is a newly added method of the range measurement. The new sensor can measure the distance by using both disparity and blur. A method of Gaussian curve fitting to quantify the image blur is presented to obtain the range image at a distance closer than 100mm.

Key words: range image sensor, multi-slit laser, disparity measurement, blur measurement

1. Introduction

The robot plays more and more important role in the manufacture or even in our daily life. In order to sense the surrounding environment, the robot vision research has also rapidly developed. Robot hand, as a widely used manipulator for manufacturing, is designed to grasp the objects. To implement grasping, a sensor which can obtain the surrounding location data accurately is necessary. Normally, when the distance sensor is installed separately from the robot hand, an occlusion caused by the robot hand itself occurs just before the grasping. A solution to solve the problem is installing the sensor directly on the robot hand. As a result, a continuous measurement without the occurring of the occlusion become possible. Therefore a light weight and compact sensor which can be easily install on to a robot hand as well as able to close range measurement is demanded.

As an example from the existing sensor for close measurement, 3D scanner TDS-A[1)] from Pulstec industrial co. ltd is a compact sensor in the market, and its measurement range is limited about 90-120mm. We have presented a compact range image sensor using a multi-slit laser projector suitable for a robot hand[2)], however the sensor is lack of the measurement ability closer than 90mm. Therefore in this paper, we present an improved sensor based on the former research. The new sensor has feature which can use a normal USB Video-device Class (UVC) camera, and widen the close measurement range by adding blur measurement algorithm. Basing on the same sensor we build, both triangulation and blur measurement can be applied to generate the range image of the target object.

2. Configuration of the sensor

2.1 Sensor Overview

As shown in Fig. 1, the sensor is built by a multi-slit laser projector and a camera. The laser projector and the camera are set horizontally in the figure. Laser projector MINI-715L (Coherent) is used in this research. It can project 15 slit laser at a 45° angle. On the other hand, considering the flexibility of the sensor, the UVC camera which can capture the images into the computer without the driver is adopted. The UVCZBS-002 board type camera to build the sensor has a resolution 1280×720 pixel at 30 fps. Beside, FUJIFILM SC-64 low pass filter is set in front of the camera lens. It cuts off the light which has a wavelength shorter than 640nm, to block the ambient light.

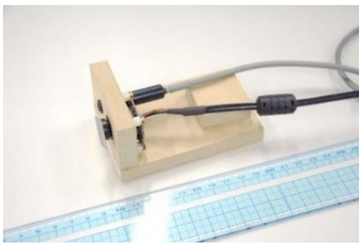

Fig. 1 Sensor structure

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The overall size of the sensor is 28mm×40mm×53mm, with a weight of 50g. The capability for installing on to a robot hand is considered.

2.2 Measurement principle

During the measurement, the camera catches the reflection of the multi-slit laser projector. In this study, two methods are used, which have different measurable ranges. The first method is calculating the distance by measuring the disparity, and the second method is calculating the distance by measuring the blur. The laser slits have been rotated at an angle to increase the count of pixel in the measurement.

By using the triangulation shown in the equation (1), after the calculation of the position of the laser slit at the distance of infinity.

$$Z = \frac{b \cdot f}{p \cdot (k - k_\infty)} \tag{1}$$

Where b represents baseline length, f represents focal length, p represents width of the pixel, and k-k_∞ represents disparity of the image coordinates of the slit image in infinity.

Meanwhile, the measurement of blur uses a Gaussian curve fitting using the equations (2) on the slit intensity distribution, shown in Fig. 2.

$$f(x) = s \cdot exp\left\{-\frac{(x-\mu)^2}{2\sigma^2}\right\} \tag{2}$$

Where μ represents middle point, s represents constant, and σ^2 represents dispersion.

By using least-square method, the dispersion σ^2 in the equation (2) can be calculated. The dispersion is small, when the object is at camera lens focus point. And the dispersion σ^2 increases, when the object is getting far away from the focus point. Figure 3 shows the relation of distance and dispersion σ^2.

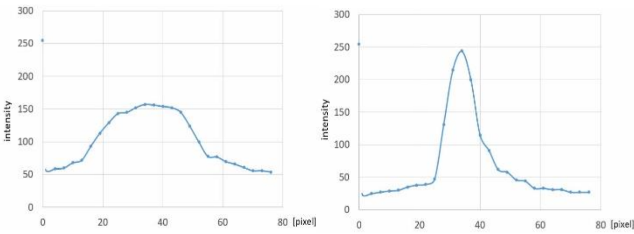

Fig. 2 Slit intensity at distance 60mm (left), and 120mm (right)

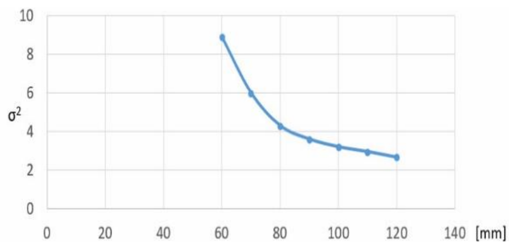

Fig. 3 Relation of distance and σ^2

2.3 Measurement procedure

At first, a scanning over the camera image is used to find the initial position of the 15 laser slits. Then detecting lines with width of 75 pixels are set on to the initial position. Next, the measurement using the disparity is processed by calculating the middle point of the slit intensity. It is hard to obtain accurate distance using disparity in case the object is closer than 100mm. The measurement of blur is then processed if the blur of the image makes it difficult to calculate the middle point of the slit intensity. The measurement of blur uses the Gaussian curve fitting to get the slit dispersion on the object. By collating the dispersion to the registration table of the distance and dispersion, the distance can be obtained.

2.4 Specification of the sensor

The sensor has a view angle at 50° horizontally and 30° vertically. The measurement range using the disparity is 100-300mm. Meanwhile, the measurement range using the blur is 50-120mm. The measurement area of the sensor is $50 \times 30\text{mm}^2$ at the distance of 50mm to $250 \times 150\text{mm}^2$ at the distance of 300mm. The measurement using the disparity has about 2000 points of measurement. The processing speed is 25 fps. The measurement using the blur has about 1200 points of measurement, now runs in offline only. The two measurement method can be used on the same sensor we build and switch to each other by demand.

3. Measurement experiment

3.1 Measurement accuracy

We made experiments to test the measurement accuracy of the sensor, using both disparity and blur.

First, in the experiments of measurement using disparity, the sensor was aimed to the flat wall as Fig. 4, took the range image every 50mm, from the distance 100mm to 300mm. The result of the experiment is shown by measurement error and standard deviation in Table 1.

Then, in the experiments of measurement using blur, the sensor was aimed to the flat wall with 2 different reflection rate. The sensor took the range image every 20mm, from the distance 50mm to 120mm. The result of the experiment is shown by measurement error and standard deviation in Table 2 – 5.

Fig. 4 Accuracy experiment using disparity and blur

Table 1 Results of disparity measurement experiment

Real distance [mm]	100	150	200	250	300
Measurement error [mm]	-4.22	-0.72	3.58	7.12	13.72
Standard deviation [mm]	3.54	1.06	2.13	3.34	6.51

Fig. 5 Experimental scenes of object measurement using disparity and blur

Table 2 Results of blur measurement against white wall

Real distance [mm]	50	70	90	110	120
Measurement error [mm]	0.50	0.79	-0.51	-3.44	-3.8
Standard deviation [mm]	1.82	1.94	3.15	5.65	6.07

Table 3 Results of blur measurement against middle gray wall

Real distance [mm]	50	70	90	110	120
Measurement error [mm]	1.32	2.64	2.81	6.44	8.08
Standard deviation [mm]	3.19	2.02	4.37	6.73	12.90

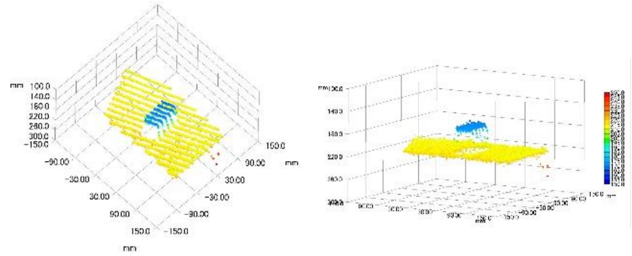

Fig. 6 Range image of box using disparity

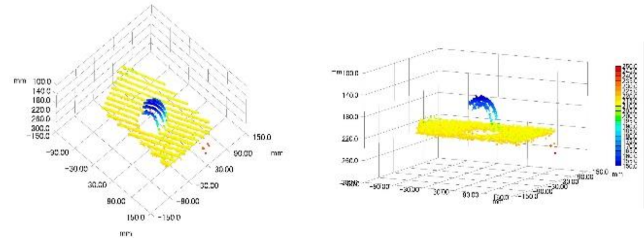

Fig. 7 Range image of ball using disparity

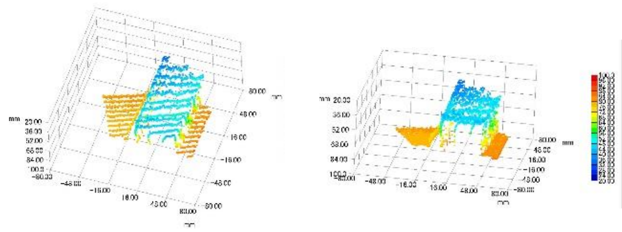

Fig. 8 Range image of box using blur

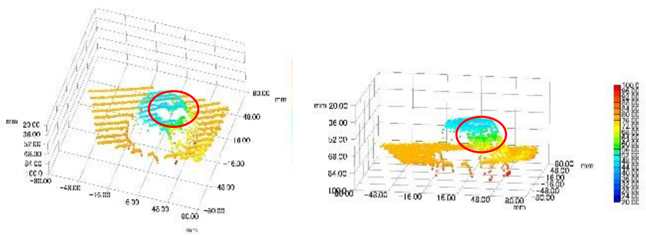

Fig. 9 Range image of ball using blur

3.2 Objects measurement

As Fig. 5 shows, the sensor was set opposite to the flat wall and 2 objects was stuck on to the wall. The two objects are: wood box ($50 \times 25 \times 25$mm) and orange Ping-Pong ball (diameter 40mm).

As Figs. 6-9 show, both the measurement using disparity and blur can measure and clearly recognize the objects. However in the experiment of Ping-Pong ball with the measurement using blur, the close part of the ball, shown in red circle, had a deficit. The reason of the deficit is considered as the laser speckle pattern in this kind of close range.

4. Conclusion

In this paper, we present the development of a compact range image sensor. The sensor now using a UVC camera which can capture the images into the computer without the driver is adopted. By adding the measurement using blur, the sensor can obtain the range image by two method. This widened the measurement range of the sensor to 50-300mm.

References

1) Retrieved Feb. 14, from Pulstec homepage, www.pulstec.co.jp
2) Yi Feng, Shinta Nozaki, Gakuto Masuyama, Kazunori Umeda, "Development of Miniature Range Image Sensor Using Multi-Slit Laser Projector and Endoscopy Camera", ICAM2015, 2015.12.