Construction of a versatile compact range image sensor

Masateru Tateishi
Dept. Precision Mechanics
Chuo University
Tokyo, 112-8551
E-mail:tateishi@sensor.mech.chuo-u.ac.jp

Kazunori Umeda
Dept. Precision Mechanics
Chuo University
Tokyo, 112-8551
E-mail:umeda@mech.chuo-u.ac.jp

Abstract

This paper discusses a range image sensor using a multi-spot laser projector. Range image sensors are generally large and expensive, and so not easy to use. If a range image sensor becomes easy to introduce, its field of application will extend. So this paper propose a compact and inexpensive range image sensor which consists of a commercially available laser projector and a CCD camera. Its effictiveness is evaluated by experiments.

1 Introduction

A range image sensor is used for many purposes, for example 3D modeling, robot vision, medical application and so on. But it is not easy to use the range image sensor because of its size and/or price. Compactness and inexpensive cost permit its use to various tasks.

In this paper, We propose a compact and inexpensive range image sensor using a multi-spot laser projector [1]. A similar sensor was also proposed by Nakazawa et al. [2]. Firstly the principle of the sensor, a device to improve it and its characteristics are discussed. Then a prototype of the sensor is constructed using a commercially available projector. Some experimental results are shown to evaluate the effectiveness of the sensor.

2 Previous Work

Range images are important sensor information for various applications in 3D space. Many methods to acquire range images have been studied in the field of computer vision, robot vision, optics etc. [3], [4], [5], and several sensors are commercially available now. But many of them are not sufficient in several aspects as size, price and measurement time.

Some methods can realize real-time range imaging. Beraldin et al. realized a video rate range imaging by scanning a laser spot using their synchronized laser scanning technique [6]. Sato et al. [7] and Kanade et al. [8] developed a special imaging detector and realized real time imaging by scanning a laser slit with the detector. These active sensors need scanning. Sorimachi [9] and Nakazawa [2] constructed sensors without scanning by projecting multi-spots. In [9], a special spot pattern that is created by a mask and a halogen lamp is projected, and by developing a special hardware, video rate range imaging is realized. In [2] and [10] spot pattern was generated by using a fiber grating and a laser.

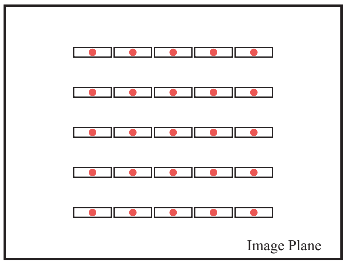
3 Range image sensor using a multi-spot laser projector

3.1 Principle of the Sensor

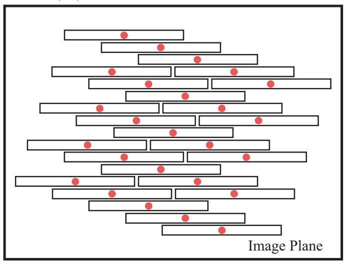
This sensor assembles a laser projector and a CCD camera. The projector can projects multiple spotlights and the CCD camera acquires scene images with the projected spots. The spots in the images are extracted and their coordinate values are measured. The distances to the projected spots are calculated by triangulation using the coordinate values. This measuring procedure is very simple. One problem to be solved is the correspondence problem. This is solved by limiting measurement range of the sensor. This sensor is assembled so that the spots move horizontally. Therefore corresponding spots can be found easily. This process is described in detail later. The distance in the direction of the CCD camera's optical axis is obtained by the following equation.

$$z = \frac{b \cdot f}{p \cdot k} \equiv \frac{\alpha}{k}, \qquad \alpha = \frac{b \cdot f}{p} \tag{1}$$

- b : baseline length (distance between the projection center and the lens center)



(a)Without Rotation



(b)With Rotation

Figure 1: Restriction for epipolar line of each spot

- f : focal length of the lens of the CCD camera
- p : width of each element of the CCD
- k : disparity for infinite distance

Note that the unit of k is pixel. So as to measure the distance by Eq.(1), it is unnecessary to give b, f, p, independently. Calibration of α is sufficient.

3.2 Rotation of the CCD camera

As mentioned above, the measurement range is limited so as to manage the correspondence problem. In the image plane, each spot moves on the epipolar line [11] according to the distance. Overlaps often occur by the large movement of spots in the same row and the spot image cannot correspond to the spot uniquely. So as to realize the uniqueness of the correspondence, moving ranges of spots in the image have to be restricted. Fig.1(a) shows this. But this limit can be relaxed by simply rotating the CCD camera as shown in Fig.2. The same idea is implicitly introduced also in [2]. Fig.1(b) shows the image of spots with rotation. This figure shows that movable ranges of spots become large. Consequently, the measurable range of the sensor becomes large, or with the same measurable range, the precision of measurement can be improved because the number of the assigned pixels for measuring the same range increases. Regions of the image originally not in use are efficiently used with rotation.

3.3 Some characteristics of the sensor

The position of the spot in the image can be measured with subpixel precision by obtaining the center of the gravity of the spot image. The precision is limited by the laser speckle [12], etc. Let the precision be σ_k and the number of pixels assigned to each spot be n. The distance can roughly be measured with the level of n/σ_k.

Let the measuring range be between z_1 and z_2 ($z_1 < z_2$) and the disparity for each distance be k_1 and k_2 respectively. Notice that $n = k_1 - k_2$. z_2 can be set to infinite. The brightness of the spot image is in principle inverse proportional to the square of the distance, and z_2 can be limited by the brightness. However, it is safer to set z_2 formally to infinite so as to decrease the possibility of wrong measurement; if an object has strong mirror reflection, it may reflect the spot directly to the camera and the spot image may become unexpectedly bright even though the object is far away. By using Eq.(1),

$$n = k_1 - k_2 = \frac{b \cdot f}{p}\left(\frac{1}{z_1} - \frac{1}{z_2}\right) = \alpha\left(\frac{1}{z_1} - \frac{1}{z_2}\right) \quad (2)$$

With this equation, parameters of the sensor are related. p is given when a CCD camera and a image board are chosen. f is defined by the required field of view to observe the whole spots appropriately. Therefore, when the measuring range (i.e., z_1 and z_2) is given, the baseline length b is calculated by Eq.(2). On the contrary, when b is given, Eq.(2) defines the measuring range.

The precision of measuring distance is also obtained with Eq.(1). By applying the law of propagation of errors,

$$\sigma_z = \frac{p}{b \cdot f} z^2 \sigma_k = \frac{1}{\alpha} z^2 \sigma_k \quad (3)$$

where σ_z is the precision of the measured distance. As is well known for triangulation, the error of measuring distance is proportional to the square of the distance.

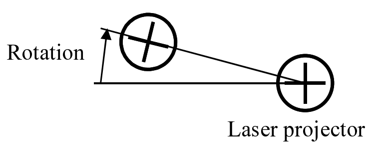


Figure 2: Rotation of CCD Camera

By substituting Eq.(2) for Eq.(3),

$$\sigma_z = \frac{z_2 - z_1}{z_1 z_2} z^2 \frac{\sigma_k}{n} \quad (4)$$

When z_2 is infinite, Eq.(4) becomes

$$\sigma_z = \frac{z^2}{z_1} \frac{\sigma_k}{n} \quad (5)$$

In addition, when $z = z_1$, Eq.(5) becomes

$$\sigma_z = z_1 \frac{\sigma_k}{n} \quad (6)$$

This indicates that the resolution for the nearest distance is obtained by dividing the distance by the number of the level (i.e., n/σ_k).

This sensor can also measure intensity values simultaneously. The difference of surface reflectance of an object can be distinguished by obtaining intensities of spots. The intensity values acquired are related to the laser's wavelength. The image created by the intensity values is called a range intensity image [13] or a reflectance image [14].

4 Prototype of the sensor

4.1 Composition

Fig.3 shows the constructed prototype of the range image sensor. The laser projector is Moritex SNF-519X which is originally made by StockerYale [15]. The wavelength of the laser is $670nm$ and its power is $10mW$. It projects 19×19, totally 361 spots. The angle between adjacent spots is $0.77°$. The CCD camera is Toshiba IK-M41MR with a $f = 15mm$ lens. A Hoya R64 filter is attached to the lens of the CCD camera and disturbance light with the wavelength less than $640nm$ is removed. The baseline length is $36.3mm$, and the projector and the camera are slightly tilted with the angle of $2°$ so that the spots come in the center of the image. The CCD camera is rotated by $18.5°$ as discussed above, and consequently, the number of pixels assigned to each spot increases from 21 to 64 pixels.

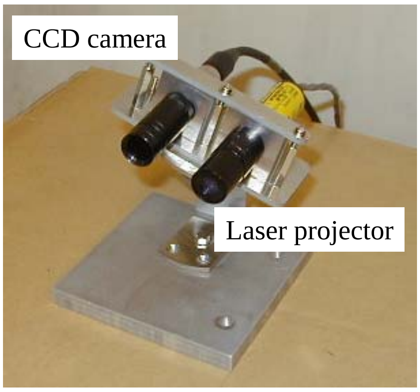


Figure 3: Constructed Prototype of the Range Image Sensor (Left: CCD camera, right: laser projector)

4.2 Precision of the sensor

Measuring range is set to larger than $1000mm$. The practical limit of the largest measurable distance is $2000mm$ because of light power. Corresponding measurement space is shown in Fig.4. Spatial resolution, that is, the distance between adjacent spots is $13.4mm$ at $1000mm$ or $26.8mm$ at $2000mm$. Fig.5 shows the experimentally obtained precision (standard deviation) of measured distances. This figure shows that the precision is in inverse proportion to the square of the distance according to the theory of triangulation. Fig.6 shows the relation between the actual and measured distances evaluated precisely in a certain distance range. The error bar represents the standard deviation. When the constructed sensor measures the

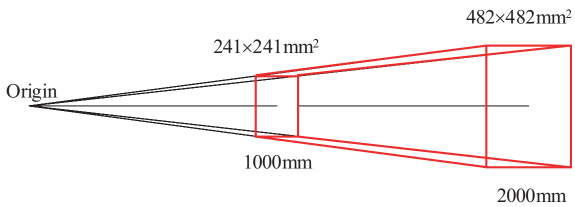


Figure 4: Measurement Space of the Prototype

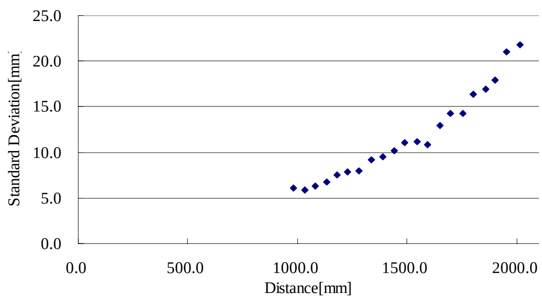


Figure 5: Standard Deviation of the Measured Distance

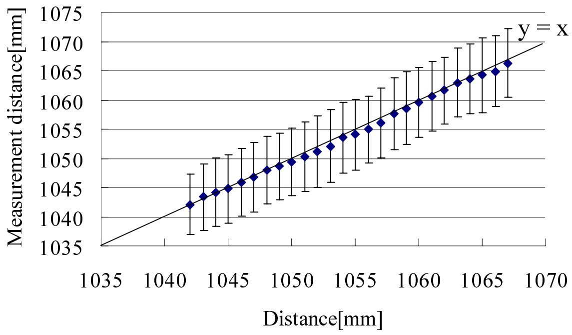


Figure 6: The Relation between the Actual and Measured Distances

distance from 1000mm to 2000mm, the spot moves about 30 pixels in the image, i.e. 1 pixel in image corresponds to about 30mm. Consequently the precision of the position of the spot image is roughly 0.3 pixels from Fig.5 and Eq.(3).

5 Experiment

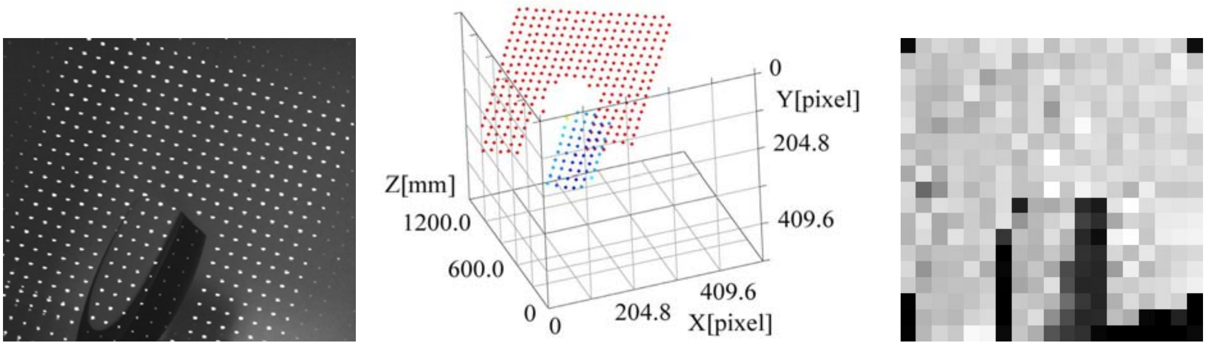
We performed some experiments with the constructed prototype sensor. Figs.7 and 8 are measurement examples. Although the obtained range images are sparse, 3D shapes can be observed to some extent. Figs.7(c) and 8(c) show the range intensity images. These images are only 19 × 19 pixels. However 2D shape recognition is also possible.

Figs.9 and 10 show measuring results for short and long ranges. Though the measurement is possible for long range, the resolution is low. Therefore, the measurement by single image is difficult for long range.

Fig.11 shows the effect of the brightness of the environment. Thanks to R64 filter, the sensor is applicable in the indoor environment without sunlight.

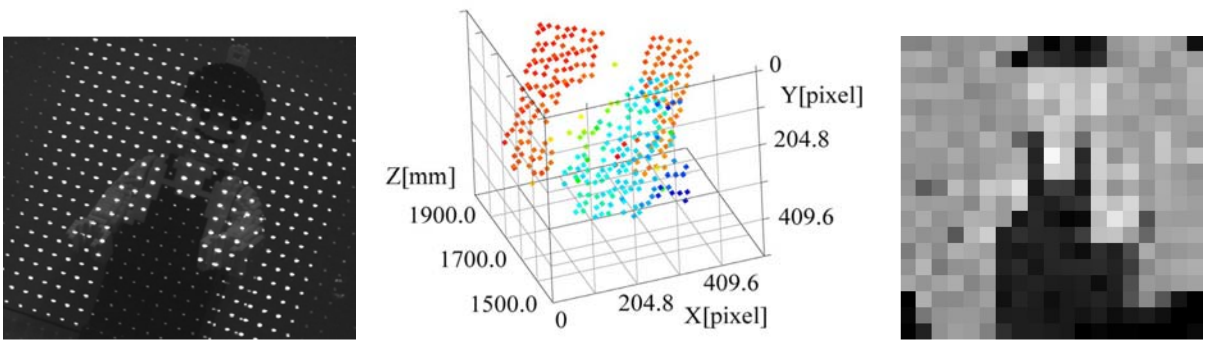
6 Discussion

The range image sensor using a multi-spot projector introduced in this paper is thought to have following advantages.



(a)Original image (b)Range image (c)Range intensity image

Figure 7: Example of an obtained range and intensity image: Speaker

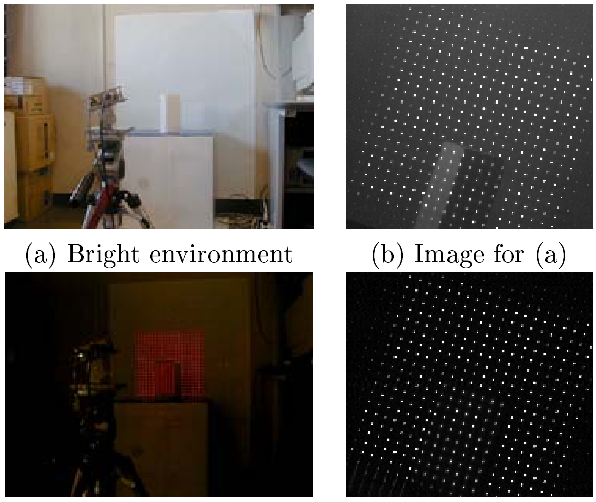


(a)Original image (b)Range image (c)Range intensity image

Figure 8: Example of an obtained range and intensity image: Doll

- No mechanical motion (no scanning)
- Compact
- Simultaneous acquisition of an intensity image

The fact that the sensor has no mechanical motion makes the sensor fault-tolerant and practically important. The compactness is also important to load on robots, etc. Additionally, the sensor can be pretty inexpensive because of its simplicity. The sensor also has disadvantages. One is its correspondence problem. However, it can be solved by the proposed method. The largest disadvantage is its sparseness and lack of precision compared to high precision range sensors [16]. The sensor may not be suitable for precise applications as modeling heritage. Notice that a dense range image can be obtained by accumulating multiple images, though each range image is sparse [17].



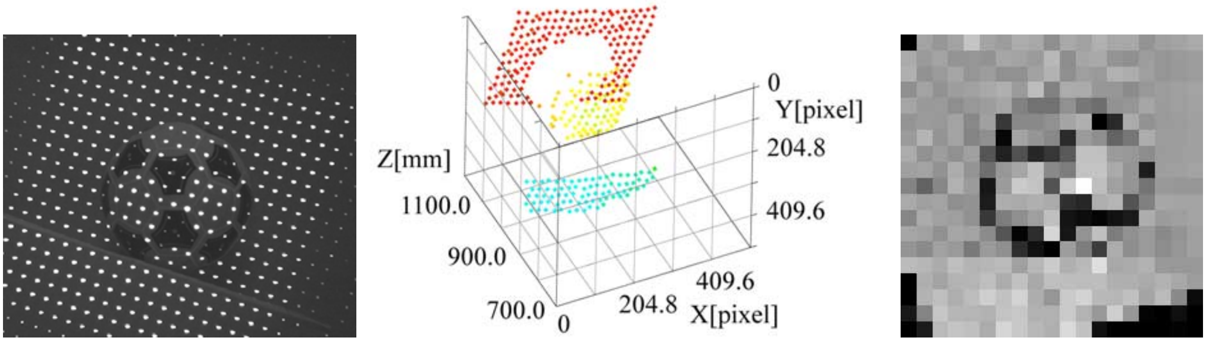
(a) Bright environment (b) Image for (a)

(c) Dark environment (d) Image for (c)

Figure 11: Images of Projected Spots in Bright and Dark Environments

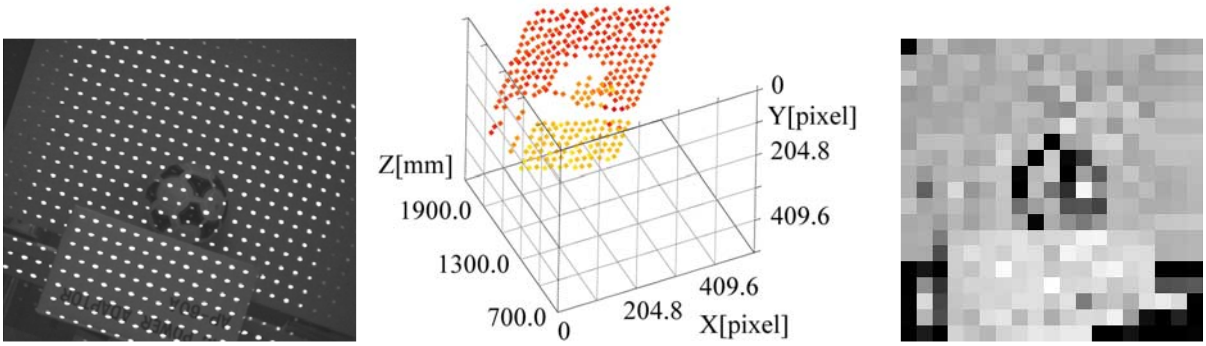
7 Conclusion

In this paper, a versatile compact range image sensor that uses a multi-spot laser projector has been introduced. Characteristics of the sensor were discussed as its principle, its measurement range and precision.



(a)Original image (b)Range image (c)Range intensity image

Figure 9: Example of an obtained range and intensity image: $\phi 150mm$ Ball (at 1000mm)



(a)Original image (b)Range image (c)Range intensity image

Figure 10: Example of an obtained range and intensity image: $\phi 150mm$ Ball (at 2000mm)

Rotation of the CCD camera to improve the sensor was discussed. A prototype of the sensor was constructed using a commercially available laser projector, and some range images with intensity images were obtained.

Future work will address 3D modeling using this sensor.

Acknowledgments

This research was partially supported by the Ministry of Education, Science, Sports and Culture, Grant-in-Aid for Young Scientists (B), 16700191, 2004.

References

[1] Kazunori Umeda, "A Compact Range Image Sensor Suitable for Robots" Proc. 2004 Int. Conf. on Robotics and Automation, pp.3167-3172, April 2004.

[2] K. Nakazawa and C. Suzuki, "Development of 3-D robot vision sensor with fiber grating: Fusion of 2-D intensity image and discrete range image," Proc. 1991 International Conference on Industrial Electronics, Control and Instrumentation (IECON '91), pp.2368-2372, 1991.

[3] R.A. Jarvis, "A perspective on range finding techniques for computer vision," Trans. PAMI-5, 2, pp.122-139, 1983.

[4] P. Besl, "Active, Optical Range Imaging Sensors, Machine Vision and Applications," Machine Vision and Applications, 1, 2, pp.127-52, 1988.

[5] F. Blais, "A Review of 20 Years of Ranges Sensor Development," Videometrics VII, Proceedings of SPIE-IS&T Electronic Imaging, SPIE Volume 5013 , pp.62-76, 2003.

[6] J.A. Beraldin, F. Blais, M. Rioux, J. Domey and L. Cournoyer, "A video rate laser range camera for electronic boards inspection," Proc. Vision '90 Conference, pp.4-1-4-11, 1990.

[7] K. Sato, A. Yokoyama and S. Inokuchi, "Silicon range finder - a realtime range finding VLSI," Proc. Custom Integrated Circuits Conf., 1994.

[8] T. Kanade, A. Gruss and L.R. Carley, "A VLSI sensor based rangefinding system," Robotics Research Fifth International Symposium, pp.49-56, 1990.

[9] K. Sorimachi, "Active range pattern sensor," J. Robotics & Mechatronics, 1, pp.269-273, 1989.

[10] A. Ohya, E. Shoji and S. Yuta, "3-D Range Sensor using Fiber Grating for Recognition of Autonomous Mobile Robot 's Passage Space," Proc. 1994 IEEE/RSJ International Conference on Intelligent Robots and Systems, pp.1759-1763, 1994.

[11] O.Faugeras, *Three-Dimensional Computer Vision,* MIT Press, 1993.

[12] R. Baribeau and M. Rioux, Influence of speckle on laser range finders, Appl. Opt., 30(20), pp.2873-2878, 1991.

[13] Kazunori Umeda, Guy Godin, Marc Rioux, "Registration of Range and Color Images Using Gradient Constraints and Range Intensity Images" Proc. ICPR2004, Vol.3, pp.12-15, 2004.8.

[14] R. Kurazume and others, "Simultaneous 2D images and 3D geometric model registration for texture mapping utilizing reflectance attribute" Proc. of Fifth ACCV, pp.99-106, 2002.

[15] http://www.stockeryale.com/

[16] J.-A. Beraldin et al., "Real world modelling through high resolution digital 3D imaging of objects and structures," ISPRS Journal of Photogrammetry & Remote Sensing V55, Nov. 4, pp.230-250, 2000.

[17] V. Popescu, E. Sacks and G. Bahmutov, "The ModelCamera: a Hand-Held Device for Interactive Modeling," Proc. Fourth Int. Conf. 3-D Digital Imaging and Modeling (3DIM2003), pp.285-292, 2003.