Rangefinding System using Hybrid Pattern Projections

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ABSTRACT

The practical three-dimensional measurement system with a high resolution based on a space code light pattern projection and a phase-shifted light pattern projection is presented. Three-dimensional measurement device's so-called, rangefinder, are expected to be applied in the apparel, medical and various fields. The performance of a rangefinder is evaluated by the measurements of time, depth, size, etc.

The system using a space code technique can stably acquire the depth of an object although the resolution of the depth is not good because an object's space is coded in the shape of a wedge. On the other hand, in a phase shift technique, the high resolution depth of an object is able to be theoretically acquired because the object's space is divided finely by phase shifted light projection. But it is difficult to stably acquire the depth of an object because of the phase connection problem.

In this paper, these problems (which are high resolution and phase connection problem) are able to be solved by both the space code technique and the phase shift technique. The effectiveness of this system is also described.

Keywords: rangefinder, three-dimensional measurement, space coding, phase shifting

1. INTRODUCTION

A rangefinder is one of the most practical three-dimensional measurement devices and consists of a camera and a projector or a laser (a floodlight). It is expected to be applied in various fields. For example, in apparel field, internet users who acquired the 3D-data of their own body shapes can select and buy the clothes. The data can be also used for made-to-order. In addition, in medical field, personal figures can be analyzed by using the data of a personal human body shape. And if personal tooth shape is obtained as 3D-data, it is very easy to cast and preserve. This technique can be used in other fields, such as the electric preservation of historic cultural assets, 3D-contents of games and so on. The performance of the rangefinder is important to implement these applications.

Three-dimensional measurements are calculated by a principle of triangulation using a triangle made by three spots, which are a camera, a floodlight and an object. There are a lot of three-dimensional measurement techniques based on the principle of triangulation, some of which are slit-light projection, space coding, phase-shift technique and etc. In the slit-light projection technique, an object is irradiated with slit-light and it is captured with a camera [1][2]. However, a great amount of data is necessary and takes a great deal of time to measure an object in detail because only one three-dimensional measurement for one slit is possible. The method which can solve this problem is space coding technique, and it is one of the most famous techniques [3][4]. In space code technique, an object's space can be coded because fringe patterns are projected to a target. Then, three-dimensional measurement can be stably calculated based on code numbers. However space resolution is not good because an object's space is coded in the shape of a wedge. In the phase shift technique, light patterns that the brightness values change to draw a sine curve are projected to an object and the phase value of each pixel is acquired [5]-[7]. Three-dimensional data with highly resolution is theoretically acquired because three-dimensional measurement of every pixel which has a unique phase value is calculated. However, an absolute depth can not be acquired because it is hard to robustly detect the point of phase changing. And there is the problem that three-dimensional measurement can not be stably calculated. There are some solutions for this problem. But optional devices are needed or number of times in the measuring occurs must increase. These lose to the advantage of the phase shift technique.

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In this paper, a three-dimensional measurement system which solves the phase connection problem and has a high resolution is presented. The space code and phase shift techniques are achieved by the same floodlight but without the optional devices and high speed measurements. This is possible because four pieces of data of the phase shift is added to eight pieces of data of space code. Section 2 describes the triangulation and projection techniques and laser control. Section 3 describes and discusses experimental result.

2. THE METHOD FOR SYSTEM

2.1 Triangulation

At first, a floodlight irradiates light onto an object and the projection lights parts are detected after the object is captured by a camera. A triangle such as Fig. 1. is made by the camera, the floodlight and the object. Then three-dimensional measurement is calculated by the principle of triangulation.

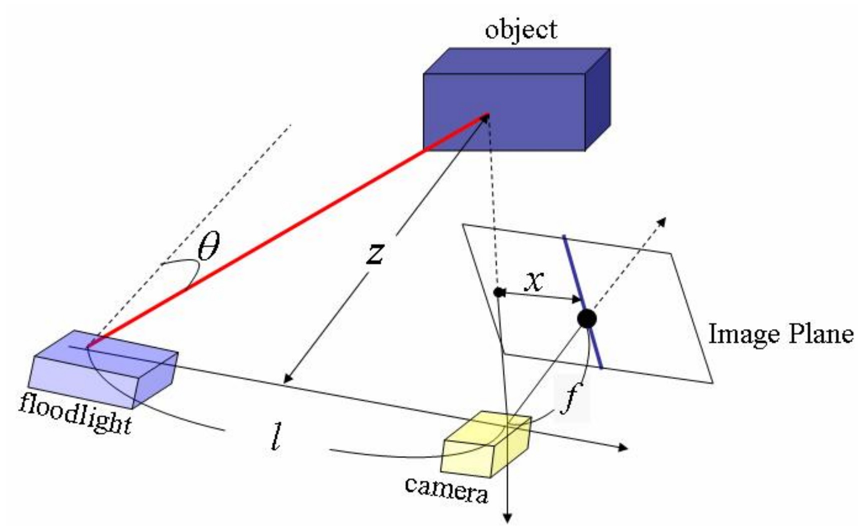


Fig. 1. Three-dimensional measurement based on the principle of triangulation

Depth z is represented as follows;

$$z = \frac{f \cdot l}{x + f \cdot \tan\theta} \tag{1}$$

, where f is focus distance of a camera, l is distance between a floodlight and a camera which is so called baseline, x is $u - u_c$ which (u, v) is image coordinate and (u_c, v_c) is center of image coordinate.

2.2 Space Code Technique

Light pattern such as Fig. 2. so-called, "Gray code pattern," is reflected to an object with a laser. Then, if red is 1, black is 0, the area which is irradiated by the laser is coded. When the *n* space coded patterns are projected, that is coded in 2^n domain. Each depth is able to be acquired based on triangulation by examining a code value because each code value is associated with the spatial direction each. Gray code patterns are used to obtain a code because Hamming Distance between a code and an adjoining code in gray code patterns is always 1, even though correct code is not detected.

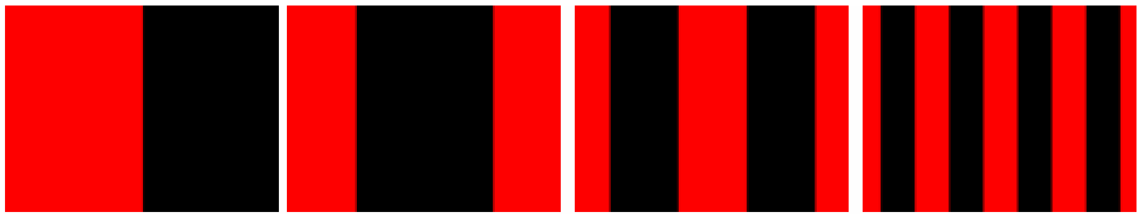
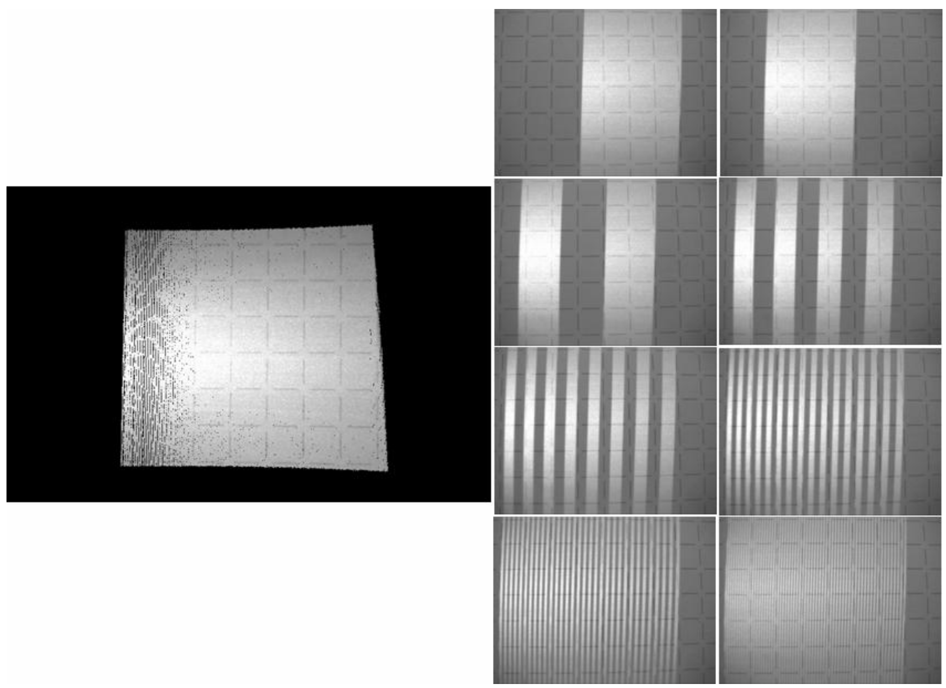


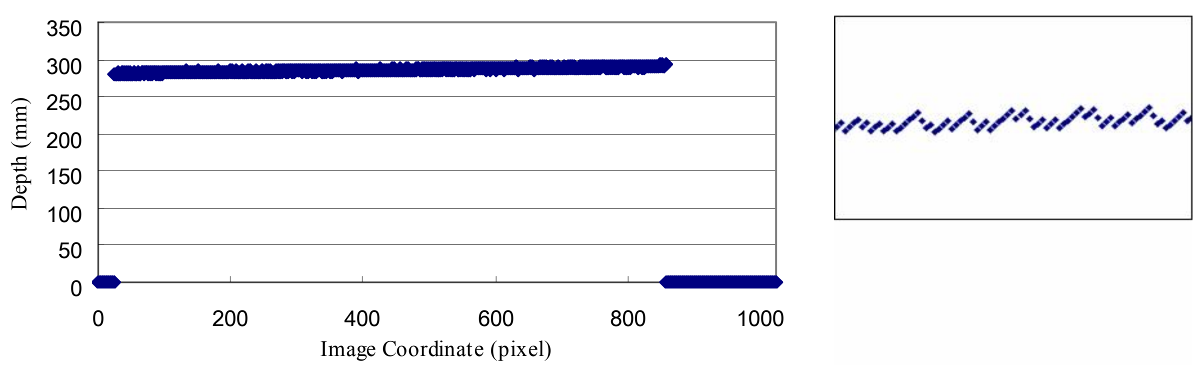
Fig. 2. Gray code patterns

Such as Fig. 4., resolution of depth doesn't improve due to the domain coded in the shape of a wedge.



(a) (b)

Fig. 3. Measurement by space code technique. ((a).Three-dimensional measurement result and (b).Pattern images)



(a) (b)

Fig. 4. A section figure of a plane ((a). *v=400* , (b). an enlargement of (a))

2.3 Phase Shift Technique

Light patterns such as fig.5 that brightness value of (u,v) are changing in the shape of a sine curve is projected onto an object four times. The phase value of (u,v) is calculated by four brightness values of (u,v) in each phase pattern image. Then, the depth value of (u,v) is provided by the principle of triangulation because the phase value of (u,v) acquired is correspond to each light projection angle. In other words, the resolution of the depth value using phase shift technique is very higher than that using space code technique.

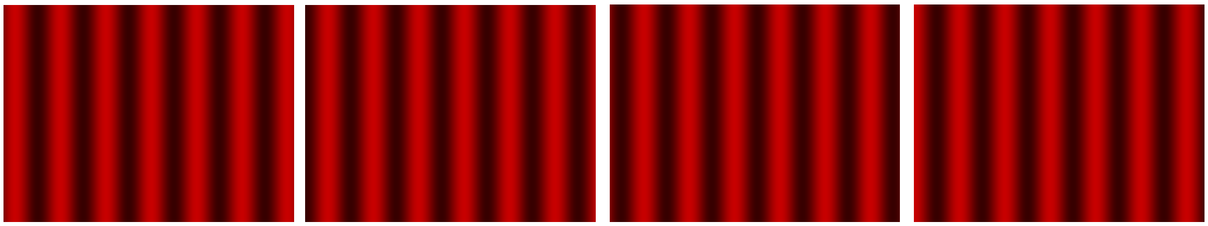


Fig. 5. (a).Three-dimensional measurement result and (b).Pattern images

Phase of phase shift pattern is shifted $\pi/2$ each. And, Brightness Value is represented as follow;

$$p_n(u,v) = A\sin\left(\alpha(u,v) + \frac{\pi}{2}(n-1)\right) + B \tag{2}$$

,where p_n is brightness value of (u,v) corresponding to nth pattern image, α is a phase value of (u,v)

$$\alpha(u,v) = \arctan\frac{p_1(u,v) - p_3(u,v)}{p_2(u,v) - p_4(u,v)} \tag{3}$$

Then, each phase value is able to be acquired.

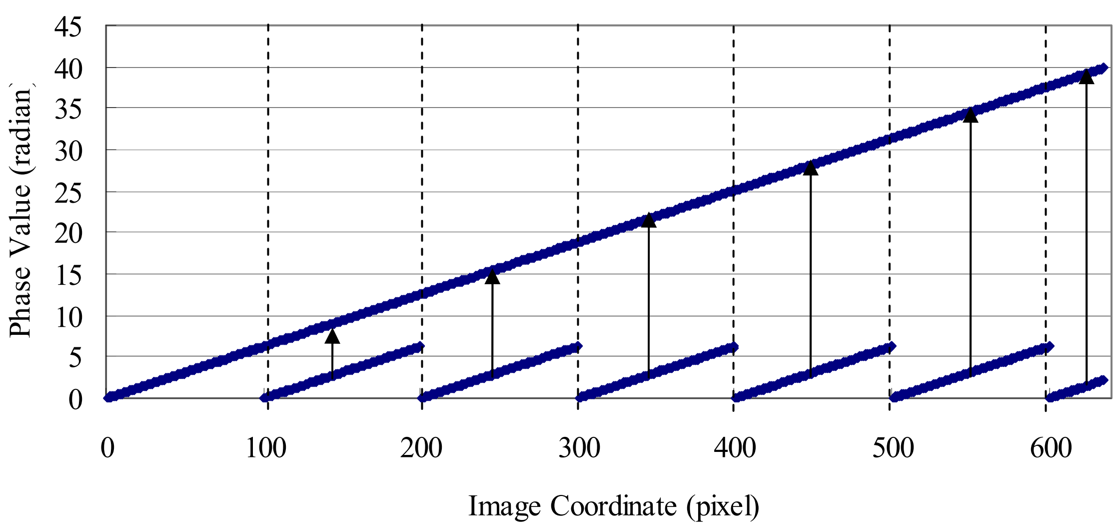


Fig. 6. Phase value acquired from phase shift pattern images and Phase connection

However, correct depth can not be acquired because phase value α is calculated between 0 and 2π . In short, the point which is changing period is detected and the phase has to be connected so called phase connection problem. (ex. periods=6, $0 \le \alpha \le 12\pi$)

2.4 Laser Control

The space code patterns and phase shift patterns are generated by a floodlight. These two kinds of patterns are realized by the same floodlight. Each code number corresponds to projection angle each. Then, code numbers are synchronized to phase values. In other words, the start phase value of each period is made to correspond with the code number. The unit period angle and the period angle of (u,v) in each period is represented as follow,

$$\Delta\phi_n = \frac{\theta_{n+1\_firstcode} - \theta_{n\_firstcode}}{2\pi} \tag{4}$$

$$\phi_n(u,v) = phase(u,v) \times \Delta\phi_n \tag{5}$$

,where $\theta_{n\_firstcode}$ is a projection angle of first code number in n period, $\Delta\phi_n$ is a unit angle in n period, $\phi_n(u,v)$ is local angle of (u,v) in n period, $phase(u,v)$ is a phase value of (u,v).

Then, the projection angle θ_{new} is represented by equation (5),

$$\theta_{new}(u,v) = \theta_{n\_firstcode} + \phi_n(u,v) \tag{6}$$

Three-dimensional measurement is calculated by equation (1) and (6) as follow,

$$z = \frac{f \cdot l}{x + f \cdot \tan\theta_{new}} \tag{7}$$

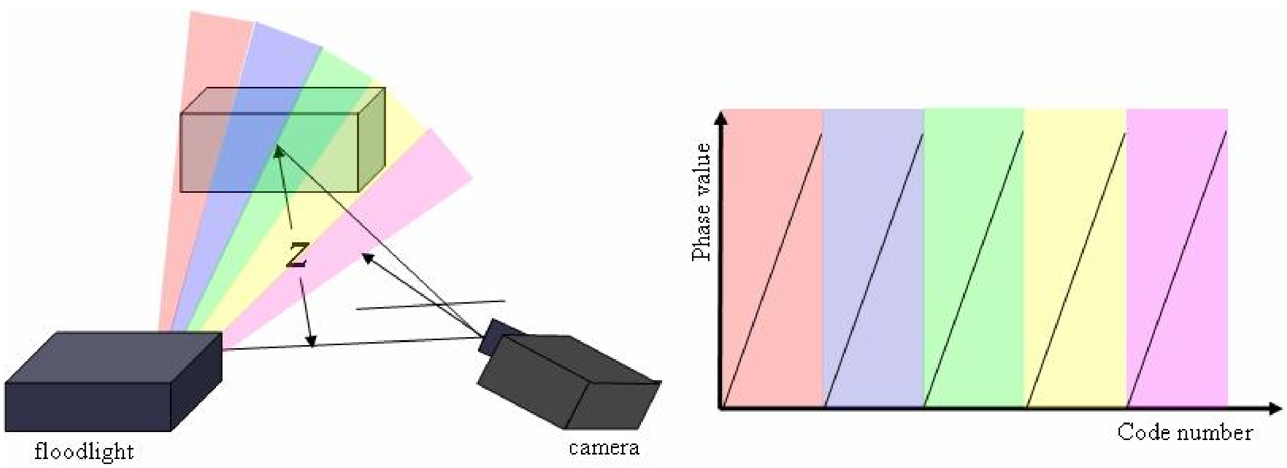


Fig. 7. Relations of the code number and the phase value

2.5 Edge Detection

The phase shift technique has another weak point besides the phase connection problem. It is hard to measure shadow parts and sudden depth change parts of an object, because a wrong phase is acquired in their area. Whereas, a suitable code number can be obtained in space code technique. These problems are solved by using code number because the area which code number is rapidly changing corresponds to a sudden depth change.

In short, the areas of their problems are detected in advance and three-dimensional measurement should be calculated in their parts.

3. EXPERIMENTAL RESULT

3.1 Calibration

The camera and laser are calibrated in advance before experimentation. The camera is calibrated based on Zhang technique [8]. The plane with a checked pattern called, a calibration board is, captured, and points of intersection are detected. The parameter sets (which are inside parameter and outside parameter) from the Image coordinate system to the World coordinate system are acquired because the points in the plane are known. The laser is calibrated based on Yamauchi technique [9]. Slit light is projected to the plane by laser and captured by camera a few times as an angle of plane is changed. The projection angle can correspond with each code number to calculate slit plane using camera parameters.

3.2 Experiment

We used the three-dimensional system made in *SPACE VISION .Inc* (which is called *Handy 3D Camera "Cartesia"*) [10]. It is the rangefinder which is composed of a camera (focus distance 6*mm*, Image size 1024×768 *pixel*) and a laser (which can generate space code patterns and phase shift patterns). Rangefinder is controlled by PC such as Fig. 8. We used measurement objects such as Fig. 9.

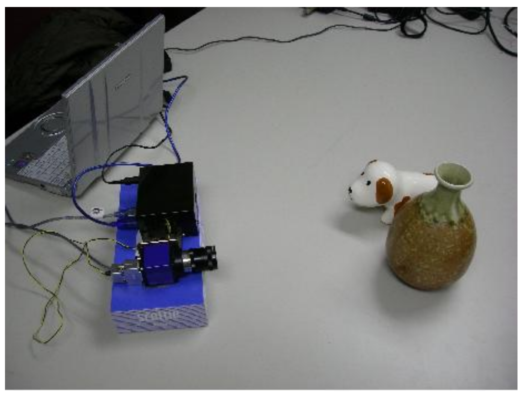


Fig. 8. Experiment scenery

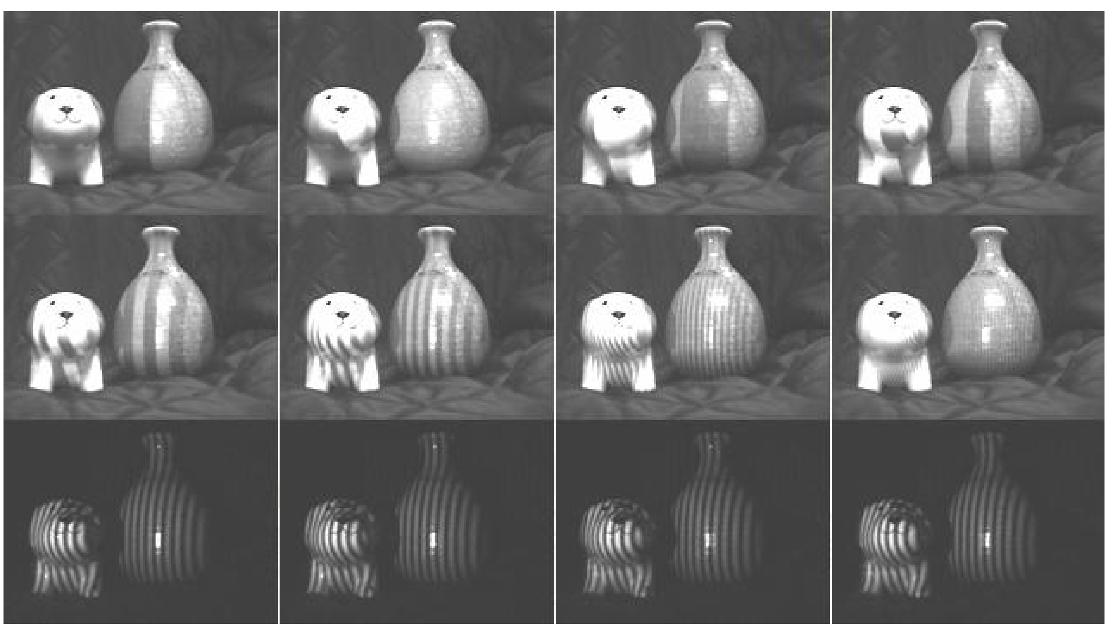


Fig. 9. Measurement object(upper two lines, space code patterns are projected and the other, phase shift pattern is projected)

3.3 Result

Fig. 9. Code Image (left figure) and white points proposed for jump edge (right figure)

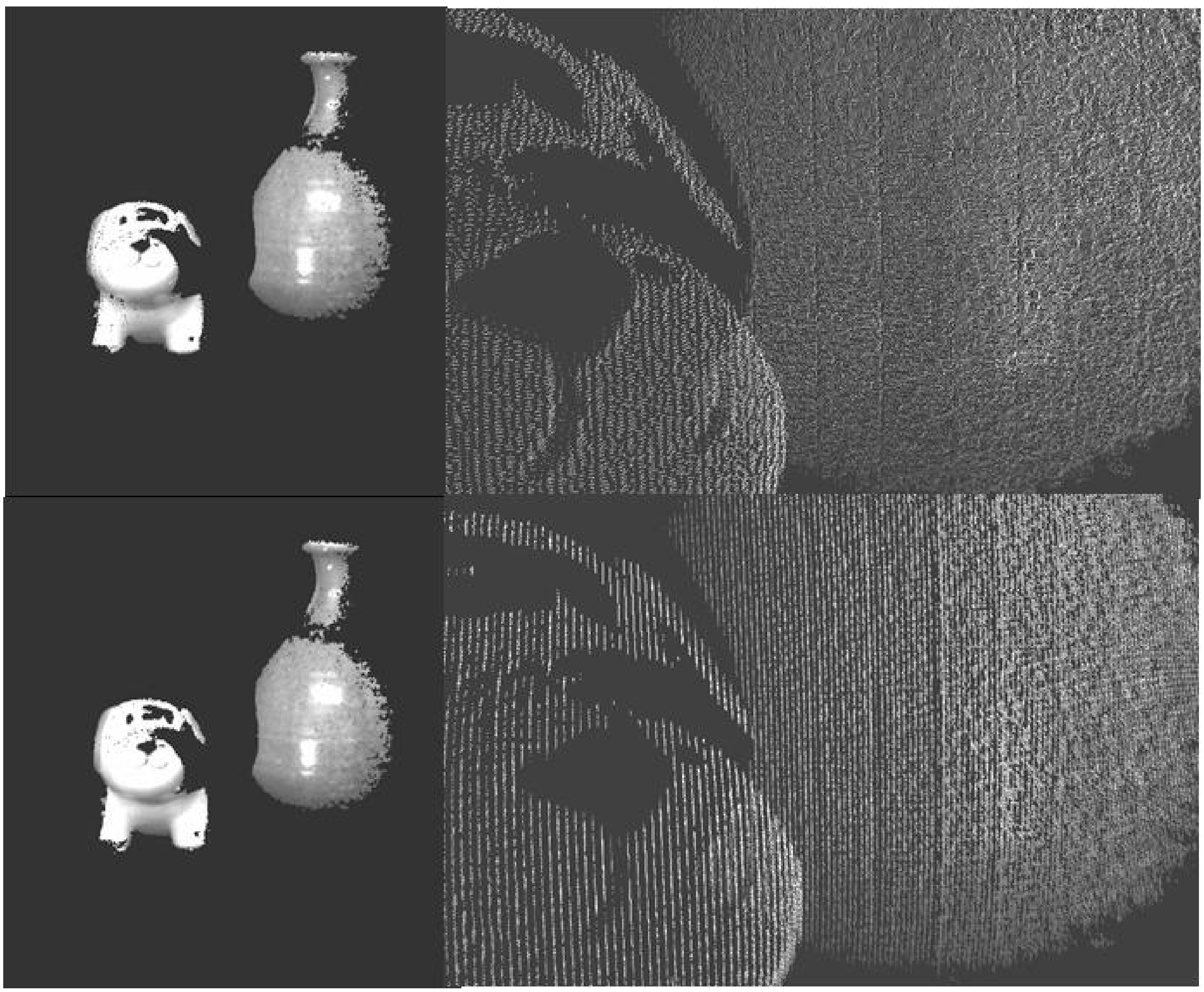


Fig. 10. Three-dimensional measurement results (upper is based on hybrid pattern technique, the other is based on space code technique)

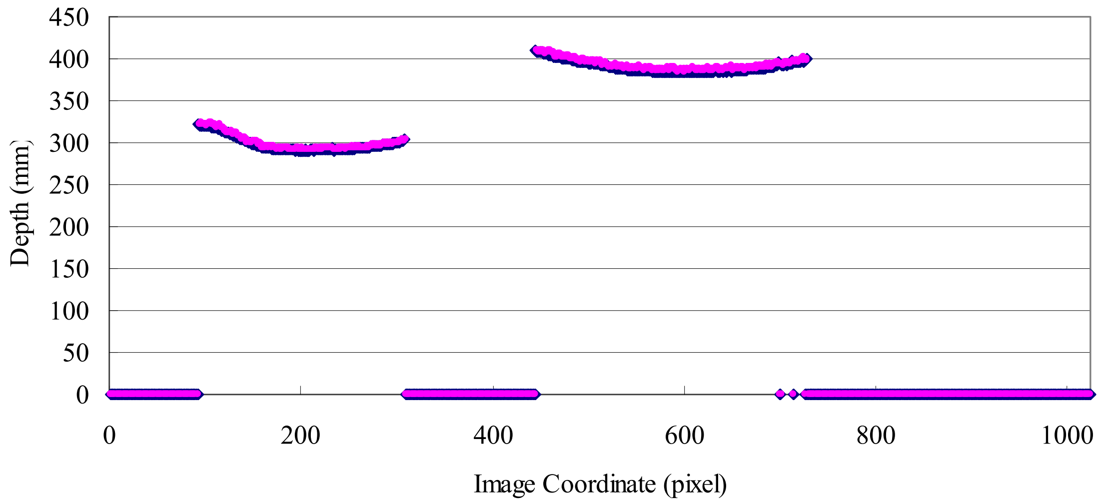


Fig. 10. Three-dimensional measurement results using the hybrid and the space coding technique (A section figure of an object, *v=400*)

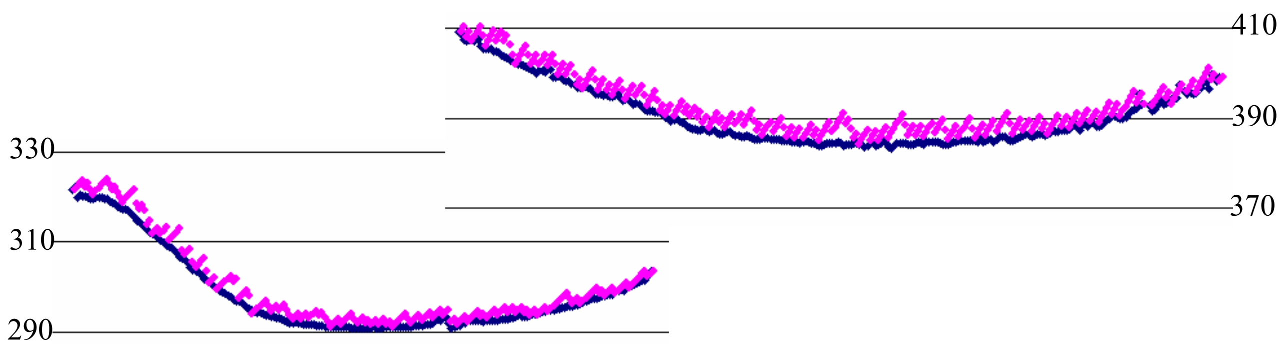


Fig. 11. enlargement figure of Fig. 10.

4. CONCLUSION

We presented the rangefinding system using hybrid pattern projections which are the space code and phase shift patterns. Three-dimensional measurement results show that the phase connection problem in the phase shift technique was solved and that the resolution of three-dimensional measurement increased because the code numbers in the space code technique were synchronized with the phase values in the phase shift technique beforehand. Three-dimensional measurement is calculated in 0.5 sec by the rangefinder made in *SPACE VISION .Inc* whose method uses eight pieces of space code patterns. The rapidity of this system is maintained because in this technique four pieces of phase shift patterns were increased to eight pieces of space code patterns. Moreover, this technique does not need the optional devices. This system can be implemented with only one floodlight, because the floodlight can generate the space code and phase shift patterns. In short, this system is a more practical range finder.

5. ACKNOWLEDGEMENTS

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