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Pattern Shift Rangefinding for Accurate Shape Information

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Abstract

In this paper, a high resolution space encoding method and its system is described. In principle some space sampling measurement error is generated by space encoding. The pattern shift method was previously proposed by the authors in order to reduce sampling error. Its ability is shown through simulations. In this paper, a measurement algorithm based on the pattern shift method using an actual rangefinder is presented. It is shown that the proposed method is effective in actual situations through measurement results.

1. Introduction

Rangefinders are an effective input method for applications which analyze 3D scenes or objects. The potential of a rangefinder is evaluated by scale factors such as accuracy of measured range image, measurement time, size of the system, and so on. The most important scale factor is depends on how the rangefinder is applied. For machine vision applications, (particularly for robot vision), measurement time and accuracy are important factors. In addition, the compactness of the system is also needed for active vision systems.

A rangefinder based on the active stereo method would satisfy the above conditions. In particular, triangulation with a laser slit ray[1] is an effective method. In this method, we can obtain high accurate range images by detecting a center of gravity on the intensity distribution of a slit line image. However, if we use an ordinary video camera as the image input device, it is time consuming to obtain a range image because only a small amount of 3D data on the slit ray can be obtained with one image exposure. Recently, some special range sensors for triangulation with a slit ray have been developed[2][3]. These sensors have a range imaging function which is realized on each pixel of a VLSI chips, and are thus very compact and have high speeds. In addition, these can obtain highly accurate range images. However, these sensors do not have sufficient resolution at this time.

To reduce the long measurement time using an ordinary video camera, the space encoding method[4][5] is effective. In this method, some stripe pattern rays divide the object space into regions which are equivalent to the slit ray and generate space codes for each region. The number of pattern ray exposure times necessary to generate the regions is less than that for the slit ray method. We therefore can decrease measurement time. However, there is measurement error (space sampling error) because of space encoding. The magnitude of this error is determined by the resolution of space encoding. A method that limits sampling error was proposed by K.Sato and S.Inokuchi[4]. With this method, the sampling error is decreased by the linear interpolation of space codes. However, interpolation cannot perfectly correct the sampling error. The authors have proposed a pattern shifting method [6] which detects projection angles on each coded region directly.

In this paper, we propose a rangefinder system based on the pattern shifting method. This system achieves a higher resolution space encoding. Our approach is to assign a more accurate projection angle to each measurement point. To achieve the above assignment of the projection angles, we have introduced pattern shifting[6] into a space encoding rangefinder with laser scanning[7]. With pattern shifting, we can increase the resolution of space encoding and can obtain more accurate range images. We will describe the pattern shifting principle briefly as well as the measurement algorithm with system realization. We will also show the ability of our system through experimental results.

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2. Space Sampling Errors

Fig. 1 shows the space encoding principle. In the space encoding method, the measurement space is divided into regions that are coded by binary numbers. The scene is obtained as a coded image so that each pixel has the number of the region that it is on [4][5][7]. Here, we have assumed that the obtained regions are as thin as a slit ray. We can then regard each region as a slit ray and we can determine the projection angle of each region. Using this angle and a position of the region projected onto an image plane, we can calculate the distance based on triangulation. In general, each region has a width as shown in Fig. 2. This figure is a sectional plan for a rangefinder which is projecting a pattern ray. In this figure, a stripe region includes some pixels in it. The

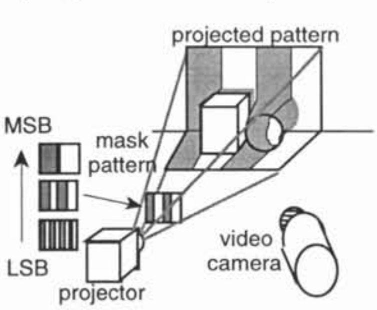


Fig.1. Space-encoding Method

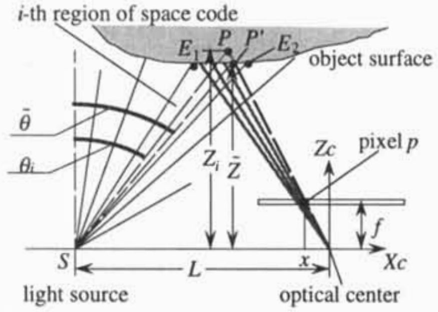


Fig. 2 Sampling error of space encoding

pixels included in the i-th region of coded space must have the same projected angle, which is represented as θ_i in the figure. Angle θ_i divides angle $\angle E_1SE_2$ equally, where E_1 and E_2 denotes cross points between the object surface and each boundary of a coded region. Now we will focus on a pixel p. Measured distance Z_i is calculated as follows:

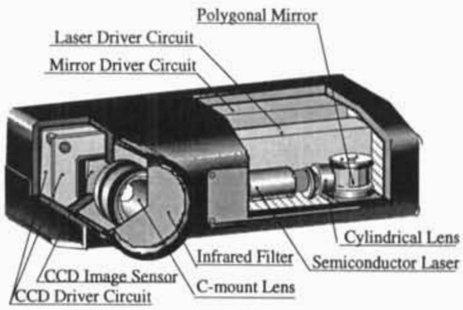
$$Z_i = \frac{fL}{x + \tan\theta_i} \qquad (1)$$

where f and L denote focal length and base line, respectively. It is easy to see that the measured point P is different from the object surface point, which is indicated as P' in Fig. 2. Each measured point P (which is generated as a cross point between a view line from each pixel on the image plane and a projection line of each space code region)is coarsely distributed. Therefore, the position of measured point P is not same as the actual P'. Let the actual distance to the point P' be $\tilde{Z}$. The difference between measured distance Z_i and actual distance $\tilde{Z}$ is the space encoding sampling error.

3. Pattern Shifting for Sampling Error Reduction

To reduce the sampling error, we believe that we can directly detect the projection angle $\tilde{\theta}$ which is the actual projection angle given by line segment $\overline{SP'}$ in Fig.2. Our solution to this problem is to move line $\overline{SP}$ to line $\overline{SP'}$ by shifting a stripe pattern ray. However, it is impossible to detect whether $\overline{SP}$ coincides with $\overline{SP'}$ because there is no effective feature, (for example intensity variation), in obtained intensity images. So, we will utilize the edge line $\overline{SE_1}$ (or $\overline{SE_2}$) instead of $\overline{SP}$. E_1 and E_2 were defined in the previous section. If we shift the edge line $\overline{SE_1}$ by each small angle, we can detect the change of intensity on each shift because of the difference of intensity in both sides of $\overline{SE_1}$. To realize this approach, it is necessary to resolve the following two problems: (1) How do we shift the pattern edge by a small angle? (2) How do we detect whether edge $\overline{SE_1}$ coincides with line $\overline{SP'}$? We will describe the solutions

(a) picture of real Cubicscope



(b) construction of Cubicscope

Fig. 3 Rangefinder "Cubicscope"

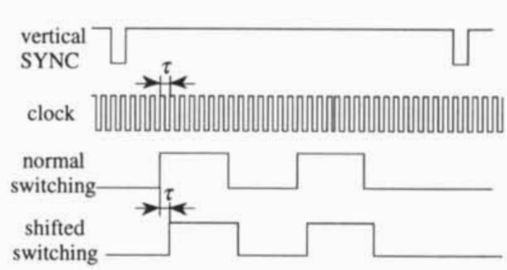


Fig. 4 Timing chart of pattern shift generation

to these problems in the following sub-sections.

3.1 Pattern Shift Realization using a Laser Scanning Rangefinder

In order to realize pattern shifting, we need a system that can project pattern ray shifting with each small angle. For this system, the laser scanning rangefinder "Cubicscope" shown in Fig.3 is available[7]. This rangefinder scans a laser slit ray that is synchronous to a video signal. While scanning the laser slit, we switch the semiconductor laser ON and OFF at arbitrary times. We can then obtain arbitrary stripe pattern images. The laser slit is scanned at a constant rotating velocity. Therefore, we can also make any desired shifted pattern if we delay or increase the timing of laser switching. We have shown a timing chart of this process in Fig.4.

3.2 Pattern Edge Detection on a Pixel

Detecting a case where edge $\overline{SE_1}$ coincides with line $\overline{SP'}$ is equivalent to detecting a case where the edge position on the image plane is on the center of pixel p. In this case, we utilized a characteristics of CCD camera that generates output intensity in proportion to the quantity of incident light. Fig. 5 shows the case where

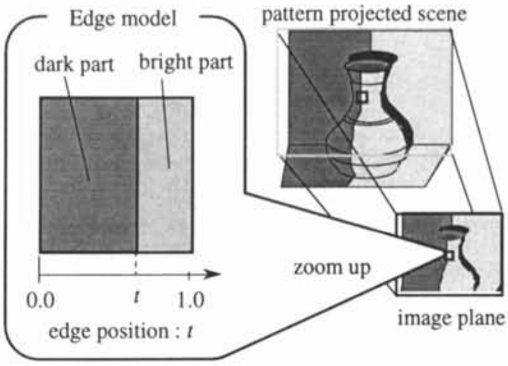


Fig. 5 Edge model on a pixel

the edge of a projected pattern light is on a pixel. Suppose that each quantity of incident light to the bright or dark region is respectively uniform and that the edge line is parallel to the vertical boundary of the pixel. We can then describe the relation between output intensity I_p of a pixel and edge position t on a pixel in the following formula (for more details, see [6]):

$$t = \frac{I_b - I_p}{I_b - I_d} \qquad (2).$$

where, I_b and I_d denote pixel intensity when the whole pixel is covered with the bright or dark part, respectively. Parameter t takes a value range from 0 to 1 as the edge line moves from the left to the right side of the pixel. Using this formula, we can detect the position of the edge line on the pixel by calculating the value t. At this point, we want to detect a pattern edge position on the center of a pixel. Therefore, we will search a pixel whose intensity satisfies $t = 0.5$. It is necessary to have obtained previously intensity I_b and I_d.

4. Measurement Algorithm with Pattern Shift

We show a measurement algorithm with the above pattern shifting method as follows:

<Measurement Algorithm>

step1: Execute space encoding measurement and obtain a space code image.

step2: Obtain whole- and non-projected images for I_b and I_d.

step3: Project an LSB stripe pattern which is shifted by a small angle and obtain its intensity image.

step4: Repeat **step3** until an edge coincides to the position of an initial neighboring one.

step5: Detect a shift count when an edge line is on the center of each pixel using formula (2).

step6: Calculate projection angle $\tilde{\theta}$ on each pixel using a small angle, the shift count, and the initial projection angle of each edge.

step7: Calculate the distance on each pixel and we get a range image.

Next, we consider measurement time. In the normal space encoding, we need $\log_2 N$ images when measuring a range image whose horizontal resolution is N. With our method, we must obtain a whole-projected image, a non-projected one and pattern shift images in addition to the space encoding images. Let the necessary number of pattern shifts be m. The time required for this method is $\log_2 N+m+2$. Shift number m is determined by the value ratio of a small shift angle and angle $\angle E_1SE_2$ in Fig.2. This method can be applied on any bit in the pattern ray of the space encoding. However, it is better to apply it to the LSB pattern ray in order to reduce the number of shifts.

5. Experimental results

We had experiments on the actual rangefinder described in 3.1. Table 1. shows the rangefinder configuration that is used in this experiments. We used pattern shift parameter $m = 10$. Fig.6 shows the projection angles that were detected by the proposed method when we measured a plane. Fig.7 shows a sectional plan for an obtained range image. We have found that the error magnitude of the projection angles and measurement distances are reduced as compared with normal space encoding. It takes about 1 second to execute a pattern shift algorithm (step1 to step4). Fig.8 shows a measurement result of a general object which has colored and curved surfaces. In this result, the error magnitude is same with the plane case in the part where both color and shape are smooth. However, there are some errors on parts that have sudden variations in color and shape. We think that the edge detection model (Fig.5) is not appropriate in these cases.

Table 1. Rangefinder configurations

CCD size	2/3	[inch]
resolution	768 x 484	[pixels]
pixel size	11.0 x 13.0	[μm]
focal length	16	[mm]
base line	120	[mm]
polygon mirror	12	[surfaces]
	1800	[r.p.m].
semiconductor laser	λ=690	[nm]
	35	[mW]
switching clock	2	[MHz]
unit shift angle	$3\pi \times 10^{-5}$	[rad]

6. Conclusions

In this paper, we proposed a high resolution space encoding rangefinder system using pattern shifting. We can obtain range images more accurately than with space encoding rangefinder. It achieves enough short measurement time (about 1 sec to obtain a range image). We realized a pattern shifting rangefinder using a laser scanning rangefinder. The laser scanning system is the best one for our pattern shift algorithm. It is particularly effective at the point where it can flexibly generate arbitrary stripe patterns. In our experiments, the ability of the proposed method is shown in actual situations. We have some problems as regards theoretical accuracy. However, considering the characteristics of our system, we think that the proposed rangefinder will be an efficient input device for many robot vision applications.

References

[1] Y.Sato, H.Kitagawa, and H.Fujita, "Shape measurement of curved objects using multiple slit-ray projections," IEEE Trans. Pattern Anal. Machine Intell., PAMI-4, 6, 641 (1982)

[2] K.Araki, Y.Sato, and S.Parthasarathy, "High Speed Rangefinder," SPIE, vol.850, pp.184-188, 1987

[3] T.Kanade, A.Gruss, and L.Richard Carley, "A Very Fast VLSI Rangefinder," Proc. of 1991 IEEE ICRA, pp.1322-1329, 1991

[4] Posdamar and Altsuler, "Surface measurement by space-encoded projected beam system," Computer Graphics and Image Processing, 18, pp.1-17 (1987)

[5] K.Sato and S.Inokuchi, "Range-imaging system utilizing memetic liquid crystal mask, IEEE 1st ICCV, pp.657-661, 1987

[6] K.Hattori and Y.Sato, "Accurate Rangefinder with Laser Pattern Shifting," Proc. of 13th ICPR, vol.3, pp. 849-853, 1996

[7] K.Hattori and Y.Sato, "Handy Rangefinder for Active Robot Vision," Proc. of 1995 IEEE ICRA, pp. 1423-1428, 1995

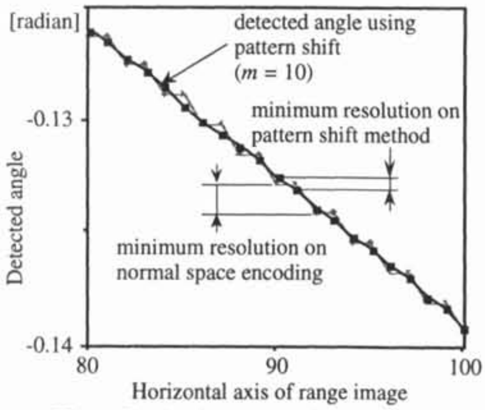


Fig. 6 Projection angle (uniform plane)

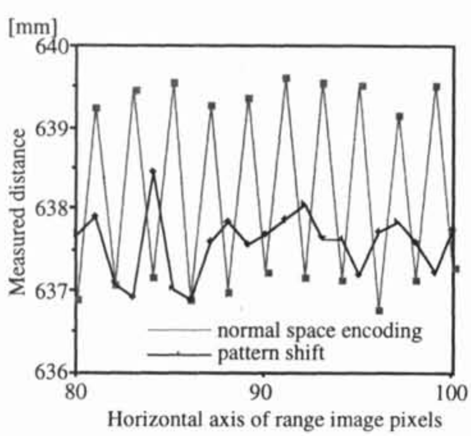


Fig.7 Measured distances (uniform plane)

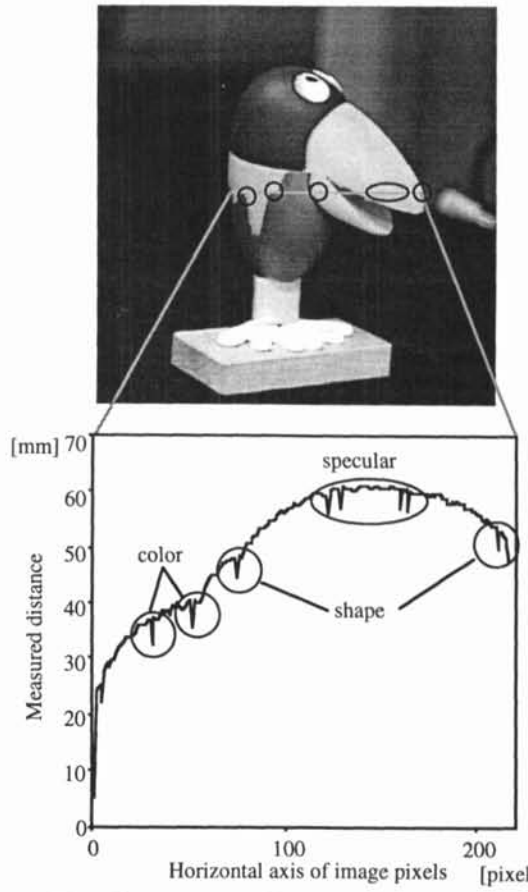


Fig.8 Experimental Results (Colored object)