DEVELOPMENT OF REAL TIME 3-D MEASUREMENT SYSTEM USING INTENSITY RATIO METHOD

Takeo MIYASAKA and Kazuo ARAKI

Graduate School of Computer and Cognitive Sciences, Chukyo University, Japan

miyasaka@grad.sccs.chukto-u.ac.jp, araki@sccs.chukyo-u.ac.jp

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ABSTRACT

Previously, we developed a real time 3-D measurement system based on slit-ray projection method, which enables us to obtain serial range images at 1/30 seconds per scene with an error within $\pm 0.3\%$. It, however, uses laser beam as light source, so it has some disadvantages in safety and applied field of it is somewhat limited. In this regards, the aim of this paper is to develop a new system for 3-D measurement using incoherent light source, which is not dangerous to surroundings and enables us to obtain serial high-resolution range images in real time.

Our new system is based on intensity ratio method. In this method, the target space is encoded by intensity ratio of two light patterns projected alternately onto the target space. In this research, a flat light pattern and a linearly increasing one along horizontal direction are used as two light patterns and projected from a DLP projector on the market. Since one range image is obtainable from two successive video images corresponding to two light patterns and procedure for range image calculation is very simple and carried out at high speed, serial range images are obtained at high speed from serial video images, which are captured by a 3CCD video camera on the market synchronizing with alternate projection of two light patterns. Thus our system realizes to obtain serial range images in real time. In addition, since one range data is obtained from one pixel of the image plane of the video camera, spatial resolution of our system is same to that of the video camera. Moreover, since each component of our system is available on the market, total cost of it is very cheap.

To improve accuracy of measurement by our system, optical characteristics of video camera and DLP projector are investigated and taken account into processing video images. Moreover, since accuracy is badly affected by the fact that reflectance on the surface of the target depends on the frequency of the light projected, monochromatic light source is used in our system.

As a result, our trial system enables us to obtain serial range images at 30 scenes per second with spatial resolution of 640×480 and an error within 1%. Thus, it may be applicable to the field of robot vision, gesture recognition, motion analyzer, recognition of moving target and so on.

1 INTRODUCTION

Recently, some kinds of 3-D measurement systems that acquire range image under non-contact condition have become at the level of actual use by advancement of computer and the peripherals. Little systems of them, however, realize real time and accurate measurement and obtain range data of moving target. So, those that obtain accurate range data in real time are highly expected in the field of motion analysis, mobile robot and so on.

In this regards, we have proposed a new type of range finder based on slit-ray projection method (Araki et al.,1991; Araki et al.,1992; Araki et al., 1995), which uses a newly developed non-scanning type image plane. The image plane is constructed by a position-sensitive device (PSD) array that is horizontally un-segmented and linear, but vertically segmented in numbers. By virtue of this configuration of the image plane, our system acquires one range image during only one scan of the slit-ray at high speed, As the result, it enables us to obtain serial range images of 128×128 spatial resolution at $1/30$ seconds per scene with an error within $\pm 0.3\%$. It, however, uses laser beam for a light source, so it has some problems in safety, and so, it is difficult to use in the circumstance where laser beam may badly affect to human beings, animals, plants and so on. Furthermore, its spatial resolution is not enough for many applications.

In such situation, the aim of this paper is to develop a new real time 3-D measurement system, which uses incoherent light source instead of laser beam and is not dangerous to environments. In this regards, intensity ratio method is, we think, most prospective, since it does use incoherent light source and is simple in principle and actual instrumentation.

Several 3-D measurement systems based on intensity ratio method have already proposed. However, they do not give sufficiently accurate measured results. The reason, we think, may result from the fact that frequency dependence of reflectance on the surface of the target is not taken into account in their systems. So, in this paper, we try to develop a new 3-D measurement system based on intensity ratio method, taking account frequency dependence of reflectance on the surface of the target.

2 METHOD

2.1 Intensity ratio method

Intensity ratio method is a kind of pattern projection methods. The key concept of it is to encode target space by light intensity ratio of two projected light patterns, which realizes highly multiple slits projection onto the target space.

Figure 1 illustrates overview of intensity ratio method.
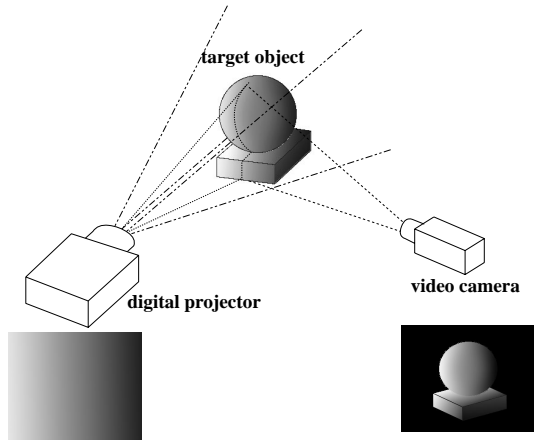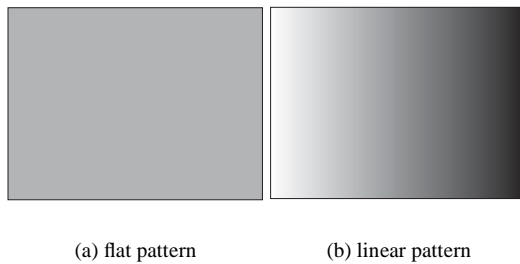
Figure 1: Overview of intensity ratio method

(a) flat pattern   (b) linear pattern

Figures 2: Projected light patterns

In the method, two types of light patterns are projected alternately onto the target space. Figures 2 show the two light patterns in this paper. Light intensity of the first one is flat through the target space and we call it "flat pattern" (Figures 2(a)). On the other hand, that of the second one increases linearly toward horizontal direction of the target space and we call it "linear pattern" (Figures 2(b)). Then, light intensity ratio of the two pattern becomes one-valued function against horizontal position of the target space as shown in Figure 3 and the area at which the light intensity ratio is equivalent belongs to a vertical thin slit-like area in the target space. Thus, the target space is encoded to infinite numbers of vertical thin slit-like areas by the light intensity ratio of the two light patterns, that is, a slit-like region in the target space is distinguished by the light intensity ratio. Hereafter, we may call the light intensity ratio of the two light patterns "slit-code" for convenience. In our system, the light patterns are produced on a computer and projected onto the target space through a DLP projector.

Next, video image of the target is captured by a video camera at every projection of the two light patternsFigure 1. Then, above mentioned "slit-code" is given from the density ratio of each pixel itself in two successive frames of video images, providing that the reflectance on the surface of the target is kept constant during successive projection of two light patterns and that reflected light intensity is proportional to incident light one with same proportional constant for two light patterns. This proposition is nearly true when image-capturing speed is high enough comparing to that of target motion. Thus, we can decide the slit-like
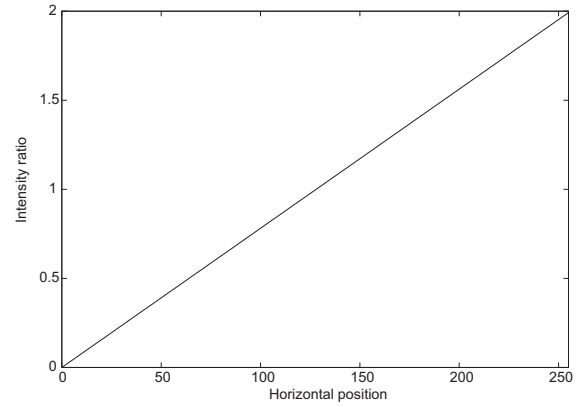

Figure 3: Intensity ratio of two light patterns

area in which the point on the target imaging on each pixel exists. So, finally, range data can be calculated through triangulation principle as in a slit-ray projection method. As "slit-code" is uniquely decided for each pixel, spatial resolution of resultant range image is equivalent to that of video camera used, resulting in extremely high spatial resolution of range image.

2.2 Improvement of accuracy

In section 2.1, video camera and DLP projector are optically idealized. But actually they are some problem to be utilized in intensity ratio method such as limited dynamic range, insufficient quantum bits of color channels, non-linear input/output property and so on. So, to improve accuracy of measurement by our system, optical characteristics of video camera and DLP projector are investigated in detail and taken account into processing video images. For example, only linear part of gamma characteristics is utilized and distortion of lens system is taken into account through least square method etcetera.

Another important factor affecting on accuracy results from the fact that reflectance of surface depends on frequency of light projected. Conventional intensity ratio methods have not yet succeeded in accurate measurement. The main reason, we think, is that they don't consider the fact mentioned-above. That is, the surface of the target has different reflectance for each frequency of light consisting incident light patterns. So, in case where the target space is encoded by gray-scale light as in most conventional intensity ratio methods, intensity of reflected light is not proportional to that of incident light as follows. Let I_R, I_G, I_B be intensity of incident light of red, green and blue, respectively and k_R, k_G, k_B be reflectance of surface for red, green and blue lights, respectively. Then, total intensity of incident light I_i and reflected light I_r is expressed as in Equation 1 and Equation 2, respectively.

$$I_i = I_R + I_G + I_B \qquad (1)$$
$$I_r = k_R I_R + k_G I_G + k_B I_B \qquad (2)$$

Thus, generally, intensity of reflected light is not proportional to that of incident light as long as reflectance of surface for each component of incident light is not equal
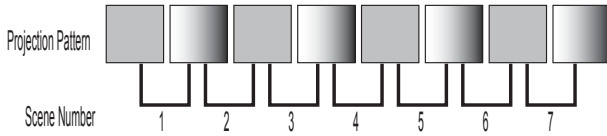
Figure 4: Continuous measurement

and/or incident light is not pure gray-scale one. Pure gray scale light is difficult to realize because of optical characteristics of devices used. So, proposition for accurate measurement by intensity ratio method mentioned in section 2.1 is not satisfied in conventional method. To overcome this problem, monochromatic light source is used in our system instead of gray-scale light. The 3-CCD video camera used in this research picks up separately light intensities of 3 monochromatic colors, i.e, red, green and blue, separately. So, we can use intensity and density ratio of red, green and blue, independently.

2.3 Continuous measurement at high speed

To obtain information on 3-D motion of moving target, it is necessary to perform continuous measurement at high speed. In this paper, it is realized as follows.

In intensity ratio method, range image of one scene is obtained from two successive frame of video image corresponding to two light patterns. In detail, the first range image is calculated from the first and second frames of video image, the second one from the second and third ones, the third one from the third and fourth ones and so on as shown in Figure 4. To perform this procedure, we only prepare inverse of "slit-code" as well as "slit-code" mentioned in section 2.1. As the result, data acquisition time becomes as same as that of video camera, although there is time lag of only one frame at the beginning.

3 TRIAL SYSTEM

Trial system is constructed by using devices shown in Table 1. Figure 5 shows a photograph of our trial system.

In this system, to projects light pattern onto target space, a DLP projector (PLUS UP-800) is used. Output pattern of projected light is generated on the computer and so, it can be controlled on line. Video image is taken at every projection of "flat" and "liner" light patterns by color 3CCD camera (SONY XC-003), which has external trigger input. To control these devices and process measured data, a computer (Pentium III 800MHz, Memory 256MB) is used. The computer outputs light pattern as video signal to projector and trigger signal to video camera and then captures video image through video camera synchronizing with projection of light pattern from the projector. Thus, high-speed projection of light pattern and capture of video image are realized continuously in this paper.

After measurement, ratio of light intensity on same pixel in successive two video images is computed on the computer

Figure 5: Photograph of our trial system

Table 1: Components of our trial system

Vision System	Sony XC-003
Projection System	PLUS UP-800
Computer	PC (Pentium III 800MHz, Memory 256 MHz)

and "slit-code" corresponding to each pixel is determined. Then, the coordinate of the respective point on the target is calculated by triangulation principle. By successively executing this process, serial range image is obtained. Our trial system enables us to obtain a range image at 1 / 30 seconds per scene, to measure a moving target and to calculate information on movement of it.

Since our system is constructed by components on the market, calibration on lens position, lens distortion and so on is necessary. It is performed by Tsai's method (Tsai,1986; Tsai,1987) in this paper.

4 RESULTS OF MEASUREMENT

To investigate accuracy of our system, white plane boards located at 662mm to 1112mm apart from focal plane are measured as the target. Errors and standard deviation are presented in Table 2 and an example of measured range data is shown in Figure 6. Error becomes less than 1%

Table 2: result of plane measurement

range (mm)	absolute error (mm)	standard divination (mm)	error (%)
662	14.19	5.64	2.14
712	7.85	1.43	1.10
762	25.65	2.06	3.36
812	33.38	0.58	4.10
862	17.42	1.076	2.02
912	2.99	0.09	0.32
962	3.04	6.47	0.32
1012	7.12	0.16	0.70
1062	35.8	0.24	3.37
1112	25.20	0.26	2.26
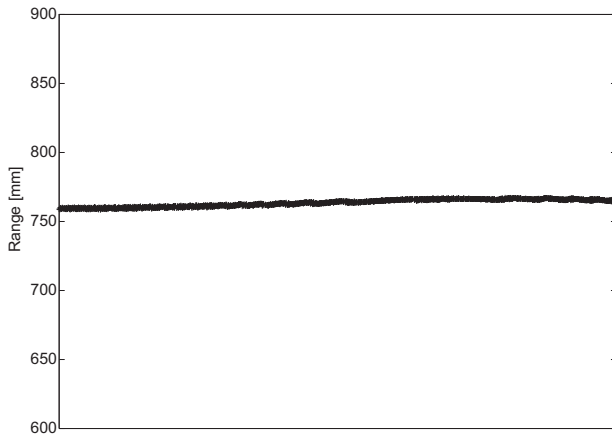
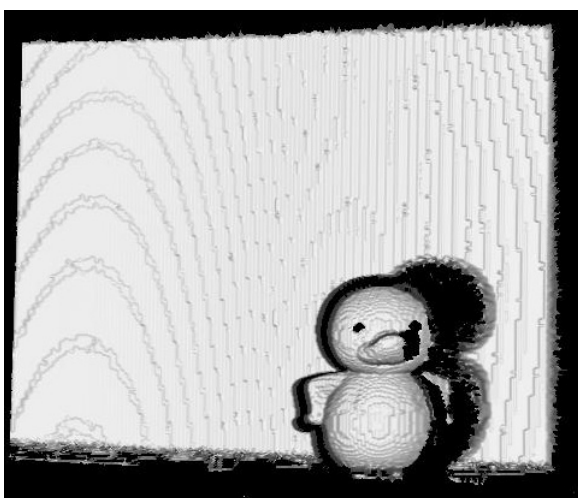Figure 6: Measured result of flat plane at 762mm

Figure 9: Texture mapping model of target object

near 1000mm range and sufficient but it becomes several percent at nearer and further distance, which may need further investigation.

Figure 8 shows the measured result of the small target shown in Figure 7, that is placed at 600mm far from CCD camera.

Since, in our method, "flat pattern" is used as one of two light patterns, ordinal color 2-D video images can be obtained at the same time of measurement and so, color 3-D surface model may be reconstructed easily through texture mapping technique. Figure 9 demonstrates color surface model of the target shown in Figure 7 thus obtained.

5 CONCLUSION

In this paper, we developed a real time 3D measurement system based on intensity ratio method. In our method, the target space is encoded by intensity ratio of 'flat' light pattern and 'linear' one projected alternately onto the target space.

To improve accuracy of measurement by our system, optical characteristics of video camera and DLP projector are investigated and taken account into processing video images. Furthermore, considering that accuracy is badly affected by the fact that reflectance on the surface of the target depends on the frequency of the light projected, monochromatic light source is used in our system.

As a result, our trial system enables us to obtain serial range images at 30 scenes per second with spatial resolution of 640x480 and an error within 1% or so. Thus, it may be applicable to the field of robot vision, gesture recognition, motion analyzer, recognition of moving target and so on.

In the future, we are planning to apply it to a human motion analysis. The human motion analysis system may be constructed by locating several number of this measurement system around the target, to obtain 3-D human motion information automatically.

Figure 7: Photograph of target object

Figure 8: Shading model of target object

REFERENCES

Araki, K., Sato, M., Noda, T., Chiba, Y. and Shimizu, M., 1991. High speed and continuous rangefinding system. IE-ICE Transactions Special Issue on Computer Vision and Its Applications E 74, pp. 3400–3406.

Araki, K., Shimizu, M., Noda, T., Chiba, Y., Tsuda, Y., Ikeg aya, K. and Sannomiya, K Gomi, M., 1992. High speed and continuous 3-d measurement system. 11th IAPR International Conference on Pattern Recognition 4, pp. 62–65.

Araki, K., Shimizu, M., Noda, T., Chiba, Y., Tsuda, Y., Ikegaya, K., sannnomiya, K. and Gomi, M., 1995. A high-speed and continuous 3d measurement system. Machine Vision and Applications 8, pp. 79–84.

Tsai, R. Y., 1986. An efficient and accurate camera calibration technique for 3d machine vision. Proceedings of IEEE Conference on Computer Vision and Pattern Recognition pp. 364–374.

Tsai, R. Y., 1987. A versatile camera calibration technique for high-accuracy 3d machine vision metrology using off-the-shelf tv cameras and lenses. IEEE of Robotics and Automation RA-3(4), pp. 323–244.