HIGH SPEED 3-D MEASUREMENT SYSTEM USING INCOHERENT LIGHT SOURCE FOR HUMAN PERFORMANCE ANALYSIS

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ABSTRACT

This paper presents a newly developed high speed 3-D measurement system, which enable us to obtain continuously range image of 768x480 spatial resolution at video rate. It is based on a light pattern projection method and uses incoherent light source instead of laser beam. So it is not dangerous to environment. To obtain one range image, it needs to project only two types of light patterns. Each light pattern has different intensity profile toward specific direction. Then, the target space is encoded to many thin slit-like regions by the intensity ratio of those two light patterns. So, taking video images corresponding to each light pattern, we can determine the slit-like region corresponding to each pixel by the density ratio of it in those two video images. As a result, we can obtain a range image by using triangulation. Trial system has ensured the performance shown in the beginning.

1 INTRODUCTION

Recently, a 3-D measurement system which acquires range image under non-contact condition has been in actuality by advancement of computer and the peripherals. Most systems, however, can measure only motionless object. Then, it is difficult that they apply to areas of measurement of a moving target, mobile robot and so on.

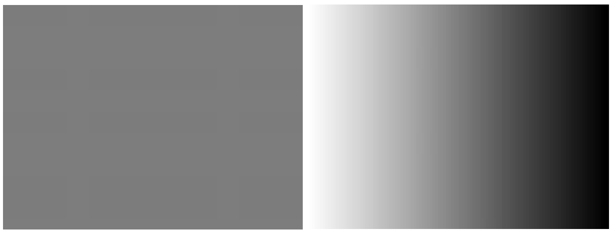
The fast 3-D measurement system has highly expected to application of above mentioned areas. To perform fast 3-D measurement, various researches have been carried out. 3-D measurement methods can be classified into two category, passive method and active method. A typical passive method is 'stereo vision'. It has been most actively studied. An example of high speed stereo vision is the multi stereo method presented by Kanade et al (Kanade and Okutomi, 1992). In this method, the moving target is taken by a number of video cameras. Successive range images can be obtained from those captured video images. It, however, requires huge computing time in the post-processing and its accuracy is not sufficient, so it is difficult to apply it to the area which needs real time operation, such as mobile robot vision and so on.

The slit-ray projection method is the most popular one of active methods. In this method, it needs to project a slit like beam onto the target and take the reflection light image. It realizes to obtain a range image in smaller computing time than a stereo vision. However, it needs a number of video images corresponding to the spatial resolution. So, it needs further improvement to perform a high speed range finding.

To resolve the problem, the pattern light projection method is proposed. In the method, the light which is structured to have 2-D pattern is projected onto the target space. The target space is 2-dimensionally encoded by the structured light. To encode the target space, some features of light pattern are used, for example, color (Boyer and Kak, 1980) (Tajima and Iwakawa, 1990) (Caspi et al., 1998) and light intensity (Carrihill and Hummel, 1985).

The one common method of light pattern projection method is a gray coded light projection method (Inokuchi et al., 1984) (Sato and Inokuchi, 1985). The method encodes the target space by the gray-coded light pattern. It is robust method because the error is decreased by using gray code. In addition, the method can measure faster than a simple slit-ray projection method. For example, number of video images needed to complete one measurement are 8 frames in case of 256 horizontal resolution. However, the measurement speed of it is not fast enough for measurement of moving target.

In such situation, Araki et al (Araki et al., 1991) (Araki et al., 1992) (Araki et al., 1995) proposed a new slit-ray projection method which uses non-scanning type of image plane. The key component is the image plane constructed by a position-sensitive device(PSD) array that is horizontally unsegmented and linear, but vertically segmented. By virtue of this configuration of the image plane, one range image is acquired during only one scan of the slit-ray at high speed, This system enables us to obtain range image of 128x128 spatial resolution continuously at 1 / 30 seconds per scene with an



(a) Flat pattern (b) Linear pattern

Figures 1: Projected light patterns

error within $\pm$ 0.3 %. By using this system, we can obtain not only 3-D shapes but also 3-D movement information of the target. The system, however, uses a laser beam for a light source, so it has problem in safety, and it is difficult to apply to areas of human face measurement and mobile robot and so on. Furthermore, it has problems in the cost, and its spatial resolution is not enough for many applications, caused by using the particular element for a image plane.

In this paper, we propose a safe and inexpensive 3-D measurement system that can continuously obtain high resolution range images at high speed. It is based on a intensity ratio method which is one branch of light projection methods. Trial system has ensured the performance of 768x480 spatial resolution and continuous measurement at video rate.

2 INTENSITY RATIO RANGE FINDING METHOD

The intensity ratio method is a kind of pattern projection methods. The key concept of it is to encode the target space by light intensity of projected light patterns.

In our method, two types of light patterns are projected alternately onto the target. They are shown in Figures 1. The first pattern of light is designed to such that light intensity profile is flat in the target space and we call it 'flat pattern'(Figures 1 (a)). The light intensity of the second pattern increases linearly toward the specific direction in the target space(Figures 1 (b)). That is called 'linear pattern'. As a result, the area, at which the ratio of light intensity by two light patterns is equivalent, belongs to a thin slit-like area in the target space. That is, the target space is encoded by the ratio of light intensity of each light pattern. So, the target space is distinguished by that ratio as a slit-like region. Therefore, we designate the ratio of intensity of 'flat' and 'linear' pattern lights as the 'slit-code'. In current system, the light pattern is produced on a computer, and it is projected onto the target space through a digital projector.

Next, the video image of the target which corresponds to each light pattern is taken by a video camera. Then, the ratio of density on each pixel gives the 'slit-code', so we can decide in which slit area the point on the object imaging on that pixel exists. So, we can calculate range data by the triangulation. As the unique 'slit-code' is decided to each pixel, the spatial resolution of obtained range images is equivalent to the resolution of the video camera used. So, our measurement method can give range images of extremely high resolution. Our method can compute range image of one scene from 2 successive frames of video images. In detail, the first frame of range image is calculated from in the first and the second video images. The second range image is obtained from the second and the third video images. By such way, the measurement speed becomes 30 scenes per second in case of using normal video camera and 120 scenes per second in case of using quadruple speed video camera which developed in a recent, although there is time lag of only one frame at the beginning. As we can obtain a color 2-D video image at the same time of measurement, highly realistic color 3-D model can be reconstructed easily. Furthermore, since our method uses incoherent light, the intensity of light can be increased. In consequence, we can measure a longer distance.

3 THE TRIAL SYSTEM

We developed the trial system based on the preceding method. The configuration of this system is shown in Figure 2.

The system uses a color 3 CCD video camera (Sony XC-003) for the image grabber. It outputs color video image sequence as NTSC signal. For the projection system, we use a color LCD projector(Epson ELP-5100) on the market. It projects above mentioned 'flat' and 'linear' light patterns which are generated by a computer. The computer is also used for control of the camera and the projector. Video images of the target space are taken by the video camera, then, captured by the computer through frame grabber. The measurement process is performed in 1 / 30 seconds.

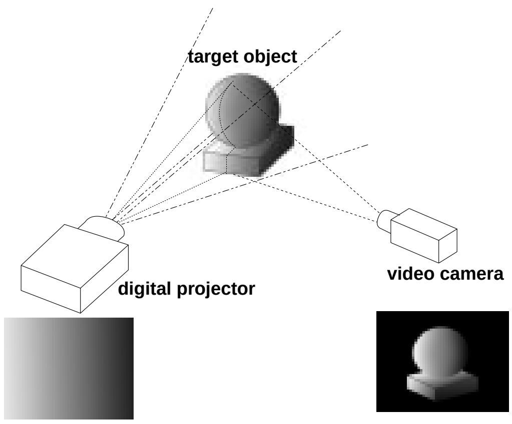


Figure 2: Outline of the measurement system

Since the system is constructed by mass production component, we must calibrate the configuration of some parameters, for example, lens position, lens distortion and so on. Which is performed by Tsai's method (Tsai, 1986)(Tsai, 1987) in this paper.

Ratio of light intensity on same pixel in successive two video images is computed on the computer. Then, the coordinate of the respective point on the target is calculated by the triangulation principle. The system can obtain a range image in 1 / 30 seconds. By successively executing the process, the range image sequence can be obtained. Thus the system enables us to measure a moving target and to calculate information on movement of it.

4 IMPROVEMENT OF ACCURATE

In intensity ratio method, it is important how to recover the intensity ratio of projected light patterns from respective video images. In other words, if the 'slit-code' corresponding to each pixel is correctly detected, the measurement accuracy is improved.

To eliminate influence of the environment, two types of light patterns are projected and the density ratio of same pixel in respective video images is used as label of the corresponding slit-code. But conventional intensity ratio method have not succeeded in accurate measurement. The reason, we think, is that they don't consider dependence of reflectance to light frequence. That is, the surface of the target has different reflectance for each frequency of light consisting incident light patterns. So, in case that the target space is encoded by gray-scale light as in conventional intensity ratio method, intensity ratio of incident light doesn't correspond to density ratio of same pixel in respective video images.

So, to improve accuracy of measurement, we must use intensity and density of monochromatic light instead of gray-scale light. The 3 CCD camera used in this research picks up separately light intensities of 3 monochromatic colors, i.e, red, green and blue. So, we can use intensity and density ratio of red, green and blue, independently. Thus we have overcome the problem mentioned above.

5 RESULT

We tried 3-D measurement by using above trial system. The result of labeling of slit-code is shown in Figure 3. This image shown slit-code number as pixel brightness. A smaller slit-code is shown as darker pixel, and larger is brighter. Figure 4 shows the range image of the target. In this figure, the depth of each pixel is shown as brightness. A closer point is expressed brighter, and far one is darker. In the result of experiment, we can obtain successive range images at video rate with an error within $\pm$ 1%.

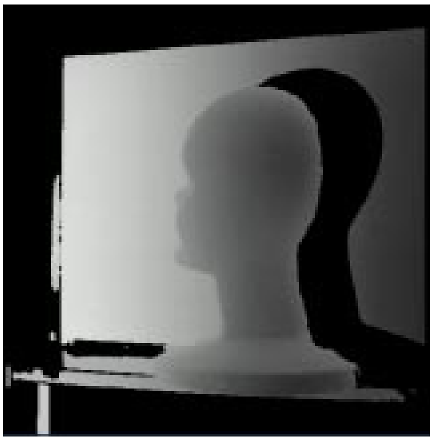


Figure 3: Labeling Image

Figure 4: Range images

6 CONCLUSION

By using proposed intensity ratio method, we achieved high speed and successive range finding. Using informations of captured video images for red , blue and green monochromatic colors separately, we can improve the system accuracy. As the result, the measurement system can obtain stable range images without influence of the environment. In addition, this measurement system is safe to environment and can be constructed in low cost.

We think that the measurement system can be applied various fields, for example the vision system in mobile robot, a movement analysis of gymnastics player and so on. In particular, we are planing to apply it to a human motion analysis. The human motion analysis system will be constructed by a number of this measurement system. The analysis system may obtain 3-D human motion informations automatically.

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