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Stereoscopy Using a Single Camera

K. Kawasue[1], Y. Kiyama[1], Y. Muraoka[1] and Y. Ohya[1]

1.University of Miyazaki, 1-1 Gakuen Kibanadai-nishi, Miyazaki, 889-2192 JAPAN
(Tel : 81-0985-58-7583; Fax : 81-0985-58-7583)
(kawasue@cc.miyazaki-u.ac.jp)

Abstract: Circular dynamic stereoscopy (CDS) has special advantages for 3-D measurement as it uses a single CCD camera without cumbersome settings. In CDS, annular streaks are recorded, with their size inversely proportional to the depth/distance of the measuring point from the CCD camera. Therefore three-dimensional information can be measured automatically by image processing techniques. In this paper, robot vision system and flow measurement system using circular dynamic stereoscopy are introduced. Experimental results show the feasibility of our system.

***Keywords*: Robot, Vision, Image processing, three dimensional measurement, CCD, Calibration**

I. INTRODUCTION

The automatic inference of depth/distance information is a primary aim of computer vision systems. The stereovision method and the slit ray projection method are often used for computer vision [1] [2]. There are, however, some limitations in the use of these systems. In stereovision systems, finding matching pairs between frames can often be problematic, particularly when there are several possible choices of matching points. When implementing the slit ray projection method, the target must be stationary while taking measurements. These systems also need sufficient space for triangulation and making measurements is cumbersome.

In this paper, a compact three-dimensional measurement system is introduced [3] [4]. By attaching an optical device in front of a CCD camera, an image of a measuring point takes a displacement from the original position in the image plane. The optical device consists of a cubical beam-splitter, and a mirror setting with 45 degree against the optical axis of the CCD camera lens. If the optical device is rotated around the optical axis of the CCD camera lens at high speed, the measuring point creates an annular streak in the image plane. The radius of the annular streak depends on the depth of the measuring point, that is, the radius is inversely proportional to the distance from CCD camera to measuring point. Therefore, by analyzing the annular streak in the image plane, three-dimensional information of the measuring point can be obtained. The experiments of flow measurement and robot vision demonstrate the feasibility of our system.

II.CIRCULAR DYNAMIC STEREOSCOPY

In order to realize the CDS in compact setup, we developed the following system that added a circular shift to the image. Fig. 1 shows schematic diagram of CDS system and Fig.2 shows the optical device on CDS system. By introducing a beam-splitter and a coupled mirror on the CCD camera lens, one of the images of the measuring point is directly recorded by the CCD through the beam-splitter and the other image is displaced by the combination between the coupled mirror and beam-splitter.

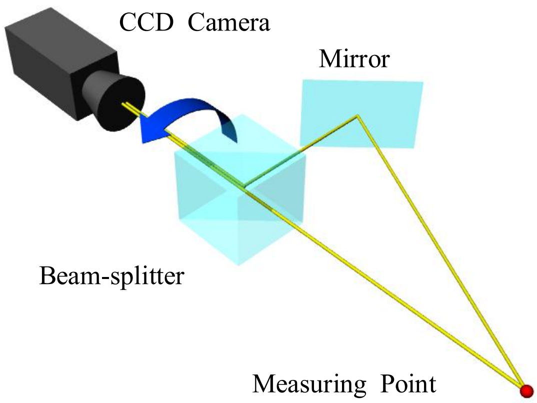


Fig.1 Schematic diagram of CDS system

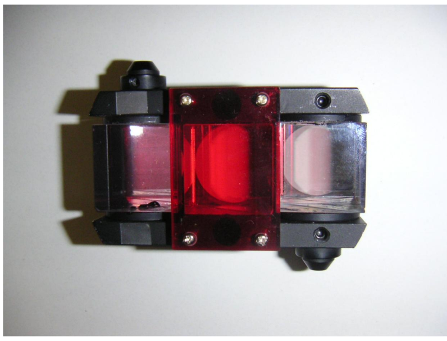


Fig.2 Optical device on CDS system

The magnitude of the displacement is related to the distance between the beam-splitter and the coupled mirror. The displacement that appears on the CCD is related to the distance between the CCD camera and the measuring point. That is, the displacement r in the image is inversely proportional to the distance D between the measuring point and the camera as:

$$D = \frac{f \cdot d}{r} \tag{1}$$

where *f* is the focal length of the camera and *d* is the magnitude of the image shifting by the beam-splitter and coupled mirror.

When the beam-splitter and the coupled mirror are rotated physically at high speed during the exposure of the CCD camera, the annular streak and its center for each measuring point appear on an image since the rotational shift is added to the image. Fig. 3.a shows the multi laser spots projected on the surface of object and Fig.3.b shows the image with circular shift produced by our system. Since the size of the streak is inversely proportional to the distance of the measuring point from the camera, each annular streak contains three-dimensional information of the measuring point. The position and the size of the annular streak in the image are related to the three-dimensional location of the measuring point.

If the measuring point is not stable, a spiral streak appears since the movement of the measuring point is added to the rotational shift. In this case, 3-Dimensional position and the velocity of the measuring point can be obtained simultaneously by analyzing the variation in the radius of spiral streak. Fig.4 shows the example of spiral streak of moving tracer particle in the water flow.

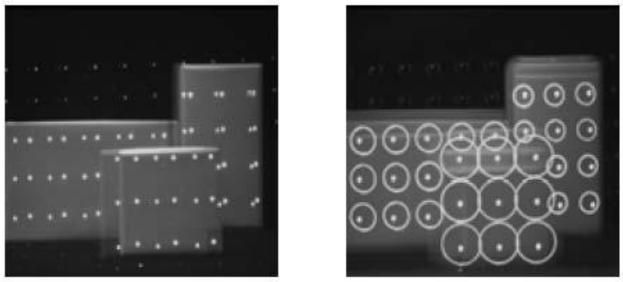
III. CALIBRATION METHOD

The information required for 3-D measurement of an image is the center position and size of the annular streak. The center (u_c,v_c) and the diameter r_c of an annular streak are obtained to sub-pixel accuracy considering the pixel intensity. The parameters of the annular streak are converted to the world coordinates (x_f,y_f,z_f) that are fixed on the focal point of the CCD camera by

$$\begin{bmatrix} x_f \\ y_f \\ z_f \end{bmatrix} = \frac{d}{r_c} \begin{bmatrix} u_c \\ v_c \\ f \end{bmatrix}, \tag{2}$$

where *d* is the magnitude of the shift by the coupled mirror, *f* is the focal length of the CCD camera, and r_c is the radius of the annular streak at this point. The values of f and d can be determined by sampling over two distinct non-coplanar points, whose world coordinates are already known.

The system is setup for calibration as shown in Fig. 6. Suppose the world coordinate system is fixed on the focal point of the camera, the x-axis and y-axis are parallel to the image plane of the CCD camera, and the z-axis is along the optical axis of the camera. A x,y scale is placed on the surface of a calibration board that can be moved along the z stage.



a. b.

a. Image without circular shift.
b. Image with circular shift.

Fig.3 Image obtained by CDS

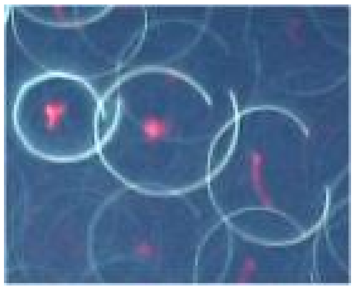


Fig.4 Spiral streak of moving tracer particle in the water flow

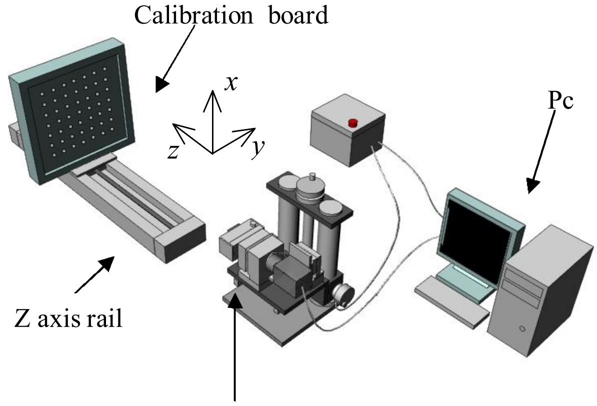


Fig.6 Setup for calibration

IV. EXPERIMENT

1. Evaluation of measuring accuracy

To evaluate the feasibility of our system, the following experiment was conducted. A plane board was set parallel to the image plane of the CCD camera at a known distance. The measuring point was illuminated on the surface of the board by a laser spot beam and was moved at a constant speed. The image was then stored in a computer and the position of the laser was calculated. The velocity of the board was changed from 10 mm/s to 150 mm/s by 20 mm/s. The result of the experiment is shown in Fig.7. If the measuring point moved, it draws spiral streak. When the movement of the measuring point is under 120 mm/s, the error was less than 2mm.

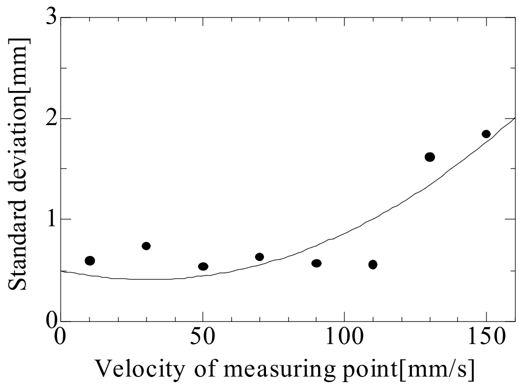


Fig.7 Accuracy of measuring system

2. Robot Vision

The CDS system is set at the tip of the robot arm. The stick with a bright LED on the top was moved. By measuring the positions of the LED at each times, the robot arm follows it in an instant. Fig.8 shows the configuration of our robot vision system.Fig.9 shows the image measured by robot vision system at each times.Fig10 shows the results of the measurement.

3. Flow Measurement

Measurement of tracer particles in water is the primary aim of this system (Particle Tracking Velocimetry). By measuring the positions of the tracer particles at each times, the three-dimensional velocity distribution within a flow can be measured. Fig. 11 shows setup for flow measurement. The distance between the center of the tank and the measuring system is approximately 500mm. Polystyrene tracer particles of 0.2mm or less in diameter are scattered onto the water. The tracer particles have a specific gravity of 1.03, so t that hey may be considered neutrally buoyant in water. These particles are illuminated by a halogen lamp. A cylindrical tank of 270mm in diameter is placed inside the rectangular tank and both tanks are filled with water to avoid any distortion of the image. Water in the cylinder tank is set into motion via a disc driven by a motor situated on top of the cylinder tank.

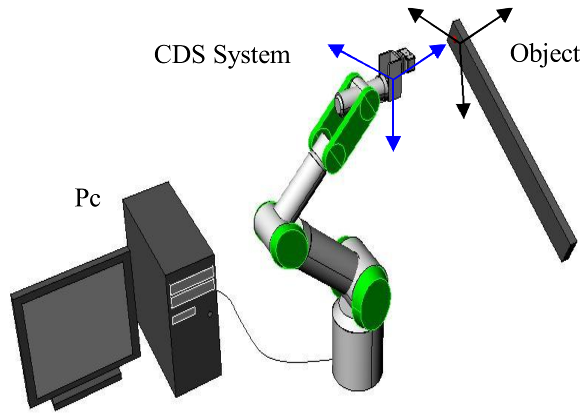


Fig.8 Robot vision system

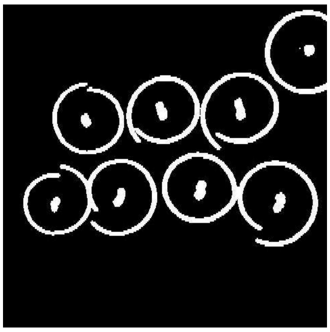


Fig.9 The image measured by robot vision system at each times

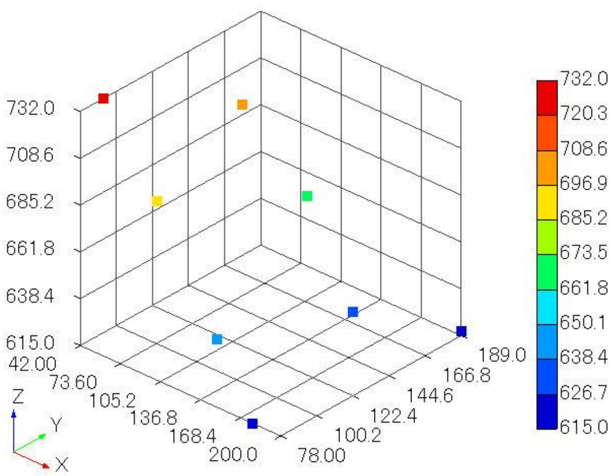


Fig10 The results of the measurement

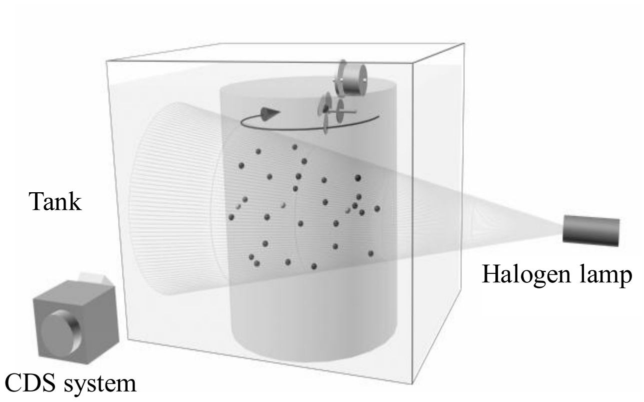
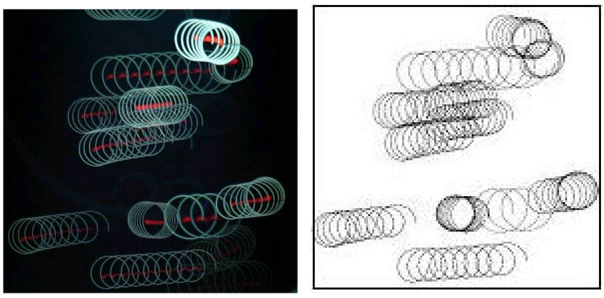


Fig. 11 Setup for flow measurement



(a) Recorded image (b) Analysis result

Fig.12 Spiral streaks of tracer particles in flow

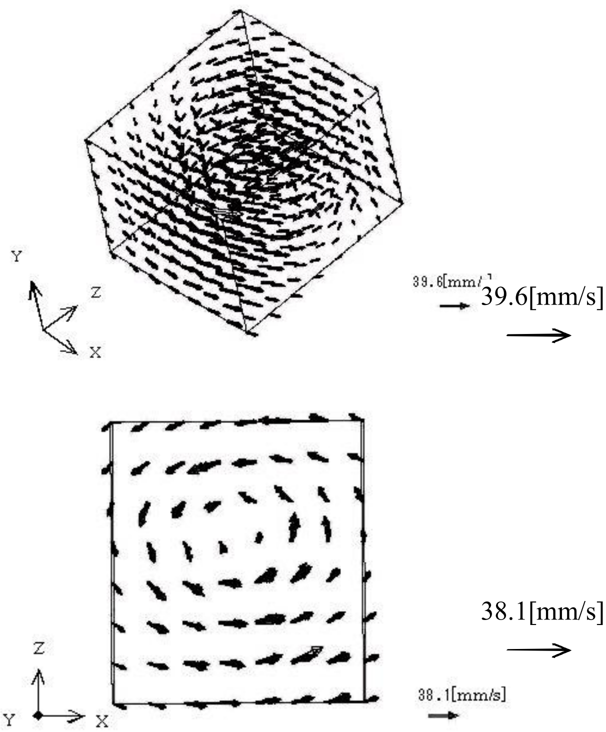


Fig.13 Velocity distribution within the cylinder tank

An example of the particles streaks is shown in Fig.12. Three dimensional positional information of tracer particle can be estimated by processing image. The estimated velocity distribution within the cylinder is shown in Fig. 13. Velocity vectors are interpolated by taking into consideration the position of the tracer particles and the velocity vector of each tracer particle.

V. CONCLUSION

We have introduced a new approach to obtain depth/distance information. A single camera and an image rotation apparatus record 3-D information on a single image. Annular streaks recorded on the image plane relate directly to the 3-D positional information of the individual measuring points. The 3-D information of the measuring points is obtained by using an image processing technique.

Our system is compact and the setup is simple since it uses a single camera. The system is thus expected to be a useful tool for various fields such as flow measurement system and robot vision system. Experimental results demonstrate the feasibility of our system.

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