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Studies on 3-Dimensional Measurement Using Multi-Images

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Abstract. Photometric Stereo technology can be used for 3D measurement and shape recovering. Point on the object can be detected in different images taken from different points of view, and the distance can be obtained according to the parallax. In this paper, binocular stereo vision was applied, using only one camera configuration with crossed axis and a rotating flat. So the effects caused by position errors and differences of performance between cameras can be eliminated. It is shown by the experiment that the measurement error is below than 5%.

1. Introduction

Many industrial applications require accurate and rapid measurement of the 3-D shapes of objects. Representative applications of 3-D shape measurement include reverse engineering, 3D replication, inspection and quality control [1]. Manufacturing industry needs a fast inspection process that can measure and analyze various 3D features on the part and determine if a feature is within the tolerance specification or not. The measurement scheme needs to be adequately accurate to eliminate measurement errors. Hence, both inspection speed and accuracy are equally important. On the other hand, synthetic images from real images processed by computer graphics (CG) technology to obtain different visual effects have been extensively applied to video making. One main aim of this work is to make the images synthesized from real images and CG look unartificial. But because depth information is lost during the process of image formation, synthesizing operation become more complicated. If the depth information could be added into images, the efficiency of synthesizing real images with CG will be greatly increased.

Coordinate measurement machines and laser based measurement techniques usually provide very accurate measurement. However, these techniques are slow because they measure various points on the part sequentially, resulting in the measurement a time-consuming and expensive task. On the other hand, vision-based techniques are usually very fast. Therefore a possible way to perform 3D measurement is to use digital cameras.

In this paper，the abstraction of 3D geometrical information from multi-images is discussed, using ordinary digital camera available in the market as input instrument. Distance and size of the objects are measured by binocular stereo vision technology.

2. 3D measurement techniques form images

3D geometrical replication from images is one of the main research issues of computer vision. Computer vision, also called 3-dimensional vision or machine vision, aims at understanding reality space from images. Some information is lost during the imaging process from real world to 2D image

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plane, so reconstruction of 3D information from images is limited. There have proposed many kinds of 3D measurement methods from images, the basic methods include the following twos.

2.1. 3D measurement from single image
Silhouette or surface profile of object can be deduced by analyzing grey variation in an image of the scene, a technology called shape from shading [2], based on the principles of perspective of optical imaging and statistical hypothesis. However, because the information provided from one single image is limited, this method has some difficulties that can not be overcome.

2.2. Stereo vision technology
There need some pre-knowledge about illumination and others to abstract 3D geometrical information from single image. On the contrary, stereo vision technology simulates the function of human eyes and can easily obtain 3D information of the object without any extraordinary requirements [3]. Taking images of one object from different points of view, detecting the position of one point on the object surface in different images, the distance of the point can be solved out according to its parallax in these images.

Two main methods to implement stereo vision technology are as following:

(1) Multiple cameras configuration with parallel axis;

(2) Multiple cameras configuration with cross axis

In this paper, techniques to measure 3D geometry of object from images based on stereo vision are studied. Experiment configuration is setup and experiment results are analyzed in the last.

3. Measurement principles

Binocular stereo vision technique was adopted in the research. The configuration with crossed axis is shown in figure 1.

For the configuration with axis-crossed two cameras setup, distance of the point on the object surface can be calculated using trigonometry measurement principles as shown in figure 2.

Pinhole model can be used to represent camera imaging, Two cameras with identical optical system and performances are intersected in the distance d0 on optical axis before each lens with the angle θ. The image from datum camera 1 is marked with footprint 1 and image from camera 2 with footprint 2. For one point P(x,y,d) in the real world, its corresponding images in two image planes are P'1(x1,y1), P'2(x2,y2) respectively. The length from lens to image plane is f. There are following relations between P , P'1 and P'2 :

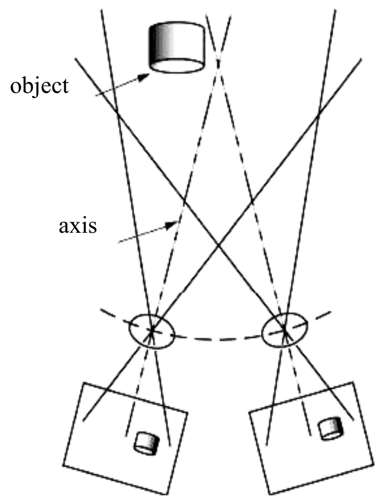

Figure 1. Stereo vision with crossed axis.

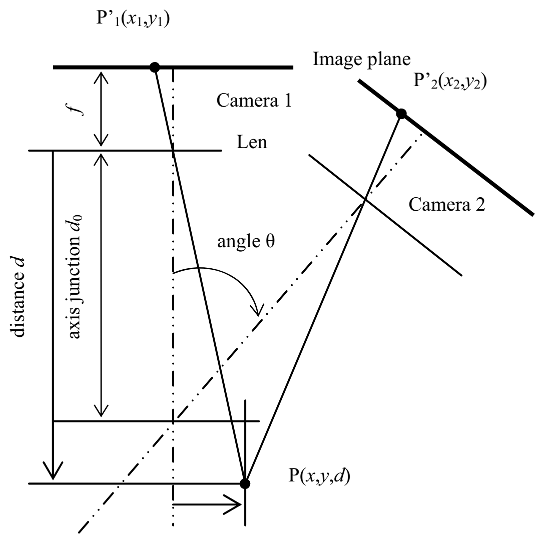

Figure 2. Sketch of coordinates calculation of object point.

$$\frac{x_1}{f} = \frac{x}{d} \tag{1}$$

$$\frac{x_2}{f} = \frac{x'}{d'} \tag{2}$$

$$y = y_1 \cdot d / f = y_2 \cdot d' / f \tag{3}$$

where

$$x' = (d - d_0)sin\theta + xcos\theta \tag{4}$$

$$d' = d_0 + (d - d_0)cos\theta - xsin\theta \tag{5}$$

Coordinates of object point P can be calculated from equations above as follows:

$$x = x_1 \cdot d_0 \cdot G(x_2) / H(x_1, x_2) \tag{6}$$

$$y = y_1 \cdot d_0 \cdot G(x_2) / H(x_1, x_2) \tag{7}$$

$$d = f \cdot d_0 \cdot G(x_2)/H(x_1, x_2) \tag{8}$$

where

$$G(x_2) = f \cdot sin\theta + x_2(1 - cos\theta) \tag{9}$$

$$H(x_1, x_2) = (f^2 + x_1 \cdot x_2)sin\theta + f(x_1 - x_2)cos\theta \tag{10}$$

4. Experiment setup and results analysis

4.1. Experiment configuration

It is almost impossible to find two cameras with identical optical system and performance, so the experiment configuration shown in figure 3 is adopted.

Center of the rotating flat is fixed on the optical axis of digital camera and the object to be measured on the flat so that images of the object from different points of view can be taken by rotating the flat with any desired angle, without moving the camera. Because only one camera is applied in the measurement, errors caused by position uncertainty between two cameras are eliminated, in favor of analyzing creating reasons of measurement errors.

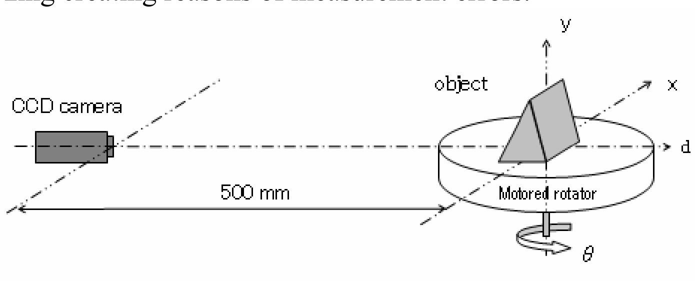

Figure 3. Experiment setup.

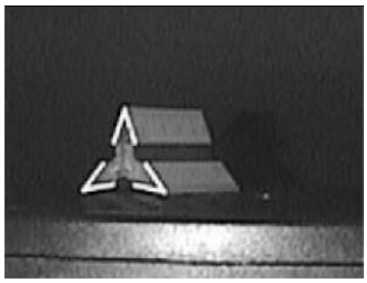

Figure 4. The object to be measured.

4.2. Position determination of optical axis intersection

In the experiment, center of rotating flat is fixed 500mm away from the end of camera lens and the position of intersection of optical axis is so determined. However, the actual position of camera lens plane is not equal to that of camera lens end, the so determined distance d_0 of the optical axis intersection is not very accuracy, hence required to be modified.

Place one object with known length L on the center of rotating flat, which is perpendicular to the optical axis of camera, and take the image. If the length of object in image is l, then the correction for d_0 can be obtained with the following expression:

$$\Delta = \frac{f \cdot L - l \cdot d_0}{l} \tag{11}$$

The camera adopted in the experiment is OLYMPUS C-4040. The correction is calculated as 28.5mm according to above expression, so the actual distance for d_0 is 528.5mm.

4.3. Distance measurement

Experiment was conducted on object with known size, as shown in figure 4. Two images were taken from two different points of view with optical axis intersectant angle as 30°, i.e. the flat is rotated by 30° between two photographing, as shown in figure 5.

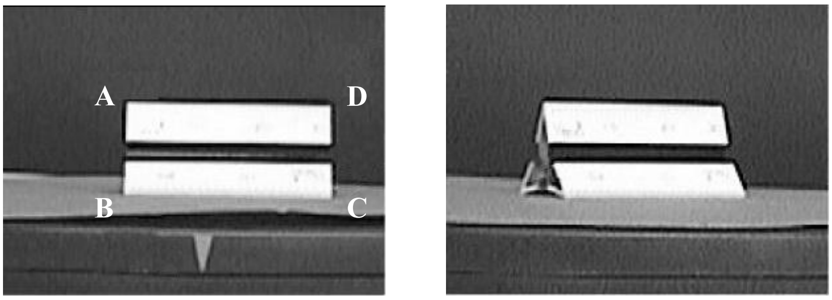

Figure 5. Images used for measurement (left-image 1, right-image 2).

4.4. Experiment results

Distances of four endpoints on the object were measured. The difference between actual distance *dt* and corresponding measured result *d* can be expressed as:

$$\delta_1 = \frac{|dt - d|}{dt} \tag{12}$$

The length of a side of the object can be calculated from coordinates of its two endpoints. The difference between actual length *Lt* and corresponding calculated result *Lm* can be expressed as:

$$\delta_2 = \frac{|Lt - Lm|}{Lt} \tag{13}$$

Here δ_1 and δ_2 are measurement errors.

Distance were measured using images shown in figure 5 and the results and measurement errors are given in Table 1. Table 2 shows calculated results of the side length of the object and corresponding errors.

Table 1. Measurement results for distance of points shown in figure5.

Points to be measured	*A*	*B*	*C*	*D*
Real distance (mm)	541	529	529	541
Coordinate d	543	528	524	532
Coordinate x	159	159	208	208
Coordinate y	135	157	158	136
Errors δ_1 (%)	0.36	0.18	0.95	1.60

Table 2. Measured length of sides of the object shown in figure 5.

Sides to be measured	*A-B*	*A-D*	*B-C*	*D-C*
Real length (mm)	24	50	50	24
Calculated results (mm)	25	51	50	25
Errors δ_1 (%)	4.20	1.8	0.64	4.26

It can be seen from tables above that the measurement errors are below than 5%. The reasons of error production were analyzed as following:

(1) Image errors caused by camera vibration during imaging process;

(2) Errors caused by deviation of the rotating flat center from the optical axis of digital camera;

(3) Errors caused by selection of endpoints of the object from images.

5. Conclusion

3D geometrical measurement can be achieved using binocular stereo vision technology from images taken by ordinary digital camera. It was shown from the research that

(1) Only one camera is utilized by using rotating flat;

(2) Effect caused by position errors between multi cameras can be eliminated by using a rotating flat.

Measurement errors production will be further explored in the future to increase accuracy. Also the application of this technology in CG video making and others will be developed.

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