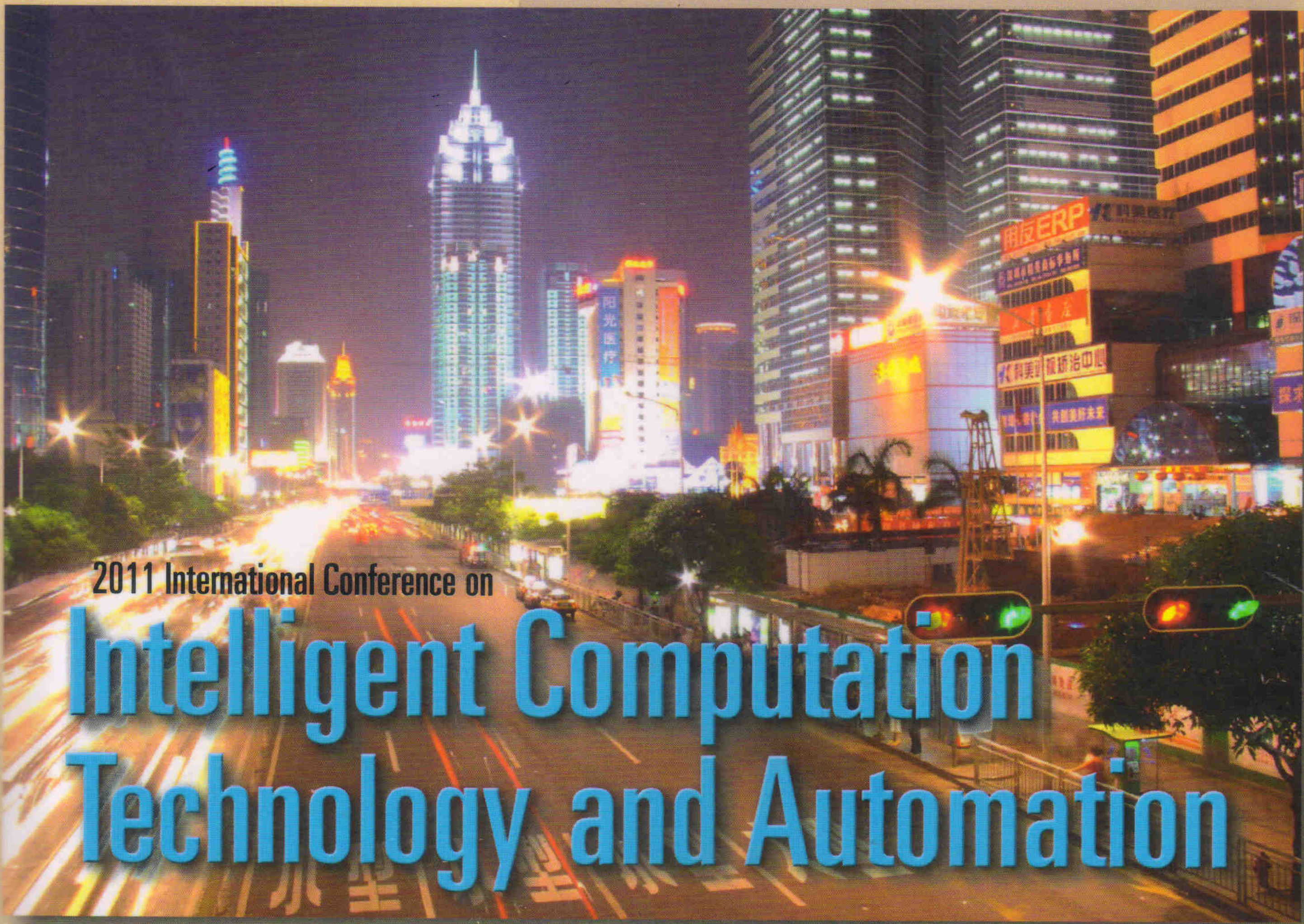

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# Build 3D Laser Scanner based on Binocular Stereo Vision

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***Abstract*—The paper presents such a low-cost and simple 3D Scanner System. The necessary hardware is a hand-held line laser and two same standard cameras. The 3D scanner system is built by using simple methods to obtain 3D information of object. So it is very easy-to use, and the results can be satisfied by normal users.**

***Keywords – scanner; binocular stereo vision; pinhole camera model; distance determination***

## I. INTRODUCTION

The 3D Scanner is a device which can obtain the 3D information of object or scene. The purpose of a 3D scanner is usually to create a point cloud of geometric samples on the surface of the subject[1]. These points can be processed and reconstructed the shape of the object. If color information of each point is also able to be collected, the surface of the object which has colors can be reconstructed. The result called three dimensional models.

There are a lot of methods for obtaining the 3D information of objects. According to different methods, it is usually divided into two types: contact and non-contact 3D scanners[1].

Contact 3D scanners need physical touch to get the 3D information. They usually has high precise. But they often need a long time to scan and it may damages the scanned object.

Non-contact 3D scanners usually uses laser or structured lighting[2] to irradiate an object and get its reflection to calculate the 3D information. Compare to contact 3D scanner, its scanning is fast, its operation is simple, more importantly, it will not damage the scanned subject. But the disadvantage is that it maybe not precise.

Many different technologies can be used to build these 3D scanning devices. And there are a lot of methods can finish 3D scanning. Each technology has its own limitations, advantages and costs. This paper proposes a non-contact and low-cost 3D laser scanner system. The necessary hardware is a hand-held line laser and two cameras. Two cameras are put at a line and they can't move when scanning. And the line laser irradiates an object vertically. Two images can be respectively got by using two cameras. There is a laser line in each image at the same time. With the position offset of laser line in two images, we can calculate the real position of points that lying on the laser line. By moving the laser like a paintbrush, the 3D data of the object are acquired until the scan results are smooth or satisfied by users.

## II. THE PRINCIPLE OF BINOCULAR STEREO VISION

Binocular stereo vision is a way of getting 3D information from two 2D images. As we all know, the pinhole camera model how 3D scene points are transformed into 2D image points. The pinhole camera is a simple [illegible] model for perspective projection as shown in Figure 1.

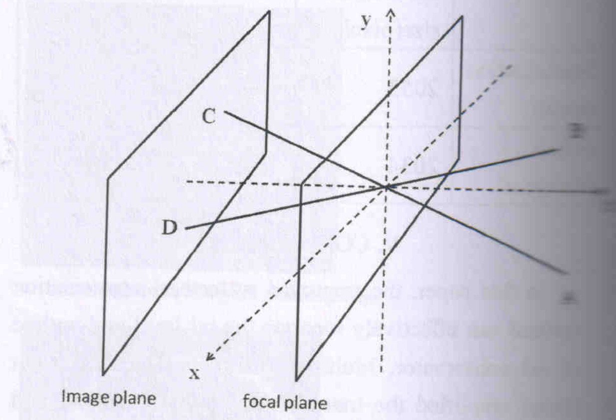


Figure 1. Pinhole camera model

In Figure 1, C, D points and A, B points [illegible] constituted a straight line respectively. And two lines [illegible] intersection. In this model, the obtained images are [illegible] images. In other words, the object image is upside down. In order to make problem convenient, the pinhole and the image plane can be swapped as shown in Figure 2[3].

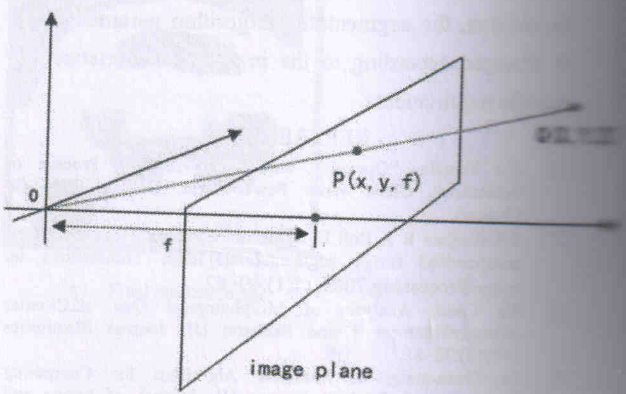


Figure 2. Swap pinhole and image plane

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As shown in Figure 3, set up a coordinate system. The left camera is at the origin of coordinates and the right camera is at the x-axes. The y-axes take the downward direction as positive. Two cameras look toward the positive direction of z-axes. $P_1$, $P_2$ are the P in left, right camera on the imaging point, respectively. L is the distance of two cameras.

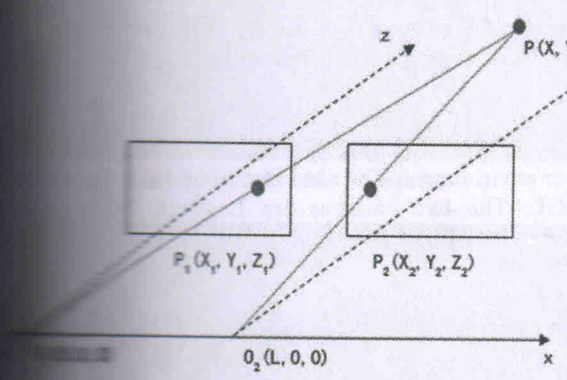


Figure 3. Binocular Stereo Vision

$O_1$, $O_2$ are at the x-axes, and the two cameras are the same type. We can know $Y_1 = Y_2$ easily. In other words, $O_1P_1$ and $O_2P_2$ are on the same plane so that they have an intersection. In Figure 3, the intersection is point P. By geometrical relations, the equation of two straight lines is:

$$\begin{cases} O_1P_1: \dfrac{X}{X_1} = \dfrac{Y}{Y_1} = \dfrac{Z}{Z_1} = t \\ O_2P_2: \dfrac{X-L}{X_2-L} = \dfrac{Y}{Y_2} = \dfrac{Z}{Z_2} = s \end{cases} \tag{1}$$

Our target is to calculate the coordinate of point P. It is necessary to know the value of t or s. By (1), the value of t can be determined as following:

$$t = \frac{Y_2 L}{X_1 Y_2 - X_2 Y_1 + L Y_1} \tag{2}$$

Bring t into the equation of the $O_1P_1$ straight line in (1), the point P can be presented as following equation:

$$\begin{cases} X = X_1 t \\ Y = Y_1 t \\ Z = Z_1 t \end{cases} \tag{3}$$

From (2) and (3), the coordinate of point P can be obtained.

## III. TECHNICAL SCHEME

The whole binocular stereo vision system is divided into five parts: Image Acquisition, Camera Calibration, Image Preprocessing and Feature Extraction, Stereo Matching, Depth Determination[4][5][6]. These five parts have their main influencing factor and guardian technique, respectively. Every part can use different methods.

In this paper, we propose a simple and fast method based on binocular stereo vision.

### *A. Image Acquisition*

In order to obtain the 3D information of an object, acquiring 2D image is the first step of stereo vision. The system usually needs two cameras at least. These cameras can be put at a line or a plane or others.

In this paper, two cameras are put at a straight line as shown in Figure 3. The distance can be known easily.

### *B. Camera Calibration*

In general, a 3D scanner system needs very complex calibration. More importantly, user often cannot finish this work. So we want to simplify this process.

As shown in Figure 3, we know that the necessary parameters are the distance of two cameras and the focal length of cameras. $Z_1$, $Z_2$ are equal to focal length. The distance of two cameras can be known easily. In general, we set this parameter to 5cm – 10 cm. Next is surveying focal length. Many cheap cameras have a fixed focal length and we can know it directly. If the camera has automatic focusing, we need to survey it. In this paper, the method of surveying focal length is not discussed.

### *C. Image Pre-processing and Feature Extraction*

The images from cameras include a variety of noise and distortion. To highlight useful information and limit useless information, it is necessary to preprocess the original image. There are two purposes. Firstly, improve the definition of images. Secondly, make images more easy to process by computer and convenient for feature analysis.

In general, the scanned subject only has about 1/3 in the image. So it is necessary to limit the scanning range. It can improve the scanning speed. More importantly, we can eliminate the background effectually. The simple method is to draw a rectangle in the image. We consider that out of rectangle is background.

The laser provides a sharp contrast to the environment. But it is also difficult to find out which pixel is the laser and which pixel is the background in two images. Image binarization is typically treated as simply a thresholding operation on a grayscale image. It is convenient for us to find out the position of laser. In this part, firstly convert original images into grayscale images, and then convert grayscale images to binary images. It can be finished by OpenCV easily.

### *D. Stereo Matching*

Stereo matching is a problem that has been argued over several decades in computer vision. Stereo matching is the most important, also the most difficult, part in stereo vision. It is the reason why we put two cameras at the same line(x-axes) and preprocess images.

As shown in Figure 3 and mentioned above, $Y_1 = Y_2$. And the line laser irradiates the object vertically. As a result, a point in left image and the matching point in right image are at the same line in the image array. Since the laser has width, we get the middle point as the matching point. As shown in Figure 4, the point (1, 3) in left image is matching the point (1, 4) in right image.

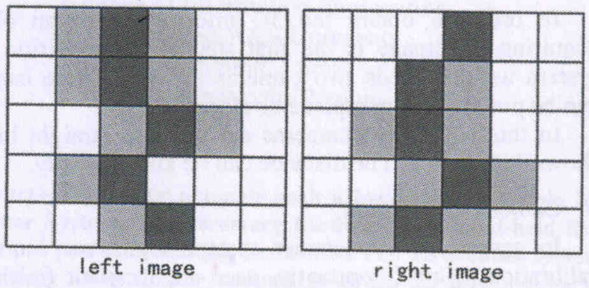


Figure 4. The green is laser line, the red is the middle line

*E. Distance Determination*

In the Figure 5, u-axes and v-axes are the coordinate system of image. Left image and right image has this coordinate system, respectively. L is the distance of two cameras.

In order to use (1), (2), (3) for calculating 3D information, it is necessary to transform 2D coordinate to 3D coordinate in space coordinate system. As shown in Figure 5, our purpose is to transform $P_1'(U_1, V_1)$ and $P_2'(U_2, V_2)$ into $P_1(X_1, Y_1, Z_1)$ and $P_2(X_2, Y_2, Z_2)$ in Figure 3.

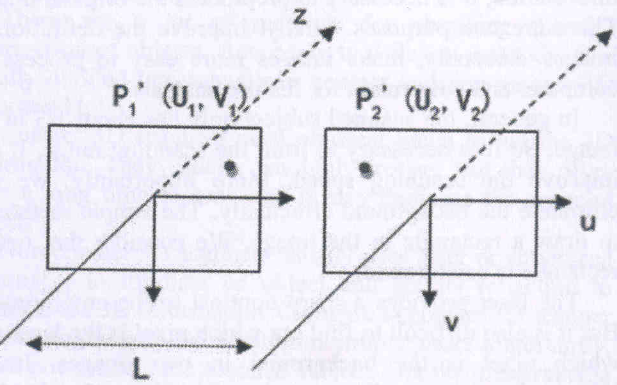


Figure 5. 2-Dimensional points coordinate

Transforming coordinate between 2D and 3D is a problem of linear algebra obviously. In following is the convert equation:

$$\begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & -\frac{w}{2} \\ 0 & 1 & -\frac{h}{2} \\ 0 & 0 & f \end{bmatrix} \begin{bmatrix} U_1 \\ V_1 \\ 1 \end{bmatrix} \quad (4)$$

$$\begin{bmatrix} X_2 \\ Y_2 \\ Z_2 \end{bmatrix} = \begin{bmatrix} 1 & 0 & -\frac{w}{2}+L \\ 0 & 1 & -\frac{h}{2} \\ 0 & 0 & f \end{bmatrix} \begin{bmatrix} U_2 \\ V_2 \\ 1 \end{bmatrix}$$

In (4) and (5), w is the width of image, h is the heig image. By moving the laser, two cameras are able to ge images continuously. Then the 3D data can be calcula until the scan results are satisfied by users.

## IV. Experimental Results and Conclusion

The programs of this system are all developed in C Creator environment. The used library includes OpenCV and OpenGL. The two cameras are Logitech QuickCam Pro 9000. The computer is Pentium(R) Dual-Core CPU T4 @ 2.10GHz.

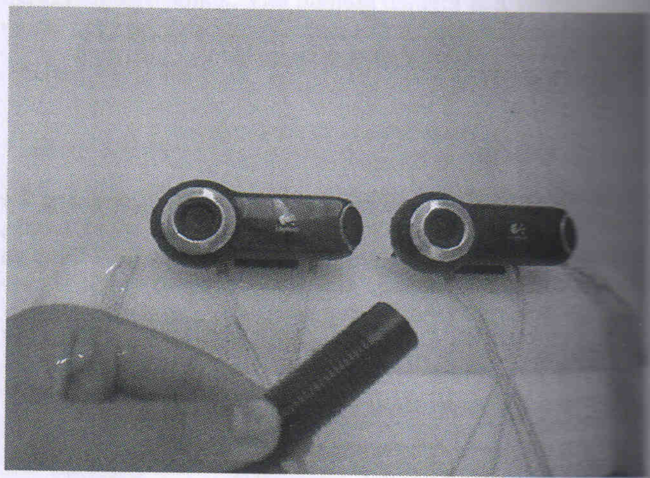

Figure 6. The hardware

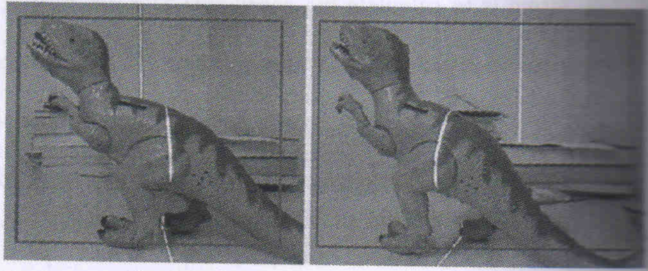

Figure 7. Limit the scanning range by rectangle

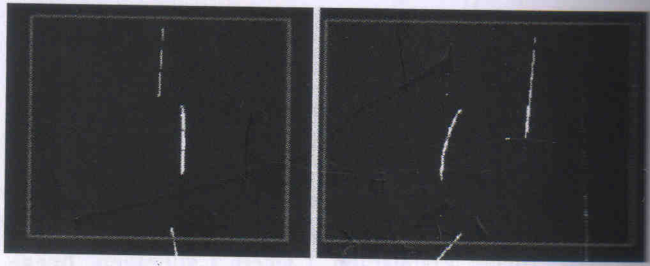

Figure 8. Image binarization

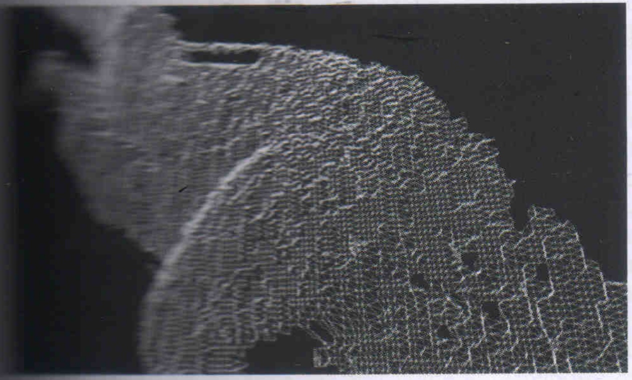

Figure 9. The result of the dinosaur model

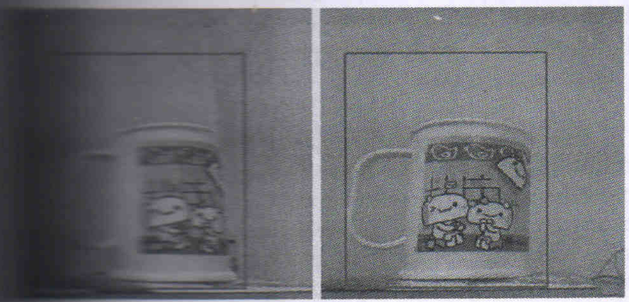

Figure 10. Scanning a cup

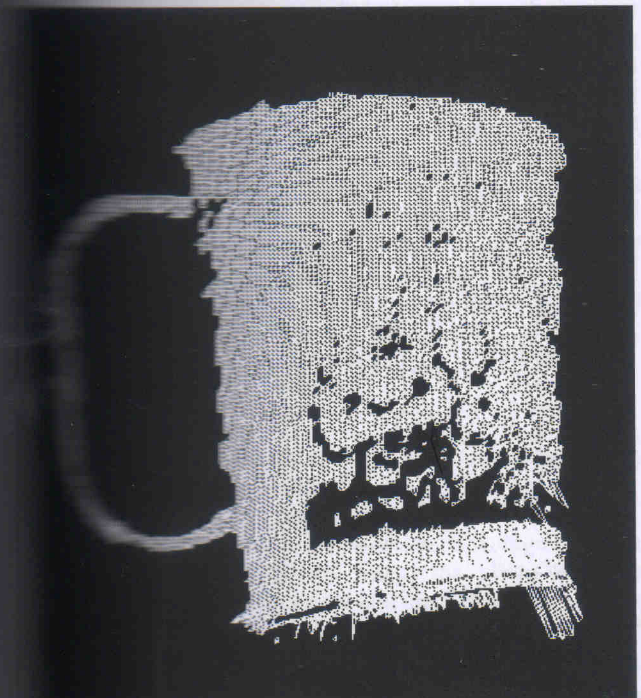

Figure 11. The result of the cup

Figure 6 shows the hardware of 3D scanner system. Figure 7 shows the images which limit the scanning range. Figure 8 shows the result of image binarization. Figure 9 shows the scanning result of the dinosaur model. Figure 10 shows another experiment which is scanning a cup. Figure 11 shows the scanning result of the cup model.

The scanning time is about 10-20s. As shown in Figure 9 and Figure 11, one side of the dinosaur model and cup model can be reconstructed. And the 3D laser scanner doesn't need complex calibration.

According to the experimental result, we can know this method can reconstruct the 3D model basically. And the precision can be satisfied by normal users. In order to get better precision, there are two methods. A method is making environment black as possible when scanning. It will make laser and background more contrast. In image preprocessing, the results will be better. Another method is increasing the resolution of images. It will make images have more particulars of object so that the result model has more points.

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