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A Camera Calibration Technique and Landscape Simulation

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Abstract: In this paper, one simple technique to calibrate the system setting of the three-dimensional measuring system is presented. Due to this technique, the three-dimensional shape of the huge structures and the buildings can be readily obtained. This technique is applied to the three-dimensional landscape simulation. Two examples are shown in this paper.

Keywords: Landscape simulation, Three-dimensional shape, Image processing, Stereo vision.

1. INTRODUCTION

In the field of urban planning and civil engineering, landscape simulation using sophisticated computer graphics is one important technique to evaluate the effects of new constructions and renovations to our environment. In almost all cases of the landscape simulation, the data processing is limited on the two-dimensional images. Of course, some landscape simulations deals with three-dimensional images. Even in such cases, three-dimensional data used are imaginary ones and not measured ones. It is a matter of fact that three-dimensional landscape simulation is more desired, of course, with the non-fictional data, possibly with data measured. One difficulty to realize the three-dimensional landscape simulation is that obtaining the three-dimensional data of the target buildings and structures is not easy. One reasonable technique to obtain the three-dimensional data is to measure the target object directly if it is possible.

One conventional technique to measure huge targets, like buildings and structures, is to use surveying instruments called theodolites. Another new technique is the photometric survey, the measuring technique is the same with the stereo vision. The photometric survey measures the three-dimensional shape of the target using the several photo those are obtained from various directions. The principle of these techniques are based on the trigonometric survey. Therefore, it is important to note that the calibrating task to establish the geometrical settings of the measuring system is inevitable to these techniques. This calibration tasks always causes troublesome adjustment of the system, and it makes the three-dimensional measurement time consuming.

One technique to cope with this troublesome adjustment is to calibrate the geometrical relation of the measuring system by the image data which are obtained by the TV camera or still camera. Many researchers have studied about this topic, and some techniques were presented. But the solution of this problem is not explicit except some special cases. One of those case is the case where at least six points whose world coordinates are known in advance can be recognized in the image. Another case is the case where the target object has some featuring shapes. Rectangular surface is one typical example of the featuring shapes. Analyzing the projected image of the rectangular surface on the film plane, the geometrical relation between the camera and the rectangular surface can be determined explicitly. Using this fact, the three-dimensional measuring of the buildings and structures can be readily executed since normal buildings and structures have rectangular surfaces and, therefore, the camera calibration is easily executed analyzing the image of this rectangular surface.

Using this technique, all we have to do is just to take images of the target buildings at arbitrary two points. Considering the feature of this technique, we applied this technique to the three-dimensional landscape simulation. Two examples of the three-dimensional landscape simulation are shown.

2. SIMPLE CALIBRATION TECHNIQUE

One simple calibration technique to derive the geometrical relation between the camera and the target regular surface is derived here.

Consider the situation as shown in Fig.1, where $X_1Y_1Z_1$ is the camera coordinate system, f is the focal length, **qi** is the position vector of i-th corner of the target regular surface, **pi**$(=(u,v,f)^T)$ is the vector to represent the projected point of the i-th corner of the target regular surface on the film plane.

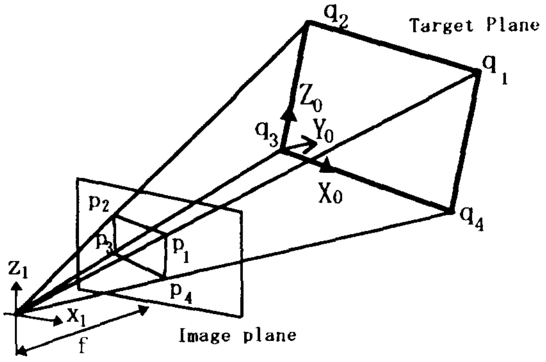


Fig.1 Camera Coordinate System

Relation between the $\mathbf{q}_i$ and $\mathbf{p}_i$ satisfies

$$\mathbf{q}_i = k_i \mathbf{p}_i$$

From the characteristics of the rectangular surface, we obtain

$$k_1\mathbf{p}_1 - k_2\mathbf{p}_2 = k_4\mathbf{p}_4 - k_3\mathbf{p}_3$$

Multiplication of $\mathbf{p}_3 \times \mathbf{p}_4$ on the both terms of the above equation gives

$$\frac{k_2}{k_1} = \frac{\mathbf{p}_1 \cdot (\mathbf{p}_3 \times \mathbf{p}_4)}{\mathbf{p}_2 \cdot (\mathbf{p}_3 \times \mathbf{p}_4)}$$

Similarly the ratio between the coefficients k_i are given by

$$\frac{k_3}{k_1} = -\frac{\mathbf{p}_1 \cdot (\mathbf{p}_2 \times \mathbf{p}_4)}{\mathbf{p}_3 \cdot (\mathbf{p}_2 \times \mathbf{p}_4)}$$

$$\frac{k_4}{k_1} = \frac{\mathbf{p}_1 \cdot (\mathbf{p}_2 \times \mathbf{p}_3)}{\mathbf{p}_4 \cdot (\mathbf{p}_2 \times \mathbf{p}_3)}$$

From the above equations, coefficients k_i are determined if k_1 is determined. This result is interesting that the ratio of the neighboring two sides of the rectangular surface can be calculated from vectors qi(i=1,,4).

Here we set the world coordinate $O_0X_0Y_0Z_0$ on the target object, where the origin O_0 is set at a corner pointed by q3, X_0 axis is set on the vector q4-q3, Y_0 axis is set on the vector q2-q3. The following relation between the camera coordinates $\mathbf{y}_1$ and the world coordinates $\mathbf{x}$ is readily obtained as

$$\mathbf{x} = \mathbf{T}_a\mathbf{y}_1 + \mathbf{x}_a \quad (1)$$

where

$$\mathbf{T}_a = \left[\mathbf{q}_4 - \mathbf{q}_3, \mathbf{q}_2 - \mathbf{q}_3, (\mathbf{q}_4 - \mathbf{q}_3) \times (\mathbf{q}_2 - \mathbf{q}_3)\right]$$
$$\mathbf{x}_a = \mathbf{T}_a(\mathbf{y}_1 - \mathbf{q}_3)$$

The above equation represents the geometrical relation between the rectangular surface and the camera.

It is also possible to calculate the focal length f of the camera from the projected image of the rectangular surface. Vector $\mathbf{p}_1 - \mathbf{p}_2$ and vector $\mathbf{p}_2 - \mathbf{p}_3$ yield a vanishing point on the image plane. Suppose the corresponding coordinates of the vanishing point on the film plane is $(u_1,v_1,f)^T$.Similarly vanishing point $(u_2,v_2,f)^T$ is determined by the vector $\mathbf{p}_1 - \mathbf{p}_2$ and $\mathbf{p}_4 - \mathbf{p}_3$. From the geometrical relation, two vectors defined as position vectors of vanishing points are perpendicular to the other. This relation gives

$$f = \sqrt{u_1 \times u_2 + v_1 \times v_2} \qquad (2)$$

Using this relation we can determine the focal length.

3. 3-D MEASUREMENT FROM TWO PERSPECTIVE VIEWS

Once the relation between the camera coordinates and the world coordinates are known using the raster coordinates of four corners of the rectangular surface, three-dimensional coordinates at any point on the target object can be determined as follows. Consider the case where two camera are settled as show in Fig.3.

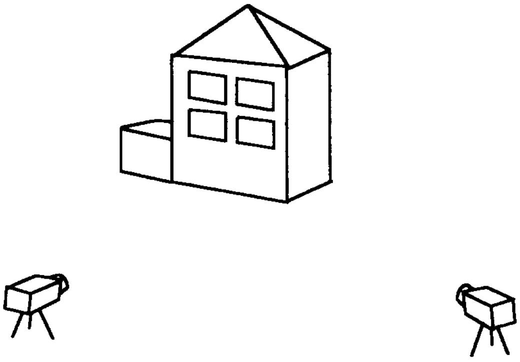


Fig.2 Experimental Setup

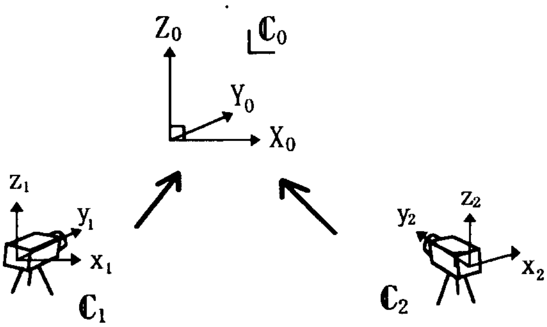


Fig.3 Definition of Coordinate Systems

Using the calibration mentioned above, the equation to transform vector on $\mathbf{y}_1$ coordinates fixed on the left-hand side camera in Fig.3 is obtained by

$$\mathbf{x} = \mathbf{T}_a\mathbf{y}_1 + \mathbf{x}_a$$

Similarly, for the vector on $\mathbf{y}_2$ coordinates fixed on the right-hand side camera we obtain the equation

$$\mathbf{x} = \mathbf{T}_b\mathbf{y}_2 + \mathbf{x}_b$$

Here we assume that one point on the target object is projected as $\mathbf{p}_1$ on the left-hand side camera, and also projected as $\mathbf{p}_2$ on the right-hand side camera. Three-dimensional coordinates of the target point can determined as $\mathbf{x}$ to satisfy the following equation.

$$\begin{aligned} \mathbf{x} &= k_1\mathbf{T}_a\mathbf{p}_1 + \mathbf{x}_a \\ \mathbf{x} &= k_3\mathbf{T}_a\mathbf{p}_3 + \mathbf{x}_b \end{aligned} \qquad (3)$$

The solution k_1,k_3 can be determined with the minimum squared error as follows.

$$\begin{bmatrix} k_1 \\ k_3 \end{bmatrix} = (\mathbf{B}^T\mathbf{B})^{-1}\mathbf{B}\mathbf{x}_c \quad (4)$$

where

$$\mathbf{B} = \begin{bmatrix} \mathbf{T}_a\mathbf{p}_1 \cdot \mathbf{T}_a\mathbf{p}_1 & -\mathbf{T}_a\mathbf{p}_1 \cdot \mathbf{T}_b\mathbf{p}_2 \\ -\mathbf{T}_b\mathbf{p}_2 \cdot \mathbf{T}_b\mathbf{p}_1 & \mathbf{T}_b\mathbf{p}_2 \cdot \mathbf{T}_b \cdot \mathbf{p}_2 \end{bmatrix}$$

$$\mathbf{x}_c = \begin{bmatrix} (\mathbf{x}_a - \mathbf{x}_b)^T \mathbf{T}_a\mathbf{p}_1 \\ (\mathbf{x}_a - \mathbf{x}_b)^T \mathbf{T}_b\mathbf{p}_2 \end{bmatrix}$$

Using Eq.(3) and(4), we can determine the three-dimensional coordinates of the target point.

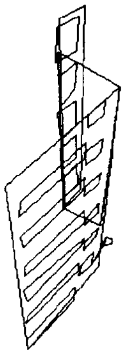
4. EXPERIMENTS

In order to test the feasibility of our technique, we took two photo of a building. Those photo are shown in Fig.4. On both photo, selected four corners of the rectangular surface (9.5 m × 17 m)are depicted on the photo. After the calibration, 84 points on the building are measured based on the trigonometric survey. The results are shown in Fig.5 as computer graphics using wire-frame representation. Estimated measuring error was about 2.4 percent.

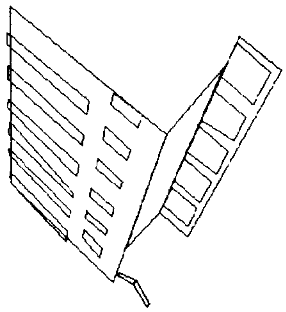
(a)

(b)

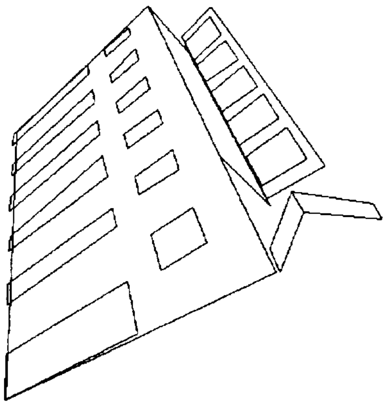
Fig.4 Measurement Object 1



(a)

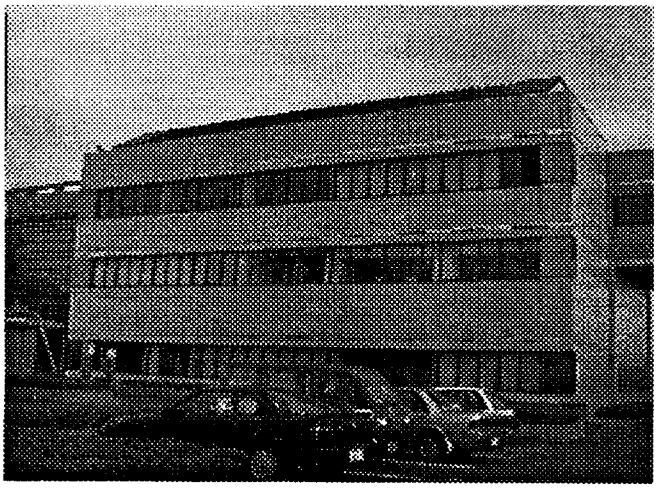


(b)

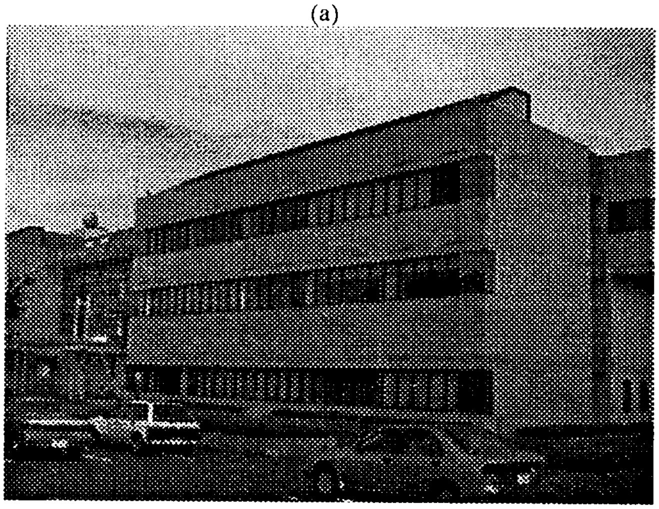


(c)
Fig.5 Experimental results 1

Another example is shown in Fig.6. This image is obtained by a handy video camera. From this image, we measured three-dimensional coordinates of 20 points. The results are shown in Fig.7.



(a)



(b)
Fig.6 Measurement Object 2

5. CONCLUSIONS

We presented one simplified technique to calibrate the system setting. Due to this technique, the three-dimensional measurement of the structures and the buildings can be easily executed. The calibration technique presented here is feasible only when the rectangular surface can be observed on the target object. This restriction is not essential. Other features of the target shape is also available to simplify the calibration procedures.

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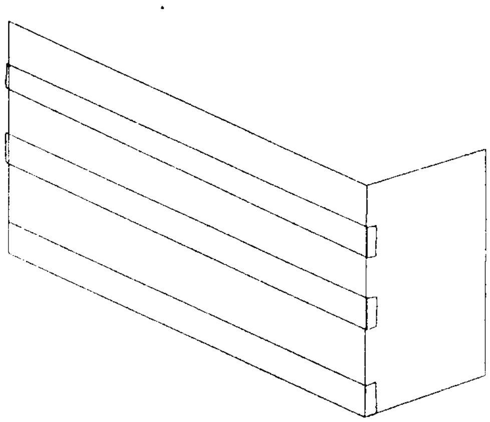
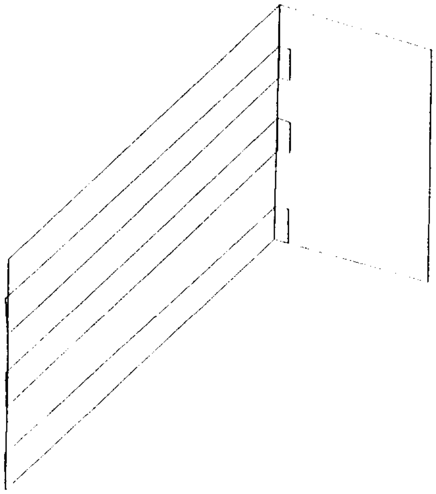


(a)



(b)
Fig.7 Experimental results 2