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Masahiko Yachida, Yoshifumi Kitamura and Masatoshi Kimachi

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Trinocular Vision : New Approach for Correspondence Problem

Masahiko Yachida, Yoshifumi Kitamura, Masatoshi Kimachi

Dept. of Control Engineering, Osaka University

1-1 Machikaneyama, Toyonaka, Osaka 560, Japan

Abstract

For recognition of 3-D shape and measurement of 3-D position of objects, it is important that a vision system can measure the 3-D data of dense points in the scene. One approach is to measure the distance on the basis of triangulation principle from the disparity of two images. This stereo method has, however, a difficult problem that is to find correspondence of features between two images. This correspondence problem can be solved geometrically by adding one more camera, that is, by trinocular vision. This paper presents the principles and implementation details of this trinocular vision.

1.Introduction

For recognition of 3-D shape and measurement of 3-D position it is important that a vision system can measure the 3-D data of dense points in the scene.

Several methods have been investigated to measure the range data in the scene [Jarvis 1983].

One approach is to measure the distance on the basis of the triangulation principle from the disparity of two images taken at two different positions, which is well known as stereo vision. Usually, feature points are first detected in both images and then correspondence of these features are found between both images. However, a problem here is that it is not easy to find correspondence of feature points. To solve this problem, several methods have been studied such as use of dynamic programming method [Ota et al 1985], relaxation method [Banard et al 1980], and coarse to fine method [Grimson 1981]. These methods take much computation time or are based on heuristic rules.

In this paper, we propose a new approach for this correspondence problem in which the correspondence problem can be solved geometrically by adding one more camera, that is, by trinocular vision [Yachida 1984, 1985, Yachida et al 1985]. This paper presents the principles and implementation details of this trinocular vision.

2. Principle of trinocular vision

Fig.1 shows the principle of trinocular vision. In the figure, F_1, F_2, and F_3 are lens centers of cameras 1,2 and 3 respectively. Let us denote the image of a point P in the scene to the image plane 1 as p_1 and to the image plane 2 as p_2. Then, to find the corresponding point of the point p_1 in the image plane 2, we search on an <u>epipolar line</u> l_2 which is the image of the line of sight F_1 p_1 to the image plane 2.

Let us call the plane made of two lines,a base line connecting two lens centers F_1 and F_2 and the line of sight F_1 p_1, as an <u>epipolar plane</u>. Then, the epipolar line can be easily obtained as the intersection between the epipolar plane and image plane 2.

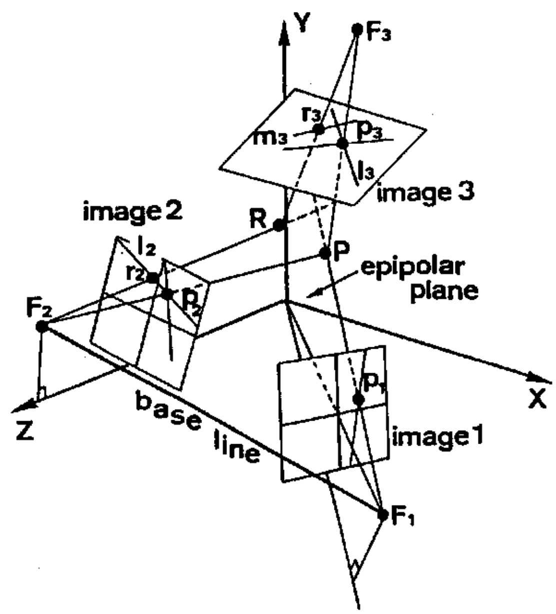

Fig.1 Principle of trinocular vision

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If there is only one point on the epipolar line l_2, it is easy to find the corresponding point of p_1. However, there are usually many points on the epipolar line because all visual points on the epipolar plane project on the same epipolar line l_2. For example, in Fig.1, a point R which lies on the epipolar plane projects on the same epipolar line l_2. Then, it is not easy to determine which of p_2 or r_2 is the true corresponding point of p_1.

This problem can be solved by introducing another camera 3. In Fig.1, p_3 and r_3 are images of the points P and R to the image plane 3, respectively. Because p_3 is the image of the point P, p_3 must lie on the epipolar line l_3, which is the image of the line F_1 p_1 to the image plane 3. However, the other points do not lie on this line l_3. Furthermore, if p_2 and p_3 are true corresponding points, p_3 must lie on the epipolar line m_3, which is the image of the line F_2 p_2.

In summary, if the point p_2 is the true corresponding point of p_1, the image of the point P must exists just at the intersection of two epipolar lines l_3 and m_3 on the image plane 3. In Fig.1, since p_1 and p_2 are true corresponding points, an image of the point P, p_3, exists at the intersection of l_3 and m_3. Thus, it is concluded that those three points p_1, p_2 and p_3 are corresponding points. Then the 3-D position of the point P is determined as the intersecting point of three lines F_1 p_1,F_2 p_2 and F_3 p_3.

In this way, by using three cameras, we can solve the correspondence problem uniquely.

3. Procedure of the trinocular vision system

Procedure to determine the 3-D position of each point by the trinocular vision system is described below.

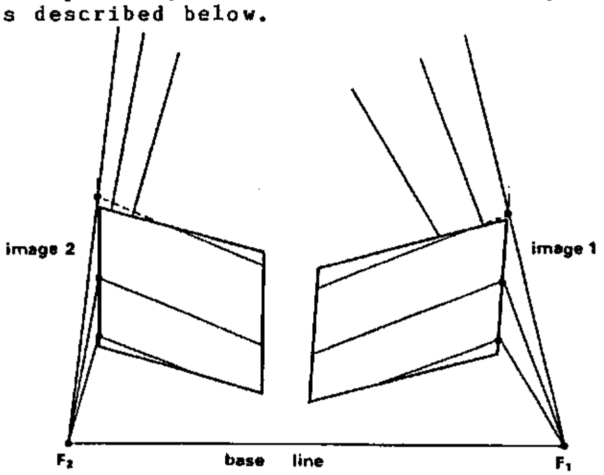

Fig.2 Generation of epipolar lines

[1] Generation of epipolar lines

Epipolar lines (l_1 and l_2) are generated in the images 1 and 2. We compute the epipolar lines l_1 and l_2 as the intersecting lines between the epipolar plane and the image planes 1 and 2.
This epipolar plane is rotated from the upper side of the image plane to the lower side of the image plane by a certain angle as shown in Fig.2. The angle is selected to a value which corresponds to one picture element. The base line is the axis of this rotation. Since those epipolar lines are constant as long as the camera arrangement is not changed, we compute the epipolar lines before hand and stores them in the table.

[2] Edge detection at each image

Sobel operator is applied each image and non-maxima suppression is applied to thin the image.

[3] Finding edges on the epipolar line

We take an epipolar line from the table of epipolar lines and search edges on the epipolar line in the image 1. If there is no edges on the epipolar line, we take the next epipolar line from the table. If there are edges on the epipolar line, goes to next step and find correspondence.

[4] Establish correspondence

If there is only one edge point at each image, its 3-D position is determined as the intersecting point of two lines F_1 p_1 and F_2 p_2.

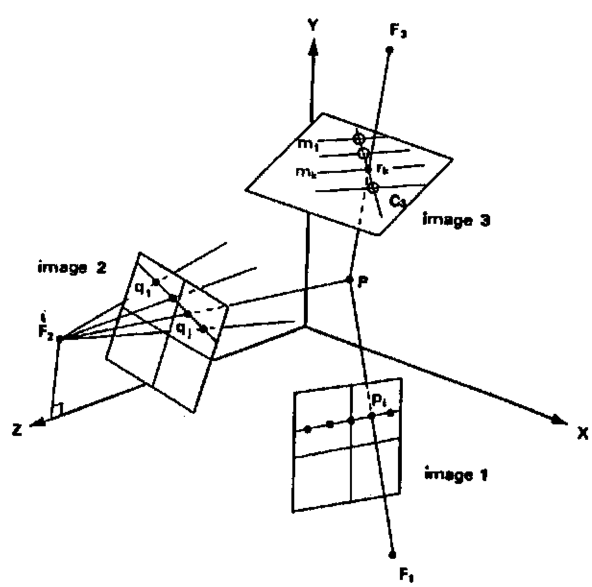

Fig.3 Finding correspondence using the third image

Otherwise, we establish correspondence using the third image (see Fig.3). From the left most point on the epipolar line l_1 of the image 1, we try to determine the correspondence.

Now, let us consider on finding a corresponding point for a point p_i. If there are n edge points $(q_1,\cdots,q_n)$ on the epipolar line l_2 in the image 2, it means that there are n candidate points for the point p_i. For each point q_j, we draw the epipolar lines $m_1,\cdots,m_n$ which are images of the line $F_2q_1,\cdots,F_2q_n$. Then there is usually an edge point at the intersecting points between the line l_3 and the lines $m_1,\cdots,m_n$.

This point is the corresponding point of p_i. From the epipolar line number where the corresponding point is found, we can also determine the corresponding point q_j in the image 2. Then, the 3-D position of the point P can be obtained as the intersecting point of three lines p_iF_1, q_jF_2 and r_kF_3.

If there is no edge point at the intersecting points, we cannot determine the 3-D position of the point p_i. This is the dead angle case where the point P is seen from the camera 1, but not seen from the camera 2 or 3.

If there are more than one edge points at the intersecting points, they are classified as candidates for correspondence. This is the rare case where some edge points other than the true corresponding point appear just on the intersecting points by coincidence.

In this case, we cannot decide which is the true one at this stage of processing. Therefore, we compute the 3-D position of each candidate point, and determine later which is the true one when the 3-D position of all other points have been obtained. That is, we select the candidate whose 3-D position is the nearest to its neighbors.

4. Experimental result

Fig.4 shows a photograph of trinocular vision system used in this experiment. Fig.5 shows cameras arrengement and world coordinates system. We measure the cameras parameters by viewing a known object put at the known position.

Then we obtain 3-D information of unknown objects using these camera parameters.

Fig.6 shows an intermediate procedure to find correspondence for a simple polyhedral scene. This is the third image. An epipolar line l_3 genarated from the first image has five intersections with epipolar lines $m_1,\cdots,m_5$ generated from the second image. However, since there exists only an edge point at these intersections, it is concluded that r_5 is corresponding point.

In this experiment, number of edge points in the scene is not so many. Therefore, only few points have multiple candidate points using only the geometrical constraint of the trinocular vision.

However, when the density of edge point increases, chances of points which have multiple candidate points also increase. Fig.7 shows the result of more complex scene. When there are multiple candidate points, we computed 3-D position for each candidate point. Therefore, those points which are not on the edge of object are false points caused by multiple candidate points.

To solve this problem we can take two approaches. First one is to use not only the geometrical constraint but also

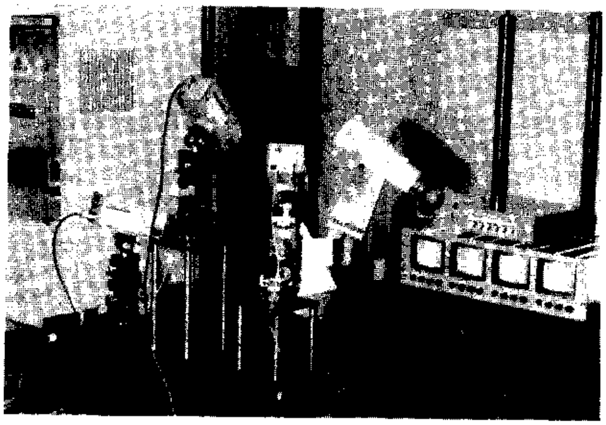

Fig.4 Trinocular vision system

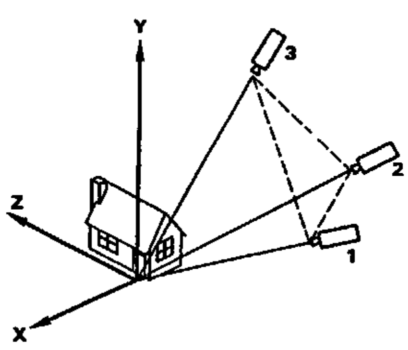

Fig.5 cameras arrengement

similarity of local properties such as brightness and edge continuity. That is, when there are multiple candidate points by geometrical constraints, we check similarity of local properties and edge continuity, and determine the true corresponding point.

The other one is to compute the 3-D position of each candidate point, and determine later which is the true one when the 3-D position of all other points have been obtained.

We have combined these two approaches. Experimental result is shown in Fig.8. You can notice that false points have been eliminated.

5. Conclusions

This paper described the principle and implementation details of the trinocular vision system. This method use more images than the usual stereo method. We plan to speed up the image processing by employing image processors now available on the market.

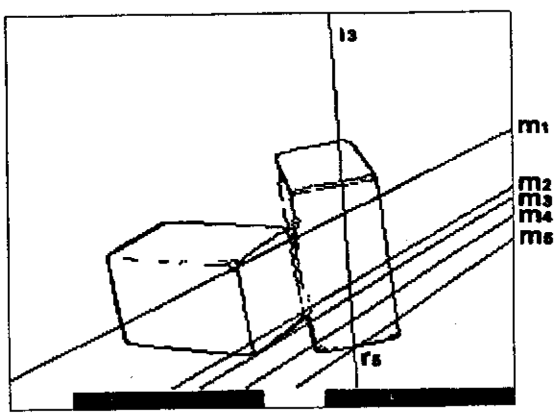

Fig.6 Correspondence procedure for a simple polyhedral scene

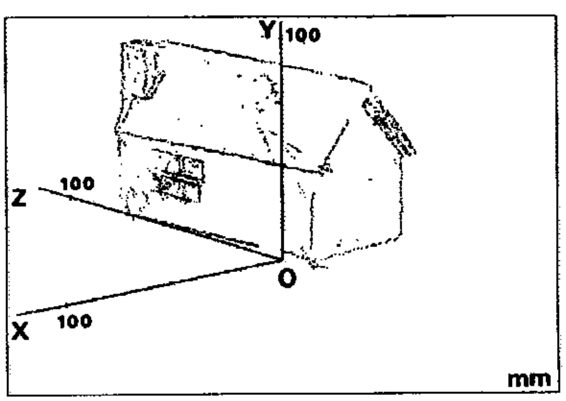

Fig.7 Result for more complex scene with only geometrical constraint

7.Acknowledgement

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References

S.T. Barnard and W.B. Thompson, 1980. Disparity analysis of images. IEEE Trans. vol PAMI-2 pp.334-340

W.E.L. Grimson, 1981. From images to surfaces, MIT Press.

R.A. Jarvis, 1983. A perspective on range finding techniques for computer vision. IEEE Trans. vol. PAMI-5, no.2, pp.122-139 March.

Y. Ohta and T. Kanade, 1985. Stereo by two-level dynamic programing, Proc. 9th IJCAI, p.1120.

M. Yachida, 1984. 3-D object recognition by multiple views (in Japanese), Nikkei Mechanical, January

M. Yachida, 3-D data acquisition by multiple views, 3rd ISRR, 1985.

Y. Kitamura and M. Yachida, Getting 3-D information by trinocular vision (in Japanese), National Conf. Robotics Society of Japan, 1985.

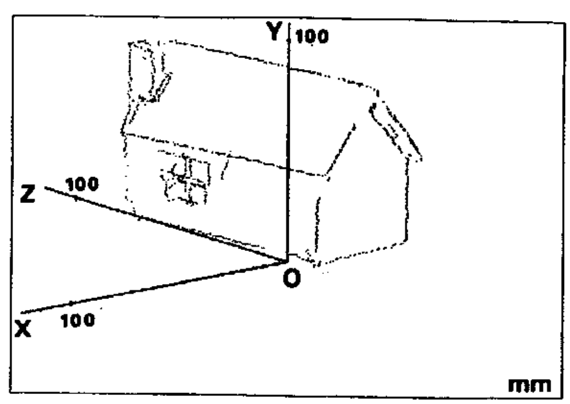

Fig.8 Result obtained when smilarity of local properties and edge continuity are also used for correspondence