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Visual Self-Location of a Mobile Robot

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Abstract *This paper presents a technique for an autonomous mobile robot to locate its own position in a visual way. The developed mobile robot perceives its surroundings through an equipped TV camera and acquires the visual information necessary for its next behavior. The robot which is assumed to move in a laboratory environment identifies its position by recognizing three different marks in the environment and analyzing the positional relation between these marks and itself. This technique was examined by an experiment and a satisfactory result was obtained.*

1. INTRODUCTION

Among many investigated mobile robots [1-4], the mobile robot described in the present paper is distinguished from others in that it is equipped solely with a TV camera as a sensor[5], and all the information necessary for giving instructions to the mobile robot on its next behavior is acquired from the images the TV camera provides. Our mobile robot research focuses its attention on realizing such a mechanism as making use of visual information as much as possible so that it can take various kinds of actions. This idea comes from the fact that 75% of the information a human acquires through his sensory organs is visual information[6]. Realization of an intelligent mobile robot which is the ultimate goal of robotics research largely depends on to what extent it can utilize the visual information. Image analysis[6,7] or image understanding[8] is, however, one of the most difficult fields of research and much work should be still continued.

Several functions have already been developed on the mobile robot under a laboratory environment. It moves on the road and turns to an indicated direction at each junction by recognizing its shape[9], traces the central part of the road with unequal width[10], and avoids obstacles on the way to its destination[11]. The present paper is involved in locating its own position by image processing. This is of great use when traveling obstructive regions or producing a map around the mobile robot automatically. An experiment for the self-location of the mobile robot is performed employing the proposed technique and some problems are discussed.

2. SYSTEM CONFIGURATION

The configuration of the whole mobile robot system has already been presented[11]. It may however be convenient to restate in the present paper how the entire system is organized.

As shown in Fig. 1, the system is mainly composed of a mobile robot equipped with a single TV camera, an image acquisition device, and a 16-bit personal computer. The robot itself contains an 8-bit micro-processor which contributes to communicating with the main computer and controling the behavior of the robot directly through a pair of wheels. Confronting scenes of the robot taken by the TV camera are successively transmitted through an equipped video transmitter to the image acquisition device where the video signals are transformed into 256×256 pixels digital images with 16 gray levels. The main computer analyzes these images to obtain the information on the robot's situation changing every moment and sends back the instructions for the next behavior to the robot.

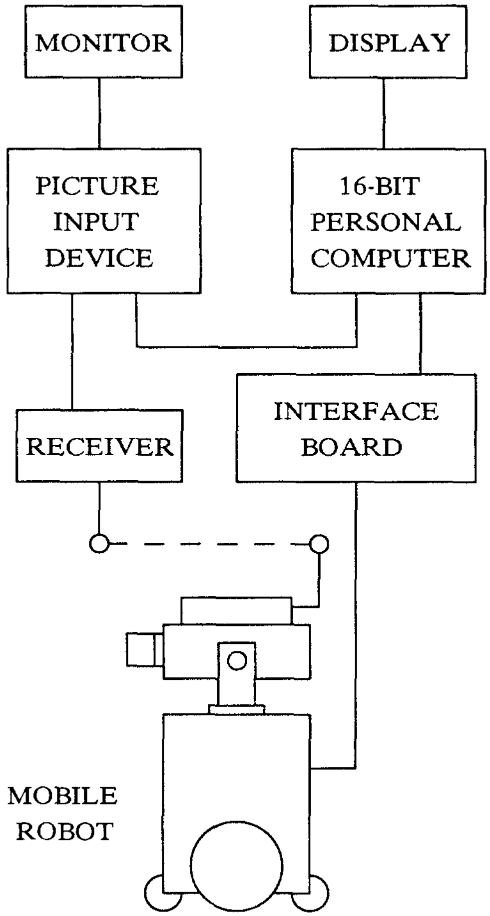

Fig. 1. Configuration of the developed mobile robot system.

The developed mobile robot is 17cms wide, 21cms long, and 31cms high, and has a pair of main wheels and two small parts for the support of the body. It has four stepping motors; two for rotating the wheels, and the other two for panning and tilting the TV camera. Panning of the TV camera ranges from −180° to 180°, while tilting from −30° to 30°. The robot travels at a controllable speed ranging from of 0.7cm/s to 2.4cm/s. The present mobile robot is rather small-sized compared with other mobile robots[1–3], since it is assumed to work in a laboratory environment. The entire system control is primarily done by the 16-bit personal computer. A larger computer such as a work station or a mini-computer was not employed for economy in the present system.

3. VISUAL SELF-LOCATION

In the present study, three marks painted on different boards are set in advance in the robot's world and the positional relation between these marks and the robot is analyzed employing the images acquired by the TV camera on the robot. This procedure is described here in detail.

3.1 The Principle of Self-Location

Let us denote the position of the mobile robot by X(x, y) as shown in Fig. 2 and assume that, among three points O, P and Q where the boards with artificial marks are set, the point O coincides with the origin of the xy rectangular coordinate system and Q exists on the y axis.

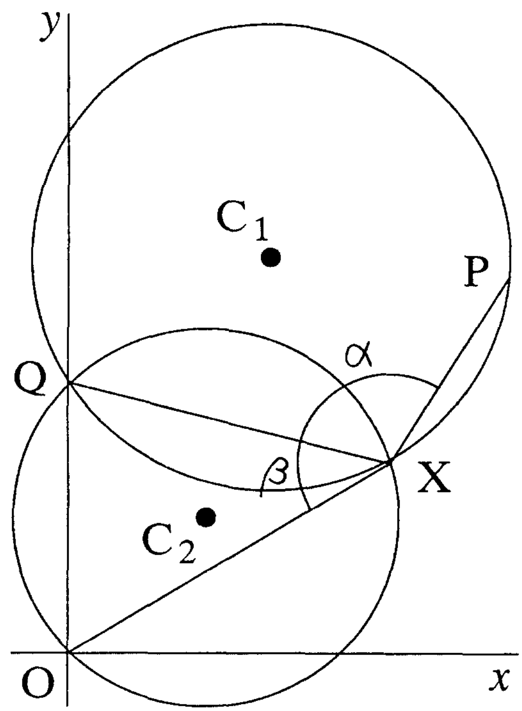

Fig. 2. Geometrical relation between the three positions where the marks exist and the position of a mobile robot. The coordinates are X(x, y), O(0, 0), P(x_p, y_p), Q(0, y_q), C_1(x_1, y_1), and C_2(x_2, y_2).

Then the coordinates of these points are denoted by O(0, 0), P(x_p, y_p), and Q(0, y_q). Note that these points are fixed in advance.

Suppose the robot measured the directions of the marks at the points O, P and Q, and obtained the result that $\angle PXQ = \alpha$ and $\angle QXO = \beta (0 \leq \alpha, \beta < \pi)$. Then the robot exists at a point where the circle passing the points P, Q and X intersects the circle passing O, Q and X. Let us denote the center and the radius of the former circle by $C_1(x_1, y_1)$ and r_1, respectively, and those of the latter circle by $C_2(x_2, y_2)$ and r_2, respectively. Then, employing the *sine theorem*,

$$r_1 = \frac{PQ}{2 \sin\alpha} \quad (1a)$$

$$r_2 = \frac{OQ}{2 \sin\beta} \quad (1b)$$

where

$$PQ = \sqrt{x_p^{\,2} + (y_p - y_q)^2} \; ,$$

$$OQ = y_q \; ,$$

holds. Since the center $C_1(x_1, y_1)$ is on the perpendicular bisector of PQ and $C_1Q = r_1$, the following equations hold:

$$y_1 = -\frac{x_p}{y_p - y_q}\left(x_1 - \frac{x_p}{2}\right) + \frac{y_p + y_q}{2} \; , \quad (2a)$$

$$x_1^2 + (y_1 - y_q)^2 = r_1^2 \; . \quad (2b)$$

In the same way, we have

$$y_2 = \frac{y_q}{2} \; , \quad (3a)$$

$$x_2^2 + y_2^2 = r_2^2 \; . \quad (3b)$$

Equations (2) and (3) settle the centers of the circles C_1 and C_2 at fixed positions, since the radii r_1 and r_2 are already known by Eq. (1).

The position X(x, y) of the mobile robot is finally calculated employing the solutions of Eqs. (2) and (3) and the relations

$$(x - x_1)^2 + (y - y_1)^2 = r_1^2 \; ,$$

$$(x - x_2)^2 + (y - y_2)^2 = r_2^2 \; .$$

3.2 Preparation

The three employed marks are made of black and white vertical stripes of different numbers and width as shown in Fig. 3 and

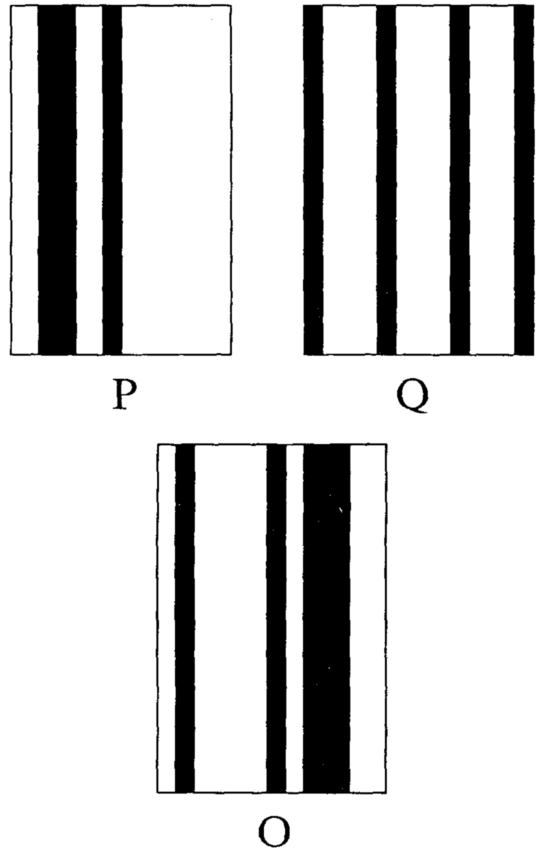

Fig. 3. Three marks P, Q and O employed for the self-location.

painted on three different boards. They are placed at corners of a rectangular area on the floor of the laboratory in which the mobile robot is assumed to travel.. In the experiment stated later, these boards exist at O(0, 0), P(373, 303) and Q(0, 333), respectively. (The unit of the coordinates is 'cm'.) It is assumed that the TV camera mounted on the mobile robot can catch these marks when it is set horizontal.

In order to find exact direction of a perceived mark, it is necessary to derive from its image the horizontal difference in position of the center of the mark from the TV camera's optical axis. Calibration is therefore performed to take correspondence of horizontal angles between an actual scene and its image. An image of a set of vertical line segments with an equal interval is acquired by the TV camera and is compared with the zoomed image of the same set of line segments to find horizontal differences in the positions of corresponding line segments. A line segment in the set having no such difference with its corresponding line segment contains the point where the optical axis and the image plane meet. As the result of the calibration, the optical axis of the TV camera intersects its image plane at the point on the column x=148 and the horizontal difference of 1° in an actual scene is equivalent to approximately 9 pixels successively chosen on a row of the image plane.

3.3 Entire Procedure for the Self-Location

The mobile robot begins self-location by initializing the TV camera direction. It then tries to find the marks by panning the TV camera from the right to the left in the model environment, and, once it succeeds in getting the directions of all the marks, calculates its own position. If the mobile robot fails in detecting at least one of the marks, it changes the observation point by making a move. This will happen when the inner product tends to zero between the unit vector on the optical axis of the TV camera and the normal of the board caught in the provided image. Figure 4 shows the flowchart of the entire self-location procedure.

3.4 Search for the Marks by Image Processing

The purpose of processing the image obtained from the TV camera is to judge if it contains one of the three marks and, once it is found, to calculate the horizontal difference between the center of the mark and the optical axis of the camera. The boards on which the marks are painted have enough height and appropriate distance from the robot to occupy not a small part of the image as shown in Fig. 5. One may also expect that it usually exists in the upper part of the image. Therefore, two rectangular regions R_1 and R_2 are considered in the upper half of the image plane to achieve the quick and exact judgment. In the performed experiment, these regions are chosen as $R_1=\{(i,j)|\ i=0,1,2,...,255,\ j=20,21,22,...,45\}$ and $R_2=\{(i,j)|\ i=0,1,2,...,255,\ j=60,61,62,...,85\}$. The region R_1 is mainly analyzed, while the region R_2 is used subsidiarily to confirm the result obtained from R_1. Each column in the region R_1 is scanned to take the average of the gray levels. Figure 6(a) shows the result of this procedure applied to the image containing the mark P in Fig. 3. These average values are binarized by a

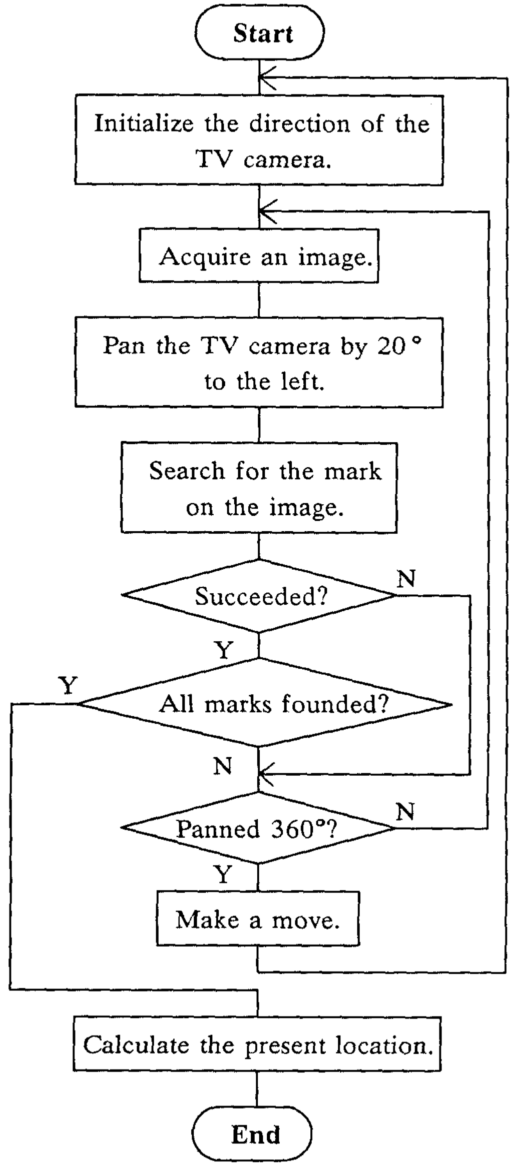

Fig. 4. The flowchart of the self-location process.

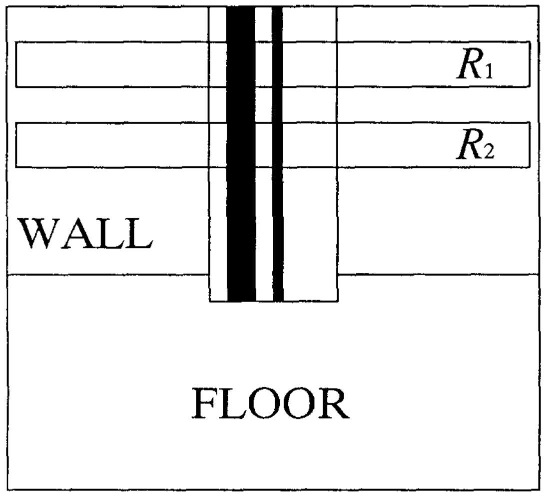

Fig. 5. The mark in an image and the regions R_1 and R_2 chosen for fast image processing.

certain threshold level so that the intervals on the abscissa corresponding to black/white stripes can be extracted easily as shown in Fig. 6(b). The width of each successive interval is then measured and their ratio is compared with that of the original marks to judge match or mismatch. The width values of those successive stripes of the original marks P, Q and O are in the ratios 3:5:3:2:11, 5:2:5:2:5 and 2:7:2:2:5, respectively. Note that five successive stripes are chosen on each mark for the comparison. The same procedure is applied to the region R_2, and if the mark detected in R_1 is also extracted at almost the same position in R_2, match is concluded finally.

4. EXPERIMENTAL RESULTS

The proposed self-locating technique for the mobile robot was examined by an experiment. The robot identified its own position at ten different points on the floor in the model environment. The results are shown in Table 1. The largest error was 11 pixels with respect to the ordinate. Note that, though the coordinates are calculated by real numbers, the results are rounded to integers.

5. DISCUSSION

The experimental results were satisfactory. The mobile robot managed to find those marks on the boards by image processing. This may be because the marks are simple shaped and have large contrast within themselves such as black and white stripes. Moreover, the boards the marks are painted are rather large enough to be extracted from the images the TV camera provides. All of these led to the satisfactory results, though, as far as the backgrounds of the boards concerned, there was no particular re-

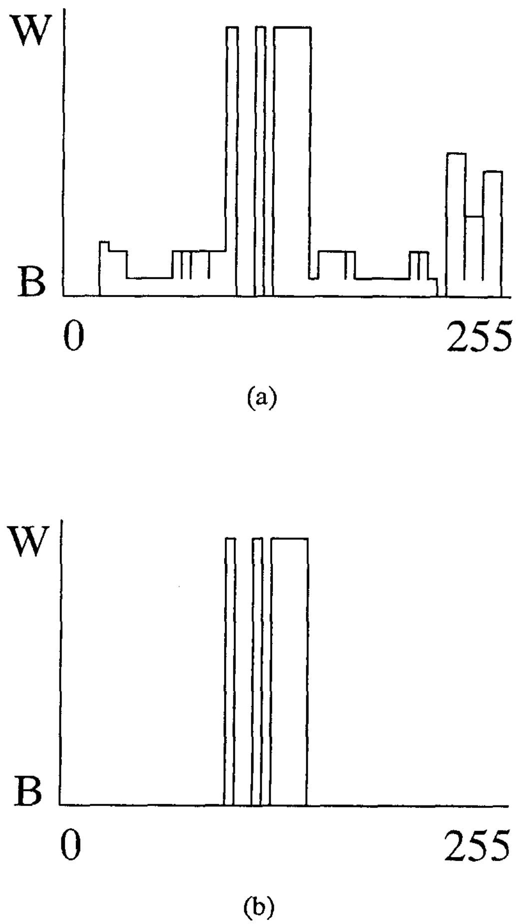

Fig. 6. The result of the image processing applied to an image containing the mark P: (a) averaging gray levels; and (b) binarization. The abscissa is the horizontal position of the image, while the ordinate shows the gray levels.

Table 1. The experimental result. True coordinates values of the mobile robot and those values observed.

	TRUE VALUES	OBSERVED VALUES
1	(91, 61)	(93, 60)
2	(164, 245)	(168, 238)
3	(164, 138)	(166, 135)
4	(164, 61)	(165, 56)
5	(256, 245)	(260, 243)
6	(256, 138)	(252, 129)
7	(256, 61)	(257, 61)
8	(340, 245)	(342, 244)
9	(340, 138)	(347, 140)
10	(340, 61)	(344, 72)

striction except that the experiment was performed in a laboratory.

Obviously, the image processing part consumes much time, since a large number of successive images need processing. Hardware implementation could be realized with this part, since the operations in the region R_1 are individually rather simple.

The proposed self-location technique of a mobile robot could be applicable to automatic map producing. It would also offer better performance with respect to the obstacles avoidance by a mobile robot[11].

The employment of artificial marks for self-location is, however, unlikely to be practical when a mobile robot travels in the real world. In this case, some well visible objects, *e.g.*, tall buildings or towers, could be employed in place of such artificial marks.

6. CONCLUSION

The system configuration was explained of a mobile robot which is equipped solely with a TV camera and moves employing the information acquired from the successive images the TV camera provides. The system was then applied to locating the position of the mobile robot in a model environment making use of artificial marks set in the environment. The technique was examined by an experiment and satisfactory results were obtained. The proposed self-location technique could be applied to automatic map production and to the travel among obstacles by a mobile robot. In order to speed up the image processing part of the proposed technique, its hardware implementation should be investigated.

REFERENCES

[1] T. Kanade: "Overview of research on autonomous mobile robots in the US", *J. Robotics Society Japan*, **5**, 5, 44–51(1987).

[2] H. Mori, S. Kotani, H. Ishiguro, S. Yasutomi, Y. Chino: "Self-contained mobile robot in campus road", *J. Robotics Society Japan*, **5**, 5, 29–42 (1987).

[3] M. Yachida, T. Ichinose, S. Tsuji: "Model-guided monitoring of a building environment by a mobile robot", *Proc. 8th Int. Joint Conf. Art. Intell.*, 1125–1127(1983).

[4] T. Matsumoto, S. Yuta: "Autonomous navigation system for mobile robots using the route map", *J. Robotics Society Japan*, **5**, 5, 19–28(1987).

[5] A. Kido, K. Gouhara, K. Ide, S. Ishikawa, K. Kato : "On a vision dependent mobile robot ", Inform. Process. Society Japan Technical Report, MC-47-5(1987).

[6] E. L. Hall: *Computer Image Processing and Recognition*, Academic Press, New York(1979).

[7] A. Rosenfeld, A.C. Kak: *Digital Picture Processing*, Academic Press, New York(1976).

[8] Y. Shirai (Ed.): *Pattern Understanding*, Ohm Book Co., Tokyo(1987).

[9] S. Ishikawa, H. Tamura, N. Harada, K. Ide, K. Kato : "A self-moving vehicle with a visual sensor ", *Bull. Kyushu Inst. Tech.*, 53, 55–62 (1986).

[10] S. Ishikawa, A. Ohishi, A. Kido, K. Ide, K. Kato : "A self-moving vehicle with a visual sensor II ", *Bull. Kyushu Inst. Tech.*, 55, 69–76 (1987).

[11] S. Ishikawa, K. Gouhara, K. Ide, K. Kato : "A vision based mobile robot travelling among obstructions", *Proc. '88 Korean Aut. Control Conf.*, 2, 810–815(1988).