3-D Range Sensor using Fiber Grating for Recognition of Autonomous Mobile Robot's Passage Space

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***Abstract*—A 3-D range sensor system for an autonomous mobile robot is reported. It is important for a mobile robot to recognize spaces of passage. In this sensor system, the passage space is detected with an active vision sensor using a Fiber Grating, laser diode, and CCD camera. The Fiber Grating vision sensor can easily obtain 3-D information about the object. In our system, the object is the floor and the system measures the height of the floor. In this case the height is nearly equal to zero, so the robot can perceive that the measured area is passagable. An image processing module using a Transputer(T805) is developed for this purpose. In this paper, the principle of the sensor and the method for passage space recognition are presented. The hardware and software of the system for our autonomous mobile robot "Yamabico" is presented. Experimental results are also presented.**

I. Introduction

When a robot moves autonomously in a real environment, a sensor system is necessary with which the robot can find obstacles, determine passage and can recognize its own position. In order to know the relationship between the world and itself and to get information about the environment. It is useful to know whether the floor is passagable or not.

We have developed an active vision sensor system using a laser slit for obstacles avoidance for an autonomous mobile robot[1]. The robot can detect obstacles using this sensor, but cannot perceive the safety of the floor. We have recently developed an 3-D range sensor system using a Fiber Grating vision sensor and an image processing module. This sensor system monitors the floor ahead of the robot and detects passage space. In this paper, the principle of this sensor and the method for the detection of passage space are presented. We examine the effectiveness of this sensor system through experiments using the autonomous mobile robot equipped with this system.

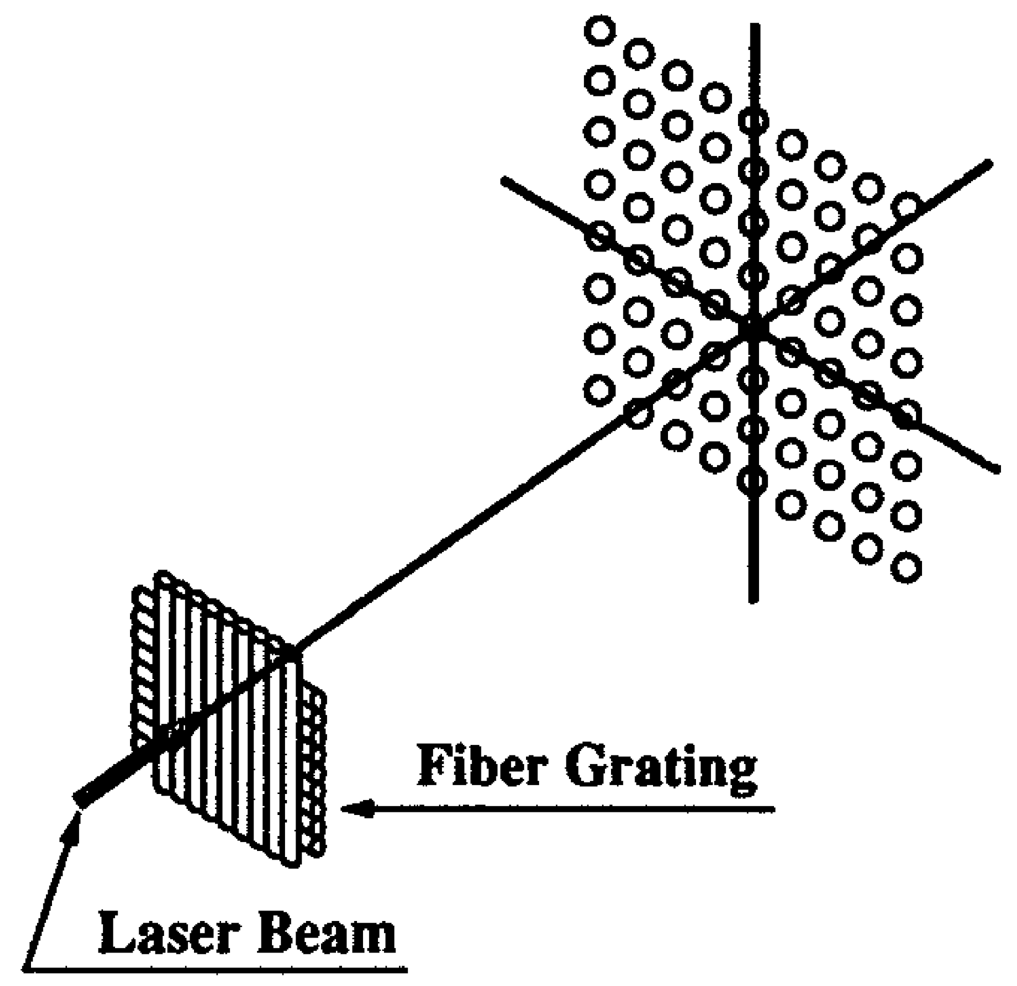

Fig. 1. 2-dimensional spot array generated by Fiber Grating.

II. Fiber Grating Vision Sensor

Fiber Grating (FG) is a diffraction grating which is constructed from overlaid two fiber sheets crossing at right angles. Each sheet consists of several hundred optical fibers lined densely[2]. When the FG is irradiated by laser light, each optical fiber works as a cylindrical lens and laser light is once condensed and diverges spherically. Every spherical waves interfere one another and tetragonal array of spot light is generated ahead of the FG as shown in Fig.1.

Fiber Grating vision sensor (FG sensor) is an active vision sensor using a FG, a laser diode, and a CCD camera[3][4]. The spot array is generated by a FG, reflected light is detected by CCD camera, and a 3-D range image is obtained by triangulation. This sensor has some merits that it can easily obtain 3-D informations about objects and that it can be easily mounted on a small size mobile robot because the sensor system is small in size and light weight.

This sensor may be influenced by the illumination of the environment. Its performance is extremely lost in the out-

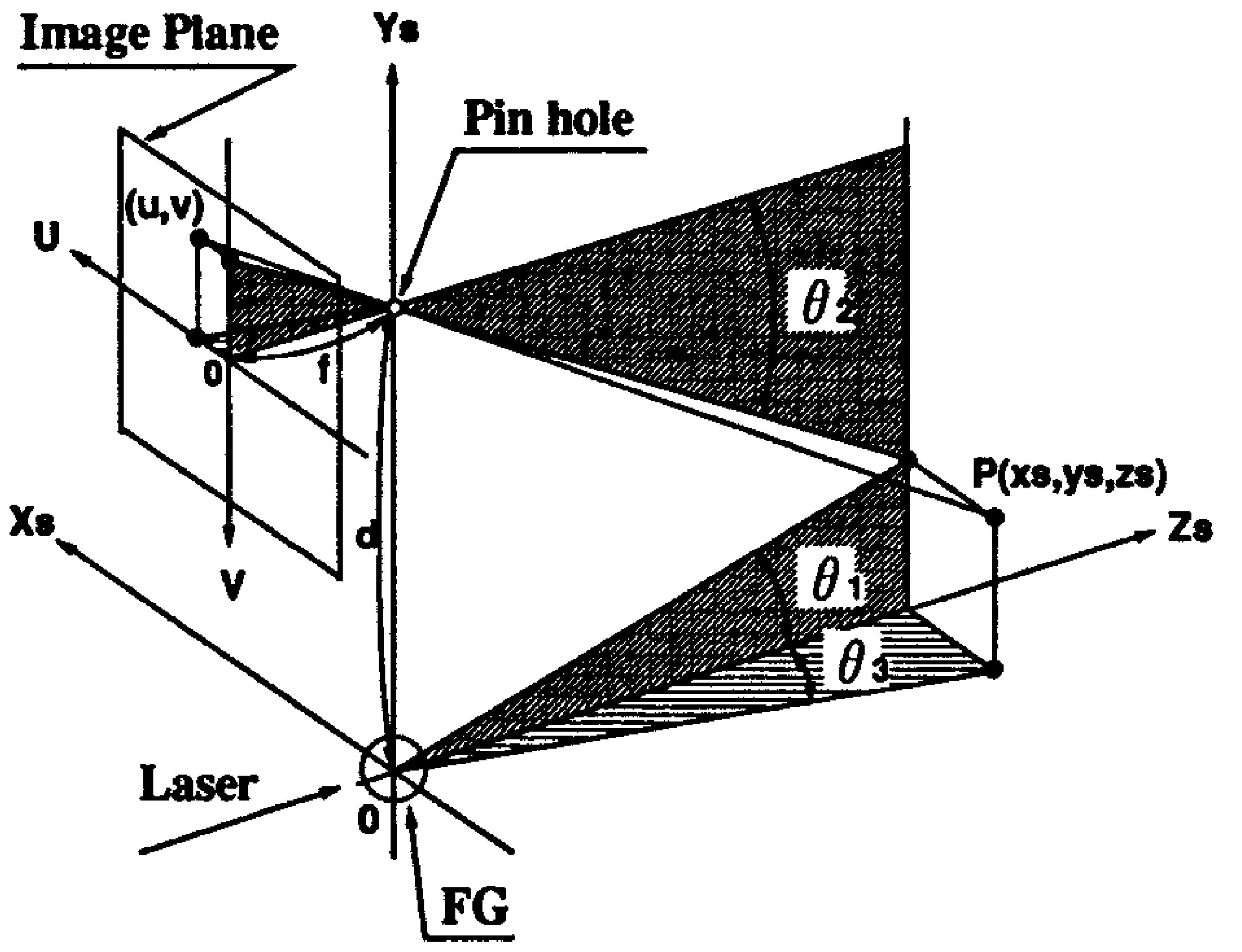

Fig. 2. Optical arrangement of FG sensor.

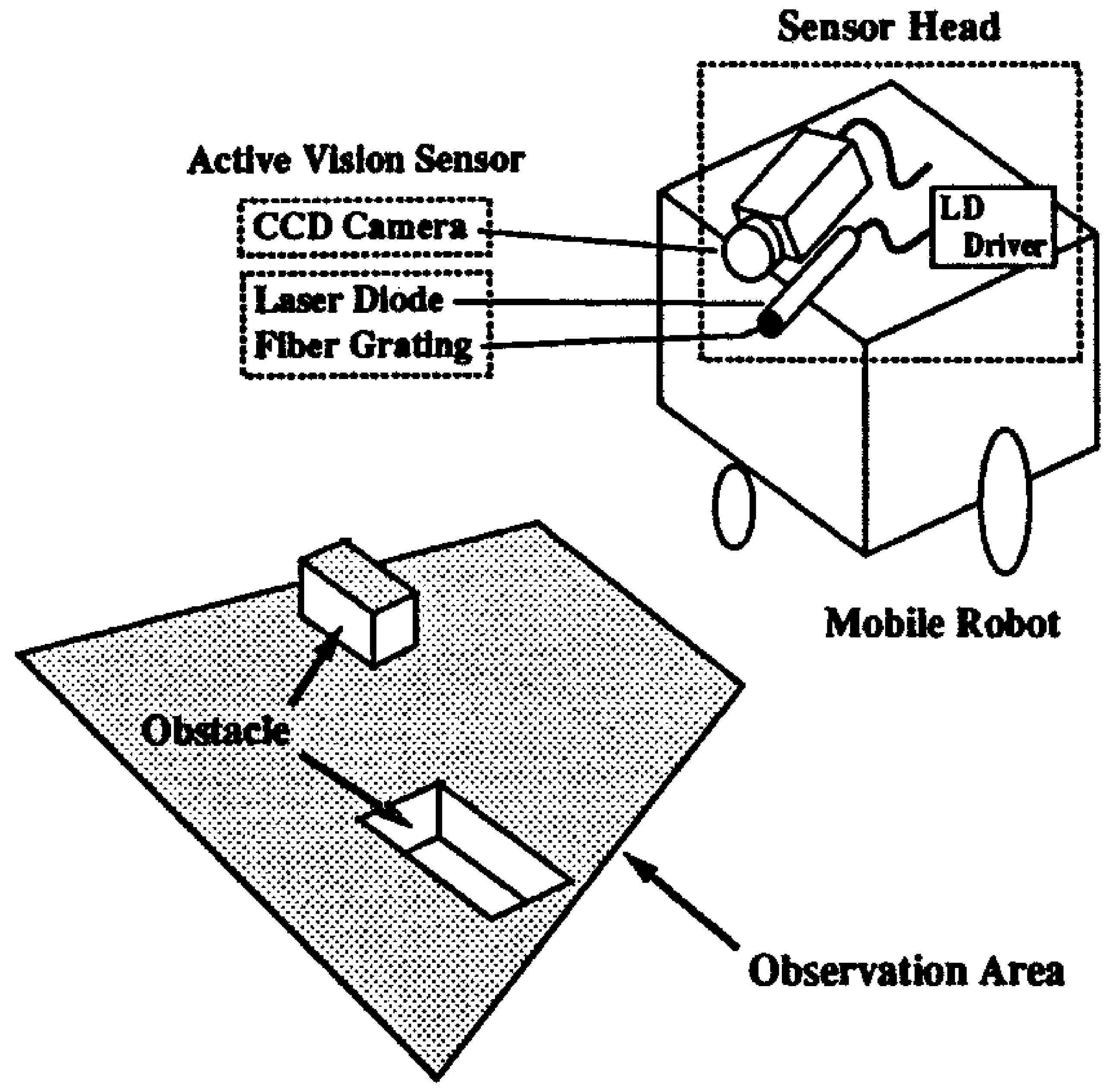

Fig. 3. Method for passage space recognition.

door environment. However, it works successfully under the ordinary indoor illumination.

Fig.2 shows the optical arrangement of the FG sensor. The position of spot moves in the direction of V axis on the image plane according to the range z_s. If the value of z_s is limited in a certain measurement space, the position of the spot on the image plane moves only in a limited area. In this case, the order of diffraction of each spot can be recognized and θ_1 is determined. θ_2 and θ_3 are obtained from the position of spot on the image plane (u, v). Thus, the 3-D coordinate (x_s, y_s, z_s) of the reflecting point of each spot is calculated by Eq.(1) using the distance d between FG and camera.

$$\begin{aligned}
\theta_2 &= \tan^{-1}\left(\frac{v}{f}\right) \\
\theta_3 &= \tan^{-1}\left(\frac{u}{f}\right) \\
x_s &= z_s \tan\theta_2 \qquad (1) \\
y_s &= z_s \tan\theta_3 \\
z_s &= \frac{d}{\tan\theta_1 + \tan\theta_2}
\end{aligned}$$

III. Passage Space Recognition

Fig 3 shows the method for determining the passage space using the FG sensor described in the previous section. The sensor is mounted on top of the mobile robot and obtains 3-D information about the floor ahead of robot in order to detect obstacles. An autonomous mobile robot which works in the indoor environment mostly moves on flat floors. In this situation, if the position and posture of the sensor are fixed, the spot array projected on the floor is detected at a constant position on the image plane. On the contrary, when an obstacle exists on the floor, the position of the spot moves according to the height of the obstacle. The passage space can be detected by checking whether spots exist at a constant position or not. This method can be easily processed and is very effective for real time obstacle detection.

This sensor system has several advantages:

1. 2-D information about the front floor can be obtained without any mechanical scanning system.
2. The system is reliable since the passage is recognized only when reflected light from the floor is detected.
3. The sensor can easily be mounted on a mobile robot because the system is small in size and light weight.

IV. Implementation of Sensor System

In order to realize this sensor system on our autonomous mobile robot "Yamabico", we construct the system and implement it on "Yamabico".

A. *Hardware*

The sensor is constructed from a laser spot array projector and CCD camera (Fig.4). The laser light source of the projector is a laser diode (wave length: 830nm, output power: 30mW) and the spot array is generated by a FG. The field of view of the camera is wide (focal length of lens: 8.5mm) and an infrared filter is used to extract only light of the laser. The spot array projector is 7.5cm

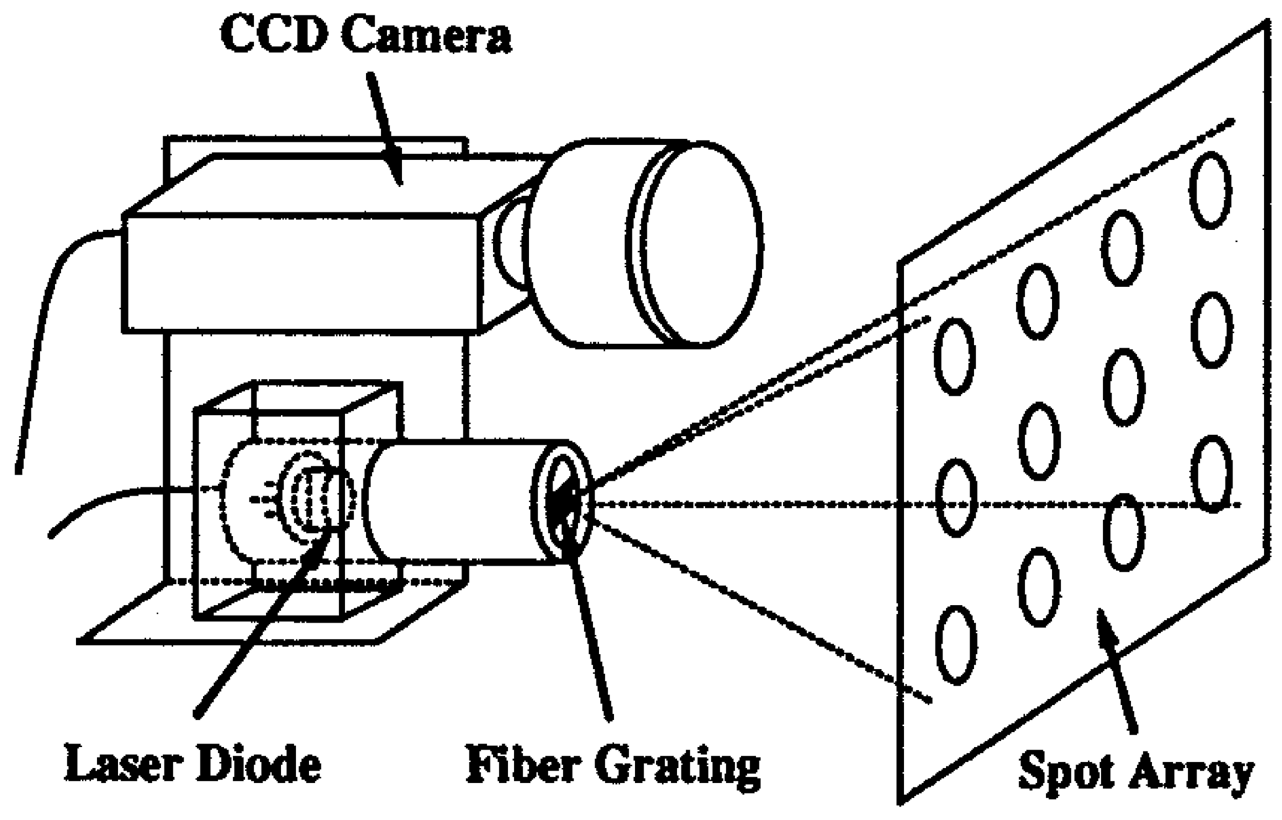

Fig. 4. Configuration of the sensor head.

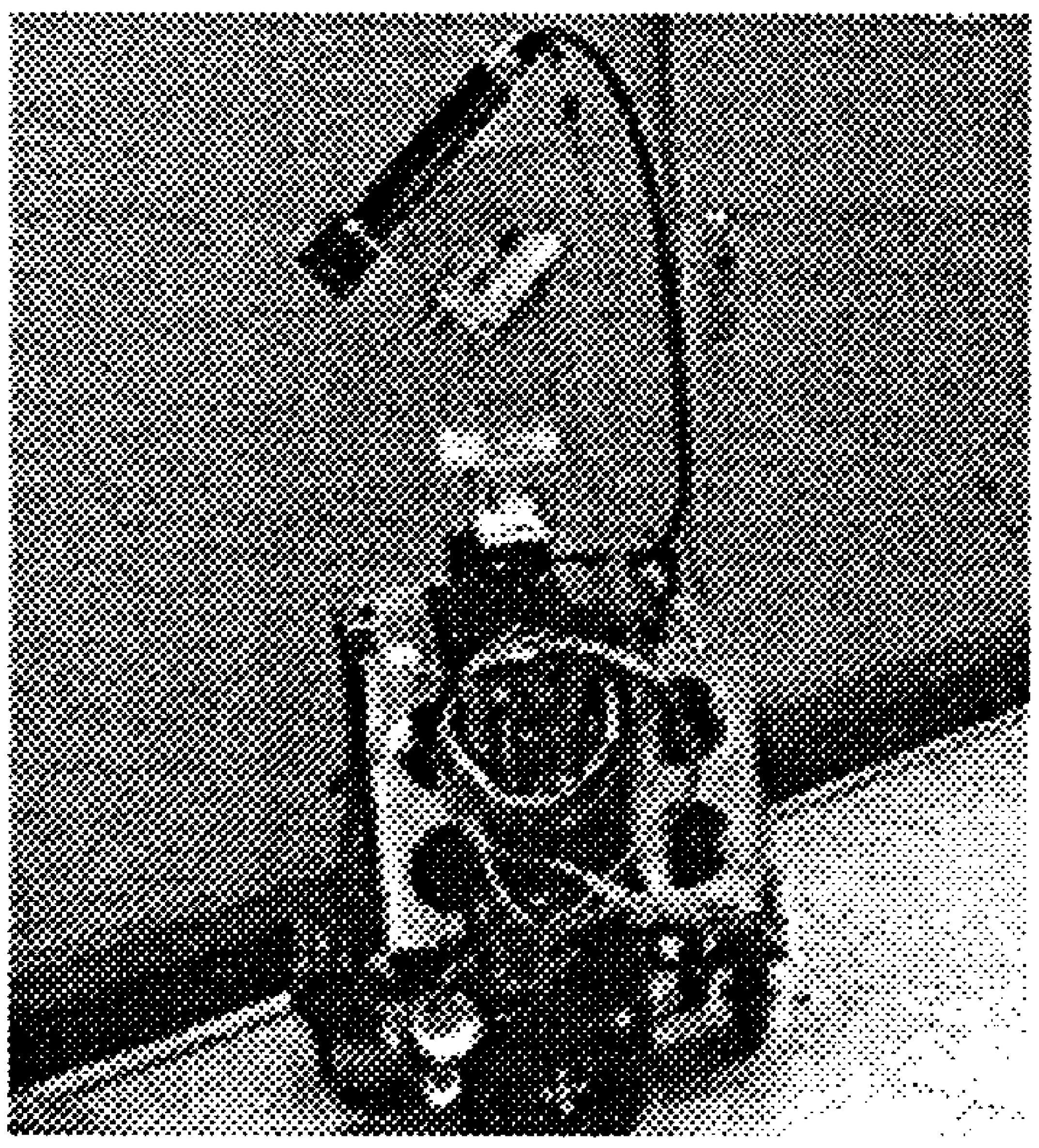

Fig. 5. Autonomous mobile robot "Yamabico".

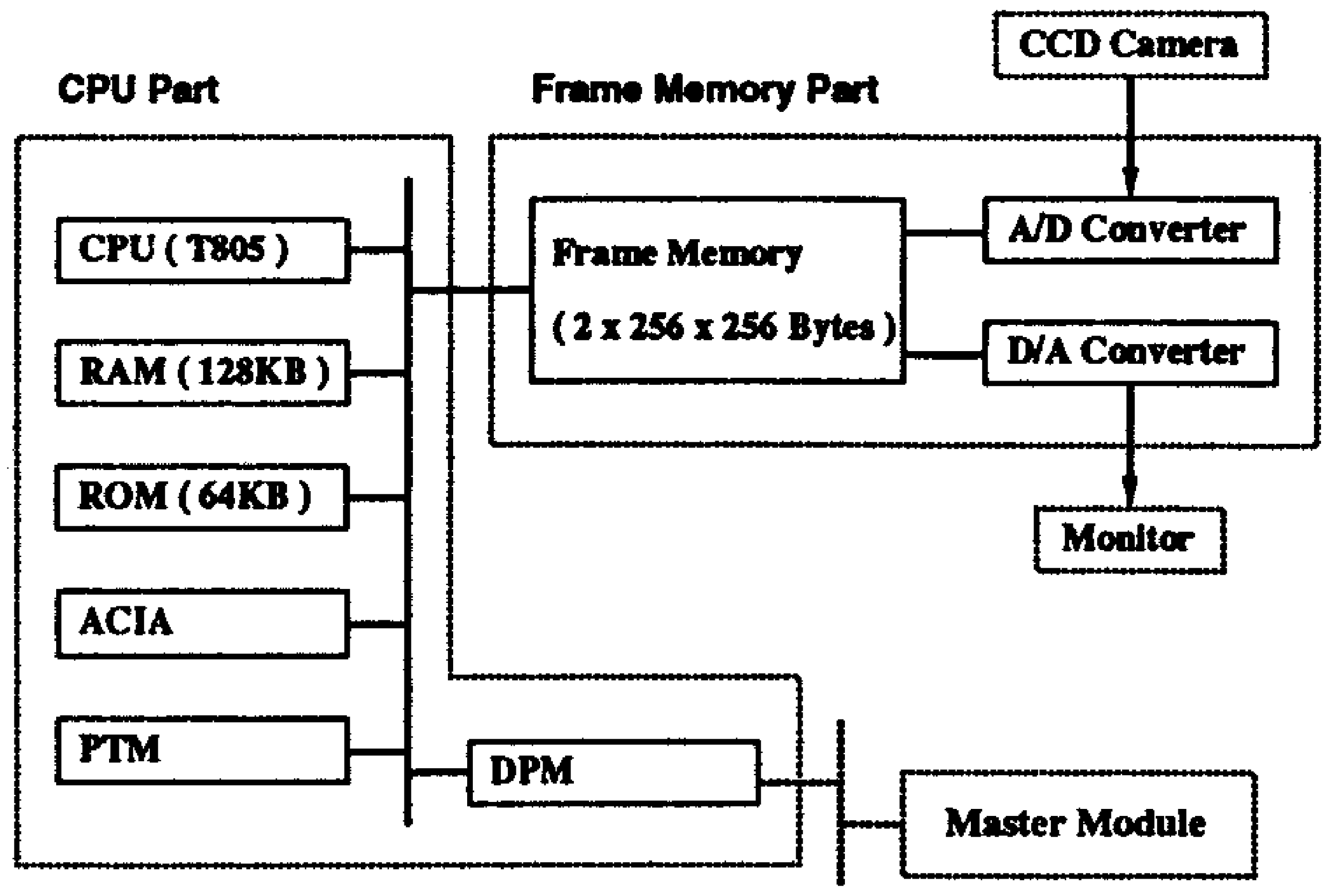

Fig. 6. Architecture of the sensor module.

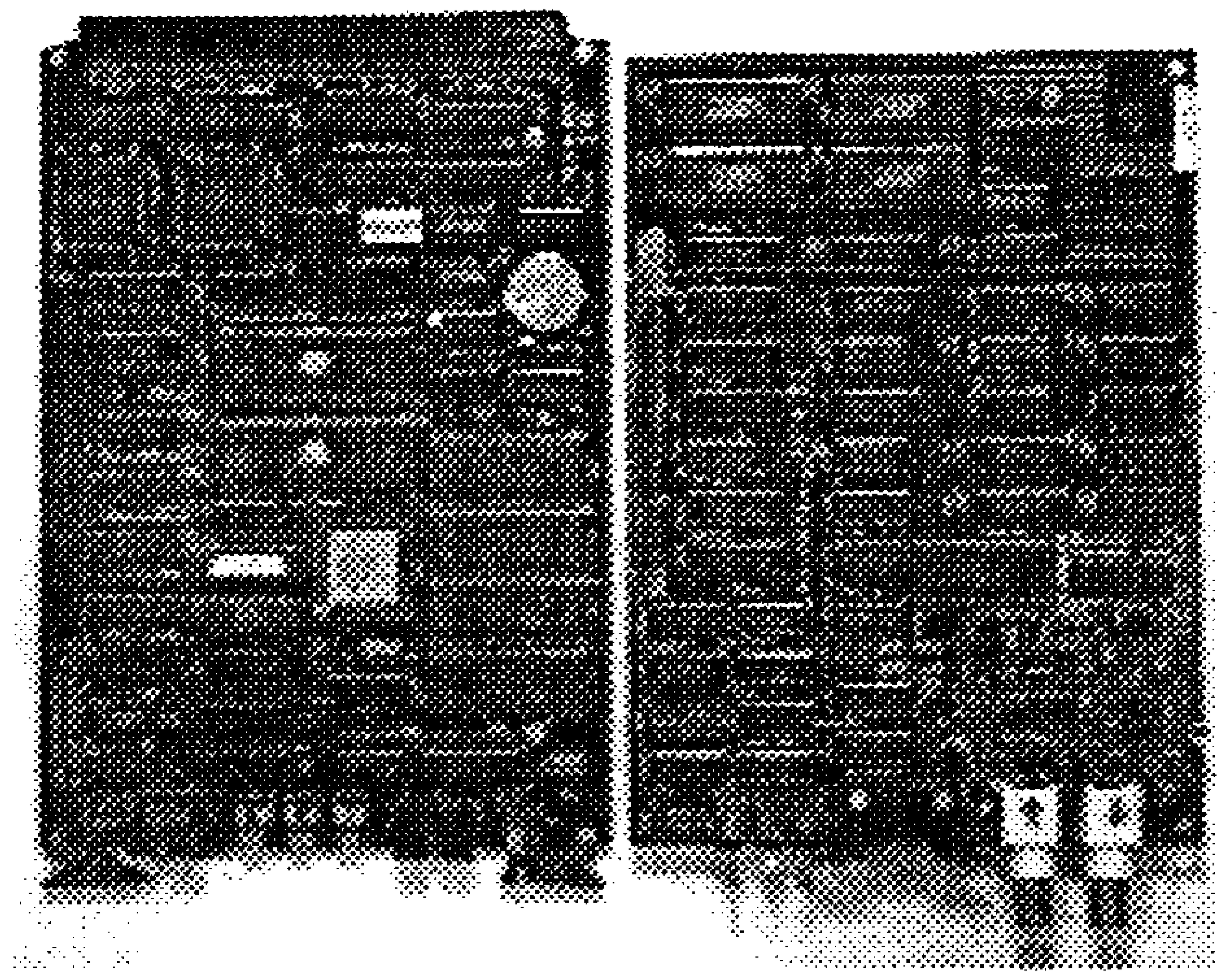

Fig. 7. Image processing module.

away from the CCD camera and is fixed in parallel with the camera. Its height is 53cm from the floor and its tilt angle is 40 degree(Fig.5). In the case of this arrangement, about 300 spots are projected, the range of 45cm to 160cm ahead of the robot can be measured and the angle of field of vision in the horizontal direction is 40 degree.

The sensor module processes the obtained images and generates sensor information. Fig.6 shows the architecture of the sensor module. This module is constructed from a CPU part and a frame memory part which can store two images (256 × 240 pixel, 256 gray scale). In this module, video signal from the CCD camera is A-D converted and can be stored in one of two image memories. The clock signal of the CCD camera is used as the timing signal for sampling in the A-D conversion. In the CPU component, a Transputer (T805) is mounted as the processor, with RAM (128KB) and ROM (64KB) also. Communication with the master module of the "Yamabico" is carried out through the Dual Port Memory (DPM; 2KB). The sensor module is implemented on a two layered circuit board (20.7cm×15.2cm; Fig.7).

B. *Software*

The software for the passage space recognition on the floor uses the following algorithm, implemented on the image processing module mentioned above.

1. Acquire the image.

2. Calculate the position of the center of gravity.

3. Safety check of the floor by comparison with reference data which is beforehand obtained when only the floor is measured.

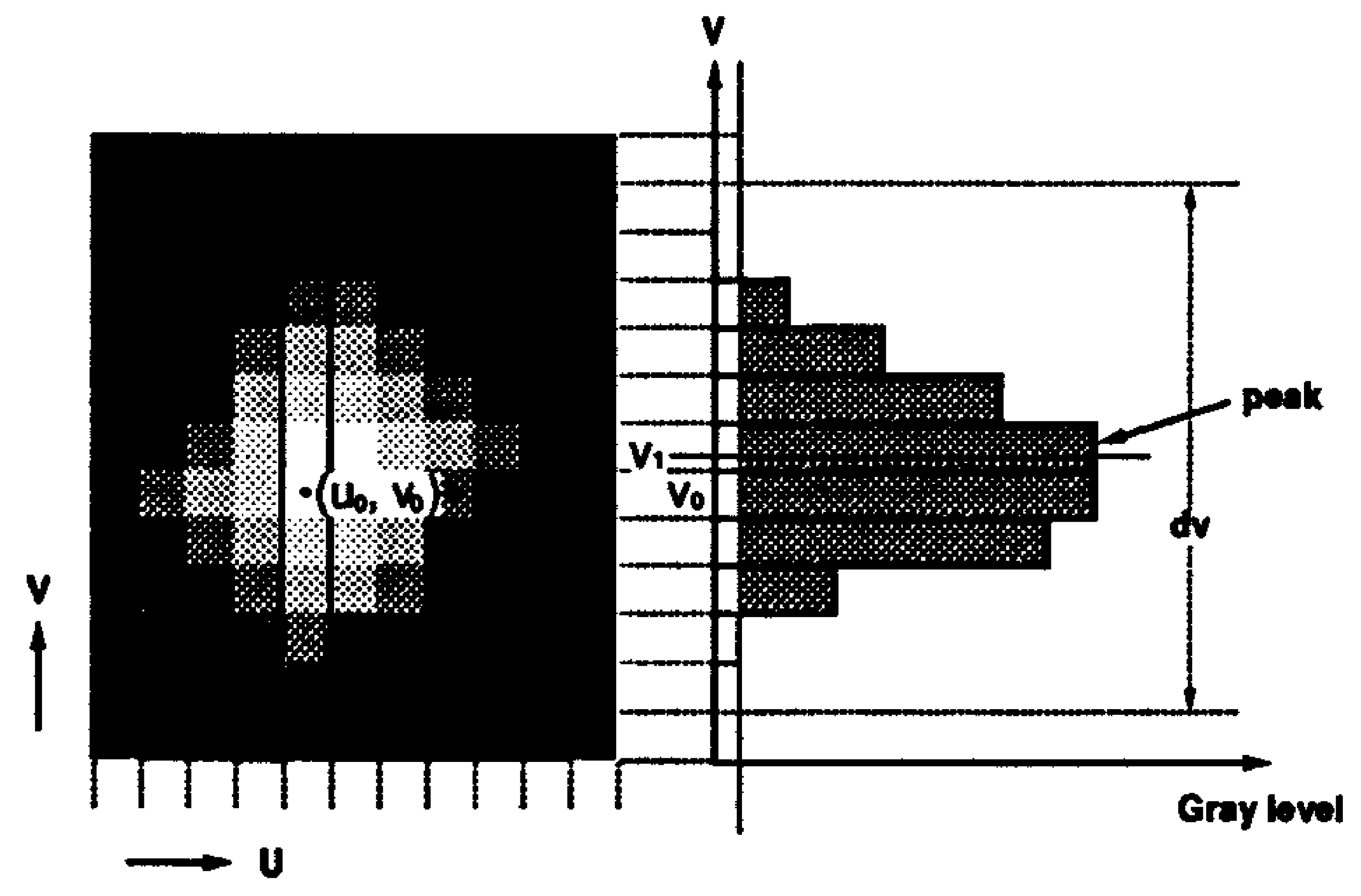

Fig. 8. Calculation method for the center of gravity of a spot.

1) Generating of Reference Data: The flat floor where no obstacles exist is measured, and the position of the center of gravity of each spot is recorded as the reference data. Finding the reference position of the center of gravity of the spot, the image is processed as follows:

1. Isolated noise such as the laser speckle noise[5] can exist. To eliminate the influence of this noise, the original image is smoothed with 3×3 averaging filter.

2. The region of the spots is extracted from the smoothed image. It is necessary that the threshold level be determined adaptively because the brightness of the background is different to the central part of the image and other parts. The original image is smoothed again with 9×9 averaging filter, and the output of the filter is used as the threshold.

3. The position of the center of gravity of each spot is calculated in the extracted region of each spot.

2) Reduction of Processing Time: The processing time for calculation of the reference data is rather long because of filtering and searching the image. The position of the spot is calculated according to the following simplified algorithm in order to reduce the calculation time.

1. The position v_p where the brightness peaks is searched on the line $u = u_0$ in the region near v_0 when the position of the reference data is (u_0, v_0).

2. The position of the center of gravity v_1 is calculated on the line $u = u_0$ in the range $[v_p - dv/2 \leq v \leq v_p + dv/2]$ (Fig.8).

Each spot is classified according to the position of its epipolar line, and the positions of the spots are checked systematically from the near region toward the far region on each epipolar line. If it is found that a spot doesn't lie on the floor, it is assumed that the area far from the position of the spot is also not floor, and the checking on the epipolar line is stopped and the checking on the next line is started.

In case of this simplified algorithm, it is supposed that variance of the position of the center of gravity is rather large because of the speckle noise. The variance is, however, not so large and is actually only about 1 pixel. The processing time is reduced to 1/10 of the calculation time of the reference data and is about 0.27s for one image.

The system recognizes that the position of the spot which is not on the floor when the difference of the position of the spot between the reference data and the measured data is larger than 2 pixels. The step (an obstacle) whose height is 2cm can be detected when the distance between the step and the robot is 45cm. A step whose height is 3cm can be detected when the distance is less than 100cm.

V. Experiment

Fig.9 shows an experimental result of the passage space detection in an indoor environment. In this case, there is a wall on the left side and a depression on the right side. The position of the spots detected on the image plane is shown in Fig.9(A), and the result of the passage space detection in the coordinate system of the robot position are shown in Fig.9(B). In these figures, '•' denotes (safe) floor area and 'o' denotes the other (dangerous) area. The boundary of the passage space is also shown. The small 'o' is the position of the reference data discussed in the previous section. It can be seen found from this result that the passage space on the floor is correctly detected.

When this sensor module detects the unsafe area in a certain region near the robot, its information is sent to the locomotion module and the robot stops.

VI. Conclusion

In this paper, the sensor system using Fiber Grating 3-D range sensor for the passage space detection was discussed. This system has advantages that 2-D information about the floor ahead of the robot can easily be obtained, the constitution of the system is failsafe, and this sensor can easily be mounted on the robot.

In the results of the experiment for passage space detection using this system in an indoor environment, it was shown that the passage space on the floor is correctly detected. The sensor system is very useful for an autonomous mobile robot.

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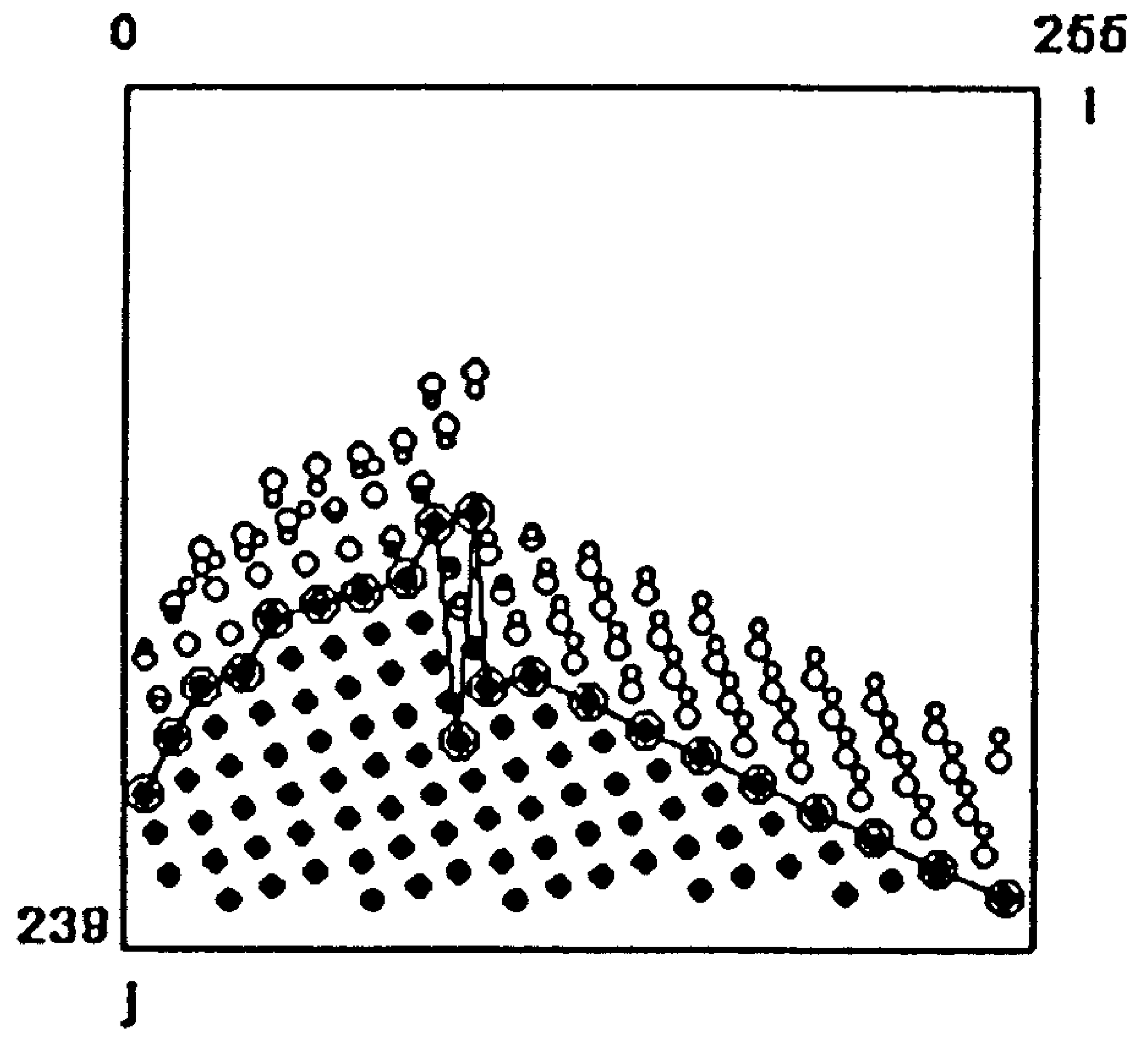
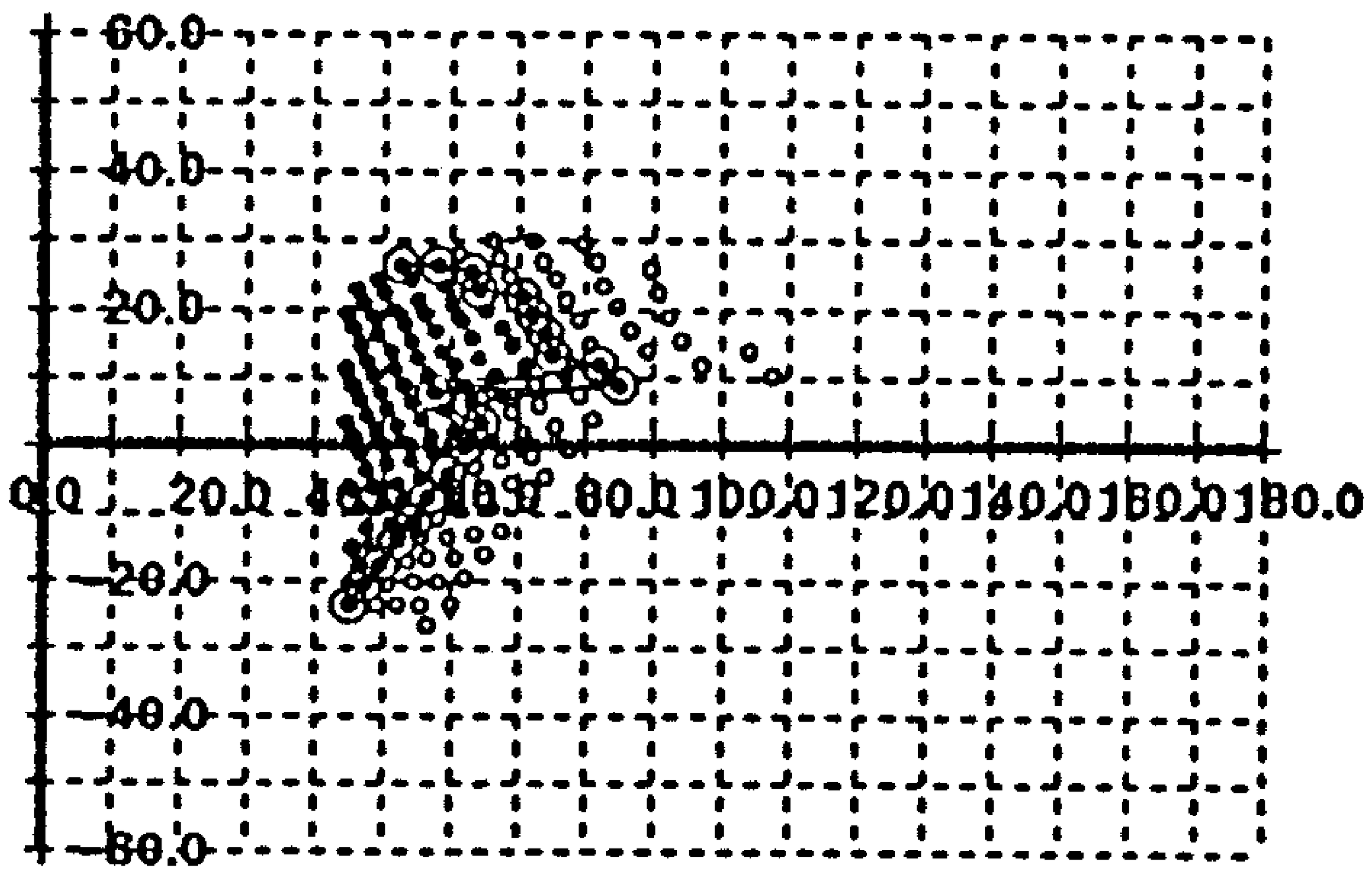


(a) Spot position on the image plane



(b) Spot position on the floor

Fig. 9. Experimental result. '•' denotes detected passage space, and 'o' denotes detected dangerous area.