Development of Practical Vision Sensor to Perform Multi-Task on Indoor Mobile Robot

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Abstract

A practical mobile robot system for transporting documents and small goods in indoor environments, where are linked by computers of each room on the inter net has been investigated and developed in our laboratory. In developing the mobile robot to actually need in indoor life space, the robot is even essential to have the abilities such as obstacle avoidance and self-position correction for safe and precise traveling. To perform these two tasks with a type of sensor, we have developed a practical vision sensor that considers the multi-task ability capable of reducing the scale of the robot system and whether it can practically be used or not in the indoor environments, where the sunlight comes in through windows and opening doors. This sensor was to improve so that the current laser range finder can deal with the sunlight that changes indoors with the lapse of time and robot's location. In this paper, we present a solution for the sunlight and the measurement accuracy of the sensor for two tasks from the navigation results performed on our mobile robot.

1. Introduction

Obstacle avoidance and self-position correction, these functions are even more important as the issues for implementing the applications of all mobile robot systems regardless of indoor and outdoor environments because the robots should be traveled safely and precisely. Hitherto, the many techniques to perform these tasks have already been proposed together with experimental results, which use the many types of sensors such as ultrasonic waves, laser range finder and image recognition by CCD camera [1][2]. However, there was the popular idea that assigns a type of sensor for one task. In other words, these idea causes robot system to increase the processing cost of software along with enlargement of hardware scale.

With this in mind, we are interested in the sensor that has capable of dealing multi-task with a type of sensor. In the development of the sensor to need on our robot, we gave attention to the following two respects.

The first is that determines what type of sensor is used to implement two tasks or more with a kind of sensor in indoor environments. We employed a range finder fashion using an infrared slit-ray laser projector and a CCD camera because took into account the edge detection for avoiding obstacles and landmark recognition for the self-position correction based on the sensitivity of the sensor.

The second is whether the sensor is practically used in the indoor environments, where the sunlight comes in through windows and opening doors. The conventional infrared laser range finders are difficult to employ in the indoor environments, where have windows in a side or both sides of the corridor, because they are usually used under the condition which no affected by the sunlight. Thus, there is the sunlight problem, which should be resolved. A popular way to eliminate the error sources such as fluorescent lamps, which influence on the camera of the infrared laser range finder, is to cover with an infrared transmitting filter on the lens of the camera and then to cut off the light of wavelengths outside of the specific light projected from the sensor. With this way, the specific light from the sensor can't be detected in the

Fig.1 An example of actual indoor environments

sunlight, which includes almost all. In addition, there were some ways to solve the sunlight problem. However, those were developed on the large scale for mars and autonomous land vehicle, and very high-priced and complicated systems [3][4]. Among the many applications, there is also the way to extract a certain specific light by image processing from the visible image. But that was not generally suited to the robot that requires the real time processing because of the processing time to extract the specific light in the sunlight [5].

Thus, we have developed a simple and practical sensor for the multi-task of the mobile robot considering the sunlight in the indoor environment as can be shown in Fig.1. We are what so called 'practical vision sensor' in a sense to be able to use in an actual spaces such as the public facilities.

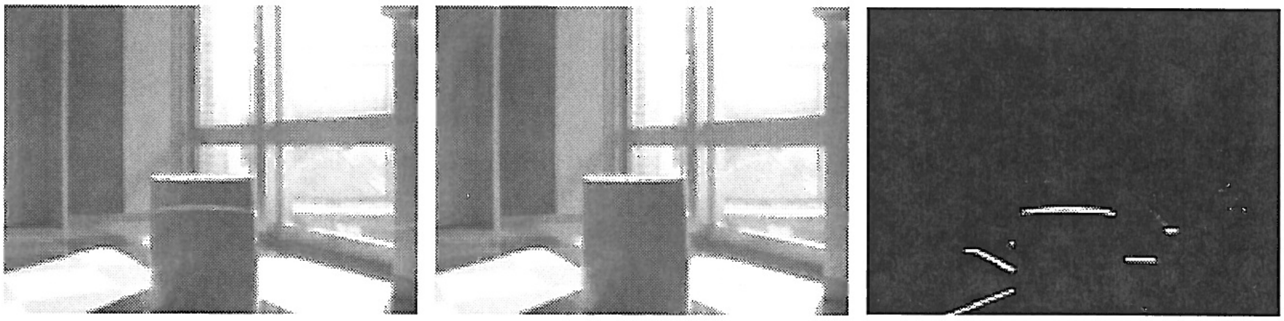
In this paper, we present the measurement accuracy and the navigation results, focusing on the practical vision sensor for the implementation of two tasks above in the indoor corridor.

2. Practical vision sensor

The practical vision sensor, which is consisted of a CCD camera and an infrared slit-ray projector, is one of the very important sensors, which are used to perform two tasks, the obstacle avoidance and self-position correction. If this sensor attempts to be actually used sensor on our robot in indoor environments, it has to be able to solve the sunlight problem. This chapter explains about the techniques to eliminate the sunlight and measure the data for two tasks.

2.1 Elimination of sunlight

In spite of the range finder on the mobile robot being used in the indoor environments, it is not easy to find out that the sensor can surely detect the obstacles in the sunlight, which comes in through windows and opening doors. To solve this sunlight problem on the practical vision sensor, we exploited the technique controlling the power of slit-ray projector depends on the condition of sunlight in the captured image. This is a way to differentiate two images at once after the sensor captures them synchronized with the power, on or off of the slit-ray projector. If a captured image has the brightness of a fixed quantity and over, the sensor is switched to take two images synchronized with the power of the projector. With this technique, we could eliminate the sunlight in the captured image and then detect only the reflected slit-ray on the obstacles. Fig.2 shows the images captured when the power of slit-ray projector is synchronized with on (a) and off (b), respectively. Fig.2(c) also shows the resultant image obtained by differentiating those two images. The sensor on our robot is continuously supposed to recognize the obstacles in an image through a series of processing, such as threshold,



(a) (b) (c)

Fig.2 Image when the slit-ray is ON (a) and OFF (b). (c) is the image differentiated by (a) and (b)

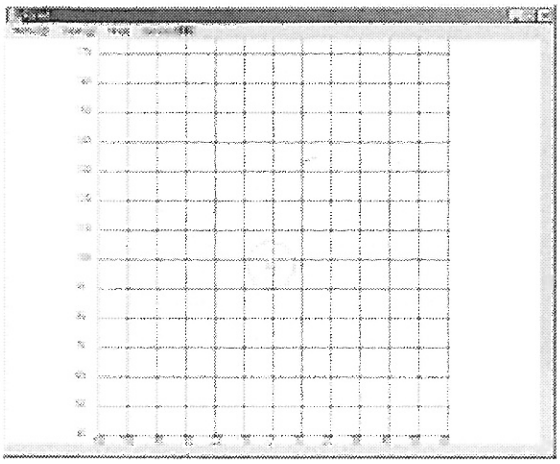


Fig.3 Recognition result of a cylinder

thinning, tracking of pixels and the measurement at an interval of 1 second. Fig.3 shows the measurement result of a cylinder recognized by the captured two images under the power control condition, which is shown in Fig.2, and a mesh size in the figure is 10cm. From the measurement results of the radius and distance to the cylinder measured with our robot in the center, we can discover that the sunlight problem is solved in the indoor environment.

2.2 Obstacle avoidance

One of the two tasks that the practical vision sensor has to do on our robot is the distance measurement to obstacles for the obstacle avoidance. Fig.4 shows the explanation diagram of the practical vision sensor. The slit-ray projector using an infrared semiconductor laser (830nm, 30mW) as the light source forms a sheet-shaped beam with cylindrical lens and locates to face down of α =15.0degree about optical axis at an upper point, y0 = 172.0cm of the camera. The camera is a popular commercial CCD camera that the lens is of the focal length f = 8.0mm and covered with an infrared transmitting filter for capturing only the slit-ray emitted from the upper projector. In a given local Cartesian coordinate system, the original point O is defined at a center of the camera lens which Z- and Y-axis are intersected. Here, the Z-axis agrees with optical axis of the camera and parallels to a floor plane. And also, Y-axis is one of the normal lines to the optical axis. A point (x, z) on the obstacle, which is laid on an indoor floor based on this coordinate system is corresponded to a pixel (u, v) in the image plane. Thus, the actual distance to the point (x, z) is calculated as follows.

$$x = \frac{u y_0}{v + f\tan\alpha}, \quad z = \frac{f y_0}{v + f\tan\alpha} \qquad ①$$

As is shown in image plane of Fig.4, as pixels of an arc-shaped cylinder in the image plane are converted into the distance data on the floor of the real space by the above formulation, the obtained data may be not aligned with the points along on an arc line, but distributed with a gathering of the points because there are the many error sources included in when making the sensor. Accordingly, the distance data should be fitted on a line by the least-squares method and then the radius and distance to the cylinder can be evaluated by using the fitted circular arc in the real space. And also, in the case of plane such as wall or pillar, the distance and angle to the robot facing the one can be measured with the same fitting method. The measurement accuracy of this sensor is within the range to be negligible for our robot navigation and will be described in section 3.1.

2.3 Self-position correction

The other of the two tasks that the practical vision sensor has to implement on our robot is the barcode recognition for the self-position correction. The self-position correction is to cause the robot to correct its own posture and distance errors that are accumulated while moving based on the dead reckoning. We used a barcode fashion as the landmark for our robot, which comes and goes between each room because it was to make possible to use the characteristics of the practical vision sensor and able to simply paste on the door of each room, as is shown in the left of Fig.5. Each pattern of the landmarks is provided with the width and number of black stripes in a fixed region. When the robot reaches to a destination due to the dead reckoning, it scans to search

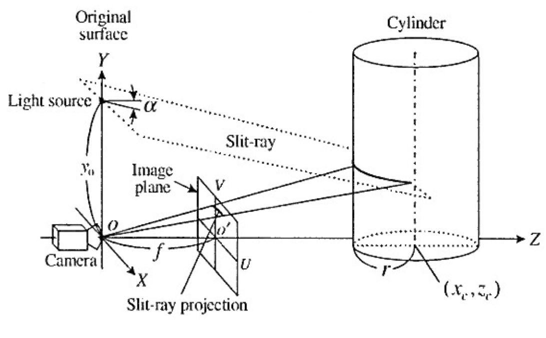


Fig.4 Slit-ray projection method

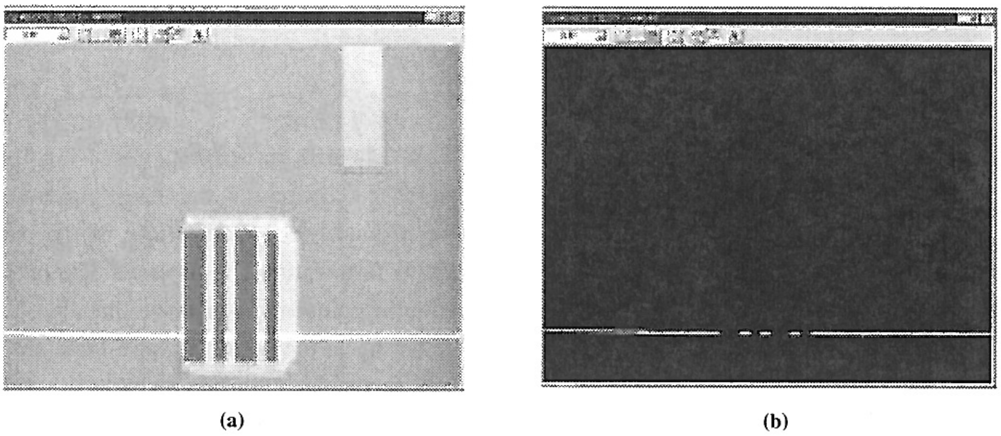


Fig.5 Visible image (a) and its filtered image captured the slit-ray on a barcode (b)

for the landmark in the three directions. Then, if a landmark is found as shown on the right of Fig.5, it is supposed to find the angle for its own posture correction and the distance for its own self-position correction. Otherwise, it repeats the action to look for a landmark in place. Fig.6 shows that the robot determines the angle and distance for its own posture and self-position correction with the recognized barcode in the center. Let's assume that a given landmark is recognized at a current robot's location O. Then, in the local coordinate system, the robot can evaluate the distance, lx and lz from a center of the barcode, and the angle α from the bias of slit-ray. In consequence, for the self-position correction in the global coordinate system of a given indoor environment, the required distance gx and gz are calculated as follows.

$$gx = co \cdot \cos \gamma, \qquad gz = co \cdot \sin \gamma \qquad ②$$

where ,

$$co = \sqrt{lx^2 + lz^2}, \beta = \tan^{-1} \frac{lz}{lx}, \gamma = 180 - (\alpha + \beta)$$

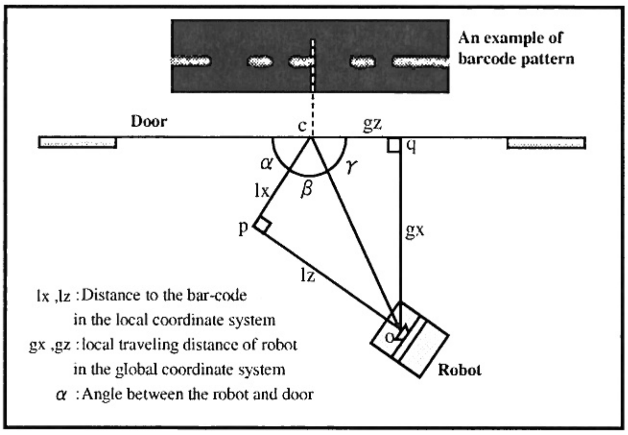


Fig.6 The self-position correction method centering a barcode

3. Experimental results

The mobile robot system for transporting documents and small goods in indoor environments, where are linked by computers of each room on the inter net has been investigated and developed in our laboratory. This is referred to as Moris, mobile otsukai(errand) robot for intelligent system, as seen in Fig.7. Moris is composed of commercially available boards including three single-board computers convenient to the maintenance, cost, version upgrade and so on. The system configuration is distributed into three modules comprising the set of one CPU and the related to peripheral tools, and each module operates in parallel, independently. Data communication between each module is performed through three dual port memory

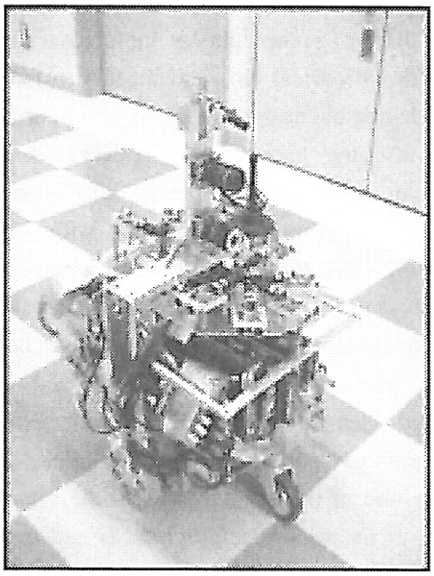
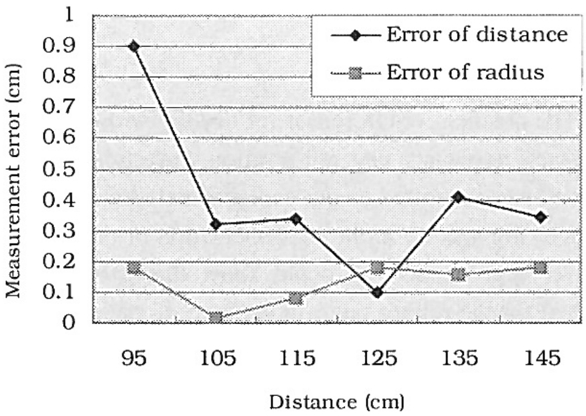
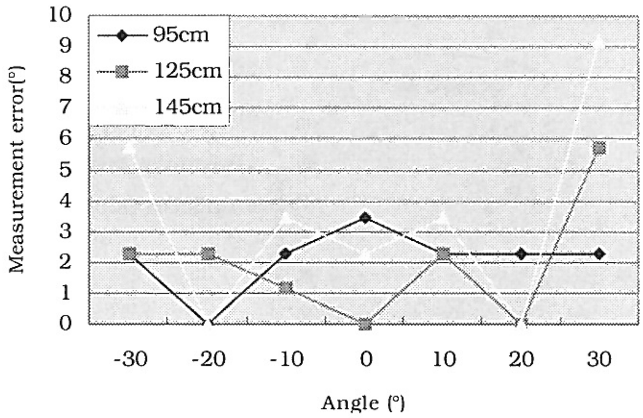


Fig.7 Moris, the overview of our mobile robot



(a) Distance and radius to the cylinder from the robot



(b) Angle of the robot to a plane

Fig.8 The results of measurement accuracy

boards made by our group, respectively. The practical vision sensor is mounted on the top of the robot and its measurement accuracies are summarized in the following sections.

3.1 Accuracies of practical vision sensor

To examine the efficiency whether the sensor is enough suited for the two tasks, the obstacle avoidance and the self-position correction, we performed the following two kinds of experiments on our robot. The first, we measured the distance and the radius data with a cylinder of radius 8.0cm, for investigating the sensor's accuracy of the obstacle avoidance. The data were averaged to measure 5 times at intervals of 10.0cm from 95.0cm to 145.0cm, taking into account the robot's location in the indoor corridor. Fig.8 (a) shows the measurement errors for the cylinder at each given distance. From this experimental result, we can know that the measurement error for the distance and radius is within 1.0 and 0.3cm, respectively.

The second, we could look into the measurement accuracy of the angle between the robot and the normal to a plane, by measuring the bias of the slit-ray projected on a plane from the sensor. The angle data are means that measured 5 times for each robot's location of 95.0, 125.0, 145.0cm away from a plane at intervals of 10 degree from –30 degree to 30 degree, defining at 0 degree when the normal to a plane aligns with the axis facing the front of the robot. Fig.8 (b) shows the measurement errors of the measured angle data. From those results, while we can discover that the error is within 4 degree except for the case of such the large angle as of 30 degree, also guess that the error will become larger in the case of more than 30 degree according to away from the robot. However, we empirically know that the case is hardly ever measured at that degree.

From two measurement results above, we could conclude that the practical vision sensor has sufficient

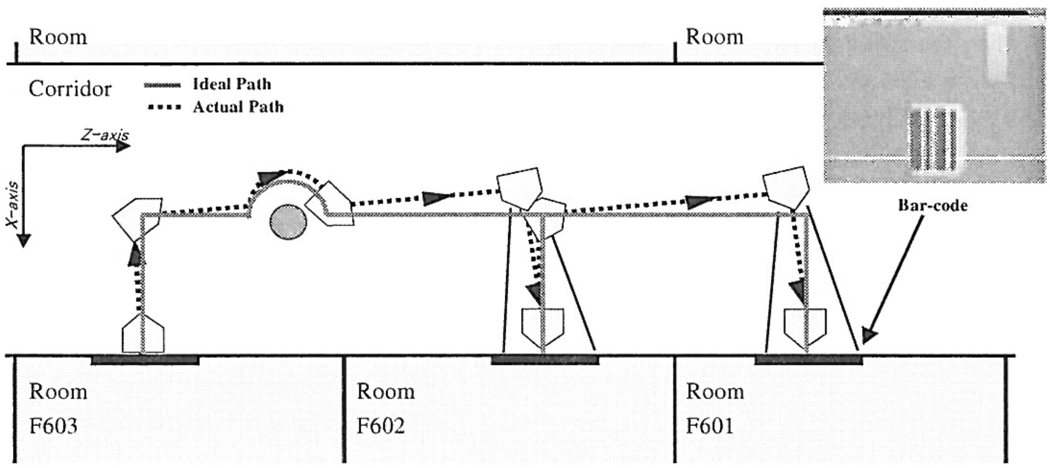


Fig.9 A result of travel experiments performed in indoor corridor

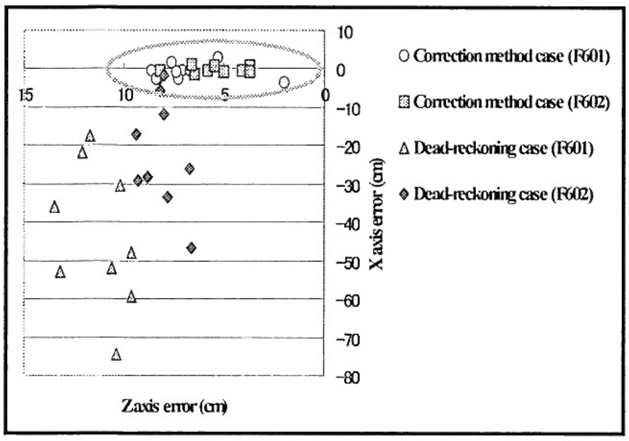


Fig.10 Measurement errors of travel experiments

accuracy when used for the tasks such as the obstacle avoidance and the self-position correction on a mobile robot, which works in indoor spaces.

3.2 Accuracy on travel experiments

The travel experiments of our robot equipped with the practical vision sensor were implemented and tested in the actual indoor corridor, width 2.4m, where is shown in Fig.1. For testing the accuracy by the self-position correction while the robot travels between each room, we compared to repeatedly measure the deviation distance on the X-axis from a given ideal course due to the dead reckoning. The path was instituted to avoid a cylinder during the traveling from the room F603 to F601 via F602, as can be seen in Fig.9. In the case of the robot's travel by dead-reckoning without the self-position correction, we could guess that the measurement error deviating from the ideal path will be gradually increased in accordance with away from the starting location. In fact, the maximum error of X-, Z-axis reached to 74.5 and 13.5cm when the robot moved on the distance of 1050cm to the room F601 via F602, as is indicated with the lowest and most left black triangle in Fig.10. On the other hand, the maximum error of the case corrected the robot's self-position by the barcode recognition reduced to 3.7 and 8.6cm for X and Z-axis, respectively, as shown in the oval of Fig.10. From these experimental results, the efficiency of the self-position correction method could be verified.

4. Conclusion

The practical vision sensor for dealing with two tasks, obstacle avoidance and self-position correction has been developed and tested on our experimental mobile robot in indoor life spaces. In the implementation of the repeated travel experiments, we could know that the sensor is suited for the robot's navigation based on edge-detection in the narrow corridor, as well as for the recognition of barcodes by nicely exploiting the reflective sensitivity of laser slit-ray. By negotiating some limitations concerning the sunlight in indoor environments, we also allowed the robot to recognize the obstacles and to avoid them. This technique is achieved by the obstacle detection based on the differentiation of two images captured by switching the slit-ray projector power depend on the brightness of an image of the practical vision sensor.

From the robot's travel experiments comprising the implementation of two tasks with the sensor, we could make sure that the measurement errors deviated from a given ideal path are within 3.7cm on the X-axis related to the walls of both sides. This means that the sensor is suited for the navigation of a mobile robot for working in the life spaces such as the public facilities.

In the future research, we are going to challenge to the robot's floor traveling using the elevator in a building.

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