

A Study on Position Determination for Mobile Robot Navigation in an Indoor Environment

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Abstract

Position estimation is one of the most important functions for the mobile robot navigating in the unstructured environment. Most of previous localization schemes estimate current position and pose of mobile robot by applying various localization algorithms with the information obtained from sensors which are set on the mobile robot, or by recognizing an artificial landmark attached on the wall, or objects of the environment as natural landmark in the indoor environment. Several drawbacks about them have been brought up. To compensate the drawbacks, a new localization method that estimates the absolute position of the mobile robot by using a fixed camera on the ceiling in the corridor is proposed. And also, it can improve the success rate for position estimation using the proposed method, which calculates the real size of an object. This scheme is not a relative localization, which decreases the position error through algorithms with noisy sensor data, but a kind of absolute localization. The effectiveness of the proposed localization scheme is demonstrated through the experiments.

1 Introduction

By the end of the 21st century, robots may not be strangers to us anymore. Compared with in recent years, the useful range for robots has gradually spread to a wide variety of areas. Mobile robots are especially being used as a substitute for humans in inhospitable environments or to do simple work that is either in or outside. In addition, they are used for investigating planets in space[1]. In such a mobile robot system, getting exact information on its current position is very important.

The mobile robot mainly calculates its position with the data acquired from a rotary encoder which is connected to the wheel, and from a gyroscope sensor, but it couldn't perceive the correct position because of slippage, a rough surface, and sensor error such as gyroscope drift. Many solutions have been proposed to overcome these unavoidable errors. For example some researchers presented a method that estimates the current position by

applying information obtained by a rotary encoder and an ultrasonic sensor by applying an EKF(extended Kalman filter)[2-3]. And a researcher updated the positioning of mobile robots by fusing data from multi-sensors such as magnetic compasses, gyroscopes, rotary encoders with the EKF[4]. These methods need much calculation for a mobile robot to perform a task, which results in a sharp drop in the total system efficiency. Another disadvantage is a great localization uncertainty which is the result of the statistical error accumulated from sensors and control over long distances.

Contrary to the methods mentioned above, which intended to reduce the position error with relative positioning sensors, the following method provides an absolute position regardless of the distance moved and working time of a mobile robot. And some researchers presented a method that estimates the position of a robot through geometric calculation, after it recognizes a landmark[5-6]. Even though a CCD camera set on a robot is used for avoiding obstacles and tracking objects and so on, in these methods, the camera system was consumed unnecessarily for a robot to search and recognize the exact landmark. Another way that is presented for a robot equipped with a CCD camera, estimates its position by recognizing a characteristic topography or an object, and compares it with the model image saved in advance[8]. In general, we have utilized some feature points such as a wall or a corner as landmark in the workspace. However it has low confidence in recognition and requires much calculation. Therefore, its disadvantage is noticed that the processing speed of the system is low.

In this paper, to overcome these problems we propose a new localization method as illustrated in Fig. 1. A camera installed on the ceiling of the corridor is utilized for the localization of the mobile robot. The system compensates for robot positioning by means of the following sequence.

First, the system recognizes whether it is a moving robot or not, with a CCD camera. Secondly, if the object is a moving robot, the system obtains the position of the robot. Finally, the system transmits the position data to the robot for the localization.

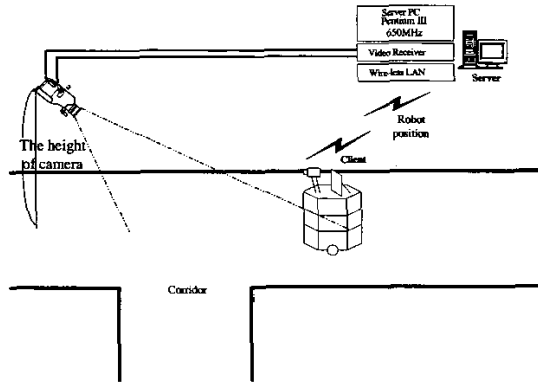


Fig. 1. Basic model.

2 Object segmentation through image process

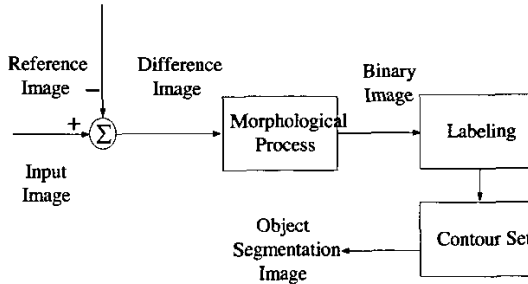


Fig. 2. Object segmentation model.

We extract moving objects using the difference image which is obtained as the difference between an input image, which is being inputted consecutively, and a reference image, which is captured and stored in advance.

2.1 Image pre-processing

In this paper, we applied a Gaussian mask with the nine pixels for removing illumination dependent image noises, and selected a modular image to shorten the processing time. In this paper, we have used modular four images which have 160×120 pixels for an image. And a filtering method that has been used widely, a morphological filtering method is adopted. Through Labeling, we can separate objects and search for their features using labels [9].

2.2 Reference image modification

In order to extract a moving object in a dynamic environment correctly, the reference image needs to be updated dynamically instead of keeping the initial reference image.

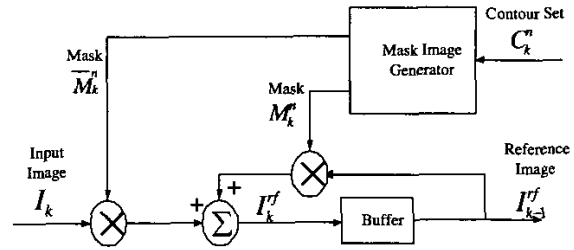


Fig. 3. Updating the reference image.

In Fig. 3, I_k^{rf} is an updated reference image that will be used for the next frame. Also, a mask image M_k^n is represented as follows:

$$M_k^n = \begin{cases} 1 & \text{if } (x, y) \in C_k^n \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

This new reference image can be represented as,

$$I_k^{rf} = \overline{M_k^n} I_k + M_k^n I_{k-1}^{rf} \quad (2)$$

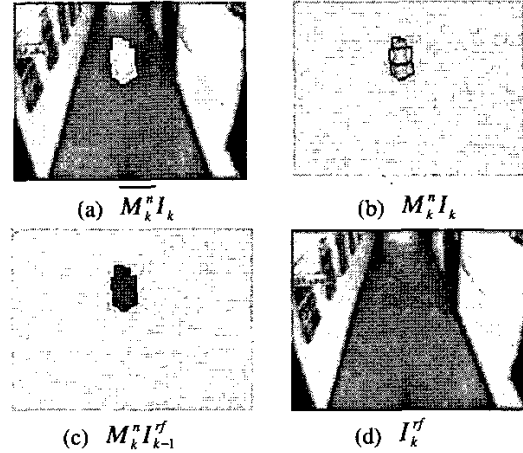


Fig. 4. Update process of background image.

3 Transformation from image coordinates to real coordinates

We obtain the distance between camera and object using a single camera so that, such distance can be represented as real coordinates[8].

As shown in Fig. 5, the solid square border in the center has a screen image for a mobile robot. This image is projection of the mobile robot on the corridor, which is in real three dimensions. Here, we can transform from the

image coordinates to real coordinates to obtain the location of the robot.

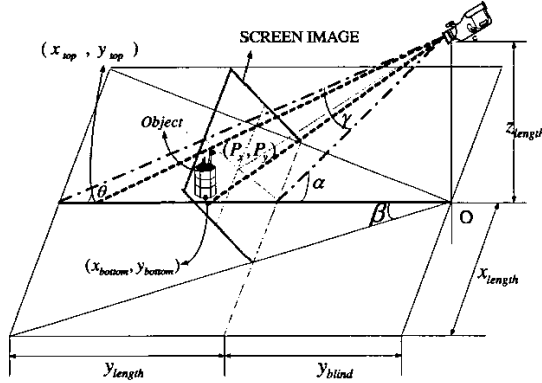


Fig. 5. Modeling for the correspondence between 2D image and 3D coordinates.

$$\alpha = \tan^{-1} \left(\frac{z_{length}}{y_{blind}} \right) \quad (3)$$

$$\beta = \tan^{-1} \left(\frac{x_{length}}{y_{blind} + y_{length}} \right) \quad (4)$$

$$\gamma = \alpha - \theta \quad (5)$$

where $\theta = \tan^{-1} \left(\frac{z_{length}}{y_{blind} + y_{length}} \right)$.

The screen image is described in detail as Fig. 6.

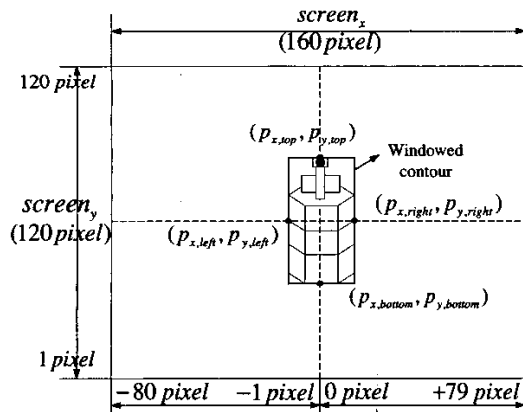


Fig. 6. Screen image.

The real coordinates of the robot center on the floor, $(x_{robot_position}, y_{robot_position})$, can be calculated as follows:

$$y_{bottom} = z_{length} \times \tan[(90^\circ - \alpha) + \gamma \times \left(\frac{p_{y,bottom}}{screen_y} \right)] \quad (6)$$

The y-axis center of the robot can be obtained as,

$$y_{robot_position} = y_{bottom} + (L/2) \quad (7)$$

where L is width of the robot. And,

$$x_{robot_position} = y_{robot_position} \times \tan \beta \left(\frac{2p_{x,bottom}}{screen_x} \right) \quad (8)$$

4 Feature extraction

4.1 Height and width of an object

we can obtain the height and width of the robot using geometric analysis.

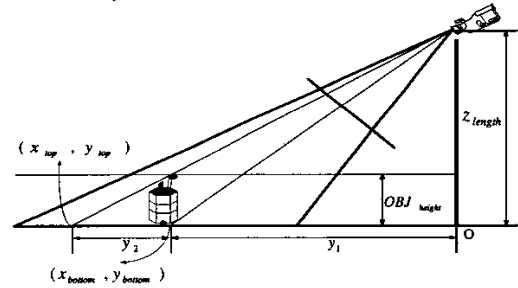


Fig. 7. Height measurement using a camera.

As shown in Fig. 7, the distance y_1 from the lowest coordinates of the object to the origin is calculated using y_{bottom} in Eq.(6) as,

$$y_1 = y_{bottom} - O \quad (9)$$

where O represents the origin.

In the same manner, y_{top} can be calculated from Eq.(6) by replacing y_{bottom} as y_{top} and $p_{y,bottom}$ as $p_{y,top}$. Therefore, the distance y_2 from the highest coordinates of the object to y_{bottom} is calculated as,

$$y_2 = y_{top} - y_{bottom} \quad (10)$$

When the coordinates, y_1 and y_2 are obtained, the height OBJ_{height} of the robot can be calculated as,

$$OBJ_{height} = \frac{z_{length} \times y_2}{(y_1 + y_2)} \quad (11)$$

from the similarity properties of triangles.

Following the same procedure, the width of the mobile robot can be obtained as follows:

The real length $length_{pixel}$ per pixel is calculated as follow:

$$length_{pixel} = OBJ_{height} / (P_{y,top} - P_{y,bottom}) \quad (12)$$

Then, the width, OBJ_{width} , of the object is calculated as

$$OBJ_{width} = length_{pixel} \times (P_{x,right} - P_{x,left}) \quad (13)$$

4.2 Extraction of color information

To recognize the mobile robot, the height, width and color information have been used for a neural network. Since most color cameras used for acquiring digital images utilize the RGB format, we get RGB values for the object image. Each R, G, B values are represented as 8 bit data and the biggest value is 255.

5 Experiment and discussion

5.1 Mobile robot for experiment

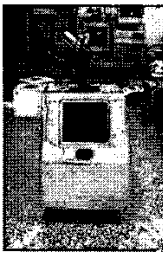


Fig. 8. Ziro3.



Fig. 9. IRL-2002.

Two mobile robots shown in Fig. 8 and 9 were used for experiment.

5.2 Object segmentation



(a) Ref. Image (b) Input Image (c) Ext. Image
Fig. 10. Extraction of mobile robot image.

We extracted the images of robots, which were navigating in corridor through the image processing. The experimental results are shown in Fig. 10.

5.3 Recognition of a robot through neural network

First of all, we need to exactly recognize an object to estimate the exact position of the robot. To do this, we have to decide whether an extracted object in the image is a robot or not. In this paper, for this purpose, a neural network is utilized.

Table 1. Success rate of recognition

Classification Object	recognition by using only color information		recognition by using color information and size information	
	number of trials	number of success	number of trials	number of success
IRL-2002	40	30	40	35
Ziro3	40	32	40	38
People	20	12	20	18

As shown in Table 1, with the size information, the success rate was improved a lot.

5.4 Acquisition of a Robot position and results of experiments

when a mobile robot was driven 10m forward, experimental results are shown in Fig. 11. Using only an encoder sensor and the kinematics of the mobile robot[7], there exists an approximately 40cm deflection along the x axis. However using our scheme, the robot trajectory was very similar to the center course of a driven corridor as seen in Fig. 11.

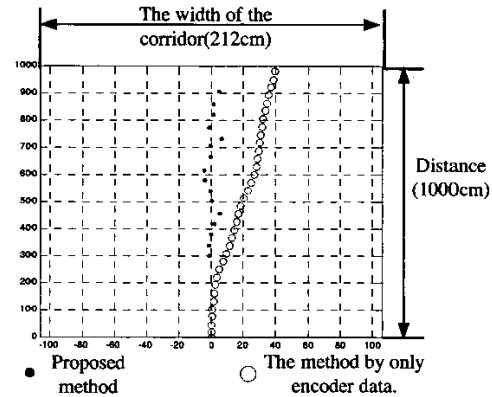


Fig. 11. Motion trajectory of a robot.

The error by the proposed method is shown in Table 2.

Table 2. Position error

Distance from camera	Axis	Maximum error (cm)	Minimum error (cm)	Average error (cm)
3m	X axis error	0.5729	0.2006	0.4195
	Y axis error	2.5828	0.1250	1.7061
4m	X axis error	2.3858	0.3178	1.1751
	Y axis error	4.833	0.3639	3.0734

As shown in Table 2, the further the robot moved from the camera, the greater the error became in real coordinates. The cause of error in the x axis is proportional to the

distance, which is influenced by the β angle and the real distance which gradually increased. Consequently, in the limited camera view area, the exact robot position is recognized accurately without missing the robot.

6 Conclusion

In this paper, a new localization method with a fixed camera is proposed, which utilizes the external monitoring camera information under the indoor environment. When a mobile robot is moving the corridor, it helps the localization of robot by estimating the current position through the geometric analysis of the mobile robot image. The exact position of the mobile robot was obtained and demonstrated to be correct by the real experiments. And through the experiments, the advantages and efficiency of the proposed method are demonstrated illustratively.

For a future research topic, an efficient image processing scheme is necessary to improve and reduce the absolute error.

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