Mobile Robot Navigation in an Indoor Environment

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Abstract: To compensate the drawbacks, a new localization method that estimates the global position of the mobile robot by using a camera set on ceiling in the corridor is proposed. This scheme is not a relative localization, which decreases the position error through algorithms with noisy sensor data. The effectiveness of the proposed localization scheme is demonstrated by the experiments.

Keywords: Navigation, mobile robot, image preprocessing

1. INTRODUCTION

The mobile robot mainly calculates its position with data acquired from a rotary encoder, which is connected to wheel, and from a gyroscope sensor, but it won't receive correct position because of slippage, a rough surface, and sensor error such as gyroscope drift. To overcome these errors, many solutions have been proposed. Some researchers presented a method which estimates the current position by applying information obtained by a rotary encoder and ultrasonic sensor to extended the Kalman filter.[1][2] , A researcher updated the positioning of mobile robots by fusing by means of an extended Kalman filter with data from multisensor such as magnetic compass, gyroscope, rotary encoder and so on.[3] These methods need much calculation for a mobile robot to perform a task, therefore it results in a drop in total system efficiency. Another disadvantage is greater localization uncertainty which develops due to statistical error accumulated from sensors and control over long distances. Another way that was presented in that a robot, equipped with a CCD camera, estimates a position by recognizing a characteristic topography or object, and compares it with the model image saved in advance.[4][5][6] Some researchers presented a method which assumes the position of a robot through geometric calculation, after making a robot recognize a landmark.[5][7] These methods consume unnecessary system for a robot to search.

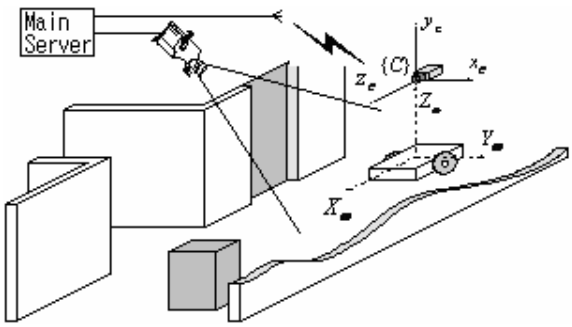


Fig.1 Between a camera and a point in the real world

2. IMAGE PROCESSING

Input images have the size of 640×480 pixel at every sampling time. It can cause the increase of unnecessary computation to apply preprocessing to total image in order to draw some necessary information. Therefore, the research on the decrease of computation time by designating a necessary part as a sub-block is being in progress. This section explains edge detection schemes based on the image processing and the central moment that plays a key role in determining the position of windows. And then it decides the optimal size of windows.

Once the image of an object is received, we must take a course that extracts the features of the object. In this paper, we applied Gaussian mask to remove the image noise for light in indoor environments, and reduced the image scale for origin to make processing time better.

$$\frac{1}{16}\begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix}$$

Fig. 2 Gaussian mask

$$I^{l}(x,y) = \sum_{i=-1}^{+1}\sum_{j=-1}^{+1} G(i,j) I^{l-1}(2x+i, 2y+j) \qquad (1)$$

Here, l is the label of image, $G(i,j)$ is Gaussian mask.

In Fig. 2, the moving object is extracted by the difference in image between background image saved in advance and consecutive input images.

Image noise occures during the image process. This noise causes the unnecessary computation of images. The filtering method that was used, was the opening and closing filtering method.

This process gives a number to each object. We can separate an object and search for its feature. Also in this paper, we use for removing labeled objects that is smaller than the established object

A windowed contour is set wrapping the most high, low, left, and right pixel of the object labeled. By these means, we extract the characteristic information of the object.

To get a background image is very important for object segmentation. Therefore, in order to look for a moving object in an environment, which changes continuously, the background image has to be updated. Refer to Fig. 3 and Fig 4.

(a) (b)

Fig. 3 Robot image in main sever

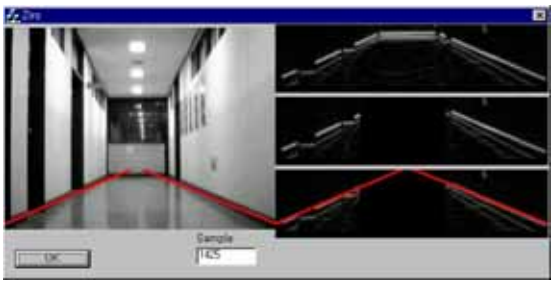


Fig. 4 Corridor information form mobile robot

3. TRANSFORMATION FROM IMAGE

Image matching method by stereo vision generally is used for acquiring the distance between camera and object We can obtain it between camera and object using a single camera and then, such distance is represented as real coordinates.

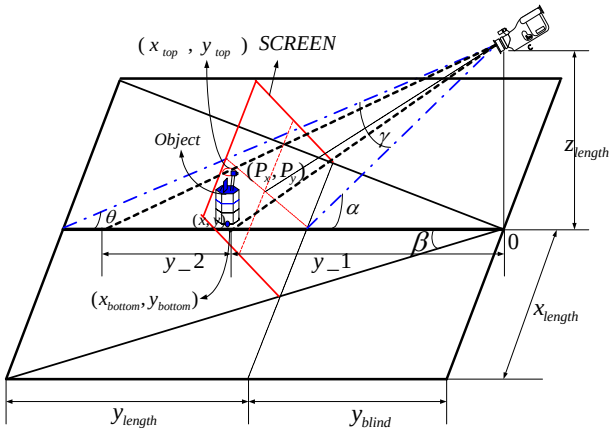


Fig. 5 Transfortation form the image

$$\alpha = \tan^{-1}\left(\frac{z_{Length}}{y_{blind}}\right) \tag{2}$$

$$\theta = \tan^{-1}\left(\frac{z_{length}}{y_{blind} + y_{length}}\right) \tag{3}$$

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

$$\gamma = \alpha - \theta \tag{5}$$

y_{bottom} is a real coordinate corresponding to the lowest pixel of the extracted object in the image. Here, $x_{robot_position}$ and $y_{robot_position}$ are each central coordinates of the robot in the x-axis and the y-axis.

$$y_{bottom} = z_{length} \times \tan[(90° - \alpha) + \gamma \times (\frac{p_{y_bottom}}{screen_y})] \tag{6}$$

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

(L is the diameter of robot.)

$$x_{robot_position} = y_{robot_position} \times \tan\beta(\frac{2p_{x_bottom}}{screen_x}) \tag{8}$$

4. NAVIGATION

In the rear, there is one free-wheeling castor. Although castors have been said to cause slipping during direction changes, it has been proven that this is may not always occur. A more complicated design that allows two DOF-motion in the plane and is based on two wheel-pair assemblies was presented in. However, this robot has been found to be very difficult to control and no satisfactory solution has been found yet.

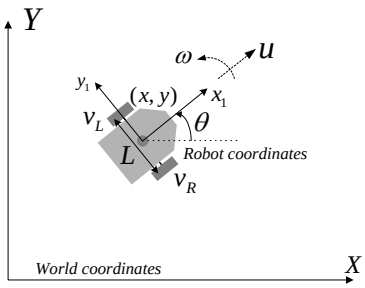


Fig. 6 Navigation of the mobile robot.

In mobile robots it is desirable to place the two drive wheels as far apart as possible, for the following reasons:

1. The stability of the robot is improved.
2. The effect of the encoder resolution on the orientation error of the robot is decreased. In the worst case, the orientation error $\Delta\theta$ is given approximately by follow.

$$\Delta\theta = \frac{\Delta x}{a} \tag{9}$$

As seen from (9), the orientation error $\Delta\theta$ is reduced by increasing the distance between the drive wheels.

3. During straight-line motion, mechanical disturbances might cause the motors to run temporarily at different angular speeds, resulting in a temporarily curved path. It can be shown by trigonometry that the radius of the curved path is directly proportional to the wheel separation distance.

4. Differences in the two wheel diameters will also cause a curved path with a radius proportional to the distance a.

On the other hand, an exaggerated base width will adversely affect the mobility within a room. In the present design the distance between the two drive wheels is 300 mm.

In Fig. 7, we set the screen image as follows. The center is 0 pixel and the furthest left to the furthest right pixel on the screen is from –80 pixel to +79 pixel. $screen_x$ and $screen_y$ are the total number of pixels on each axis.

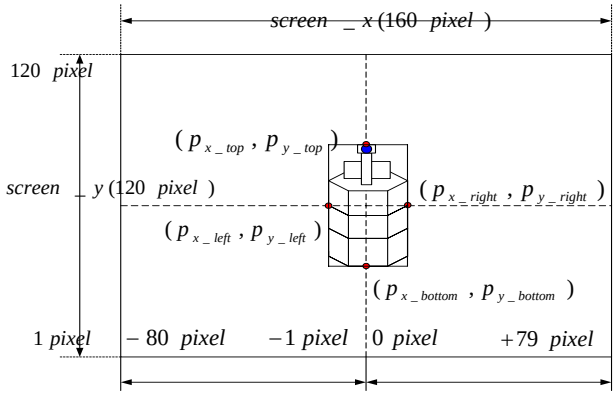


Fig. 7 Main server image

In Fig 7, we obtained real x, y coordinate. If we use these, we can calculate the height, and width of the robot.
Shown in Eq.(10), and (11), we used the proportional relation of geometry.

$$h_2 = \frac{z_{length} \times (L2 - L1)}{L2} \tag{10}$$

$$h_1 = \frac{z_{length} \times (L4 - L3)}{L4} = \frac{z_{length} \times (L6 - L5)}{L6} \tag{11}$$

Using Fig .6,7, and 9, we represented the following formulas.
From Eq.(7)

$$y_{top} = z_{length} \times \tan[(90° - \alpha) + \gamma \times (\frac{p_{y_top}}{screen_y})] \tag{12}$$

$$y_1 = y_{bottom} - O \tag{13}$$

$$y_2 = y_{top} - y_{bottom} \tag{14}$$

Using Eq.(13), and (14), we can measure the height of the object.

$$OBJ_height = \frac{y_2}{y_1 + y_2} \times z_{length} = \frac{y_{top} - y_{bottom}}{y_{top} - O} \times z_{length} \tag{15}$$

Using Eq.(7), y_{left} and y_{right} are calculated.

$$x_{left} = y_{left} \times \tan\beta(\frac{2p_{x_left}}{screen_x}) \tag{16}$$

$$x_{right} = y_{right} \times \tan\beta(\frac{2p_{x_right}}{screen_x}) \tag{17}$$

From Eq.(18), we can measure the height of the object.

$$OBJ_width = x_{right} - x_{left} \tag{18}$$

5. EXPERIMENT AND RESULT

All experiment must be done indoor environment under 700~1000lux, because the light is influencing image processing.

Fig 8 Mobile Robot

The state of mobile robot is represented as the vector $\vec{\mathbf{P}} = [x, y, \theta]^T$, which has the position and the direction like that in Fig. 1. In general, the motion of the mobile robot is modeled in Eq.(19), and (20) which has the translation velocity and the angular velocity.[19]

$$u = \frac{1}{2}(v_R + v_L) \tag{19}$$

$$\omega = \frac{1}{L}(v_R - v_L) \tag{20}$$

Here, v_R , and v_L are the right and left velocity.

The L is the distance between two wheels. The velocity $\dot{\mathbf{P}}$ is represented by Eq.(21) using the Jacobian matrix.

$$\dot{p} = J(p)\dot{q}$$

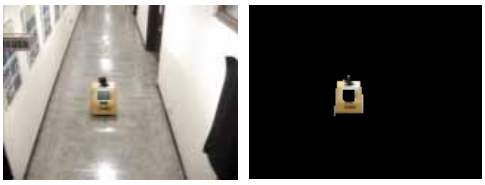
$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos(\theta) & 0 \\ \sin(\theta) & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} u \\ \omega \end{bmatrix} \tag{21}$$

The position vector P is the integration form of Eq.(21) like Eq.(22).

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos(\theta) & 0 \\ \sin(\theta) & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} u \\ \omega \end{bmatrix} \tag{22}$$

From this Kinematics, we calculate the position of the robot by control period.
In this paper, we equipped a wireless LAN card so as to monitor the state of the robot and to control robot. The LAN used is the PC24E-H-FC model from the Lucent Technology.
From part2, we accounted for image preprocessing. By using it, we obtained Fig. 9. Most of the images were extracted but several was disturbed by the light.

Fig. 9 Background image



(d) (e)

Fig. 10 The result image of the object segmentation

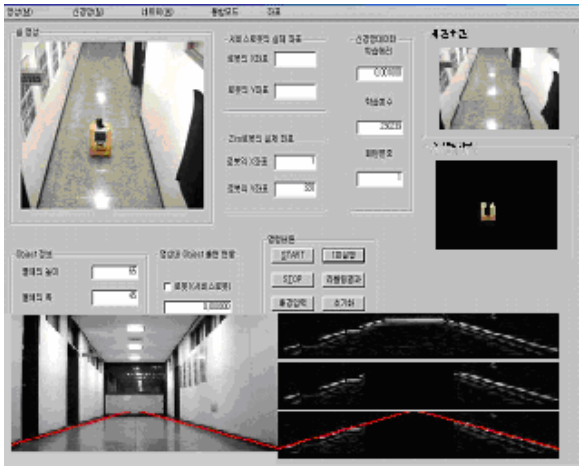


Fig. 11 Result of navigation

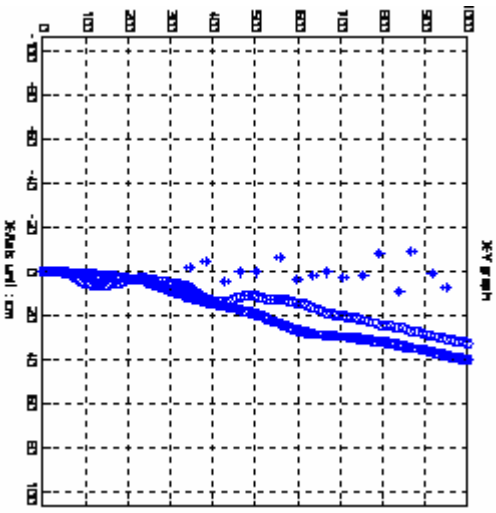


Fig. 12. The positions of a robot

Fig. 12 is error of a robot position results from the wheel slippage, a rough surface, and sensor error and so on. And, in Consecutive circles represent the positions that are made by encoder sensor and many star marks represent the positions that are calculated by presented method.

Finalize this paper, a new localization method is proposed, which utilizes the external monitoring camera information under the indoor environment. When the moving object is a mobile robot in 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 proved to be correct by the real experiments.

Also, it is possible to distinguish between two robots and other objects through the neural network with the data which were acquired by the feature point extraction. This scheme is applied to a number of robots with the new localization method.

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