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자율이동로봇의 동적 장애물 회피를 위한 효율적 방법

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An Effective Approach to Dynamic Obstacle Avoidance for Mobile Robots

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Abstract - This paper presents an effective approach to dynamic obstacle avoidance for mobile robot. The main concept of this approach includes modified polar mapping for recognition of the moving obstacle in vision-based robot systems. To simplify the segmentation of the moving obstacle from the background and to obtain its relative position data the modified polar mapping is proposed. Dynamic moving obstacles are avoided with a vision sensor and stationary obstacles are avoided with a sonar sensor.

1. Introduction

Dynamic obstacle avoidance is one of the key issues for pratical applications of mobile robots. A wide variety of approaches and algorithm have been proposed[1-5]. When unexpected or un-modelled objects (static or moving) appear, the robot should have the ability of dynamically avoiding them, without any collision, and returning to the normal path after these objects have been passed or removed. Dynamic obstacle avoidance is also called local or reactive obstacle avoidance. In contrast to static and global path planning, the dynamic obstacle avoidance approach only uses the local information of the surrounding environment. Consequently, it cannot always generate an optical path, but it can make the robot react fast to unexpected obstacles. In this paper, we used the CCD camera for detecting the moving obstacle and ultrasonic sensor for detecting the static obstacle. We present the modified-polar mapping to segment moving obstacle from the background and define two behaviour table for safety navigation.

Section 2 of this paper describe the detecting dyanmic and static obstacle. Here, we discusses the modified polar mapping. Section 3 defines the two behaviour table to avoid obstacle. Conclusions are presented in section 4.

2. Detecting dynamic and static obsta

We extracts a relative position between obstacle and mobile robot using the single camera and sonar. The camera is mounted on the mobile robot and the sonar positions in all arrays are fixed to the robot : one on each side, six facing outward at 20-degree intervals(See figure 1).

2.1. Modified Polar Mapping

To segment moving objects from the background, we first transform the image to a different coordinate

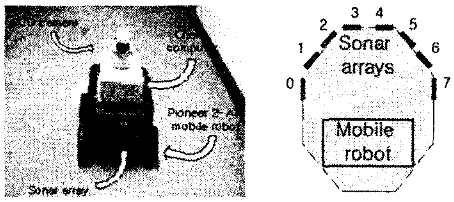


Figure 1. The experimental mobile robot and sonar arrangement.

system. The image is transformed to modified-polar coordinates using

$$r=\sqrt{(x-x_r)^2+(y-y_r)^2} \quad (1)$$

$$\theta=\tan^{-1}\left(\frac{x-x_r}{y-y_r}\right) \quad (2)$$

where the coordinates (x_r, y_r) is the closest to the mobile robot and r is the radial distance from the (x_r, y_r) to the detected moving obstacle coordinate, and a θ represents the angle (from 0 to π) subtended by the rectangular image coordinates (x, y).

After transforming the image to modified polar coordinates, the problem of detecting a moving obstacle is to find vertical motion along an angular axis in sequence of transformed images. The basic idea of this approach is as follows. If a horizontal edge in an image moves horizontally then the overlap between the edge from one image to the next image is very large. On the other hand, if a horizontal edge moves vertically, there is very little overlap[1]. Hence, the qualitative measure of the motion is obtained by detecting the vertical motion of edges present in the transformed image. Let I_i is the modified polar transformed image of the first image that obtained from the robot and I_{i+1} is the modfied polar transformed image of the next image obtained from the robot. Let $I_{(i)sobel}$ and $I_{(i+1)sobel}$ be the edge images of I_i and I_{i+1} by using Sobel operator. Then the detected image I_{mot} obtained as

$$I_{mot}= I^2_{(i)sobel}- I_{(i)sobel}\cdot I_{(i+1)sobel} \quad (3)$$

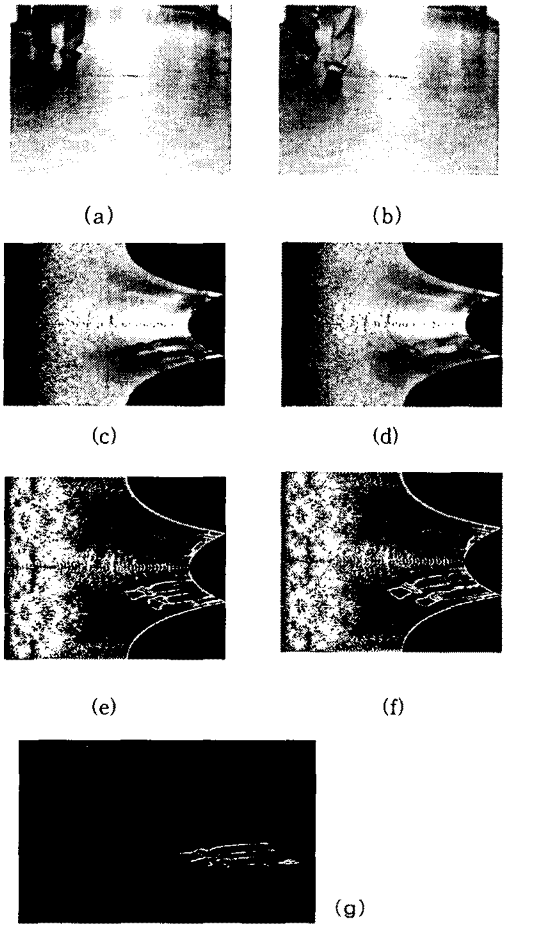


Figure2. (a),(b) Two images from a typical sequence in a corridor. (c),(d) Modfied polar mapping of the images. (e)(f) The edges detected in the images (g) The detected motion obtained (e)*(e)-(e)*(f).

2.2. Extracting the relative position

2.2.1 Relative position calculation by image

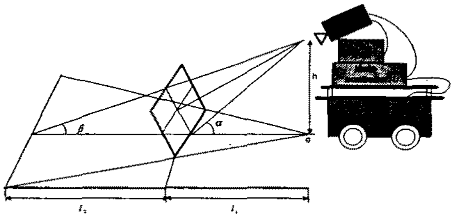


Figure 3. Relative distance calculation

Between robot and obstacle, to calculate distance of the each other, it must be obtained that the height(h) of camera, real the longest distance ($l_1 + l_2$) and short distance (l_1). Then the angles and distance can be calculated by follow equations[4].

$$\alpha = \tan^{-1}\left(\frac{h}{l_1}\right) \tag{4}$$

$$\beta = \tan^{-1}\left(\frac{h}{l_1 + l_2}\right) \tag{5}$$

$$R = h \times \tan\left[(90 - \alpha) + \left(\frac{r}{C}\right)(\alpha - \beta)\right] \tag{6}$$

$$\theta = \frac{\theta_1 + \theta_2}{2} \tag{7}$$

In the equation (6), C is the number of column pixel. The r is the minimum value from 0 to 640. The R is estimated real distance. The θ_1 is the minimum theta value and the θ_2 is the maximum theta value in the theta range. See figure 4. The θ is the angle $(0 \sim 2\pi)$ from mobile robot to moving obstacle.

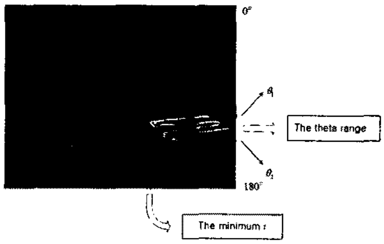


Figure 4. The accumulated histogram each column and row.

2.2.2 Relative position calculation by sonar

Supposing the mobile robot is located in the 2 dimensional Cartesian coordinate system, the configuration of the mobile robot is as follow Figure4.3.

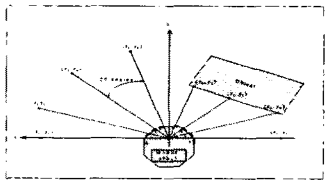


Figure 5. Configuration of the robot

Here (x_i, y_i) is the point acquired from the sonar sensor, r_i is the distance from the mobile robot to (x_i, y_i) and θ_i is the angle of the mobile robot with respect to the coordinates.

$$r_i = \sqrt{x_i^2 + y_i^2} \quad (i = 0, 1, 2 \ldots 7) \tag{8}$$

$$\theta_i = \tan^{-1}\left(\frac{x_i}{y_i}\right) \quad (i = 0, 1, 2 \ldots 7) \tag{9}$$

We make the mobile robot acquire the points from the number of sonar 0 to 7. The decision of the steering angle with sonars is conducted as follows. First, the mobile robot sorts the distances by the size of each sonar's distance ($r_1 \sim r_6$). Second, the robot recognize the sonar's number sensed the biggest dsitance. Third, the robot turns its direction according to the steering angle (ϕ_i) defined by the behaviour table. The behaviour table is the robot's rotation degree by the selected seonsor's number in the second procedure.

$$\phi = \frac{\theta_1 + \theta_2}{2}, \quad \phi_2 = \frac{\theta_1 + \theta_2 + \theta_3}{3},$$

$$\phi_3 = \frac{\theta_2 + \theta_3 + \theta_4}{3}, \quad \phi_4 = \frac{\theta_3 + \theta_4 + \theta_5}{3},$$

$$\phi_5 = \frac{\theta_4 + \theta_5 + \theta_6}{3}, \quad \phi_6 = \frac{\theta_5 + \theta_6}{2} \quad (10)$$

3. The behaviour table

3.1 The static behaviour table

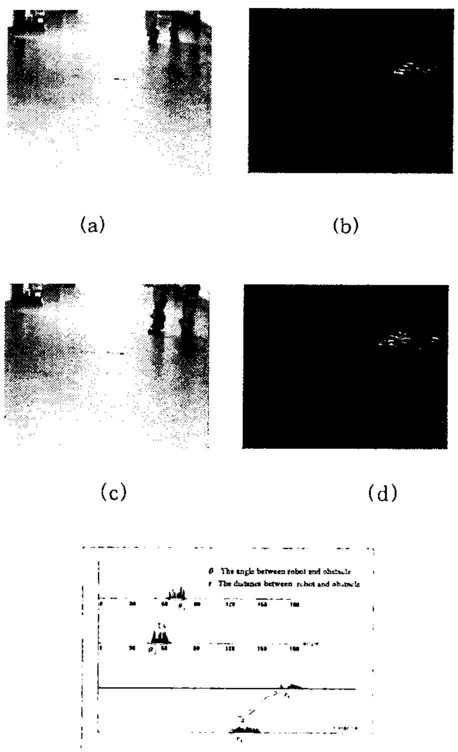
If the moving obstacle doesn't exist, the mobile robot translates by a predefined distance and the steering angle is decided by the follow static behaviour table.

SONAR NUMBER	NO0	NO1	NO2	NO3	NO4	NO5	NO6	NO7
STEERING ANGLE	·	ϕ_1	ϕ_2	ϕ_3	ϕ_4	ϕ_5	ϕ_6	·

Table 1. Static behaviour table

3.2 The dynamic behaviour table

If the moving obstacle exist, the robot obtains the first detected moving motion image(Figure 6(b)). Then the robot obtains the second detected moving motion image after time interval(Figure 6(d)). The Figure 6(e) is the variation of the relative angle, distance. To avoid collision, we define a dynamic behaviour table. The steering angle is decided by the dynamic behaviour table.



(a) (b)

(c) (d)

(e)

Figure6. (a),(c) Two images from a typical sequence in a corridor. (b),(d) The detected motion obtained by the modified polar mapping. (e) The variation of the relative angle and distance.

First detected angle	Comparison with second detected angle		Steering angle		
$\theta_1 \le 90°$	$\theta_2 > \theta_1$	Sonar number	NO4	NO5	NO6
		angle	ϕ_4	ϕ_5	ϕ_6
	$\theta_2 < \theta_1$	Sonar number	NO1	NO2	NO3
		angle	ϕ_1	ϕ_2	ϕ_3
$\theta_1 > 90°$	$\theta_2 > \theta_1$	Sonar number	NO4	NO5	NO6
		angle	ϕ_4	ϕ_5	ϕ_6
	$\theta_2 < \theta_1$	Sonar number	NO1	NO2	NO3
		angle	ϕ_1	ϕ_2	ϕ_3

Table 2. The dynamic behaviour table

4.Conclusion

The methods for dynamic and static obstacle avoidance have been implemented in Pioneer 2-AT mobile robot. The static obstacle and moving obstacle are detected by the sonar sensor and vision sensor respectively. The proposed method has shown several advantages in the collision avoidance following the problem compared to the other approaches : (1) It was shown that the robot could avoid obstacle(including moving or static obstacle) using only visual and sonar data without any knowledge of the structure of the environment. This shows the proposed navigation method is suitable for unknown environments. (2) It was shown that the detection of the moving obstacle is simplified with the use of modified-polar mapping. Besides, The robot could estimate moving obstacles relative angle and distance which acquired from the modified-polar mapping to decide the path of the robot. (3) The detection of moving obstacle is fast and reasonably accurate. Also, the system is simple to implement. The proposed method can be used for enhancing the performance of many other mobile robots to expand their application domains.

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