Back-Parking Control of the Car via Tri-ultrasonic Sensors and CCD Camera

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Abstract

To move efficiently in an uncertain environment, a mobile robot must use observations taken by various sensors to construct information for path planning and execution. In this paper, the tri-ultrasonic sensors and CCD camera are installed on a car-like mobile robot to control back-parking behavior. All of the path planning that likes a man who drives a car back into the parking space. . In general, the speed of the car is not fixed, so we must exploit the human experience to implement the back-driving behavior.

Keywords: Ultrasonic sensor, CCD, Mobile Robot, back-parking

摘要

為了使一台行走機器人在一個不確定的環境中，行動的更有效率，必須使用各種不同的感測器，建構出機器人行走的路徑。在本篇論文中，將三個超音波感測器及 CCD 攝影機安裝於行走機器人上，用來控制倒車入庫的行為。整個路徑之規畫類似駕駛員將車子倒車入庫一般。一般而言，車行的速度並不是固定的，所以我們必須以人類的經驗來完成車子倒車入庫的行為。

關鍵詞：超音波感測器，CCD 攝影機，行走機器人，倒車入庫。

1. Introduction

The back parking problem is always a troublesome matter for a driver in the real world. In recent years, interest in car parking problems has increased. Parromtchik and Laugier [1] presented an approach to parallel parking for a nonholonomic vehicle. In the approach a parking space is scanned before the vehicle reverses into the parking bay. K.Jiang [2] presented a sensor guided parallel parking system for nonholonomic vehicles. He presented an automatic parallel parking planning system for a car-like vehicle, with the intention to apply the research results of robot motion planning into real-world applications.

A study of the back parking problem for a car-like mobile robot is presented. This study is a part of a research project in the development of an automated parking system. In this paper, tri-ultrasonic Sensors and a CCD camera were combined to provide a sensor system for a mobile robot. An external sensor is very important for a mobile robot to recognize its environment and its own position. Yoshiaki Nagashima and Shin ‘ichi Yuta [3]measured the normal direction of the wall by using a system made of one transmitter and two receivers.

Kai-Tai Song and Wen-Hui Tang [4] used ultrasonic sensors for distant measurement and a vision system for object-boundary detection. Others classified the target surface as a corner and a plane using the magnitude information of the received signals [5]. In section 2,the hardware architecture of the robot and the sensor system is briefly described. Section 3 describes the Automated parking process. The experimental results and discussion are shown in the section 4. Finally, the conclusion and recommendations are given in the last section.

2. The hardware architecture of the robot and the sensor system

The car-like mobile robot features in a rectangular rigid body and a four-wheel mechanism with two degrees of freedom (dof), which are a linear dof for forward and backward movement and a rotation dof for changing orientation. The signal processing block diagram of a PC-based robot is shown in Fig.2-1. The appearance of the real autonomous mobile robot is shown in Fig.2-2.

The sensor system consists of three ultrasonic transducers where one is on the center of the rod and the two others are on the both sides of the rod, a CCD camera which is installed upon the center of the rod, and the rod is controlled by a step motor. The sensor system is mounted in the front of the robot.Fig.2-3 shows the figure of the sensor platform.

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3. Reference path planning

3.1 Modeling of the car-like mobile robot

The mobile robot we consider is as shown in Fig.3-1. The dynamic equations of the mobile robot motion can be derived by the nonholonomic constraints [6],

θ : angle between the main axis of the truck and the x axis;

ϕ : steering angle, defined as the angle between the main axis of the truck and the front wheels;

L : length of the mobile robot;

V : speed of the front wheels of the mobile robot;

$F(x_f, y_f)$: position of the front wheel center of mobile robot;

$R(x_r, y_r)$: position of the rear wheel center of the mobile robot;

The motion of vehicle is described as

$$x_r = v \cdot \cos\theta \cos\phi \tag{1}$$

$$\dot{y}_r = v \cdot \sin\theta \cos\phi \tag{2}$$

$$\dot{\theta} = v \cdot \frac{\sin\phi}{L} \tag{3}$$

3.2 Reference path based back parking

Kai-Ren Shih [7] proposed a reference path for back parking. The reference rear path during back parking is presented as a function $y_r = f(x_r)$.The general form of a second- order polynomial is given by

$$(x_r - x_e)^2 + (y_r - y_o)^2 = x_e^2 \tag{4}$$

We propose a method based on the back reference path that presented in [7].Traditionally, a reference path is provided for a path planner with the consideration of the environmental model as well as the mobile robot's dynamics and constraints. Fig.3-2 shows the back parking reference path. Assume the car is parallel to the parking space, and we make the steering angle ϕ maximum and fixed. Due to the structure of mechanical constrain, we can obtain the angle of ϕ and D_x. The angle φ can be adjusted by moving the mobile robot forward or backward according to the distance D_y between the mobile robot and the parking lot .The relationship between D_y and φ can be obtained by equation (5)

$$\varphi = \tan^{-1}(D_x / D_y)$$

(5)

Hence, the mobile robot can follow the curve $C_1 \sim C_n$, as long as D_y is greater than the distance, that is to avoid collision between the mobile robot and obstacle.

4. Automated parking process

The automated parking process consists of three phases, which are tracking, scanning, and maneuvering to the goal position. Figure 4-1 illustrates a typical back parking process that includes the three phase. In tracking phases, the mobile robot moves from Position 1 to Position 2 to keep parallel with the plane. In scanning phases, the mobile robot obtains the information about the parking environment using ultrasonic sensor and CCD. In positioning and maneuvering phases, the mobile robot moves from Position 2 to the parking Position 4.

4.1 Plane Tracking

In this phase, we propose a single-input-single-output fuzzy controller for the plane tracking . Using the proposed method [3], a mobile robot can recognize the inclination angle of walls, which is computed from the difference of TOF between left and right receivers. Figure 4-2 illustrates the expected wall from measured distance and direction. The inclination angle of wall 'α' is obtained by equation (6),(7),(8) .

$$\sin\alpha = \frac{\Delta l}{2d} \tag{6}$$

$$\Delta l = (T_l - T_r) \bullet V \tag{7}$$

$$\alpha = \frac{\Delta l}{2d} \text{ (rad)} \tag{8}$$

where V is the speed of sound, and T_l and T_r is the TOF which is measured on the left and the right receivers, respectively.

The angle 'α' is a fuzzy input and the steering angle of the robot is a fuzzy output. The range of input - output variables are shown in table 4-1. The fuzzy rule table is shown in table 4-2. The membership function for each input-output variable is a triangular graph shown in Figure 4-3. Using the information gained through laboratory work, we make a fuzzy control rule of IF-THEN structure and decide the steering angle of the mobile robot using the fuzzy inference result. Max-min method (Mamdani method) is used for the fuzzy inference. The center of gravity method is shown in equation (9).

$$\phi_a = \frac{\int \mu_c(\phi) \bullet \phi d\phi}{\int \mu_c(\phi) d\phi} \tag{9}$$

where $\mu_c(\phi)$: degree of membership

ϕ : steering angle

ϕ_a : output

4.2 Scanning Parking Space

In this phase, the distance between the mobile robot and wall and the mobile robot orientation φ are detected by the ultrasonic sensors and CCD, as shown in Fig.4-4. 'D_y' is detected by the ultrasonic sensor which is on the center of the rod, and the orientation φ can be obtained by (5). The middle of the parking lot is detected by the CCD camera. Here, we choose the high pass filter, which is called Sobel filter, to enhance the vertical lines. The center of two lines is regarded as the middle of the parking lot. Then we can calculate the angle 'φ_1'that the step motor has turned and move the robot forward or backward based on the difference between 'φ'and 'φ_1'until the gap is smaller than a predefined value.

4.3 Maneuvering

In this phase, the robot moves from Position 2 to Position 3 following a path with 1/4 circle that planed in section 3. The moving curve is fixed in the phase, because the steering angle is a constant. A general case is shown in Fig.4-5. The wheel encoder is used to calculate the lengths that the robot has moved. The robot moves from Position 2 directly until the length reach to the predicted value (position 3) .Now, the body of the robot faces to the parking space. Then the robot moves from Position 3 to Position 4 in straight line. Ultrasonic sensor is used to detect the distance between the robot and the bottom of the parking space in Position 4.

5. Experimental Result

The physical parameters of the car-like mobile robot are as follows: length = 37cm, width =20 cm, front wheel steering angle $\phi = 0^o \sim 30^o$, back wheel steering angle $= 0^o$,distance between the front and the back axes L=25.5cm, and distance between left and right wheels on each axle = 15.5 cm. The width of the parking space is set to W=37.5 cm and the depth of the parking space is set to D=81 cm. Figure 5-1 shows a typical parking example.

6. Conclusion

The paper presents a easy path planning of the back parking problem for a car-like mobile robot. The parking system, guided by ultrasonic sensors and CCD camera, work in three phases, tracking, scanning, and maneuvering. The fuzzy controller is used to make the body of the robot parallel to the parking space, the distance between the robot and parking space and the image of the parking space are used to determine whether the robot needs to drive forward or backward. Then the robot moves to the parking space, followed by unified maneuvers to reach the goal position.
The system is implemented on a car-like mobile robot. Ultrasonic sensors and CCD camera are mounted on the rod used to detect the environment. The experimental results illustrate the capability of the automatic back parking system.

7. References

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Table 4-1. Quantized variables

The inclination angle of wall'α' (degree)	Steering Angle 'ϕ' (degree)	Quantized Level
20	30	2090
10	15	2160
0	0	2230
-10	-15	2300
-20	-30	2370

Table 4-2. The fuzzy rule table

(input α)	PB	PS	ZE	NS	NB
(output ϕ)	PB	PS	ZE	NS	NB

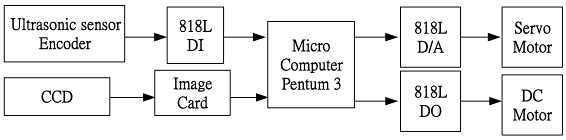


Fig.2-1. **The signal processing block diagram of a PC-based robot**

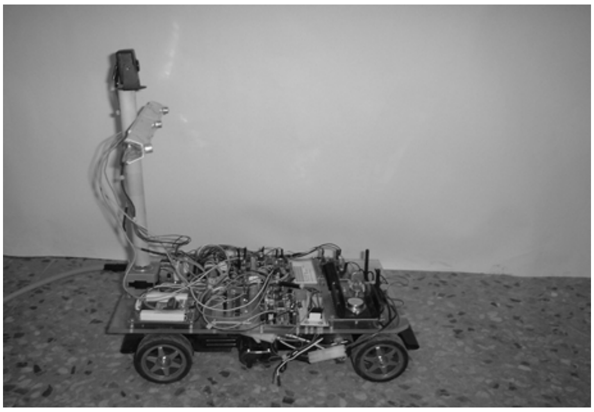


Fig.2-2**. The appearance of the real autonomous mobile robot**

Fig.2-3. **A picture of sensor platform**

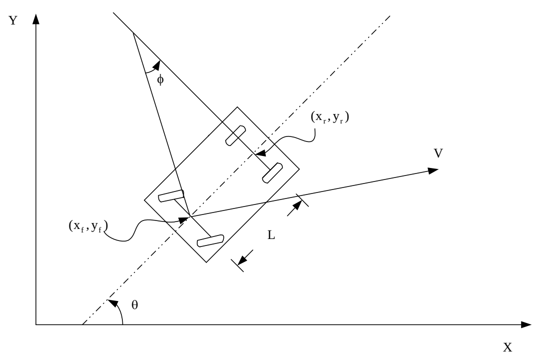


Fig.3-1. **Parameter configuration of the car**

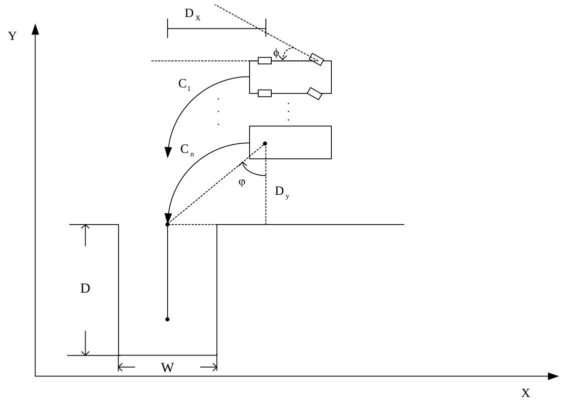


Fig.3-2. **The back parking reference path**

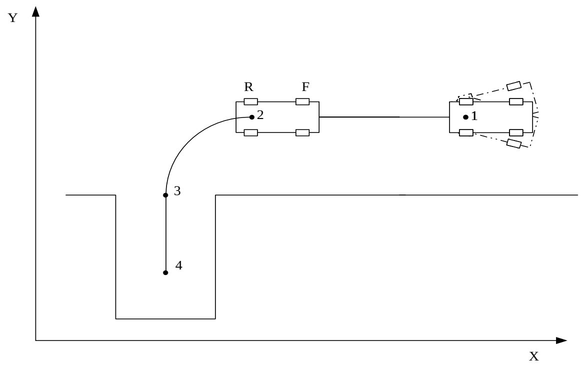


Fig.4-1**. Parking Example**

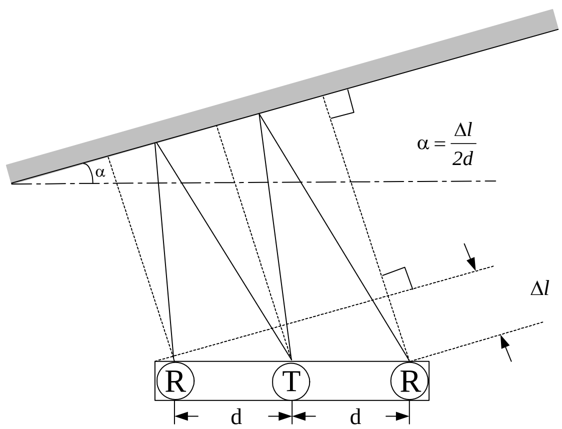
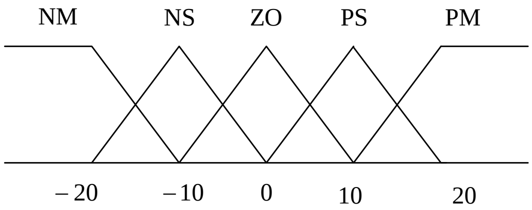
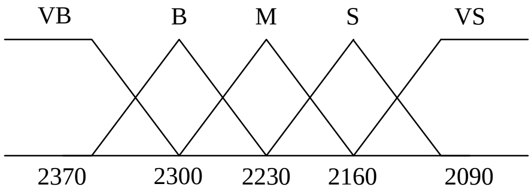


Fig.4-2. **The method of measuring the distance and direction of reflecting point for the smooth surface of object**



(a) fuzzy input (α)



(b) fuzzy output (ϕ)

Fig 4-3. **Membership function**

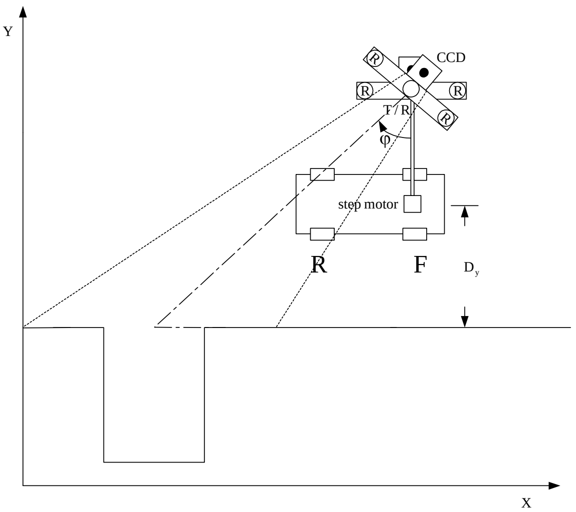


Fig.4-4. **The distance between the mobile robot and wall and the mobile robot orientation φ**

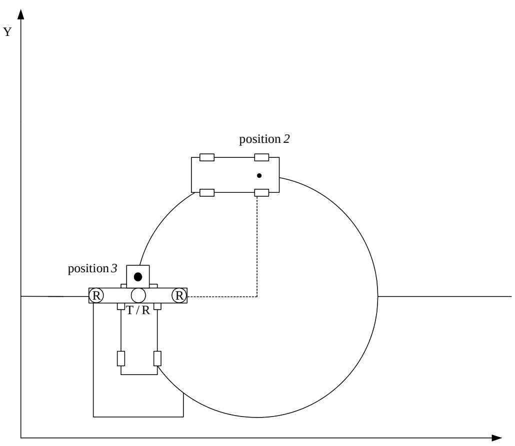
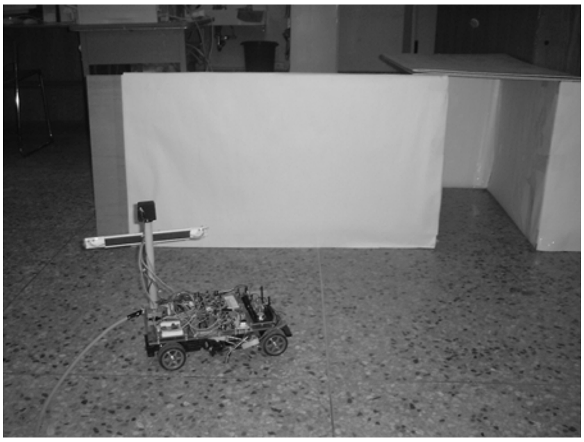
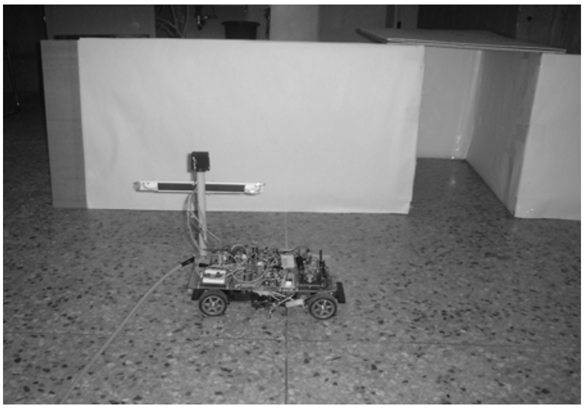


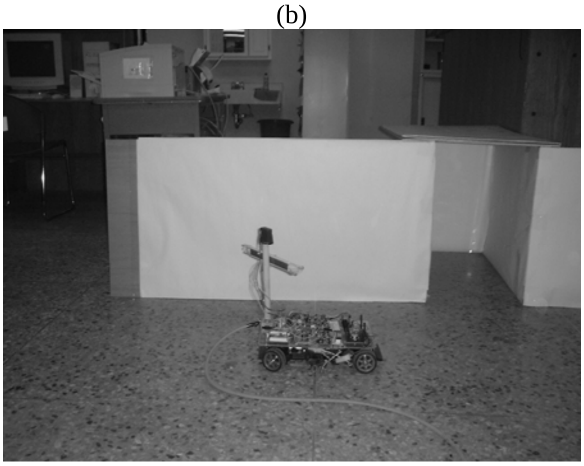
Fig.4-5. **The robot moves from position 2 to position 3 following a path with 1/4 circle**



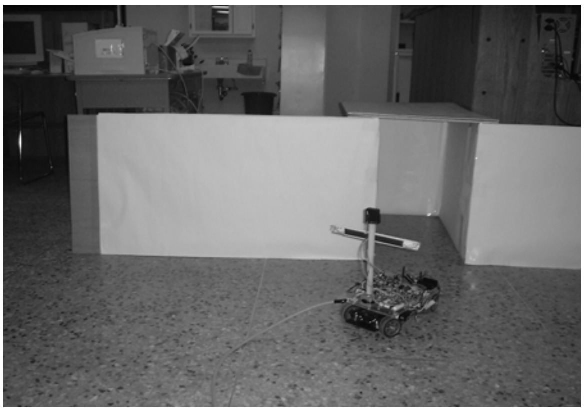
(a)



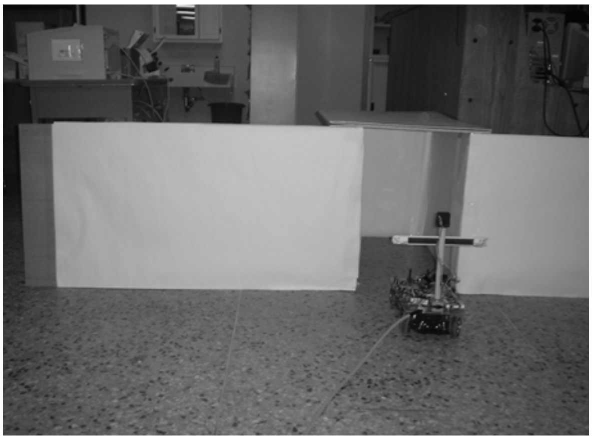
(b)



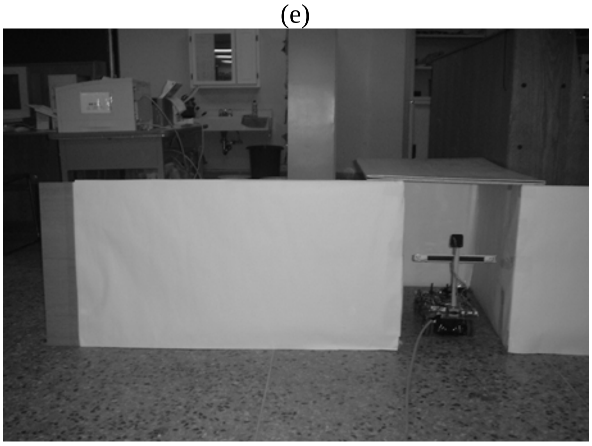
(c)



(d)



(e)



(f)

Fig.5-1. **A typical parking example**

- **(a) The mobile robot is at initial position.**
- **(b) The mobile robot is moving.**
- **(c) The mobile robot is moving.**
- **(d) The mobile robot is moving.**
- **(e) The mobile robot is moving.**
- **(f) The mobile robot is at terminal position.**