Autonomous Parking Control Design for Car-Like Mobile Robot by Using Ultrasonic and Infrared Sensors

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Abstract. This research presents the design and implementation of the intelligent autonomous parking controller (APC) and accomplishes it in a car-like mobile robot (CLMR). This car possesses the function to accept and estimate the environment by integration of infrared and ultrasonic sensors. We propose five parking modes including parallel-parking mode, a narrow path parallel-parking mode, garage-parking mode, a narrow path garage-parking mode, and none parking mode. And the CLMR can autonomously determine which mode to use and park itself into the parking lot. Finally, it is perceived that our intelligent APC is feasible from the practical experiments.

1 Introduction

In recent years, an increasing amount of the CLMR researches has focused on the problem of autonomously parking and avoidable collision. The parking problem of the car-like mobile robot consists of finding the parking lot and planning the trajectory for parking. Basically, the parking problems can be classified into two categories: garage-parking problem and parallel-parking problem [1-20]. In this research, we propose an autonomously parking control base on the fuzzy logic control (FLC). In this control we fuse the measurements of infrared sensor and ultrasonic sensor as the inputs of the FLC.

To solve the problem of the path-planning from the usage of sensor point of view, An et al. [8] develop an online path-planning algorithm that guides an autonomous mobile robot to a goal with avoiding obstacles in an uncertain world with a CCD camera, and Han et al. [21] use the ultrasonic sensor to build the environment about the car, follow a moving object and avoid the collision.

For parking control, [18] utilizes the CCD camera to detect the global vision of the parking lot, [19] adopts six infrared sensors to measure the relative distance among the CLMR and the surroundings, and [20] uses the sensor fusion techniques to combine the ultrasonic sensors, encoders, and gyroscopes with a differential GPS system to detect and estimate the dimensions of the parking lot. In this paper, we want to integrate the information of the ultrasonic and infrared sensors to measure the parking environment.

Fuzzy set theory is arisen from the desire of linguistic description for complex system and it can be utilized to formulate and translate the human experience. This

A. Bredenfeld et al. (Eds.): RoboCup 2005, LNAI 4020, pp. 472 – 479, 2006.

kind of human intelligence is easily represented by the fuzzy logic control structure. Most advanced control algorithms in autonomous mobile robots can benefit from fuzzy logic control. In this paper, the CLMR equips with infrared and ultrasonic sensors. We fuse the measurements of the two kinds of sensors on the car to obtain the information in an unknown environment, and utilize this information to determine the velocity and the steering angle of the car by the proposed FLC.

This paper is organized as follows. In Section 2, parking lot measurement, kinematic equations, and the FLC for garage parking and parallel parking are derived. The parking lot measurement can help to decide the trajectory of the CLMR. Section 3 addresses the hardware architecture of the CLMR that consists of the following four parts, CLMR mechanism, FPGA module, sensor module, and electronic driver module. Experimental results about the intelligent APC in different modes are given in Section 4. Section 5 concludes this paper.

2 Design of APC

The main advantage of the study is that the developed APC can park the car successfully, though the absolute coordinates of the car and parking lot are unknown. Fig.1 presents the appearance of the CLMR and the top view and the sensor arrangement of the CLMR.

In the beginning, we address the fuzzy wall following control (FWFC) problem. By the FWFC in [19], the X_d and X_e are the inputs and ϕ is the output of the FLC. X_d is the distance between the CLMR and the wall that is defined in equation (1), and X_e is the sloping angle of CLMR that is described in equation (2). In this paper, we introduce a new variable X, which is the sum of X_d and X_e, to reduce the number of fuzzy if-then rules. The corresponding rule table is listed in Table 1. Fig. 2 indicates the member functions of the input and output of the FLC.

$$X_d = Right_1 - dis \tag{1}$$

$$X_e = Right_1 - Right_2 \tag{2}$$

$$X = X_d + X_e \tag{3}$$

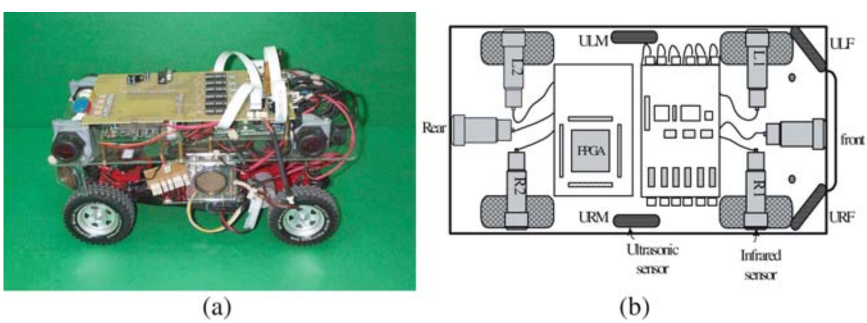
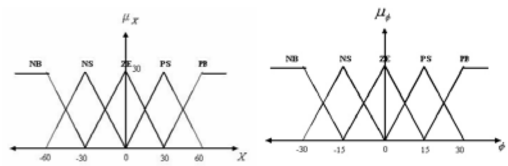


Fig. 1. (a) The appearance of the CLMR (b)Top view and the sensor arrangement of the CLMR

where $Right_1$ is the information of the right front infrared sensor, *dis* presents the safety distance of the CLMR, and $Right_2$ is the information from the right rear infrared sensor.



(a) (b)

Fig. 2. (a) Fuzzy membership function for the CLMR in put X (b) Fuzzy membership function for the CLMR output ϕ

Table 1. Fuzzy rule table of the steering angle

Antecedent part		Consequence part	
If X is	NB	then ϕ is	NB
	NS		NS
	ZE		ZE
	PS		PS
	PB		PB

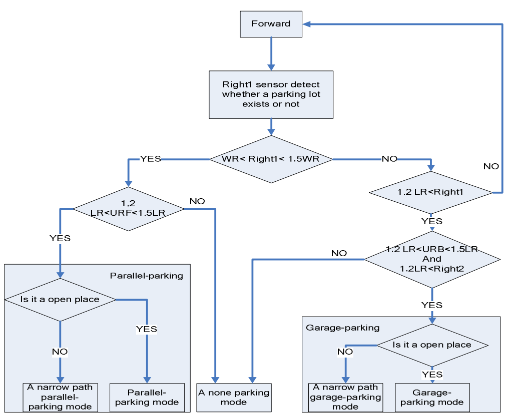


Fig. 3. Flow chart of mode detection

In order to autonomously park the CLMR, the parking lot detection is an important issue. In this paper, we consider five parking modes for the CLMR. The flow chart of mode detection is shown in Fig. 3, where the WR is the width of the CLMR and LR is the length of the CLMR. In fact, three parking conditions are included and will be examined as follows.

Case 1: Parallel-parking condition
The basic constraints are
(WR<Right 1<1.5WR) and (1.2LR< URF<1.5LR).

In this case, there are two modes should be considered. One is parallel-parking mode and the other is a narrow path parallel-parking mode. At first, we explain the parallel-parking mode, which is showing Fig. 4(a). For backward parking, the CLMR passes though the parking lot a little distance once the sensors have detected the parallel-parking lot. Then we turn the steering wheel to the right end and drive the car backwards. If the rear and Right 2 infrared sensors detect the CLMR is entering the lot then the CLMR will turn the steering wheel to straight until the front infrared sensor detect the wall. Then we make the steering wheel turn left until the rear sensor detect the wall is close to the safety distance or the car is parallel to the wall. Now, we discuss how to execute a narrow path parallel-parking mode. In this mode, we not only use the same parallel-parking mode but also consider the left sensors' information to avoid colliding with the wall. If both the left 1 and 2 sensors measure the distance between the left wall and the car is less than 0.7 WR, which means that there is not enough distance for the CLMR to turn round, and then we terminate the parking mission.

Case2: Garage-parking condition
The primary conditions are
(WR<Right 1<1.5WR) and (1.2LR< URM<1.5LR) and (1.5WR<Right 2)

In this situation we also consider two modes. One is the garage-parking mode, which is depicted in Fig. 5(a), and the other is the narrow path garage-parking mode. The detection of the garage-parking condition is accomplished by combining three sensors. At first, Right 1 sensor can detect whether a parking lot exists or not. And if both the measurements of the ultrasonic sensor URM and the infrared sensor Right 2 satisfy the constraint 1.2LR< URM<1.5L and 1.5WR<Right 2, then one can conclude that the parking lot is deep enough to execute the garage parking and there is not any obstacle or car in the parking lot. For garage-parking control, we turn the steering wheel left and move forward a little distance as the Right 2 sensor detects that the CLMR passes the parking lot. Then, we turn the steering wheel right and move backward to the garage. As the Right 2 and Left 2 detect the CLMR enters the garage then the CLMR turn the steering wheel to straight and move backward until the rear sensor detects the CLMR is close to the safety distance. If it is not in the center position then goes forwards and backwards by using the FWFC. For narrow path garage-parking control, the basic concept is the same as that of the narrow path

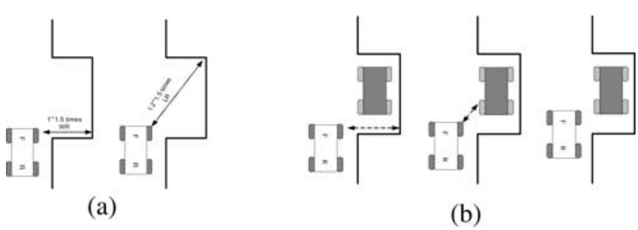


Fig. 4. (a) Parallel- parking mode. (b) None parking mode.

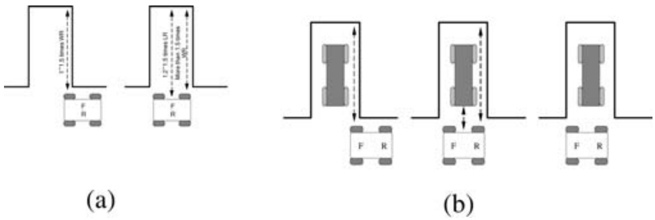


Fig. 5. (a) Garage- parking mode. (b) None parking mode.

parallel-parking control. That is, suppose the Left 1 and 2 sensors find that the distance between the left wall and the CLMR is less than 0.7 WR, then we stop the parking command.

Case 3: None parking condition
It is seen in Fig. 4(b) and Fig. 5(b) that the CLMR notice there is a car in the parking lot. In these cases, we call the CLMR is in none parking condition. We stop the car once it passes though the parking lot.

3 Hardware Architecture

The CLMR consists of the following four parts, CLMR mechanism, FPGA module, sensor module, and electronic driver module. The CLMR mechanism includes car body, driving motor, and steering motor. The car body is a 1/10th scale four-wheeled mobile robot vehicle with rear wheel drive system and front steering wheels. The robot carries FPGA board, daughter board and battery.

The FPGA module is the Altera FLEX 6000 family. The Altera FLEX 6000 programmable logic device (PLD) family provides a low-cost alternative to high-volume gate array designs. The FPGA utilizes these information come from the sensor module to determine the velocity and the steering angle of the car.

The sensor module contains six infrared sensors and four ultrasonic sensors. All of them are reflection sensors, so we need the reflective object. The specifications of the infrared sensor (UF55MG) are: measurement range 50~500mm, input volt 20~30V, output volt 0~10V, response time 10ms, and opening angle 12°.

Because the measurement rang of the infrared sensor is only 50mm~500mm, we can not measure obstacle out of this range. For this reason, the ultrasonic sensors (6500 Sonar Module) are adopted in the CLMR. The 6500 Series is an economical sonar ranging module, with a simple interface, is able to measure distances from 6 inches to 35 feet.

The electronic driver module consists of a STL293D DC motor driver IC and a FPGA. The STL293D IC is assembled in a PCB board to drive the DC motor to change the speed of the rear wheels. We employ the FPGA to generate PWM signal to drive the DC servomotor to control the steering angle of the front wheels.

4 Experiment

Fig. 6 shows that the developed CLMR can detect there is a parallel-parking place and perform the parallel-parking control successfully. Fig. 7 illustrates the CLMR can

Fig. 6. Experimental results of the parallel-parking control

Fig. 7. Experimental results of the garage-parking control

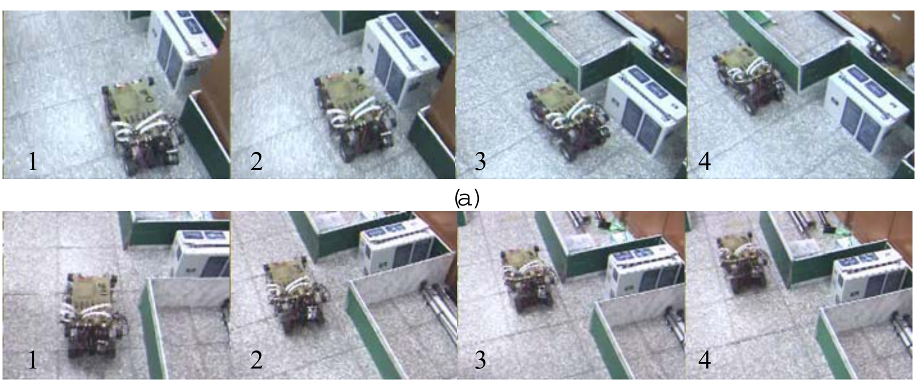


Fig. 8. None parking case: (a) Obstacle in parallel-parking lot, (b) Obstacle in garage-parking lot

detect the existence of a garage-parking place and successfully execute the garage-parking control. Experimental results depicted in Fig. 8 demonstrate that there are obstacles in the parking lot, and then the CLMR can just pass the parking lot and stop.

5 Conclusion

In this paper, we have succeeded in solving the parking problems by the proposed intelligent APC on the basis of the infrared and ultrasonic sensors. Five parking modes have been developed in the APC and realized in the FPGA chip. The developed scheme can be also applied to a real car if it equips with these sensors and the FPGA or micro processors. For future study, we want to set up the CMOS sensor on the CLMR. The CMOS sensor does not need the reflective object and can get more information about the environment.

Acknowledgment

This work is supported by the National Science Council, Taiwan, Republic of China, under grant NSC 93-2213-E-006-129.

Reference

1. M. Sugeno and K. Murakami, "An experimental study on fuzzy parking control using a model car," in Industrial Applications of Fuzzy Control, M. Sugeno, Ed. North-Holland, The Netherlands, 1985, pp. 105–124.
2. M. Sugeno, T. Murofushi, T. Mori, T. Tatematsu, and J. Tanaka, "Fuzzy algorithmic control of a model car by oral instructions," *Fuzzy Sets Syst.*, vol. 32, pp. 207–219, 1989.
3. A. Ohata and M. Mio, "Parking control based on nonlinear trajectory control for low speed vehicles," in *Proc. IEEE Int. Conf. Industrial Electronics*, 1991, pp. 107–112.
4. S. Yasunobu and Y. Murai, "Parking control based on predictive fuzzy control," in Proc. IEEE Int. Conf. Fuzzy Systems, vol. 2, 1994, pp. 1338–1341.
5. W. A. Daxwanger and G. K. Schmidt, "Skill-based visual parking control using neural and fuzzy networks," in Proc. IEEE Int. Conf. System, Man, Cybernetics, vol. 2, 1995, pp. 1659–1664.
6. A. Tayebi and A. Rachid, "A time-varying-based robust control for the parking problem of a wheeled mobile robot," in Proc. IEEE Int. Conf. Robotics and Automation, 1996, pp. 3099–3104.
7. M. C. Leu and T. Q. Kim, "Cell mapping based fuzzy control of car parking," in Proc. IEEE Int. Conf. Robotics Automation, 1998, pp.2494–2499.
8. H. An, T. Yoshino, D. Kashimoto, M. Okubo, Y. Sakai, and T. Hamamoto, "Improvement of convergence to goal for wheeled mobile robot using parking motion," in Proc. IEEE Int. Conf. Intelligent Robots Systems, 1999, pp. 1693–1698.
9. D. Lyon, "Parallel parking with curvature and nonholonomic constraints," in Proc. Symp. Intelligent Vehicles, Detroit, MI, 1992, pp. 341–346.
10. I. E. Paromtchik and C. Laugire, "Motion generation and control for parking an autonomous vehicle," in Proc. IEEE Conf. Robotics Automation, vol. 4, Minneapolis, MN, 1996, pp. 3117–3122.

11. C. Laugier, T. Fraichard, I. E. Paromtchik, and P. Garnier, “Sensor-based control architecture for a car-like vehicle,” in Proc. IEEE Int. Conf. Intelligent Robots Systems, 1998, pp. 216–222.
12. K.Y. Lian, C. S. Chin, and T. S. Chiang, “Parallel parking a car-like robot using fuzzy gain scheduling,” in Proc. 1999 IEEE Int. Conf. Control Applications, vol. 2, 1999, pp. 1686–1691.
13. K. Jiang and L. D. Seneviratne, “A sensor guided autonomous parking system for nonholonomic mobile robots,” in Proc. IEEE Int. Conf. Robotics Automation, vol. 1, 1999, pp. 311–316.
14. K. Jiang, “A sensor guided parallel parking system for nonholonomic vehicles,” in Proc. IEEE Conf. Intelligent Transportation Systems, 2000, pp. 270–275.
15. J. Xiu, G. Chen, and M. Xie, “Vision-guided automatic parking for smart car,” in Proc. IEEE Intelligent Vehicles Symp., 2000, pp. 725–730.
16. D. Gorinevsky, A. Kapitanovsky, and A. Goldenberg, “Neural network architecture for trajectory generation and control of automated car parking,” IEEE Trans. Contr. Syst. Technol., vol. 4, pp. 50–56, Jan. 1996.
17. S. Lee, M. Kim, Y. Youm, and W. Chung, “Control of a car-like mobile robot for parking problem,” in Proc. IEEE Int. Conf. Robotics Automation, 1999, pp. 1–6.
18. T.-H. S. Li and S.-J. Chang, “Autonomous fuzzy parking control of a car-like mobile robot,” IEEE Transactions on Systems, Man, and Cybernetics, vol. 33, pp. 451–465, 2003.
19. T.-H. S. Li, S.-J. Chang, and Y.X. Chen, “Implementation of human-like driving skills by autonomous fuzzy behavior control on an FPGA-based car-like mobile robot”, IEEE Trans on Industrial Electronics, vol. 50, NO.5, pp. 867-880, 2003.
20. I. Baturone, F. J. Moreno-Velo, S. Sánchez-Solano, and A. Ollero, “Automatic design of fuzzy controllers for car-like autonomous robots” IEEE Transactions on Fuzzy Systems, vol. 12, NO. 4, pp 447-465, 2004.
21. Y. Han, M. Han, H. Cha, M. Hong, and H. Hahn, “Tracking of a moving object using ultrasonic sensors based on a virtual ultrasonic image” Robotics and Autonomous Systems, vol.36 pp. 11–19, 2001.
22. C. S. Ting, T. H. S. Li, and F. C. Kung, “An approach to systematic design of the fuzzy control system,” Fuzzy Sets Syst., vol. 77, pp. 151–166, 1996.
23. T. H. S. Li and M. Y. Shieh, “Switching-type fuzzy sliding mode control of a cart-pole system,” Mechatronics, vol. 10, pp. 91–109, 2000.