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An Intelligent Parking System for Vehicles Using an Image-based Fuzzy Controller

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***Abstract*—Automatic parking system is one of the interesting topics in developing intelligent vehicles. However, if the parking controller is not designed properly, it may endanger the vehicle and the driver. In this paper, a car-like mobile robot that possesses automatic parking capability is designed by using an image-based fuzzy controller. The proposed system consists of two parts. In the first part, a robot equipped with a single camera detects the parking lines which are drawn on the floor and generates the desired target line to be followed by the robot using a Hough transform. The fuzzy controller is designed with two inputs, which are the slope and intercept of the target line, and one output that is the steering angle of the robot to complete a parking task on the second part. The simulation and experimental results are presented to confirm the effectiveness of the proposed method.**

***Index Terms*—Image-based control, car-like mobile robot, fuzzy control, automatic parking, visual servoing.**

I. INTRODUCTION

Autonomous parking of a car-like mobile robot has become an interesting and challenging problem for both academics and automobile industries. In many recent works, a number of different approaches have been developed to build an automatic parking system. Many of these concepts rely on the ideas in [1], where an optimal algorithm was proposed to calculate the path for a car which moves both forwards and backwards in an obstacle free environment. However, it is only to control a vehicle which goes from one position to another position and does not consider the constraint of the parking lot.

An automatic parking system consists of a parking lot detection module and an automatic parking algorithm. A method for detecting camera vision-based parking lots is discussed in [2] and the ultrasonic sensors are employed to detect the parking lots in [3]. For the experimental study of fuzzy garage parking control, Li and Chang [4] utilized the CCD camera to detect the overall vision of the parking lot, Li et al. [5] adopted the six infrared sensors to measure the distances between the robot and the surroundings, and [6] used 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.

The goal of this study is to build an automatic parking system upon the concepts of image-based control system. To the best of our knowledge, there is no image-based visual servoing (IBVS) controller developed for automatic parking system of car-like mobile robots. The IBVS does not need to know the geometric representation of the environment and can operate a robot by controlling only image information which is acquired from a camera image without using the robot position. In this work, the error which is used to compute the control law is calculated in the 2D image space. The image-based approach reduces the computational time, does not need image interpretation, and eliminates the errors due to camera modeling and calibration. However, it needs to design a special controller to combine the behavior of the robot with the image features. For this reason, it was decided to use a model-free fuzzy controller. Especially, adopting a fuzzy controller [7], [8] allows us to design it without estimating image depth.

The application of fuzzy logic does not need much detailed knowledge of the system and utilizes the human (expert) knowledge and intuition instead of the mathematical knowledge of the system. The human intelligence is easily represented by the fuzzy logic control structure. Most advanced control algorithm in autonomous mobile robots can benefit from fuzzy logic control.

In this paper, an image-based fuzzy controller is developed for an automatic parking system of a car-like mobile robot (CLMR). A red color parking frame on the floor is detected from a robot equipped with a web camera and a target line for an automatic parking system is generated from a captured image by using an image processing technique with a Hough transformation. The fuzzy controller for the CLMR is designed to follow such a target line. Although the proposed method is a simple way, some simulation and real robot experiments show its usability.

II. PROBLEM SETTING

The objective of this research is to design and implement an image-based fuzzy controller for an automatic parking system of the CLMR. A red color parking frame drawn on the floor is detected from a robot equipped with a web camera by using image processing.

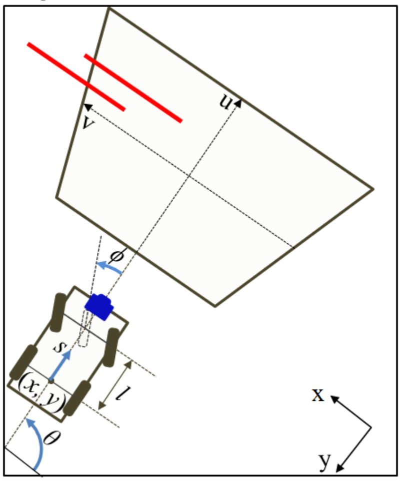
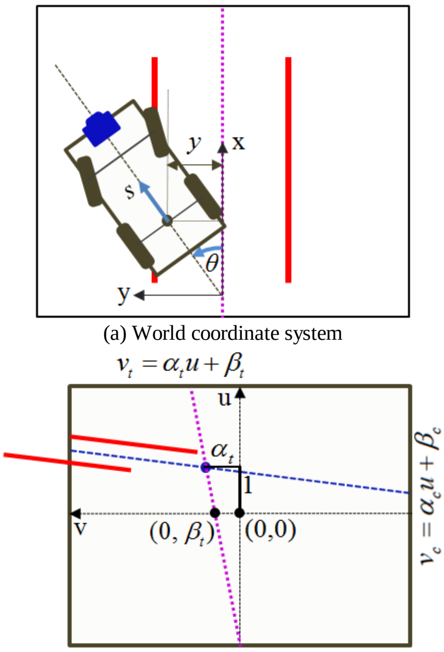


Fig. 1. Experimental overview



(a) World coordinate system

(b) Image coordinate system

Fig. 2. Coordinate systems used for the automatic parking system

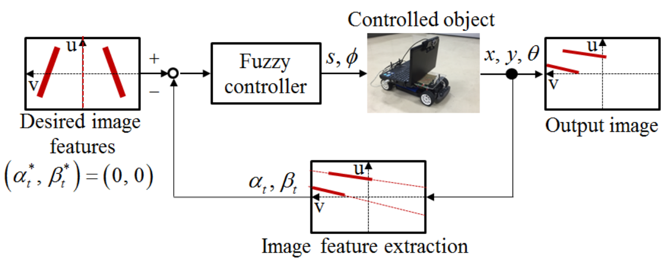


Fig. 3. Block diagram of the image-based fuzzy parking control

Figure 1 shows the experimental overview of the automatic parking system. The world coordinate is represented by x-y coordinate and the image coordinate of the camera is described by u-v coordinate as shown in Fig. 2(a) and (b). The image size is W (Width) × H (Height), in pixel. The following equations represent the center line and the target line of the parking frame on the image coordinates,

$$v_c = \alpha_c u + \beta_c \tag{1}$$

$$v_t = \alpha_t u + \beta_t \tag{2}$$

where α_c and α_t are the slopes and, β_c and β_t are the intercepts of the lines. These values can be obtained from an image processing. The controlled object is a four-wheel steered mobile robot and it model is expressed by:

$$\begin{aligned} \dot{x} &= s\cos\theta \\ \dot{y} &= s\sin\theta \\ \dot{\theta} &= \frac{s\tan\phi}{l} \end{aligned} \tag{3}$$

The state of the robot is described as (x, y, θ), where (x, y) are the coordinates, located at mid-distance of the rear-wheels and θ is the orientation of the robot with respect to the x-axis. The wheelbase is denoted by l and the control inputs for our parking system are composed of the forward speed and the steering angle, (s, ϕ). Our controller determines the control inputs (s and ϕ) from the image features (α_t and β_t) in the image coordinate to drive the vehicle in an appropriate parking position. If the vehicle can follow our desired target line completely, it would say that the robot can park in the parking frame correctly. The block diagram of the image-based fuzzy parking control is shown in Fig. 3, where the robot is controlled without referring to its position.

III. Detection of the Parking Space and Generation of a Target Line Using Image Processing

In intelligent automobiles, image processing is widely used for the detection of parking space up to now. The steps of image processing on the captured image are discussed to detect the red color parking lines and generate the target line of an automatic parking system in this section. Figure 4 shows the summary of an image processing algorithm which is used in this study. At first, some threshold functions are used to extract red color and remove a noise on the captured image. To obtain the edges of the parking lines on the binary image, a canny edge detector is used. Next step is to find the parking lines in the binary image using Hough transform. It is one of the most popular methods for the detection of line in the binary image.

The Progressive Probabilistic Hough Transform (PPHT) was used for extracting the parking lines and finding the endpoints of the parking line segments in our research. The endpoints of the each parking line are defined as (u_0, v_0) and (u_1, v_1). The slope, α and intercept, β of each line are calculated using the following equations:

$$\alpha = \frac{v_1 - v_0}{u_1 - u_0} \tag{4}$$

$$\beta = \frac{u_1 v_0 - u_0 v_1}{u_1 - u_0} \tag{5}$$

The center line of the parking frame denoted as v_c in section II is estimated by grouping, and averaging the slopes and intercepts of those lines as shown in Fig. 5(a). Finally, the mid-point of such a line is calculated and the target line for

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our parking system is constructed depending on the point, where the resultant image is shown in Fig. 5(b).

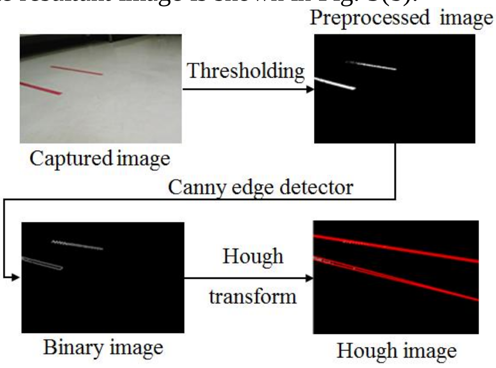
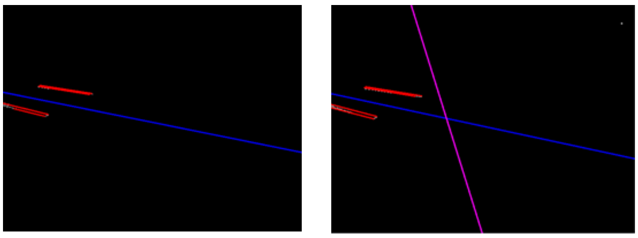


Fig. 4. Image processing algorithm



(a) (b)

Fig. 5. Resultant images: (a) the center line and (b) the target line

IV. Fuzzy Parking Control

It is difficult to derive the relationship function between the state variables, (α_t, β_t), on the image coordinate and the control inputs, (s, ϕ) because it depends on the depth of each pixel. For this reason, a model-free fuzzy controller was designed by using so called min-max centroid method in this study. To park the vehicle in an appropriate parking position, the proper steering angle has been determined according to some image features of the captured image.

According to the skills of an experienced human driver, a two-input-single-output fuzzy logic control scheme is derived to command the steering angle of the robot for the parking task. The state variables to be used as inputs for the controller are the slope and intercept of the target line and the output of the controller is the steering angle of the robot. The input variables α_t and β_t are decomposed into three fuzzy partitions with triangular membership functions, and the output variable ϕ is the fuzzy singleton-type membership function with three partitions. The partitions and the shapes of the membership functions are shown in Figs. 6(a) and (b), where fuzzy term sets are denoted by N (Negative), ZE (Zero) and P (Positive). The range of each membership function is [0, 1]. μ_{α_t} and μ_{β_t} represent the membership functions to calculate the grades of states, α_t and β_t. The membership function to calculate the grade of the output, ϕ is represented as μ_ϕ.

The fuzzy reasoning rules for the steering angle ϕ of an automatic parking system are summarized in Table I. For the control rules, the desired control inputs are set in the form of if-then rules manually, depending on the use of fuzzified state variables. For example, one rule is taken to explain. The rule: "if α_t is P and β_t is P, then ϕ is P" represents that one should turn the steering angle to the left to go along the target line.

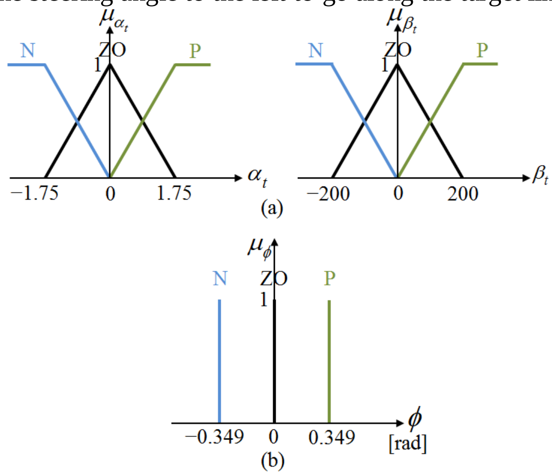


Fig. 6. Membership functions of (a) the input variables α_t and β_t, and (b) the output variable ϕ

TABLE I. Fuzzy Rules for Φ

Antecedent part				Consequence part	
If α_t is	N	And β_t is	N	Then ϕ is	N
	N		ZO		N
	N		P		ZO
	ZO		N		N
	ZO		ZO		ZO
	ZO		P		P
	P		N		ZO
	P		ZO		P
	P		P		P

The control inputs on the fuzzy sets are transformed into real numbers through a defuzzification. The defuzzification is the calculation of a weight mean by a simplified fuzzy reasoning method with singletons as follows:

$$\phi = \frac{-0.349 h_{\phi,\mathrm{N}} + 0.349 h_{\phi,\mathrm{P}}}{h_{\phi,\mathrm{N}} + h_{\phi,\mathrm{ZO}} + h_{\phi,\mathrm{P}}} \quad (6)$$

where $h_{\phi,\mathrm{P}}$ denotes the grade of conformity with the consequent "ϕ = P."

V. Experiments

In this section, the simulation and real robot experiments were conducted to confirm that the designed image-based fuzzy controller was able to park the vehicle to the appropriate parking position. For both simulation and experiment studies, our image-based fuzzy parking controller was tested with two different initial postures of the robot, case 1 and case 2. The initial postures of the vehicle are located at (x, y, θ) = (−0.55 [m], 0.55 [m], − 70 [deg]) for case 1 and (−0.55 [m], −0.55 [m], 70 [deg]) for case 2. Table II shows the parameters of the robot and parking frame used in this study.

A. Simulation Experiment

The position and orientation of the robot are expressed by (x, y, θ), where (x, y) is assumed to be located at the middle distance of the rear wheels. Maintaining of $y = 0$ and $\theta = 0$, was considered to be an accomplishment of our parking system. The working volume of the steering angle was −0.349 rad < ϕ < 0.349 rad. The camera was mounted on the robot with its height of 26 [cm] and the direction of 60 [deg] to the front from the vertical downward. The camera's focal distance is 0.02 [m] and its angle of view is 2.09 [rad] in a horizontal plane.

The simulation results for both cases are illustrated in Figs. 7 and 8. There are only the small amounts of orientation error and error in y-axis about −0.022 [rad] and −0.023 [m] for case 1. For case 2, the amount of orientation error is about 0.022 [rad] and the error in y-axis is about 0.023 [m]. It can be clearly seen from all these results that our image-based fuzzy controller was able to park the vehicle to the appropriate parking position.

TABLE II. PARAMETERS FOR THE CAR AND THE PARKING FRAME

Parameters	Value [m]
Length of the robot	0.37
Width of the robot	0.18
Wheelbase	0.26
Length of the parking frame	0.39
Width of the parking frame	0.23

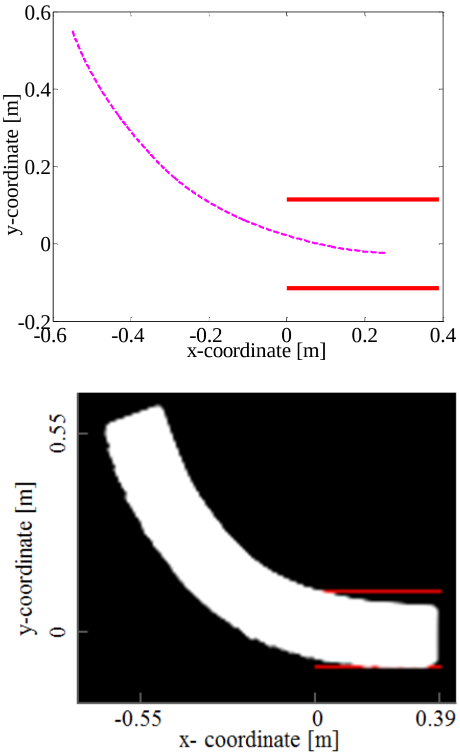


Fig. 7. Simulation result of Case 1

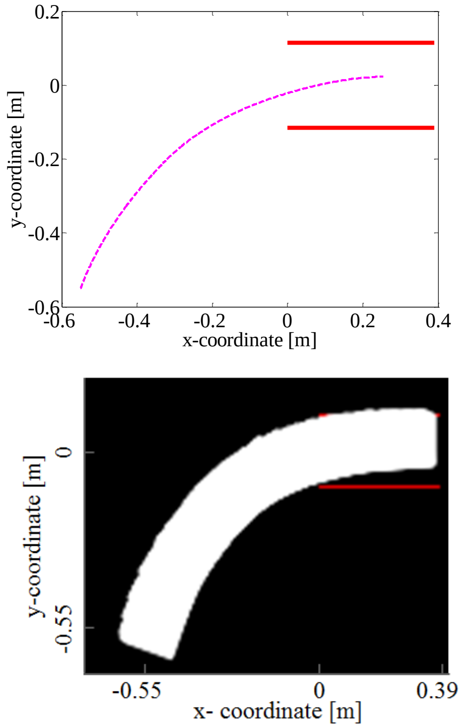


Fig. 8. Simulation result of Case 2

B. Real Robot Experiment

To verify the performance of the proposed algorithm, a real robot experiment was conducted in this study. Figure 9 shows the real robot of the experiment which was a front-wheel steered mobile robot. The robot was made by modifying a commercially available radio controlled car to control it by a microcontroller. A web camera is used to detect the parking frame and the captured image from the camera is sent to the Laptop PC. Each frame captured by the web camera at each sampling has 640 × 480 pixels and each pixel has three eight-bit-depth color channels (red, green, and blue). The Laptop PC executes the image processing to extract α_t and β_t using the PPHT from the captured image. The robot has two kinds of motors, one is the DC motor used for controlling the speed, and the other one is the DC servo motor used for controlling the steering angle of the robot.

The experimental results for our automatic parking system are shown in Fig. 10(a) and (b). According to the results, there are only the small amounts of the orientation errors for both cases. The camera position and angle are quite effective on the target line of our parking system because it deeply depends on the image information of the captured image. Changing the camera position and angle is really effective on the results. To obtain the best results for both cases, it needs to consider two steps. The first step is to find the most suitable camera position and angle by performing the experiment over and over again. The second one is to optimize the width of the membership functions of our image-based fuzzy controller through the optimization techniques such as genetic algorithms.

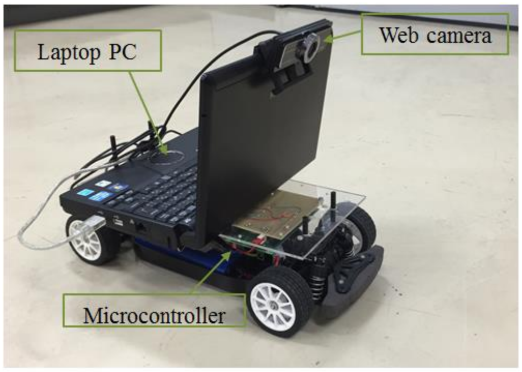


Fig. 9. Experimental robot

(a) Case 1

(b) Case 2

Fig. 10. Experimental result

VI. CONCLUSION

In this paper, an image-based fuzzy control scheme which enables the car-like mobile robot to park towards the red color parking frame drawn on the floor, has been described. The image-based control method was able to reduce the amount of calculations because it did not need to perform the position estimation processes. The results of both simulation and real robot experiments showed the effectiveness of the proposed control scheme. We have to use a genetic algorithm to optimize the width of the membership functions of our controller as future work.

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