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자율주행 차량을 위한 지능형 경사 주차 시스템 설계

Design of Intelligent Parking System for Autonomous Vehicle at the Slant Space

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요 약

무인자동차에 관한 연구가 활성화되면서 자율주행 차량에 대한 주차가 중요 과제로 대두되고 있다. 여기서는 경사 주차 공간에서 자율주행 차량이 지능적으로 주차할 수 있는 알고리즘을 제안하고자 한다. 차량의 진입과 경사 주차 공간 사이의 최적의 주차 경로를 설계하고, 이를 기반으로 퍼지논리 기반의 지능형 주차 시스템을 설계한다. 설계한 시스템의 효용성을 확인하기 위하여 컴퓨터 시뮬레이션을 수행한다.

Abstract

Recently, it is widely progressed that the research of the performance improvement of an intelligent vehicle. Among them, its parking problem has attracted a great deal of attention and have been examined in many papers in the literature. In this paper we design a fuzzy logic based parking system at the slant parking space which is a important part for designing an autonomous parking system. We first design a parking path for the slant space and propose a fuzzy logic based parking algorithm. We present its simulation results and show the effectiveness of the proposed method.

Key Words : Slant Parking Space, Parking Algorithm, Fuzzy Logic System, Autonomous Vehicle.

1. Introduction

In recent years, it is widely progressed that the research of the performance improvement of an intelligent vehicle. More intelligent technologies are being applied to automobiles. And autonomous parking problems have attracted a great deal of attention. The garage parking, parallel parking, and backward and forward parking schemes have been proposed in many papers ([1]-[7]). The basic method is to design a control algorithm that makes an automobile follow a reference trajectory via a tracking scheme.

Sugeno and Murakami [1] proposed an experimental study on fuzzy logic system using model car, which is equipped with on-board microprocessor and two supersonic sensors for the measurements of the relative distance and direction. Sugeno *et al.* [2] adopted the similar hardware arrangement as that in [1] to execute the garage parking by employing fourteen fuzzy oral instructions. In [3], a control law for guiding a car from any position to an appointed parking position was studied through trajectory simulations. They showed that the car could be guided along the minimum path combined with changing a straight guideline. Yasunobu and Murai [4] studied the state evaluation fuzzy logic system and the predictive fuzzy logic system to achieve the drive knowledge. Some computer simulations showed the effectiveness of the proposed parking control system. Daxwanger *et al.* [5] presented a skill-based visual parking control using neural networks and fuzzy logic system. They used two control architectures, the direct neural control and the fuzzy hybrid control, to generate the automatic parking commands. In [6], authors developed a near-optimal fuzzy controller for maneuvering a car in a parking lot. Near-optimal car trajectories were here created from the cell mapping data, and trajectories with similar features were collected to form groups. Fuzzy control rules and membership functions were then expressed with respect to the trajectory groups instead of individual cells. An *et al.* [7] developed an online path-planning algorithm that guides an autonomous mobile robot to a goal with avoiding obstacles in an uncertain environment. The established autonomous mobile robot could not move omni-direction and run on two wheels equipped with a CCD camera. A study on autonomous fuzzy parking

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control of a model car was described in the reference [8], which was simulated by using real-time image processing. In [9], authors suggested a fuzzy logic based backward and forward parking system at a rectangular parking space. They designed two systems of the conventional FLS(Fuzzy Logic System) and simple-structured FLS.

In this paper, we propose two fuzzy logic based parking systems for the slant parking space. It is more general case. The rectangular space can be considered as a special case of general slant parking area. We first find a path for the parking of an autonomous vehicle and then design fuzzy logic based parking systems for the desirable parking. We perform some computer simulations to show the effectiveness of the proposed systems.

2. Autonomous Mobile Car and Reference Trajectory

The controlled process is the four-wheeled car shown in Fig. 1 [8].

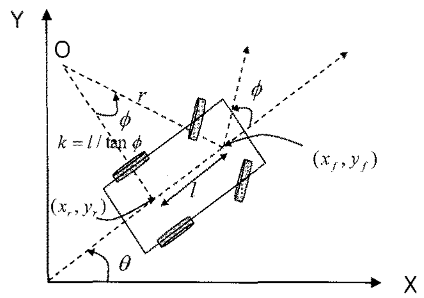


Fig. 1. Kinematic model of autonomous mobile car.

We assume that the wheels are fixed parallel to car body and allowed to roll or spin but no side-slipping. The front wheels can turn to left or right, but the left and right front wheels must be parallel. All the corresponding parameters of the mobile car depicted in Fig.1 are defined as Table 1.

Table 1. The meaning of parameters for a mobile car

Parameter(s)	Meaning
(x_f, y_f)	position of the front wheel center
(x_r, y_r)	position of the rear wheel center
ϕ	orientation of the steering-wheels with respect to the frame of the mobile car
θ	angle between vehicle frame orientation and X-axis
l	wheel-base of the mobile car
O	center of curvature
r	distance from point O to point (x_f, y_f)
k	curvature of the fifth-order polynomial

The rear wheel is always tangent to the orientation of the vehicle. The no-slipping condition mentioned previously requires that the mobile car travels in the direction of its wheels. Thus, we have

$$\dot{y}_r cos\theta - \dot{x}_r sin\theta = 0. \tag{1}$$

This is the so-called nonholonomic constraint.

The front of the mobile car is fixed relative to the rear, thus the coordinate (x_r, y_r) is related to (x_f, y_f)

$$\begin{aligned} x_r &= x_f - l\cos\theta \\ y_r &= y_f - l\sin\theta. \end{aligned} \tag{2}$$

Differentiating both sides of (2), we have

$$\begin{aligned} \dot{x}_r &= \dot{x}_f + \dot{\theta} l \sin\theta \\ \dot{y}_r &= \dot{y}_f - \dot{\theta} l \cos\theta \end{aligned} \tag{3}$$

By substituting (3) to (1), we can get

$$\dot{x}_f sin\theta - \dot{y}_f cos\theta + \dot{\theta} l = 0. \tag{4}$$

From Fig. 1, we have

$$\begin{aligned} \dot{x}_f &= v\cos(\theta+\phi) \\ \dot{y}_f &= v\sin(\theta+\phi). \end{aligned} \tag{5}$$

Substituting (5) to (4), we can derive

$$\dot{\theta} = v\frac{\sin\phi}{l}. \tag{6}$$

Equations (5) and (6) are the kinematic equations of autonomous mobile car with respect to the axle center of the front wheels.

These equations are used to generate the next state position of the vehicle when the present states and control inputs are given.

Similarly, we can get the kinematics of mobile car with respect to the axle center of the rear wheels:

$$\begin{aligned} \dot{x}_r &= v.\cos\theta\cos\varnothing \\ \dot{y}_r &= v.\sin\theta\cos\varnothing \\ \dot{\theta} &= v.\frac{\sin\varnothing}{l}. \end{aligned} \tag{7}$$

It is need to find the reference trajectory such that the autonomous mobile car successfully accomplish the garage parking. If the reference trajectory is far from a feasible one, then the vehicle is unable to follow the trajectory accurately. So we have to set up a reference trajectory for the good parking.

We consider the parking space is somewhat slanted as illustrated in Fig. 2.

Fig. 2 illustrates a slant parking space. Here (x_o, y_o) is the connection point between a circular motion and a straight motion of the car, (x_e, y_e) is the initial location of the reference trajectory, (x_g, y_g) is the final location for (x_f, y_f), and θ is the slant angle of parking space. We can see that if the θ is 90^0 then it becomes the rectangular parking space. That is, a rectangular parking space is the special case of a slant parking space.

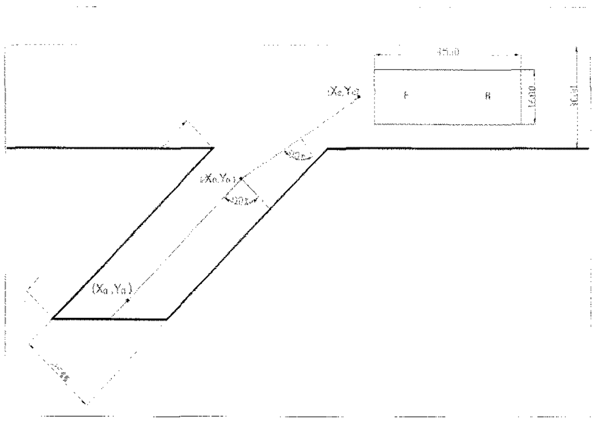


Fig. 2. Slant parking space.

In order to implement a parking system for the slant parking space, we adopt a circular arc and a straight line as a reference trajectory. The circular arc is generated at the section between (x_e,y_e) and (x_o,y_o). It is important to find the circular arc for the best parking. In fact, many circular arcs can be used to generate the reference trajectory. We assume two lines: one is the vertical line to the line between (x_e,y_e) and (x_o,y_o) and passes its center point, and the other is the vertical line to the tangent line of the circular arc and passes the connection point (x_o,y_o). We decide that the intersecting point of two assumed lines is the center point of the circular arc. This scheme gives the best straight line motion for the parking because the straight-line becomes the tangent line of the circular arc at (x_o,y_o). Fig. 3 shows the proposed trajectory and main coordinates including the center point (x_v,y_v) of the circular arc.

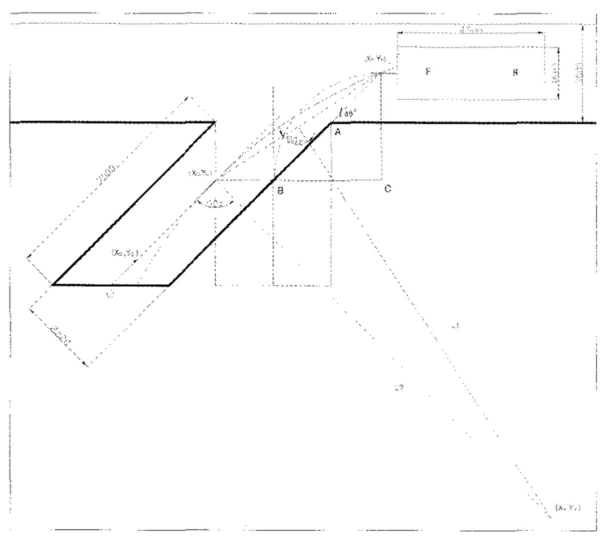


Fig. 3. Reference trajectory and main points for a slant parking space.

The reference trajectory for forward parking at the slant space is represented as a function $y_f = f(x_f)$. The detail derivation of the function of the reference trajectory is examined as follows.

Consider two straight lines in Fig. 2: one is the line between (x_o,y_o) and (x_g,y_g), and the other is the line between (x_e,y_e) and (x_o,y_o). We can now get another two straight lines L_1 and L_2 from above two straight lines: L_1 is the line which is vertical to the line between (x_e,y_e) and (x_o,y_o) and passes its center point. L_2 is the line which passes the point (x_o,y_o) and is vertical to the line between (x_o,y_o) and (x_g,y_g). The line equations for L_1 and L_2 are as follows:

$$L_1:\ y_1 = -\frac{x_e - x_o}{y_e - y_o}.(x_1 - \frac{x_o + x_e}{2}) + \frac{y_o + y_e}{2}, \quad (8)$$

$$L_2:\ y_2 = -ctan\theta(x_2 - x_o) + y_o. \quad (9)$$

Now we find the crossing point of the lines L_1 and L_2, which is the center point (x_v,y_v) of the circular arc motion considered in here.

The values of the coordinate are obtained by equations (8) and (9) as follows:

$$x_v = \frac{-(x_e^2 - x_o^2) - (x_e - x_o)^2 + 2x_o(x_e - y_o)ctan\theta}{2[(y_e - y_o).ctan\theta - (x_e - x_o)]}, \quad (10)$$

$$y_v = -ctan\theta(x_v - x_o) + y_o. \quad (11)$$

We finally obtain a reference trajectory as follows:

The equation for a circular motion is given by

$$(x_f - x_v)^2 + (y_f - y_v)^2 = (y_o - y_v)^2 + (x_o - x_v)^2, \quad (12)$$

and the equation for the line motion becomes

$$y_f = \tan\theta(x_f - x_o) + y_o \text{ and } y_g \le y_f \le y_o. \quad (13)$$

Now the vehicle can be correctly parked in the slant parking space along the derived parking trajectory.

3. Design of Fuzzy Logic Systems and Its Simulations

In this section, we design fuzzy logic systems for the slant parking space of an autonomous mobile car.

The main role of the parking system is to make the mobile car follow the reference trajectory from the start position to the end position. The parameters used to implement the parking system is shown in Fig. 4, where (x_{f1}, y_{f1}) is the desired position of the reference trajectory at some sampling instants, θ_1 is its orientation angle corresponding to the X-axis, θ_2 is the orientation angle of the mobile car, and θ_3 denotes an orientation angle between the X direction and the line from (x_{f1}, y_{f1}) to (x_{f2}, y_{f2}).

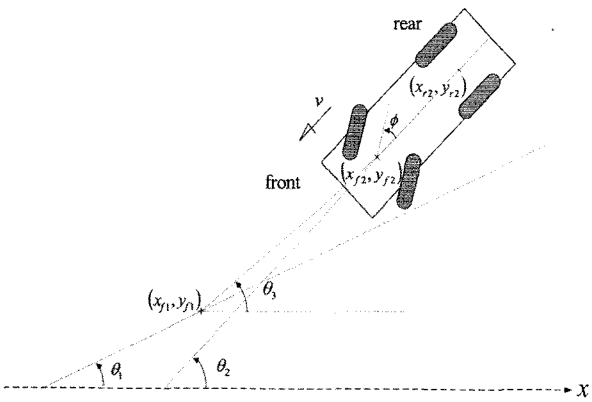


Fig. 4. Definition of parameters for parking system.

A FLS is an algorithm that can convert the linguistic control strategy based on the knowledge of expert or operator into an automatic control strategy. The rules of a FLS are usually determined by the human operator's behavior. The kernel of the FLS is a set of linguistic control rules. According to the parking skill in our daily life, fuzzy reasoning rules for the parking system can be expressed in linguistic form.

We first design a two-input single-output FLS for the parking task.

We define its input variables as follows:

$$u_1 = \theta_3 - \theta_1 \\ u_2 = \theta_2 - \theta_1 \quad (14)$$

If we introduce another variable as follows, we can easily see the meaning of control rules.

$$s = u_1 - u_2 \\ = \theta_3 - \theta_2 \\ = 0 \quad (15)$$

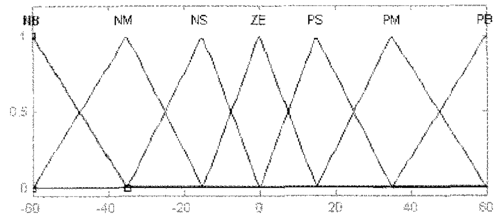
That is, $s = 0$ or $\theta_3 = \theta_2$ means that the mobile car follows the trajectory.

If we define the output linguistic variable as the steering angle $\varnothing$, we can set up control rules for the conventional FLS as Table 2.

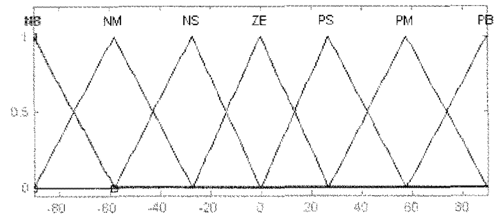
Table 2. Rule table for the FLC.

u_1 \ u_2	NB	NM	NS	ZE	PS	PM	PB
PB	NB	NB	NB	NB	NM	NS	ZE
PM	NB	NB	NB	NM	NS	ZE	PS
PS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
NS	NM	NS	ZE	PS	PM	PB	PB
NM	NS	ZE	PS	PM	PB	PB	PB
NB	ZE	PS	PM	PB	PB	PB	PB

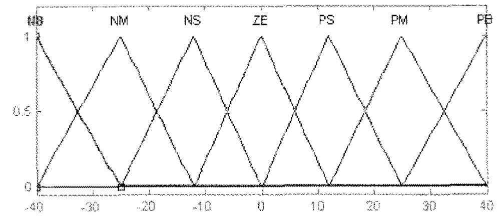
The membership functions of u_1, u_2 and $\varnothing$ are shown in Fig. 5, where they all are decomposed into seven fuzzy partitions, such as negative big(NB), negative medium(NM), negative small(NS), zero(ZE), positive small(PS), positive medium(PM), and positive big(PB).



(a) Membership function of u_1.



(b) Membership function of u_2.



(c) Membership function of Φ.

Fig. 5. Fuzzy membership functions for the input-output variables of the conventional FLS.

Now we can define another new variable for the simple-structured FLS as follows. We can slightly change the Table 2 of control rules to Fig. 6. Any rule table like Table 3 can be reconstructed by the similar form to Fig. 5.

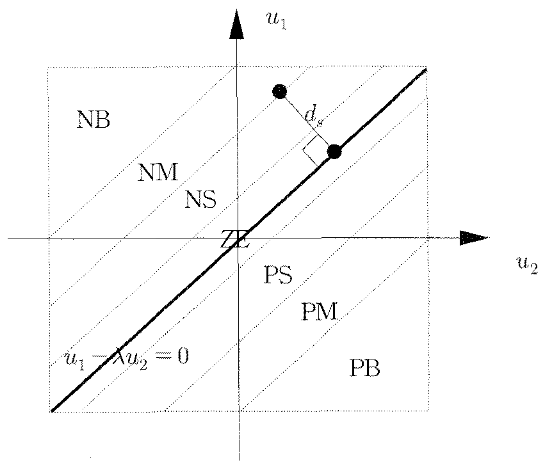


Fig. 6. Depiction of Table 2 with infinitesimal quantization levels.

We can now derive a single variable d_s from Fig. 6 [10], which is operating the distance from a point of the switching line which is through the original point to a particular operating point: as illustrated in Fig. 6. :

$$d_s = \frac{u_1 - \lambda u_2}{\sqrt{1+\lambda^2}} \tag{16}$$

If we use d_s as an sole input variable for simple-structured FLS, the rule table 2 is changed to Table 3 as follows:

Table 3. Rule table for the simple-structured FLS.

d_s	NB	NM	NS	ZE	PS	PM	PB
∅	NB	NM	NS	ZE	PS	PM	PB

We now simulate to demonstrate the effectiveness of the proposed scheme. Taking account of the real life, the length of the garage is about 2 times wider than that of a car for the parking.

Figures 7 and 8 show simulation results for the conventional FLS and simple-structured FLS, respectively. The result gives as follows, we can see that the vehicle can follow this reference trajectory very well.

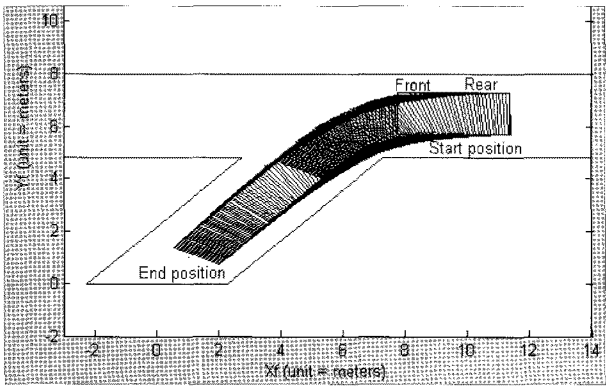


Fig. 7. Simulation result of the conventional FLS.

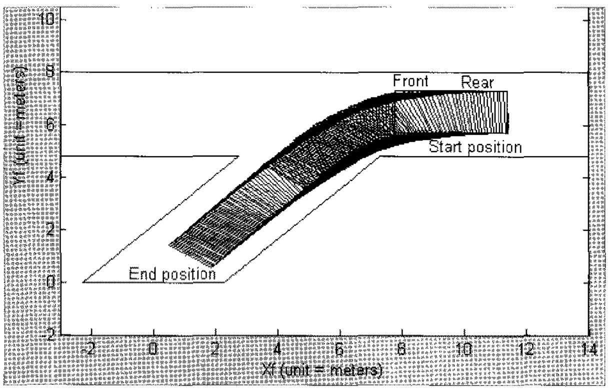


Fig. 8. Simulation result of the simple-structured FLS.

4. Concluding Remarks

We have designed two fuzzy logic based parking system for an autonomous mobile car at the slant space. We showed that the rectangular parking space is a special case of the slant parking space. We also obtained a parking trajectory for the general parking space.

We performed computer simulations to confirm the effectiveness of the proposed systems. The results were good. This slant parking system can be easily changed to the case of the rectangular parking space by substituting the slant angle to 90 degree.

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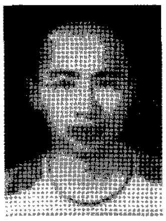

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