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지능형 자동차를 위한 퍼지논리기반 주차 시스템 설계

Design of Fuzzy Logic Based Parking Systems for Intelligent Vehicles

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요 약

무인자동차에 관한 연구가 활성화되면서 무인 주차 또한 중요한 과제로 대두되고 있다. 본 논문에서는 무인 차량을 위한 주차 편의 시스템 설계를 위하여 퍼지논리시스템에 의한 주차 알고리즘 설계를 제안하고자 한다. 기존의 논문들이 제시한 장단점을 분석하여 새로운 단일 입력을 가지는 퍼지논리시스템을 통한 주차 알고리즘을 설계하고, 시뮬레이션을 통하여 그 효용성을 확인하고자 한다.

Abstract

Recently, autonomous parking problems have 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 which is an important part for designing an autonomous parking system. We first analysis the existed papers and design a single-input fuzzy logic system for the parking algorithm and illustrate the effectiveness of the new method via the simulation results.

Key Words : Backward parking system, Forward parking system, Fuzzy logic system, Single-input FLS, Autonomous vehicle.

1. Introduction

In recent years, autonomous parking problems have attracted a great deal of attention and more intelligent technologies are being applied to automobiles. An important part of them is the autonomous parking problem. The garage parking and parallel 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 method.

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 auton-

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omous fuzzy parking 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 simple but powerful FLS design method using a sole fuzzy input variable instead of the error and the change-of-error to represent the contents of the rule antecedent.

In this paper, we design a conventional FLS and SFLS(Single-input Fuzzy Logic System) [9] for the backward and forward parking of an autonomous vehicle. The SFLS uses only 7 rules compared to 49 of the conventional FLS. Simulation results illustrate the effectiveness of the new method of SFLS.

2. Mobile Car and Reference Trajectories

A. Modeling of a mobile car [8]

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

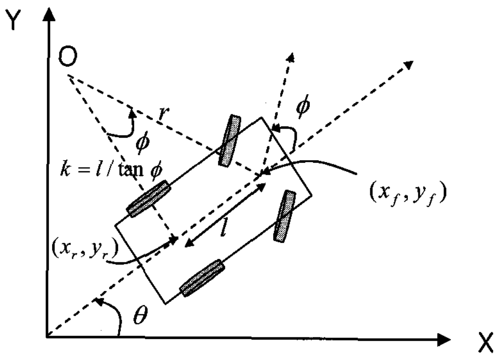


Fig. 1. Kinematic model of mobile-car.

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.

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

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

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)

$$x_r = x_f - l\cos\theta$$
$$y_r = y_f - l\sin\theta. \quad (2)$$

Differentiating both sides of (2), we have

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

$$\dot{x}_r = \dot{x}_f + \dot{\theta} l \sin\theta$$
$$\dot{y}_r = \dot{y}_f - \dot{\theta} l \cos\theta \quad (3)$$

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

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

From Fig. 1, we have

$$\dot{x}_f = v\cos(\theta + \phi)$$
$$\dot{y}_f = v\sin(\theta + \phi). \quad (5)$$

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

$$\dot{\theta} = v\frac{\sin\phi}{l}. \quad (6)$$

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

These equations are used to generate the next backward 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:

$$\dot{x}_r = v.\cos\theta\cos\varnothing$$
$$\dot{y}_r = v.\sin\theta\cos\varnothing$$
$$\dot{\theta} = v.\frac{\sin\varnothing}{l}. \quad (7)$$

B. Reference Trajectories for Garage Parking

It is need to find the reference trajectory such that the 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 to track. We present two cases: backward parking and forward parking.

For backward garage parking we typically turn the steering wheel to the right and back the car. Then the car will result in an arc trajectory as entering the garage. Thus, a quarter circle is used to form this trajectory. The reference trajectory for backward garage parking includes a circular motion and a straight-line motion. Fig. 2 shows the proposed trajectory, where (x_e, y_0) is the virtual center of the circle, (x_g, y_o) is the connection point, (x_e, y_e) is the initial location of the reference trajectory, and (x_g, y_g) is the final location for (x_r, y_r).

The reference rear trajectory during backward garage parking is represented as a function $y_r = f(x_r)$. The general form for circular motion and line motion are as follows:

$$(x_r - x_e)^2 + (y_r - y_o)^2 = (x_e - x_g)^2. \quad (8a)$$

$$x_r = x_g \text{ and } y_g \le y_r \le y_o. \quad (8b)$$

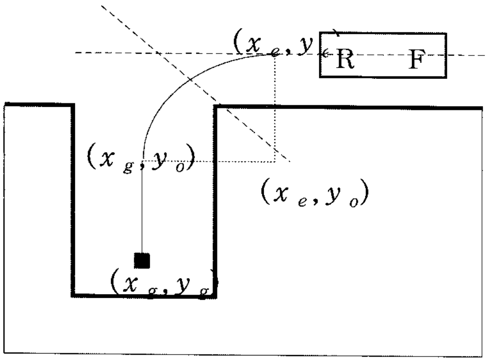


Fig. 2. Reference trajectory for backward garage parking.

If the vehicle follow this trajectory completely, the vehicle is parked in the garage correctly.

Next, consider the forward garage parking. We assume that the garage is wide enough to park the vehicle directly. The corresponding reference trajectory is shown in Fig. 3.

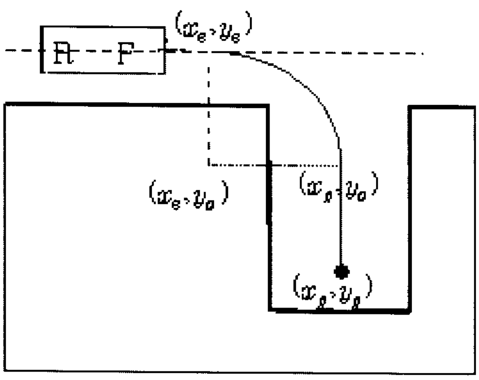


Fig. 3. Reference trajectory for forward garage parking

The reference trajectory during forward garage parking is represented as function$y_f = f(x_f)$. The general form for circular motion and line motion are as follows:

$$(x_f - x_e)^2 + (y_f - y_o)^2 = (x_g - x_e)^2. \quad (9a)$$

$$x_r = x_g \text{ and } y_g \le y_r \le y_o. \quad (9b)$$

3. Design of Fuzzy Logic Systems for Garage Parking

In this section, we design 2 fuzzy logic systems for the garage parking of a mobile car.

A. Backward parking system via the conventional FLS

The main role of backward parking system is to make the mobile car follow the reference trajectory from the start position to the end position. The parameters used to construct the backward parking system is shown in Fig. 4, where (x_{r1}, y_{r1}) 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_{r1}, y_{r1}) to (x_{r2}, y_{r2}).

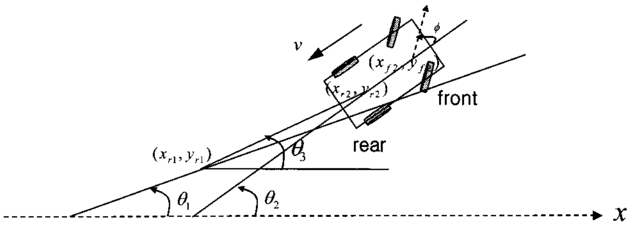


Fig. 4. Definition of parameters for backward parking system.

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 backward parking system can be expressed in linguistic form.

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

We define its input variables as follows:

$$u_1 = \theta_3 - \theta_1$$
$$u_2 = \theta_2 - \theta_1 \quad (10)$$

Then a sliding line is defined as follows:

$$s = u_1 - u_2$$
$$= \theta_3 - \theta_2 \quad (11)$$
$$= 0$$

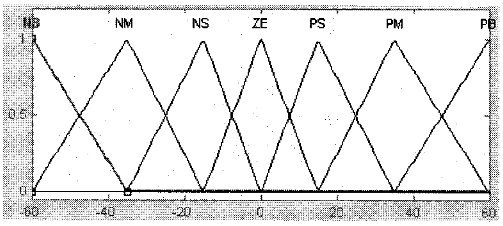
That is, $s = 0$ or $\theta_3 = \theta_2$ means that the mobile car follows the trajectory.

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.

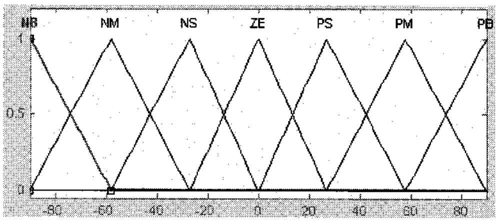
Table 2. Rule table for the conventional FLS (backward parking).

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

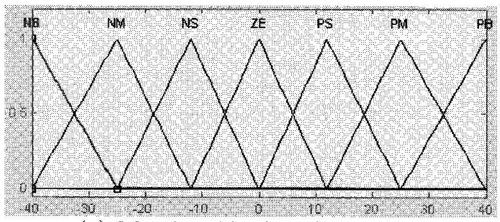
The membership functions of u_1, u_2 and $\varnothing$ are shown in Fig. 5, where they all are decomposed into seven fuzzy partitions, such as negative big(NB), negative medium(NM), negative small(NS), zero(ZE), positive small(PS), positive medium(PM), and positive big(PB).



(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.

B. Backward parking system via the SFLS

We can slightly change the Table 2 of control rules. Any rule table like Table 2 can be reconstructed by the similar form to Fig. 6.

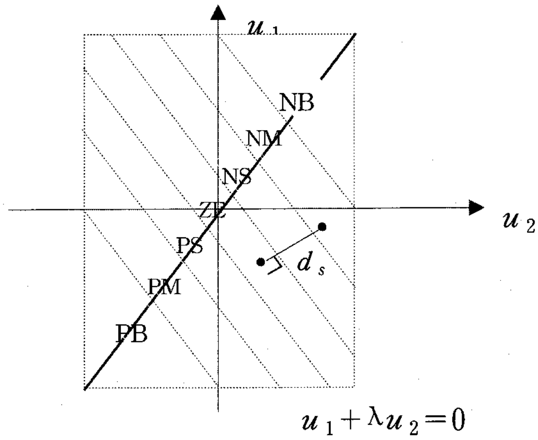


Fig. 6. Depiction of Table 2 with infinitesimal quantization levels.

Consider the line which passes the origin and is parallel to straight lines which are boundaries of control regions.

$$s_l:\ u_1+\lambda u_2=0 \qquad (12)$$

We call it the switching line.

We can now derive a single variable d_s from Fig. 6 [9]:

$$d_s=\frac{u_1+\lambda u_2}{\sqrt{1+\lambda^2}} \qquad (13)$$

It represents the distance with a sign from $s_l=0$ to an operating point. Then the control rule table can be established by a single variable of d_s instead of two variables of u_1, u_2. We call it SFLS(Single-input Fuzzy Logic System).

The output linguistic variable is still the steering angle $\varnothing$. Therefore the rule form for the SFLS is given as follows:

$$R_{SI}^{k}:\ IF\ d_s\ is\ LDL^{(k)}\ THEN\ u\ is L\varnothing^{(k)},$$

where $LDL^{(k)}$ is the linguistic value of d_s in the kth rule. $L\varnothing^{(k)}$ is the linguistic value taken by the process state variable. Then the rule table is established by Table 3.

Table 3. Rule table for the SFLS (backward parking).

d_s	NB	NM	NS	ZE	PS	PM	PB
$\varnothing$	NB	NM	NS	ZE	PS	PM	PB

The membership function of d_s for the SFLS is shown in Fig. 7.

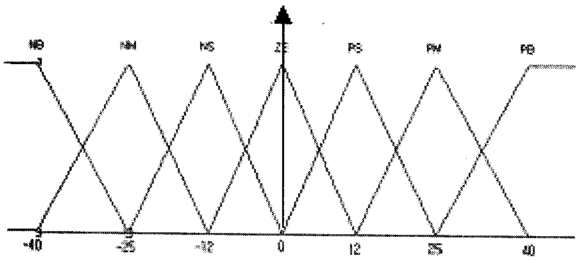


Fig. 7. Membership function of d_s.

From Table 3, we can see that the total number of rules is greatly decreased compared to the case of conventional FLS. So we can easily increase the number of rules for the purpose of a fine control.

C. Forward parking system via the conventional FLS

The reference trajectory for the forward garage parking was shown in Fig. 3 and equations (9a) and (9b).

In this case, if the mobile car is above the ideal trajectory, one should turn the steering angle to the right with a medium force to go along the trajectory. So, we can derive the following rule: if u_1 is NS and u_2 is PS, then ϕ is PM. The control rules for the forward parking system are listed in Table 4, which is skew-symmetric to Table 2.

Except for the rule table, all the parameters and settings of the forward parking system are the same as those in the backward one.

D. Forward parking system via the SFLS

The corresponding reference trajectory and equations are the same as those described in Section C. In the forward parking system, the rule table for the SFLC is derived as Table 5 via the similar manipulations to Section B:

Table 4. Rule table for the FLS (forward parking).

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

Table 5. Rule table for the SFLS (forward parking).

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

4. Simulations

We simulate some cases 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 garage parking.

A. Backward parking case

Suppose the start postures of the mobile car is located at $(x_r, y_r, \theta_2) = (5, 6.5, 0^0)$.

First, we just simulate it with a result of a line from the center position of the front wheels to the center position of the rear wheels. Simulation results are shown in Fig. 8 and Fig. 9. These are the cases of conventional FLS and SFLS, respectively. As we can see in figures, their results are almost the same.

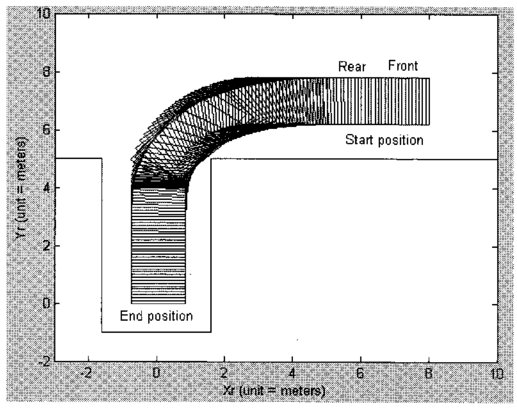


Fig. 8. Simulation result of the conventional FLS.

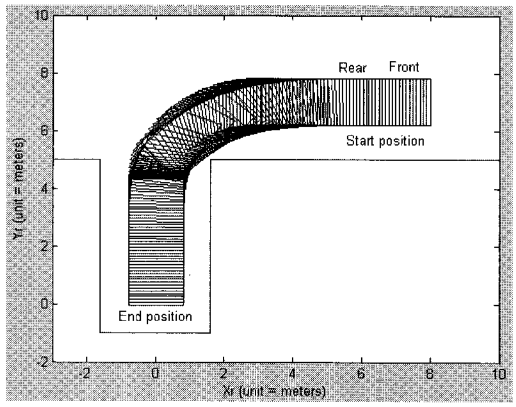


Fig. 9. Simulation result of the SFLS.

B. Forward parking case

We will now simulate the case of the forward parking system. We suppose the start postures of the mobile car is located at $(x_f, y_f, \theta_2) = (-5, 6.5, 0^0)$. Simulation results are given in Fig. 10 and Fig. 11. These are the cases of conventional FLS and SFLS, respectively. Similar to the backward parking case, their results are almost the same.

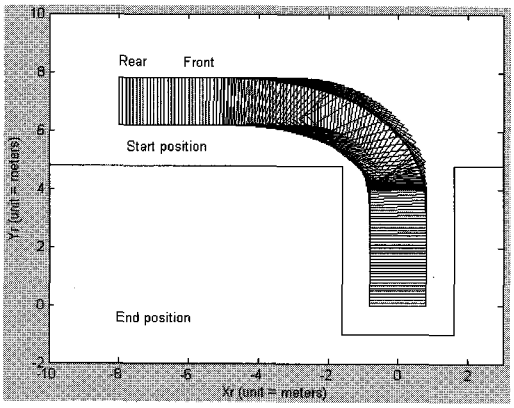


Fig. 10. Simulation result of the conventional FLS.

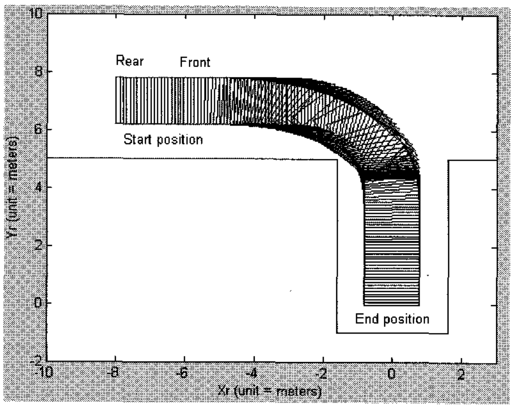


Fig. 11. Simulation result of the SFLS.

5. Concluding Remarks

In this paper, we have designed fuzzy logic based backward and forward parking system for an autonomous mobile car. We here introduced the reference trajectories for their garage parking. We have also designed the SFLS for the forward parking and backward parking system, respectively. They have many advantages. One of them is to reduce the number of the control rule greatly. Nevertheless we could see the fact that the system performance is almost the same.

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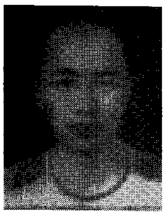

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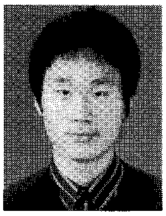

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