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퍼지논리에 의한 후방주차 시스템 설계

Design of Backward Parking System using Fuzzy Logic

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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 알고리즘을 설계하고자 한다. 기존의 논문들이 제시한 장단점을 분석하여 새로운 단순 구조 형태의 규칙표를 통한 주차 알고리즘을 설계, 구현하고, 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 garage parking system which is a important part for designing a autonomous parking system. We first analysis the existed papers and design a single-input fuzzy logic control for the parking algorithm and illustrate the effectiveness of the new method via the simulation results.

Key Words : Backward parking system, Fuzzy logic control, Simple-structured FLC, Autonomous vehicle

1. INTRODUCTION

In recent years, autonomous parking problems have attracted a great deal of attention and more and more intelligent technologies are being applied to automobiles. An important part of them is the autonomous parking problem. The garage-parking schemes [1]-[3] have been proposed in many papers. The basic method is to design a control algorithm that makes an automobile follow a reference trajectory via a tracking method.

A skill-based visual parking control using neural networks and fuzzy logic system is discussed in the reference[1]. The development of a near-optimal fuzzy controller for maneuvering a car in a parking lot is described in the reference[2]. An *et al.*[3] developed an online path-planning algorithm that guides an autonomous mobile robot to a goal with avoiding obstacles in an uncertain world. The established autonomous mobile robot cannot move omni-direction and run on two wheels equipped with a CCD camera.

A study on autonomous fuzzy parking control of a model car, which is simulation by using real-time image processing is described in the reference[4].

In this paper, we design a conventional FLC and SFLC(Simple-structured Fuzzy Logic Control) for the backward parking of an autonomous vehicle. The SFLC uses only 7 rules compared to 49 of the conventional FLC. Simulation results illustrate the effectiveness of the new method of SFLC.

2. KINEMATIC EQUATIONS AND REFERENCE TRAJECTORIES

A. Modeling of a Mobile-Car

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

(x_f, y_f)	position of the front wheel center;
(x_r, y_r)	position of the rear wheel center;
$\varnothing$	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 state space equations of the axle center of the front wheels are as follows:

$$\dot{x}_f = v.\cos(\theta + \varnothing)$$
$$\dot{y}_f = v.\sin(\theta + \varnothing)$$
$$\dot{\theta} = v.\frac{\sin\varnothing}{l}. \quad (1)$$

The equations of the axle center of the rear wheels will be described as:

$$\dot{x}_r = v.\cos\theta\cos\varnothing$$
$$\dot{y}_r = v.\sin\theta\cos\varnothing$$
$$\dot{\theta} = v.\frac{\sin\varnothing}{l}. \quad (2)$$

Equations (2) are used to generate the next backward state position of the vehicle when the present state and control inputs are given.

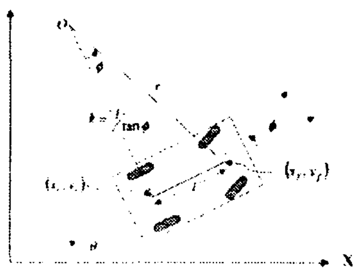


Fig 1. Kinematic model of mobile-car.

B. Reference Trajectories for Garage Parking

If the reference trajectory is far from a feasible one because of the unmodeled dynamics or modeling inaccuracy, then the vehicle is unable to follow the trajectory accurately.

According to our driving experiences, we always turn the steering wheel to the ight and back the car for backward garage parking. 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, (y_g, y_o) is the connetion point, (x_c, y_c) is the initial location of the reference trajectory, and (x_g, y_g) is the final location for (x_r, y_r).

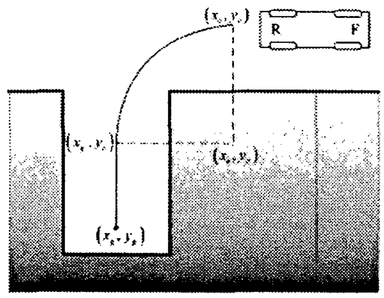


Fig.2. Reference trajectories for backward garage parking.

The reference rear trajectory during backward garage parking is represented as a function $y_r = f(x_r)$. The general form for circular motion is given by

$$(x_r - x_e)^2 + (y_r - y_o)^2 = (x_c - x_g)^2. \quad (3)$$

And the line motion becomes

$$x_r = x_g \text{ and } y_g \le y_r \le y_o. \quad (4)$$

If the vehicle can follow this reference trajectory completely, one can definitely say that the vehicle parks in the garage correctly.

3. Design of FLC

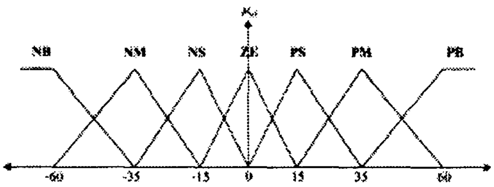
In this section, we design 2 fuzzy logic system for back-drive parking. They are to use the conventional FLC and the SFLC, respectively. After providing the reference trajectories,

A. Backward parking system via the conventional FLC

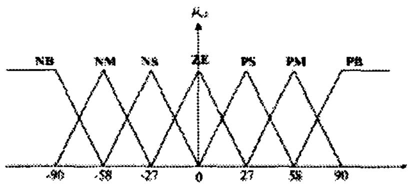
The parameters used to construct the backward fuzzy garage parking control is shown in Fig.3, where (x_{r1}, y_{r1}) is the desired position of the reference trajectory at some sampling instant, θ_1 is its orientation angle corresponding to the X-axis, θ_2 is the orientation angle of the Mobile-Car, and θ_3 denotes an orientation angle between of the X direction and the line from (x_{r1}, y_{r1}) to (x_{r2}, y_{r2}).
We first design a two-input single-output FLC for the garage parking task.
Its input variables are defined as

$$u_1 = \theta_3 - \theta_1$$
$$u_2 = \theta_2 - \theta_1. \qquad (5)$$

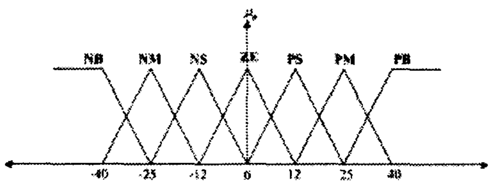
The output linguistic variable is the steering angle $\varnothing$. The membership functions of u_1, u_2 and $\varnothing$ are shown in Fig.3.



(a) Membership function of u1.



(b) Membership function of u2.



(c) Membership function of control output $\varnothing$.

Fig.3. Fuzzy membership functions for the input-output variables of the conventional FLC.

Table 1. Rule table for the conventional FLC.

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

B. Backward parking system via SFLC

We can slightly change the Table 1 of control rules. Any rule table like Table 1 can be reconstructed by the similar form to Fig.4.
We can derive a single variable d_s from Fig.4:

$$d_s = \frac{u_1 + \lambda u_2}{\sqrt{1+\lambda^2}}. \qquad (6)$$

The output linguistic variable is the steering angle $\varnothing$. The membership functions of d_s and $\varnothing$ are shown in Fig.5.

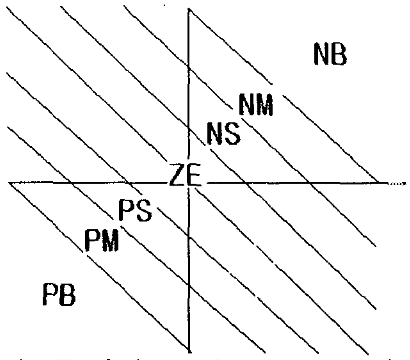
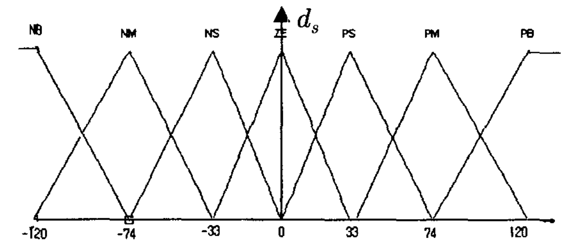
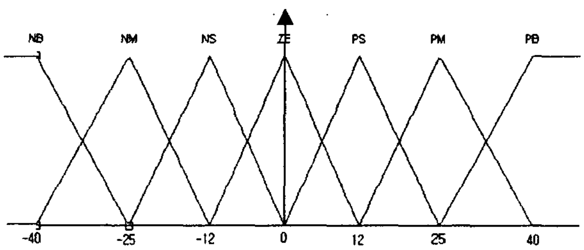


Fig. 4. Depiction of rules on infinitesimal quantization levels of Table 1.



(a) Membership function of d_s.



(b) Membership function of control output $\varnothing$.
Fig5. Fuzzy membership functions for the input-output variables of the SFLC.

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

$$s_l : u_1 + \lambda u_2 = 0, \qquad (7)$$

The rule form for the SFLC is given as follows:

$$R_{SI}^{k}: \ IF\ d_s\ is\ LDL^{(k)}\ THEN\ u\ isL\varnothing^{(k)}, \quad (8)$$

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 on a one-dimensional space like Table 2.

From Table 2, we can see that the total number of rules is greatly decreased compared to the case of conventional FLC. Therefore, we can easily increase the number of rules for the purpose of a fine control.

Table 2. Rule table for the SFLC.

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

4. Simulation

The computer simulation results are given to demonstrate the effectiveness of the proposed control scheme. Taking account of the real life, the length of the garage is about 2 times wider than that of the car for back-drive garage parking.

Suppose the start postures of the mobile-car is located at $(x_{r2}, y_{r2}, \theta_2) = (5, 7, 0^0)$.

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 with the same start postures are illustrated in Fig. 6 and Fig. 7. These are the cases of conventional FLC and SFLC, respectively.

Their results are almost same.

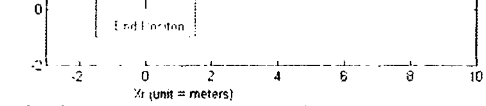


Fig.6. Simulation result of the conventional FLC.

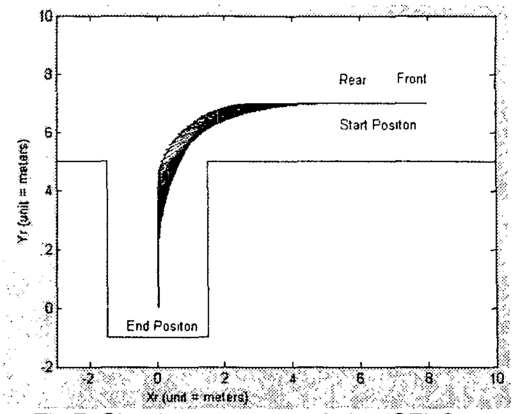


Fig.7 Simulation result of the SFLC.

5. Concluding Remarks

In this paper, we have designed fuzzy logic based backward parking system of an autonomous mobile-car system. Where we introduced the reference trajectories for garage parking. The simulation results illustrate that the SFLC is indeed effective and feasible.

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