자율주행 차량을 위한 지능형 경사 주차 시스템 설계

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

학양화, 김태균, 최병재
Yang-Hua Hao, Tae-Kyun Kim and Byung-Jae Choi

School of Electronic Engineering, Daegu University
대구대학교 전자공학부

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 과정을 시뮬레이션으로 제시한다.

Abstract

Recently, parking problems for an autonomous vehicle 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 at the slant parking space which is a important part for designing a autonomous parking system. We first design an optimal parking path for the slant space and present the simulation results of the fuzzy logic based parking system.

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

1. Introduction

In recent years, parking problems for autonomous vehicles have attracted a great deal of attention and more intelligent technologies are being applied to automobiles. An important part of them is the design of the autonomous parking system. 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. A study on autonomous 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 and powerful FLS(Fuzzy Logic System) 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 propose an autonomous parking system at the slant space. We first find a parking path for an autonomous vehicle and then design a control system for the optimal parking. We perform some simulations to show the effectiveness of the proposed system.

2. Mobile Car

A. Modeling of a autonomous vehicle [8]

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

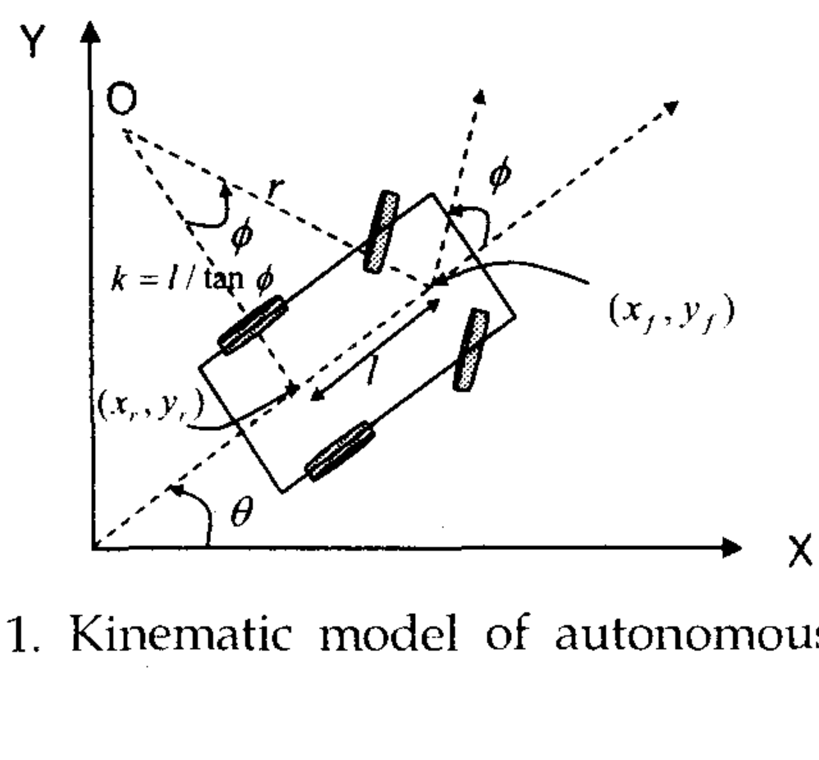

Fig. 1. Kinematic model of autonomous car.

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.

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 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:

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

It is need to find the reference trajectory such that the 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 tracking.

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

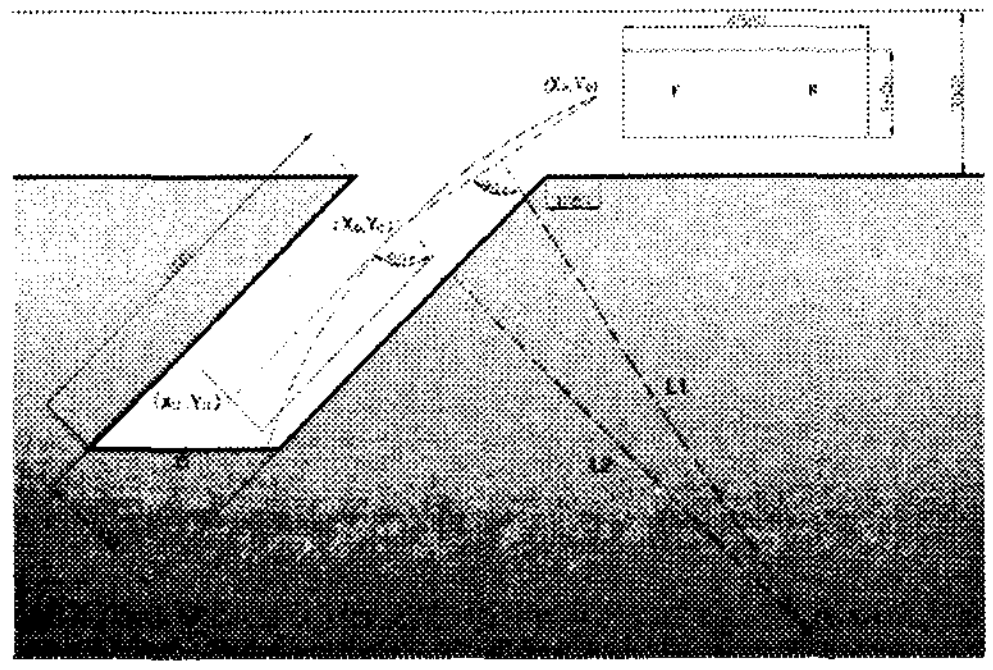

Fig. 2. Reference trajectories for forward garage parking in a slant parking space.

Fig. 3 illustrates the algorithm of the proposed trajectory, where (x_v, y_v) is the virtual center of the circle, (x_o, y_o) is the connection point, (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 will be like the garage parking space.

In order to implement the slant parking system, we adopt a circular arc and a tangent line of the circle though the connection point (x_o, y_o). In fact, several curves have been used to present the reference trajectory in the circular arc such as a circular arc through the initial location point (x_e, y_e) and the connection point (x_o, y_o) and a point at the right corner of the bottom in the parking space, etc. However, the straight-line should be the tangent line of the circular arc at the straight-line motion and then the trajectory will be smooth.

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

We can get two functions for a straight line: one is though the points (x_o, y_o) and (x_g, y_g), and the other is though the points (x_e, y_e) and (x_o, y_o). Thus we can get another two lines L_1, L_2, L_1 is the line which passes the center point of the line function between (x_e, y_e) and (x_o, y_o) and is vertical to the line which is though the points (x_e, y_e) and (x_o, y_o). L_2 is the line function which passes the point (x_o, y_o) and is vertical to the line which is though the points (x_o, y_o) and (x_g, y_g).

$$l_1:\ y_1 = -\frac{x_e - x_o}{y_e - y_o} \cdot (x_1 - \frac{x_o + x_e}{2}) + \frac{y_o + y_e}{2}, \tag{8}$$

$$l_2:\ y_2 = -ctan\theta(x_2 - x_o) + y_o. \tag{9}$$

We can now get the crossing value of the lines L_1, L_2, which is the center point of the circular arc (x_v, y_v) considered in here.

The values of x_v, y_v are as follows:

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

$$y_v = -ctan\theta(x_v - x_o) + y_o. \tag{11}$$

We obtain the reference trajectory as follows. The general form for a circular motion is given by

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

and the equation of the line motion becomes

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

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

3. Design of Fuzzy Logic Systems and Its Simulations

In this section, we design a fuzzy logic system for the slant parking of a 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.

(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}).

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

We define its input variables as follows:

$$\begin{aligned} u_1 &= \theta_3 - \theta_1 \\ u_2 &= \theta_2 - \theta_1 \end{aligned} \tag{14}$$

Then a sliding line is defined as follows:

$$\begin{aligned} s &= u_1 - u_2 \\ &= \theta_3 - \theta_2 \\ &= 0 \end{aligned} \tag{15}$$

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 1.

Table 1. Rule table for the conventional FLS.

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

We can slightly change the Table 1 of control rules. For this we derive a single variable d_s [9]:

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

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 as established by Table 2.

Table 2. Rule table for the SFLS.

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

Suppose the start postures of the mobile car is located at $(x_r, y_r, \theta_2) = (5,7,0^0)$.

The result gives as follows, we can see that the vehicle can follow this reference trajectory very well.

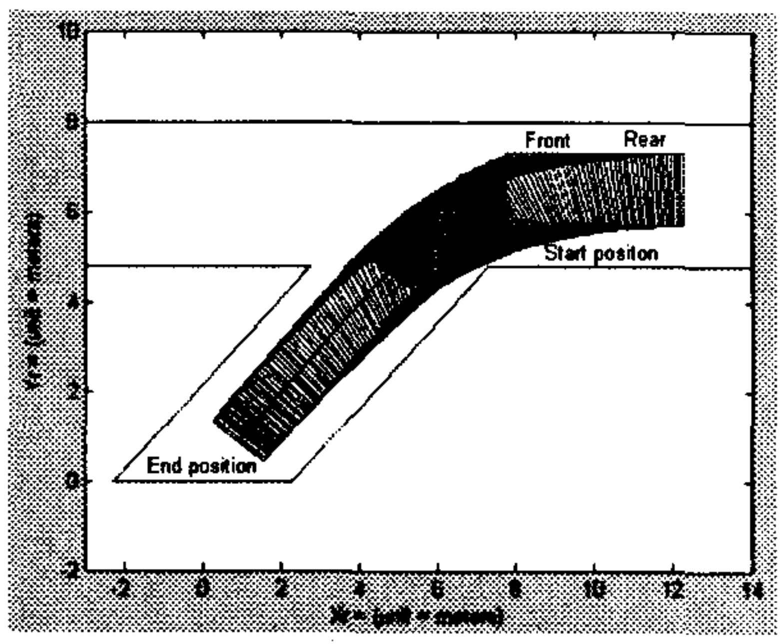

Fig. 3. Simulation result of the slant garage parking.

4. Concluding Remarks

In this paper, we have designed forward parking trajectory for a slant garage parking space. And designed a fuzzy logic based parking system. We showed that the result is indeed effective and feasible. This slant parking system can easily be changed to the case of the rectangular parking space by substituting the slant angle to 90 degree.

REFERENCES

[1] M. Sugeno and K. Murakami, *"An experimental study on fuzzy parking control using a model car,"* in Industrial Applications of Fuzzy Control, North-Holland, The Netherlands, pp. 105 - 124, 1985.

[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, pp. 107 - 112, 1991.

[4] S. Yasunobu and Y. Murai, *"Parking control based on predictive fuzzy control,"* in Proc. IEEE Int. Conf. Fuzzy Systems, vol. 2, pp. 1338-1341, 1994.

[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, and Cybernetics, vol. 2, pp. 1659 - 1664, 1995.

[6] M. C. Leu and T. Q. Kim, *"Cell mapping based fuzzy control of car parking,"* in Proc. IEEE Int. Conf. Robotics Automation, pp. 2494 - 2499, 1998.

[7] 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, pp. 1693 - 1698, 1999.

[8] T.-H. S. Li, *"Autonomous fuzzy parking control of a car-like mobile robot,"* IEEE Trans. in SMC (A), vol.33, no.4, July 2003

[9] B. J. Choi, S. W. Kwak and B. K. Kim, *"Design and stability analysis of single-input fuzzy logic controller,"* IEEE Trans. on SMC (B), vol. 30, no. 2, pp.303-309, 2000.

[10] 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 and Automation, vol. 1, pp. 1-6, 1999.

[11] M. Khoshnejad and K. Demirli, *"Autonomous parallel parking of a car-like mobile robot by a neuro-fuzzy controller"*, in Proc. IEEE Int. Conf, Fuzzy Information Processing Society, pp. 814-819, 2005.

[12] T.-H. S. Li and S.-J. Chang, *"Autonomous fuzzy parking control of a car-like mobile robot"*, in Proc. IEEE Int. Conf, Systems, Man and Cybernetics, Part A, vol. 33, pp. 415-465, 2003.