Fuzzy Parking and Point Stabilization: Application Car Dynamics Model

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Abstract

The first specific problem in this paper is to park a car to a given goal x-position at right angle starting from a given configuration by controlling the acceleration or deceleration force and the steering angle of the wheels. After dealing with the parking problem, two fuzzy controllers are proposed, the first generates the steering angle from position and orientation errors of the car, while the second controller generates the acceleration or deceleration force from the generated steering angle and the speed of the car. From these controllers and with a geometric transformation, we design a new control method for the second purpose in this study which consists to stabilize the car to specified coordinates and an orientation starting from a given position. Simulation results using dynamics car are successfully performed.

Key Words: Fuzzy control, Car navigation, Dynamics model car.

1 Introduction

The simulation of the vehicle behavior by varying the force of propulsion (acceleration force) or the force of braking (deceleration force) and the steering angle of the wheels which represent the control actions requires the consideration of vehicle dynamics model. Hence, to study the behavior of the car with precision, we must take into account most of its degrees of freedom (complex models). Generally, the dynamics model of the vehicle is a multi-input multi-output. Such dynamics models have been developed [1][2], and are used by car constructors [3] in order to simulate the vehicle behavior. However, the complex form of these models do not allow to perform a easier control law.

Normally, vehicles are used to transport goods or passagers. Most of them are manually controlled. But there are situations where manual control is not desirable. For example in a polluted environment such as chemical factories and nuclear power stations. In such situations, the necessity of auto-guided vehicles arises.

Some papers have been reported related to the vehicle control problem. Sugeno [4][5] has designed a fuzzy controller to navigate and to park a car. Nguyen and Widrows [6] developed a neural network controller for the truck backer upper to a loading dock problem from an arbitrary initial position by manipulating the steering. Kong and Kosko [7] proposed a fuzzy control strategy for the same problem. In [8], Wang solved the same problem by generating fuzzy rules using learning algorithms.

In this paper, we firstly propose to drive a car to a given goal x-position at right angle starting from an arbitraly configuration by controlling the acceleration or deceleration force and the steering angle of the wheels. The second purpose is to stabilize the car to a given position and orientation.

To solve these two problems, we apply the fuzzy logic principles. An interesting point of a fuzzy control system is that it is easy to implement a system that deals with many situations without defining any analytical control model, but simply by representing relationships between inputs and outputs in an **if-then** manner and constructing a knowledge base. In control vehicle case, it is possible to build fuzzy controller which takes similar decisions as expert driver would take after observing the current position and velocity of vehicle. In other words, it is possible to propose simple solutions for parking and point stabilizing the car as will be shown in this paper.

This paper is organized as follows. In section 2, we give the car dynamics model. After a discussion of mechanism of the parking, fuzzy controllers are proposed, in section 3. Then, section 4 is devoted to the control design for the point stabilization of the car. The resulting controllers are tested on given car dynamics model. Finally, our conclusions are summarized in section 5.

2 Car Dynamics Model

Consider the dynamics equations describing the vehicle, as introduced in [2] :

$$\dot{u}=\frac{1}{M}\left\{Ta-Tb+M v.r-M f.g+Cf.q.\frac{v}{u}+a.Cf.q.\frac{r}{u}+u^2.(f.k_1-k_2)\right\}$$

$$\dot{v}=\frac{1}{M}\left\{(Ta-fb.Tb).q-M u.r+Cf.q-(Cf+Cr).\frac{v}{u}+(b.Cr-a.Cf).\frac{r}{u}\right\}$$

$$\dot{r}=\frac{1}{Iz}\{a.(Ta-fb.Tb).q-M f.h.u.r+a.Cf.q$$

$$-(a.Cf-b.Cr).\frac{v}{u}+(b^2.Cr-a^2.Cf).\frac{r}{u}\}$$

$$\dot{x}=u.\cos(\phi)-v.\sin(\phi)$$

$$\dot{y}=u.\sin(\phi)+v.\cos(\phi)$$

$$\dot{\phi}=r$$

The vehicle is presented as a six degree of freedom system. These degrees correspond to longitudinal and lateral displacement (x, y), longitudinal and lateral velocity (u, v), the angular velocity r with respect to vertical axe, and the orientation angle ϕ of the car with respect to the horizontal. The control actions of the vehicle are the force of propulsion *Ta* or the force of braking *Tb* and the steering angle θ (Fig. 1).

Other parameters of the used model are presented in appendix with their values employed in simulation studies.

This dynamics model is multi-input multi-output system with six state variables and three control actions

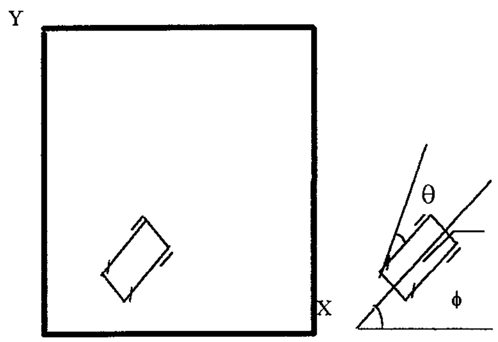

Fig. 1. Diagram of simulated vehicle

The goal here is to design a control system allowing the car point stabilization which consists in reaching a given goal position and orientation (xf,yf,ϕf), starting from a given initial configuration (x0,y0,ϕ0). First, we design a control system for the purpose of making a car arrive to a given goal x-position xf, at right angle (ϕf=90°) starting from a given initial configuration. From this control system and with a geometric transformation, we design a new control method for the point stabilization. Then, we have to determine the acceleration or the deceleration force and the steering angle θ at each point of the car trajectory.

3 Controllers Design for Car's Parking

3.1 Basics of Fuzzy Controllers

In this section, We deal with the parking control car.

A car driver acts on the steering wheel (steering angle) and on the throttle (acceleration force) or on the brake (deceleration force). In case of controlling a vehicle, it is possible to transcribe the reactions of the expert driver by rules which give a decision to take after observing the current position and velocity of the vehicle.

the fuzzy controllers have to generate two control actions, the car steering angle and the traction force or the braking force.

The steering angle θ has to be controlled in such a way that the car can move toward the desired configuration. The main idea is to reduce the position error dx between the reference position xr and the current position xc, and the orientation error dϕ between the reference direction ϕr and the current heading direction ϕc until both errors converge to 0.

The control *T* which represents two variables of control, the force of traction *Ta* and the force of braking *Tb* has to be controlled in such a way that the car can be driventravel at high speed on a straight line, and at low speed when it turns.

The inputs of the second fuzzy controller are the wheel's direction θ, and the euclidean norm V of the three car velocity u, r and v, where :

$$V=\sqrt{(u^2+v^2+r^2)}$$

The control system architecture is shown in Fig 2.

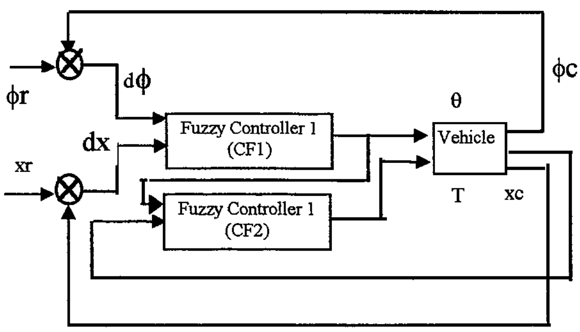

Fig 2

3.2 Fuzzy Controllers for Vehicle

The fuzzy rules of the FC1 have to be generated in such a way that the steering angle θ can be big when the vehicle is at a point far away from the desired configuration and small when the robot reaches the destination. For example, let's consider the case when the vehicle is located in a situation with an orientation such that $d\phi$ is positive middle and dx is zero (Fig.3-a.). In this situation, the steering angle θ has to be negative middle to decrease dx. Therefore, we obtain the following rule :

if $d\phi$ is positive middle and dx is zero then θ is negative middle.

Now, let's consider the case when $d\phi$ is zero and dx is positive middle (Fig.3-b.). In this situation, a negative middle of the steering angle θ is required to reduce dx. The corresponding rule is then :

if $d\phi$ is zero and dx is positive middle then θ is negative middle

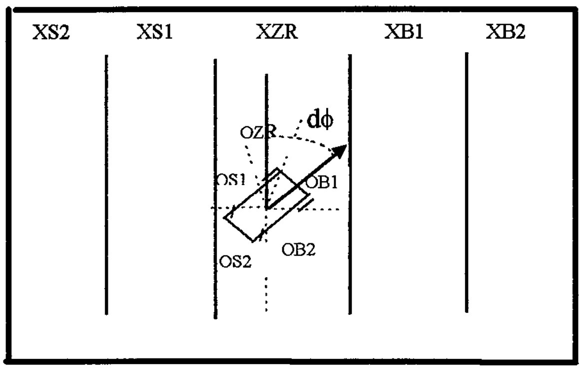

fig. 3-a

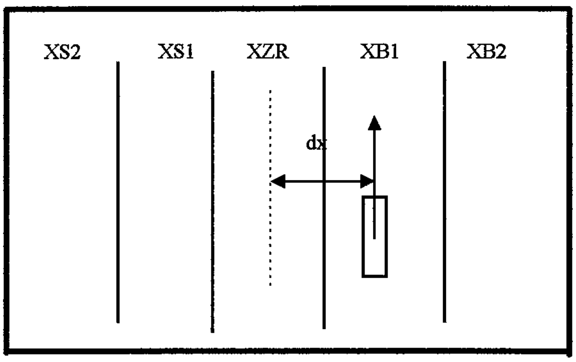

fig. 3-b

All possible configurations are summarized in table 1. The speed of the vehicle is controlled by acting a force of traction or a force or braking. These two actions of control are generated from the steering angle obtained by the previous CF1, and the velocity V. Since the acceleration force is positive value, and the deceleration force is negative value, therefore, one output control T only has to be introduced as an output for the CF2. The membership function of T posses positive region for the acceleration force and negative region for the deceleration force. Then, when one of both forces are different from zero, the other is nil. Based on the above analysis the fuzzy rules of the FC2 have to be generated as follows : For example, let's consider the case when the vehicle is located in situation with an orientation such that θ is zero and the velocity is middle. In this situation, the control T has to be positive middle (throttle) to increase the speed. Therefore, we obtain the following rule :

if θ is zero and v is middle then T is positive middle.

Now, let's consider the case when θ is positive big and v is big. In this situation, the control T has to be negative big (brake) to decrease the speed. Therefore, we obtain the following rule:

if θ is positive big *and v is big then T is negative big.*

The resulting control rules are shown in table 2. Based on the above qualitative analysis, we are able to design the control output allowing the convergence of the vehicle to the desired configuration. For the FC1, each linguistic variable takes five fuzzy sets (S2, S1, ZR, B1, B2). Membership functions m(dx), $m(d\phi)$ and $m(\theta)$ are defined as shown in Fig. 4. For finer adjustments near the destination, the fuzzy region relevant to the desired configuration are designed to be narrower (i.e. the regions XZR, OZR, ZR). The wider fuzzy sets allows rough control far from the destination. The universe of discourse of the position error dx is normalized to [-1,1], while the orientation error $d\phi \in$ [-180,180], the steering angle $\theta \in$ [-30,30] and the speed $V \in$ [0,150]. The fuzzy set shown in Fig.5 is used to controll the speed of the vehicle

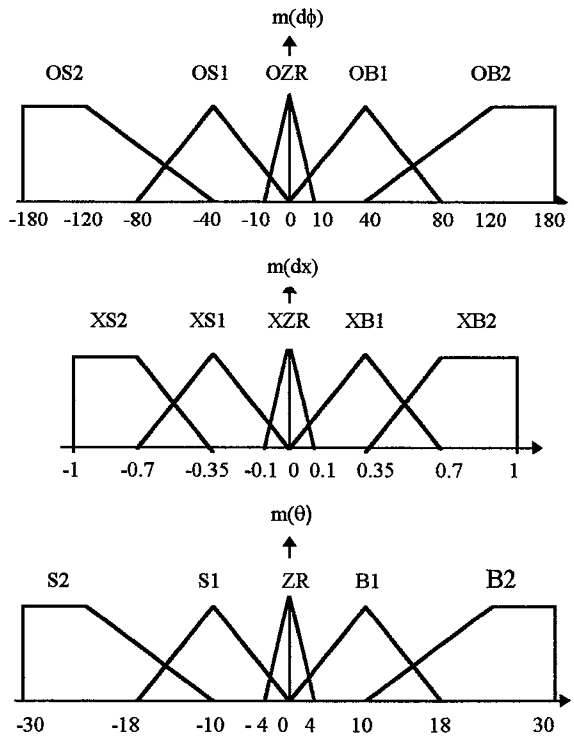

Fig. 4. Fuzzy membership for the CF1

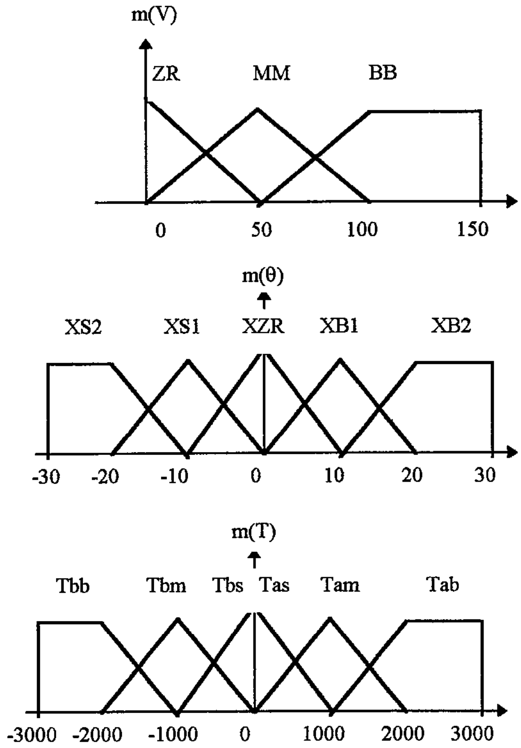

Fig. 5. Fuzzy membership for the CF2

$d\phi$ \ dx	XS2	XS1	XZR	XB1	XB2
OS2	B2	B2	B2	B1	B1
OS1	B1	B1	B1	B1	ZR
OZR	B2	B1	ZR	S1	S2
OB1	ZR	S1	S1	S1	S1
OB2	S1	S1	S2	S2	S2

Table 1.

V \ θ	NB	NM	ZR	PM	PB
ZR	Tbs	Tam	Tab	Tab	Tbs
MM	Tbm	Tam	Tam	Tam	Tbm
BB	Tbb	Tas	Tas	Tas	Tbb

Table 2

3.3 Simulation Results

In order to illustrate the effectiveness of these fuzzy controllers, simulation results have been performed. We used the Max-Min inference and the center average defuzzification [11]. The used membership functions are shown in Fig. 4. Table 1 and Table 2 give the linguistic rules.

The objective is to reach a given x-position and orientation, starting from a given configuration. Three arbitrarily chosen initial states, $(x0,\phi 0)=(30,30°)$, $(50,220°)$, $(60,-30°)$ and two desired configurations $(xf,\phi f) = (30,90°)$, $(90,90°)$ were used to test the fuzzy controllers.

Fig. 6 shows the car trajectories. We see that the fuzzy controllers successfully control the vehicle to the desired configurations starting from all three initial states.

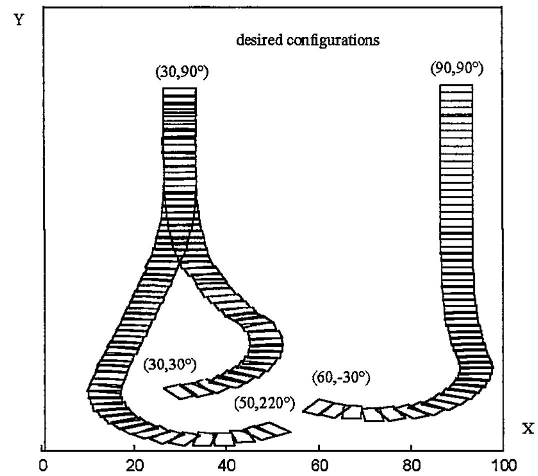

Fig.6 vehicle trajectories using fuzzy controllers

4 Fuzzy Point Stabilization Control

4.1 Basis of fuzzy control

We have shown the parking control in section 3. The task in this section is to design the point stabilization control which consists in reaching a point destination $(xf,yf,\phi f)$ from a point source $(x0,y0,\phi 0)$ (see Fig. 7).

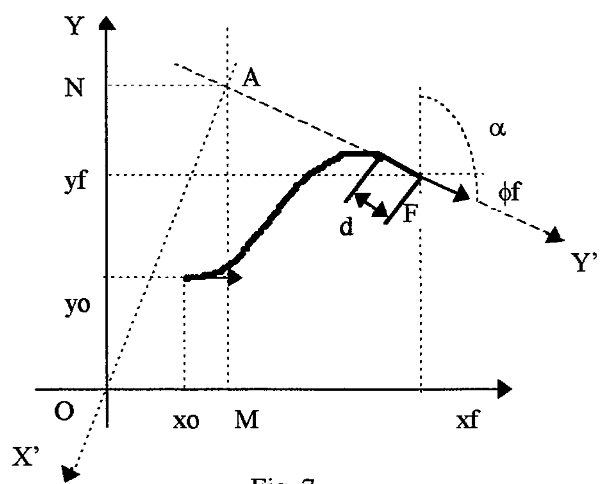

Fig. 7

We can transform this point stabilization problem into the parking problem by stopping the car while it reaches a desired configuration. Indeed, the point stabilization problem in the frame (O,X,Y) amount to the parking problem in the fictive frame (A,X',Y') where the axe Y' is characterized by (xf,yf,ϕf), the axe X' is perpendicular to Y' and passes by the origin O, and A is the intersection of both axes. In other words, for the two fuzzy controllers CF1 and CF2 designed in the previous section, the car seems park, when it really converges to the desired posture.

Therefore, by a geometric transformation defined by vector translation AO(M,N) and angle rotation α which is the angle of the desired direction with respect to the vertical, the frame (A,X',Y') becomes the frame (O,X,Y). Indeed, a point P(x,y,ϕ) becomes another point P'(x',y',ϕ') such that, by using the homogenate coordinates, we obtain:

$$[x' \;\; y' \;\; 1] = [x \;\; y \;\; 1].\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ M & N & 1 \end{bmatrix}\begin{bmatrix} cos(\alpha) & sin(\alpha) & 0 \\ -sin(\alpha) & cos(\alpha) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\phi' = \phi + \alpha$$

M and N are not known, then we must compute them.

By writing the two equations of both lines (AF) and (AO) and by remarking that the point A is the intersection of both lines. Then, after a brief calculus, we obtain :

$$M = \frac{-yf + tan(\alpha - \pi/2).xf}{tan(\alpha - \pi/2) - tan(\alpha - \pi)}$$

$$N = tan(\alpha - \pi).\left[\frac{-yf + tan(\alpha - \pi/2).xf}{tan(\alpha - \pi/2) - tan(\alpha - \pi)}\right]$$

In order to stop the car, we define a straight line distance d to the desired position (xf,yf). When the vehicle is in the interior of the distance d, we apply a deceleration force which allows to stop the car in the desired position (final velocity V_f is nil) from the current position. This force of braking is derived by the following relation :

$$V_f^2 - V_0^2 = 2.\Gamma.(y_f - y_0)$$

where V_f is the final velocity (in our case, V_f is nil), V_0 is the initial velocity, y_f is the final y-coordinate of the car, y_0 is the initial y-coordinate, and Γ is the acceleration. This latter is function of the force of braking Tb:

$$Tb = M.\Gamma$$

where M is the total mass of the car.

Based on the above analysis, we are able to design the method control allowing the convergence of the vehicle to the desired posture (xf,yf,ϕf).

The architecture of the navigation control system is shown in Fig .8

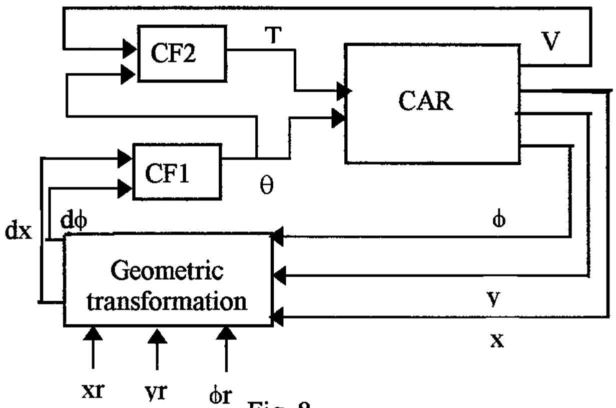

Fig. 8

4.2 Simulation Results

In order to illustrate the effectiveness of this fuzzy control method, simulations have been performed.

The goal is to reach a given position and orientation, starting from a given point source. Three arbitrarily chosen initial states, (x0,y0,ϕ0) = (-20,150,45°), (110,108,-60°), (0,0,-30°) and respectively three desired destinations (xf,yf,ϕf) = (100,100,-30°), (40,70,180°), (100,40,30°) were used to test this fuzzy control method.

Fig. 9 shows the car trajectories using fuzzy point stabilization. We see that this fuzzy control method successfully controls the vehicle to the desired postures starting from all three initial states.

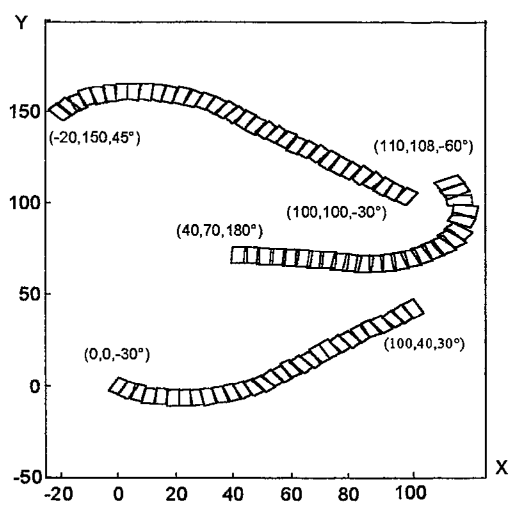

Fig.9 vehicle trajectories using fuzzy point stabilization

5 Conclusion

In this work, we have applied fuzzy logic techniques in order to solve two problems : parking and point stabilization problems. To solve the former problem, two fuzzy controllers are proposed, the first generates the steering angle from position and orientation errors of the car with respect to the desired configuration, while the second controller generates the acceleration or deceleration force from the generated steering angle and the speed of the car. While, to solve the latter problem, we cut it up in two parts : in the first part we used a geometric transformation which allowed to transform the point stabilization problem to the parking problem. Next, once the frame transformation is solved, we made the car straight line in such a way that it reaches the destination with a nil velocity. The two fuzzy control methods are tested on car dynamics model, we have shown that the results of these simulation studies give good performances. The attractive features of the control method are : (1) No analytical model of the car » is required for the controller design. (2) Taking into account the human experience in the establishment of the rules. (3) Taking into account control saturation and kinematics constraints.

Appendix

symbol	Name	Value
a	Distance, c.g. to front axle	1050 mm
b	Distance, c.g. to rear axle	1630 mm
h	c.g. height	530 mm
M	Total mass	1480 kg
f	Nominal friction coefficient	0.02
g	Acceleration of gravity	8.81 m/sec^2
Cf	Front roll stiffness	135000 N/rd
Cr	Rear roll stiffness	95000 N/rd
k1	portance parameter	0.005 N.sec/m
k2	drag parameter	0.41 N.sec/m
fb	distribution coefficient front/rear	0.6

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