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Predictive Fuzzy Control and Parking Control

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Abstract

Fuzzy control method can make an algorithm from control know-how of a skilled human operator or control engineer by fuzzy sets. The drive of the car is operated by the drive knowledge of the driver who knows the dynamic characteristic of the car well. To achieve the control based on this drive knowledge, a car operation system was constructed of fuzzy control scheme that consisted of predictive fuzzy control. The computer simulation of the parking control was executed by using this system. It was confirmed that the proposed method is effective.

1. Introduction

Fuzzy set is a concept that allows machines to handle fuzziness that arises from human subjectivity [1]. A fuzzy control technology can make up an algorithm from control knowledge of a skilled human operator by fuzzy set. It is an effective method to develop a controller operate a system as skillfully as a human expert [2]. There are proposed two approaches as follows; (1) State evaluates fuzzy control: A control command is decided from experiences and states of the present time, (2) Predictive fuzzy control: A control command is selected from evaluation of predicted states and objectives.

The predictive fuzzy control method is applied to train systems, by which a train can be started, kept to a limited speed and stopped at a target position of a station [3]. This controller is currently being applied to Sendai-city subway system's automatic train operation system since 1987, and the Tokyo subway line No.12 since 1991. These real systems are showing that the fuzzy control system can operate trains as skillfully as human experts do.

In this paper, the predictive fuzzy control method is applied for a parking control of four-wheeled vehicle.

2. Predictive Fuzzy Control

2.1. Advantage of fuzzy set theory

Fuzzy set theory can handle the impression arising from human judgment. As an example, we discuss the evaluation of the position error in the control. In the concept of the conventional crisp set, the taking value is 1 (truth) or 0 (false). For example, if we have an acceptable range of ± 50 cm then an error of 50 cm is judged to be acceptable, but 51 cm is unacceptable (Figure 1(a)). To handle this minute dividing line between good and bad, we need a complex algorithm.

On the other hand, human beings don't make such clear-cut judgments. The boundary is vague. This human vagueness can be quantitatively described. Fuzzy sets are a way for computers to handle this vagueness.

In fuzzy set theory, we define "The error is good." by a membership function that takes a value from 0.0 to 1.0 as shown in Figure 1(b). For example, the degree of "The error is good." become 0.5 at +50 cm and 0.49 at +51 cm. It is possible to process these errors equally with a computer. Therefore, the state of the system can be handled in the word (symbol) with a certain degree.

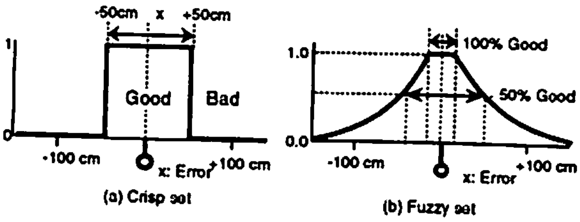

Figure 1: Crisp set and fuzzy set.

On the other hand, in an object system the relation between the amount states "Pressure" and "Temperature" have been precisely processed by a linear function or a nonlinear function of the form of "y=f(x)." Related knowledge of result "y" of input "x" is clearly described by some expressions of a computer, and has been processed (Figure 2(a)).

However, when a system is described by a precise function, we get little knowledge of its characteristics. The characteristics of a system are understood by many isolated fragments of knowledge such as "If x is about x1, then y is about y1." The overall view can be described using fuzzy knowledge. Using a fuzzy reasoning based on this knowledge, the result of "about Yo" is obtained from input of "about Xi" (Figure 2(b)).

The fuzzy control system assumes this fuzzy set theory as its base. The control data for the system is fuzzy knowledge for judging numerical values described by subjective words with the expression processing the overall situation. As a result, it can achieve flexible processing suitable for the situation.

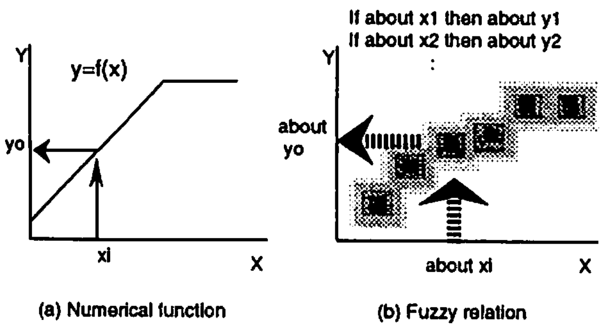

Figure 2: Knowledge description of numerical relation

2.2. Predictive fuzzy control method

The predictive fuzzy control method is applied to real robotics and mechatronics system using a dynamical system model. A control rule of this method is described for example by "If u is C1 → x is Good and y is Big, then u is C1." This fuzzy control generates control command alternatives, predicts control results' x and y using a dynamical system model, and finally selects the best control command from the alternatives (Figure 3). In this way, the predictive fuzzy control decides the best control command based on the dynamical system model from observed present states [3, 2, 5].

3. Parking by Human Operation

Man roughly recognizes the situation and the movement speed in surroundings. Then he can park a car to the target position. The computer can drive a car by using the man's drive knowledge as a proxy.

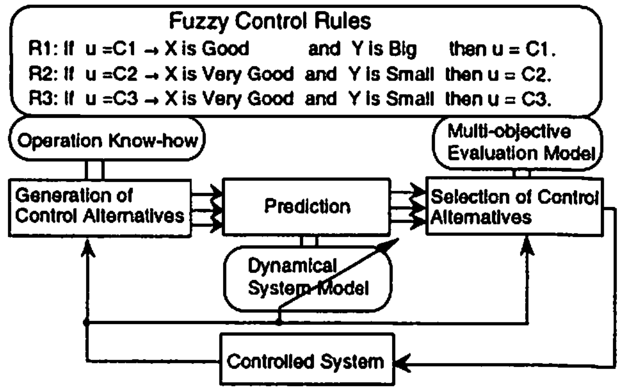

Figure 3: Control sequence of predictive fuzzy control

3.1. Steering mechanism for four-wheeled vehicle

We think about the case to do the turn movement at low speed that the four-wheeled vehicle of the front wheel steer can disregard the generation of the centrifugal force. The car will have the turn center in the circle turn of the body in the rotation center axis each wheel extension. This extension's intersecting with the extensions of two front vehicle circle axes by one point becomes a condition because the wheel axis is on one wheel axis after the inside and outside. This intersection C is a turn center.(Figure 4)

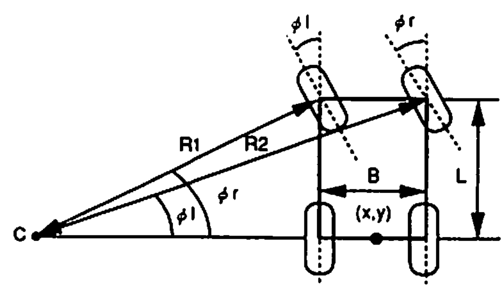

Figure 4: Geometrical relation in turn of four-wheeled vehicle.

When the vehicle keeps the above-mentioned turning relation, the equations of motion are as follows.

$$\begin{aligned} \frac{dx}{dt} &= v\cos\phi\cos\theta \\ \frac{dy}{dt} &= v\cos\phi\sin\theta \\ \frac{d\theta}{dt} &= \frac{v}{L}\sin\phi \end{aligned} \qquad (1)$$

The average speed of the front wheel is v. The distance of the front and rear wheel (wheel-base) is L. The azimuth of body is θ. The front wheel's angles are ϕr and ϕl. ϕ is the average of ϕr and ϕl. The car position is (x, y) (Hereafter, it is called the position of the body) in the middle of two wheels in the back.

3.2. Manual operation process of a car by skilled person

It is possible to think about the drive operation of the skill person as three hierarchies shown next.

3.2.1 Watch for state of car: He watches that the car arrived already or didn't arrive at the target position. When the car attains it, he switches the target to next one.

3.2.2 Setting of target: He sets a temporary target to reach the final target on the way. From the position and the azimuth of a present body, the temporary target is decided by operator's know-how as follows; "A target position is in the front of left and if the azimuth of the car is parallel, the body should be turned to a little left in the intermediate position."

3.2.3 Driving wheel operation: To reaches to the target, the driving wheel operation is executed. The experience rules are shown as follows.

- If driving wheel is maintained, it will approach well to the target, then the driving wheel should be maintained.
- If the car goes straight, it will approach well to the target, then it should go straight.
- If driving wheel is right turn, it will approach accurately to the target, then the driving wheel should be right turn.
- If driving wheel is left turn, it will approach accurately to the target, then the driving wheel should be left turn.

These experience rules assume that the driving wheel operation to do straight advancement, right turn, and left turn, evaluate those execution results, and execute the most appropriate operation.

4. Parking Controller by Hierarchical Predictive Fuzzy Control

4.1. Hierarchical fuzzy control algorithm

The controller that makes an intellectual activity concerning the man's knowledge for parking that is described in Chapter 3 is regarded. We propose a fuzzy control controller that consists of these three hierarchies is regarded (Figure 5).

Watch part: The target and present system states are compared. If the car does not attain to a temporary target, the target is maintained. When the car attained to target or it stopped, a target reset command is outputted.

Decision part: The temporary target in consideration of the control strategy decided in this decision part is outputted. From the numerical value based on the experience of the past now, present states and system parameters, the best control target is decided. A temporary target (position (xn, yn), target azimuth (θn), and traveling speed (vn)) is obtained now by the characteristic of car, position (x, y) and azimuth (θ).

Practice part: These predictive fuzzy control rules are the same form as the experience rules of the car operation of the skill person. Then, this control method is used to operate the driving wheel. Figure 6 shows performance (fuzzy sets) of distance and azimuth for driving wheel operation.

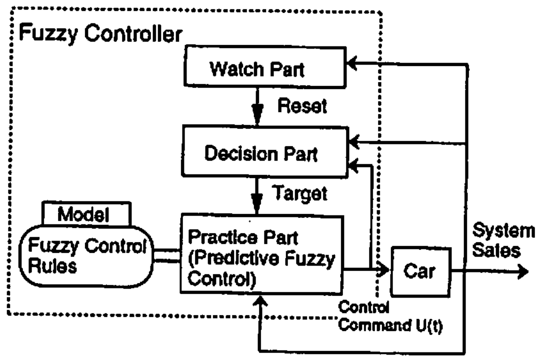

Figure 5: Structure of hierarchical fuzzy control.

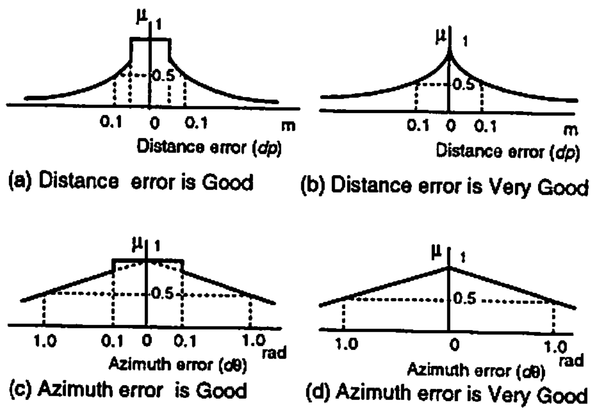

Figure 6: Membership functions of fuzzy evaluation indices.

4.2. Predictive fuzzy control rules

We described 8 control rules from the experience of the skill person as follows.

- If ($\phi = 0° \rightarrow dp$ is Good, $d\theta$ is Good) then $\phi = 0°$.

- If (ϕ = 10° → dp is Very Good, $d\theta$ is Very Good) then $\phi = 10°$.
- If (ϕ = −10° → dp is Very Good, $d\theta$ is Very Good) then $\phi = -10°$.
- If (ϕ = 20° → dp is Very Good, $d\theta$ is Very Good) then $\phi = 20°$.
- If (ϕ = −20° → dp is Very Good, $d\theta$ is Very Good) then $\phi = -20°$.
- If ($\phi = \phi + 0°$ → dp is Good, $d\theta$ is Good) then $\phi = \phi + 0°$.
- If ($\phi = \phi + 5°$ → dp is Very Good, $d\theta$ is Very Good) then $\phi = \phi + 5°$.
- If ($\phi = \phi - 5°$ → dp is Very Good, $d\theta$ is Very Good) then $\phi = \phi - 5°$.

Where, $\phi + 5°$ means to add the left of 5° in here from a present front wheel angle. The dp is difference of the target position and predicted position. The $d\theta$ is difference of the target azimuth and the predicted azimuth.

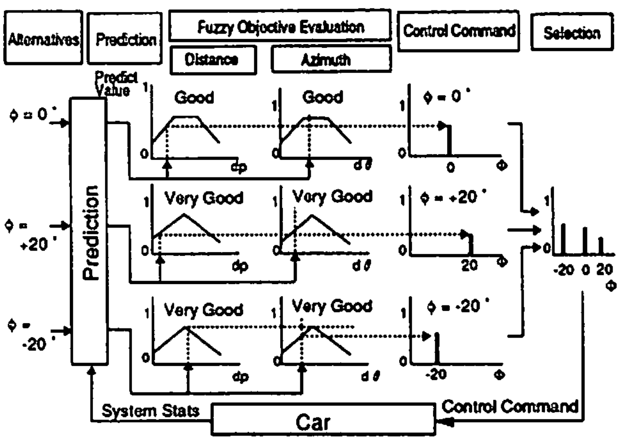

Figure 7: Inference process of driving wheel operation.

Figure 7 shows a reasoning process of driving wheel operation by predictive fuzzy control. Three candidate control instructions of 0 degree, +20 degree, -20 degree can be taken. The predictive calculation of the state in the future is done by using equation of motion by which the system situation of the control object was shown in value and assumption expression (1) now. The predictive value of a certain control purpose (x, y) (for instance, the future position 10 seconds after) is obtained. The fuzzy set by which distance error (dp) is called "Good" (it is in the range of the allowance) or "Very Good" (it is accurate), is defined by Figure 6. Moreover, it is similar, another control purpose azimuth error ($d\theta$) is evaluated.

These evaluated values are integrated by the logical product. And the inference result of the control instruction is obtained. The control command is selected by the highest grade of this inference result.

5. Simulation Results and Discuss

The parking control system based on the predictive fuzzy control method with car dynamics system model was proposed. The movements of the vehicle were simulated in the computer. The control performance was evaluated by fuzzy sets. The results of simulation of a move to the next lot and a garage parking are shown here. As for the vehicle, final target position (xe,ye) and final target azimuth (θe) are operated from initial position (x0,y0) and initial azimuth (θ0) aiming shown as follows. It was assumed that traveling speed V of the car is $0m/s$ (Stop), $0.4m/s$ (Forward), or $-0.4m/s$ (Back), wheel-base (L) is $2.6m$, tread width (B) is $1.7m$, maximum front wheel angle (ϕmax) is 25° and nominal minimum turn radius (Rmin) is 6.0 m.

5.1. Move to the next parking lot

In this simulation, a car moves to the next parking lot. The final target position is true side. Initial position is (x0,y0) = (4.0m, 0.0m) and initial azimuth is θ0=90°. Final target position is (xe,ye) = (0.0m, 0.0m) and final azimuth is θe=90°. Figure 8 shows a track of the car at every three second in traveling. The stop position is (x,y)=(0.1m,0.0m), θ=85.9°. In this case, to take the position where the car can park easily to back in the final target, the decision part put a temporary target (xt=0m,yt=9.2m,θt=90°) forward of that. The controller got the final target after reaching the temporary target.

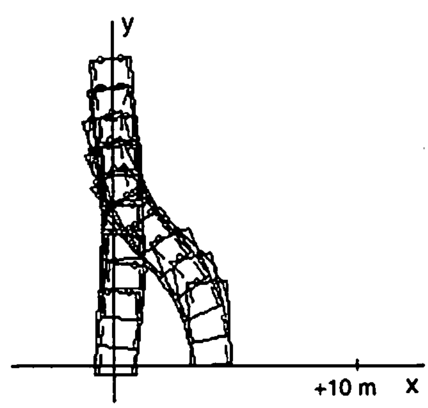

Figure 8: Simulation result of move to the next lot.

In the watching part, the first temporary target is watched and changed. In the decision part, a temporary target can be skillfully set by using a car dynamics model. In the practice part, predictive fuzzy control outputs the driving wheel command to reach the target well. This control system was applied to a 1/10 scale model car. The field test of this model car showed that it can operate a car well. [6]

5.2. Simulation of garage parking

In this simulation, the car parks to a garage front on a narrow road (road width is 7 m). Initial position is (x0,y0)=(10.0m, 8.0m) and initial azimuth is $\theta 0 = 180°$. Final target position is (xe,ye)=(0.0m,0.0m) and final target azimuth is $\theta e = 90°$. Figure 9 shows a track of the car at every three second in this case. The stopped position is (0.2m,0.0m), and azimuth is $\theta = 84.6°$. The controller set a temporary target on (0.0m,2.3m) and $\theta = 90°$, after that set on (-5.0m,8.4m) and $\theta = 180°$, based on man's parking strategy. It is understood to reach the final target smoothly by operating driving wheel that is good through the target on the way of this.

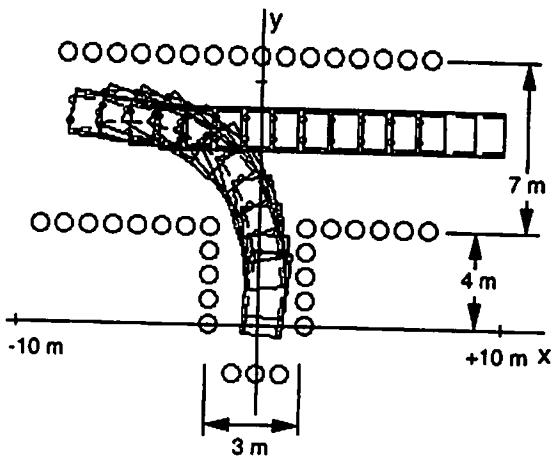

Figure 9: Simulation result of garage parking(the width of a road is 7m).

This simulation parks a car to a garage front on a narrow road (road width is 6 m). Figure 10 shows a track of the car at every three second. The stopped position is (0.2m,-0.3m), and azimuth is $\theta = 90.6°$. The controller set a temporary target on (0.0m,2.3m) and $\theta = 90°$, after that set on (-5.0m,8.4m) and $\theta = 180°$. In this case, practice part can't select full turn back, because front bumper is near to the wall. So, the controller set a new target on (0.0m,6.7m) and $\theta = 90°$, and set the final target.

These simulation results show that the parking control is executable for various situations by the proposed hierarchical fuzzy control system.

6. Conclusion

In this paper, the controller consists of three hierarchies of predictive fuzzy control method is proposed and it's applied for parking control. As a result, it was confirmed to be able to execute a good operation

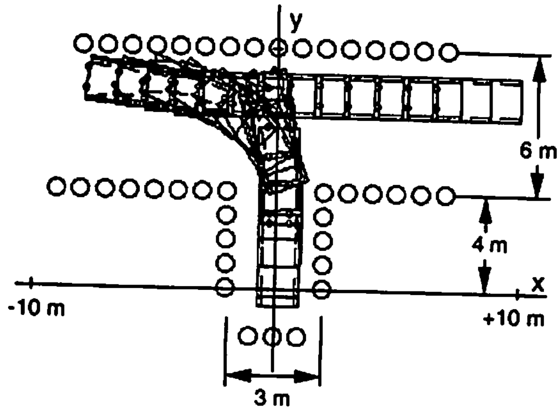

Figure 10: Simulation result of garage parking(the width of a road is 6m).

by the proposed method even in a complex control like the garage parking with narrow road width. The car was able to be moved well to the target position by operating the driving wheel. The predictive fuzzy control method was used for the practice part of this controller. This predictive fuzzy control method can achieve a gentle control for human. In this paper, the thing to which the proposed method was effective was shown by the computer simulation. This method will compose a drive system by which the computer cooperated with human.

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