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Intelligent Vehicle Control in Narrow Area based on Human Control Strategy

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Abstract

In this paper, an intelligent control system designed based on human control strategy and applied to park a vehicle in narrow area is proposed. The basic reason to use human control strategy is that it is not easy to apply automatic control to non-linear and non-holonomic system like a four-wheel vehicle. However, human can easily control such a system even if it is in a narrow area. One of the possible reasons is because human can flexibly set multilevel targets. In this paper those target are final target, strategy target and tactical target. Strategy target is a general situation target to reach the final target while the tactical target is an operational target to reach the strategy target. The effectiveness of this scheme is confirmed by simulation results.

Keyword: Predictive fuzzy control, Human control strategy, Narrow area, Intelligent control, Vehicle control, Non-holonomic system.

1. INTRODUCTION

It is difficult to control a system using controller based on a linear model for non-linear and non-holonomic system like a four-wheel vehicle. However, human can easily control such a system even if it is in a narrow area. There are many methods to design the controller based on the human control strategy. For example, neural network which can be used to mimic human control strategy base on the past experience [8]. GA (Genetic Algorithms) is also can be employed as a learning method for setting up the human control strategy using the natural selection and natural genetics paradigms. Moreover, the effectiveness of predictive fuzzy control for parking vehicle in a wide area was confirmed [5][6].

In this paper, the effectiveness of fuzzy rules, which used fuzzy sets as linguistic variables for implementing human control strategy, is preferred. However, because parking a vehicle in a narrow area is more difficult than in a wide area, the system need to be developed in order to be used in a narrow area. Because of that reason, the technique which used human control strategy to achieve flexibility in a narrow area is proposed and evaluated

2. HUMAN CONTROL STRATEGY

In order to design a human control strategy, the way of man/woman as a driver when they are parking a vehicle should be analyzed.

First of all, when the driver wants to park a vehicle, he can understands the situation around his vehicle and the current state of the vehicle (position, direction, etc.). After that, the driver will compare the current state of the vehicle and the parking lot. Finally, the driver will set the target by considering the characteristic of the vehicle when he is driving a vehicle toward the final target (the parking lot).

The target itself can be divided into three parts: the strategy target, the tactical target and the final target. The strategy target is a general situation target. The strategy target is decided from a relative relation to the current state of the vehicle in order to reach the final target. In purpose to control the vehicle toward the strategy target, the tactical target is created. In other word, to decide the strategy target and to move the vehicle, the tactical target is determined. The control method brought close to the tactical target is decided by the prediction based on the experience in the past. This step is repeated until the final target is achieved.

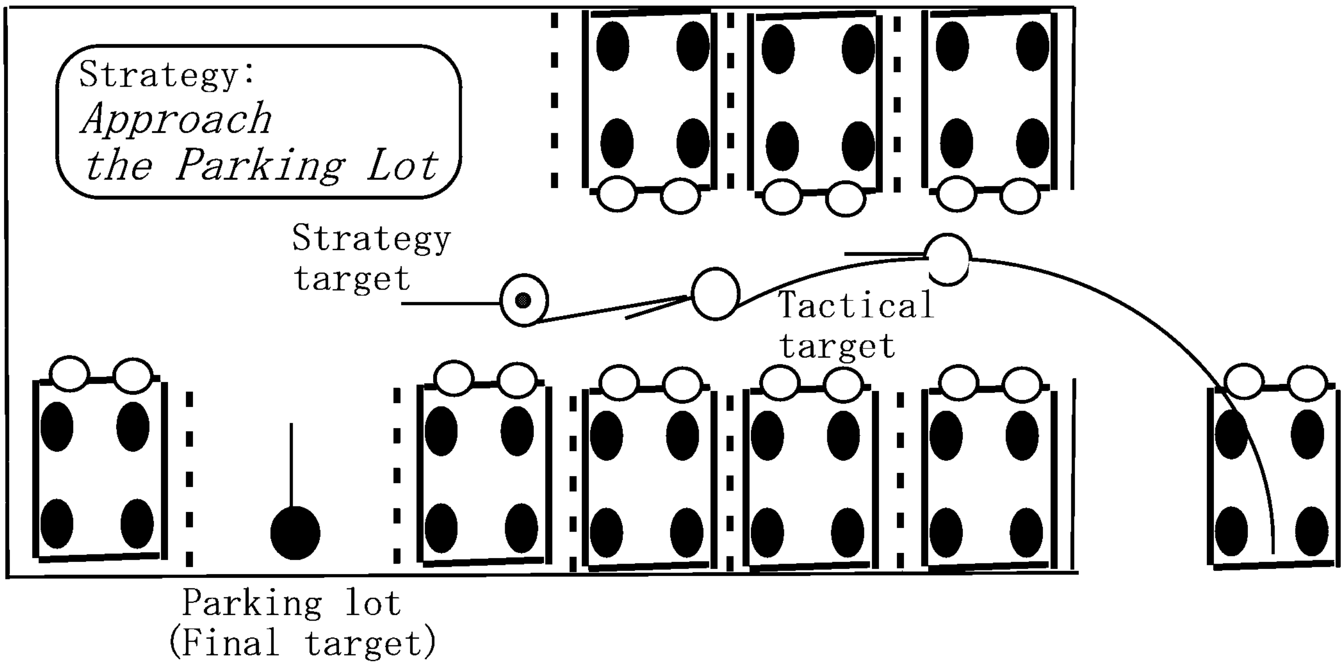

Figure 1: Example of human control strategy

The method for parking control as describes above can be illustrated as follows (see figure 1):

1. The shape of the parking site, obstacle, etc. are confirmed.
2. The strategies such as *approach the parking lot* or *enter the parking lot* are mapped out by setting the relative position between the parking lot and the current state.
3. Compare the current states with the strategy target and create the tactical target.
4. Use predictive fuzzy control (the control method using prediction based on experiences) to reach the tactical target.

These steps are repeated until the process of parking vehicle is completed

3. DESIGN OF INTELLIGENT VEHICLE CONTROLLER

Outline of the System

Figure 2 shows the outline of the intelligent control system based on human control strategy.

First of all, the relative position to the final target, the direction, the speed and the steering wheel condition as a state of the vehicle are detected by this system. After that, the system detects the shape of the segmented obstacles. These constraints are considered in the control system. Then, the coordinate system is made using the final target as origin. The position of the vehicle is defined by the center axis of the rear wheel. The direction angle is defined as an angle toward the direction and the X-axis.

After the states of the vehicle are known, the contact to the obstacle and the attainment to the target are observed in the detector part. The target set instructions is resulted if needed. In the target setting part, when the target set instructions are obtained, current states are compared with the final target. The strategy is selected according

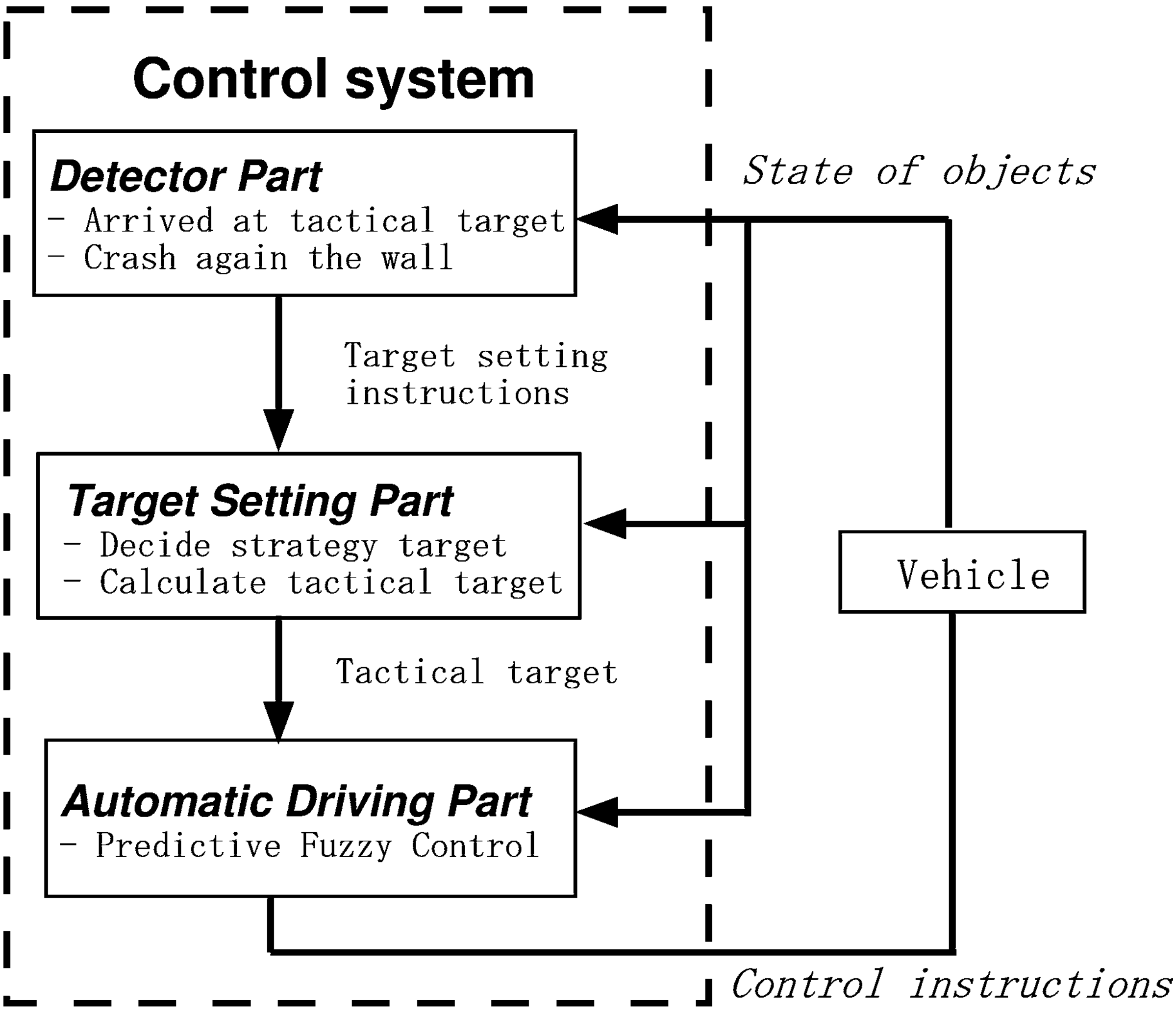

Figure 2: Outline of the system

to fuzzy rules, which express human control strategies. Each strategy has a specific strategy target. To reach the strategy target, the tactical target is calculated in consideration of the characteristic of the vehicle.

In the automatic driving part, the control instruction is decided while repeating prediction toward the calculated tactical target.

The final target is reached by repeating the above procedures. By doing this, a flexible control in the narrow area can be achieved. This is a control system, which is designed based on human control strategy.

Detector Part
The function of the detector part is to detect the current state of the vehicle and the obstacles. When contact to the obstacle can be predicted, a new tactical target is needed. Moreover, a new tactical target for automatic driving part is needed if the current tactical target was attained. The attainment of the tactical target determined by passing the line. This line is longitudinal with the tactical target. When the detector part has decided as mentioned above and a new tactical target is necessary, the target set instruction is sent to the target setting part. Finally, when the strategy target and the tactical target reached the final target, the detection procedure is finished.

Target Setting Part
When the target setting part received instruction from the detector part, the current state of the vehicle is compared with the final target. Using the fuzzy rules, the strategy is selected. The strategy, which used by human for parking a vehicle, can be categorized as follows:

- Change the direction: the direction should be change in order to reach the final target. This change of direction can be to horizontal, make counter direction from current direction or do the same direction with current direction.
- Approach the parking lot: aproaching the parking lot means to find the nearest and easiet way to reach the parking lot.
- Enter the parking lot: entering the parking lot is done when the strategy target is almost same as the final target.
- The control is finished: this condition is satisfied when the vehicle reached the final target.

To attaint the strategy target, the tactical target is calculated. After that, the state of the tactical target is sent to the automatic driving part.

Strategy target: the strategy target are selected based on the strategy when human parking a vehicle. The strategies below are selected to be used in the simulation.

Rule 1: if *the distance from current position to final target is very far* and *the direction is same or counter direction to reach the final target* then *change the direction to horizontal.*

Rule 2: if *the distance from current position to final target is very far* and *the direction is about horizontal then aproached the parking lot.*

Rule 3: if *the distance from current position to final target is far* and *the direction is same or counter direction to reach the final target then change the direction to horizontal.*

Rule 4: if *the distance from current position to final target is far* and *the direction is horizontal then approach the parking lot.*

Rule 5: if *the distance from current position to final target is near* and *the direction is same or counter direction to reach the final target* then *change the direction to horizontal.*

Rule 6: if *the distance from current position to final target is near* and *the direction is about horizontal* then *enter the parking lot.*

Rule 7: if *the distance from current position to final target is very near* and *the direction is same with current direction* then *enter the parking lot.*

Rule 8: if *the distance from current position to final target is very near* and *the direction is counter direction to parking lot* then *change direction to horizontal.*

Rule 9: if *the distance from current position to final target is very near* and *the direction is horizontal* then *approach the parking lot.*

This strategy is implemented in the IF-THEN rules for computer execution. These rules are obtained from human strategy for expressing qualitative measures.

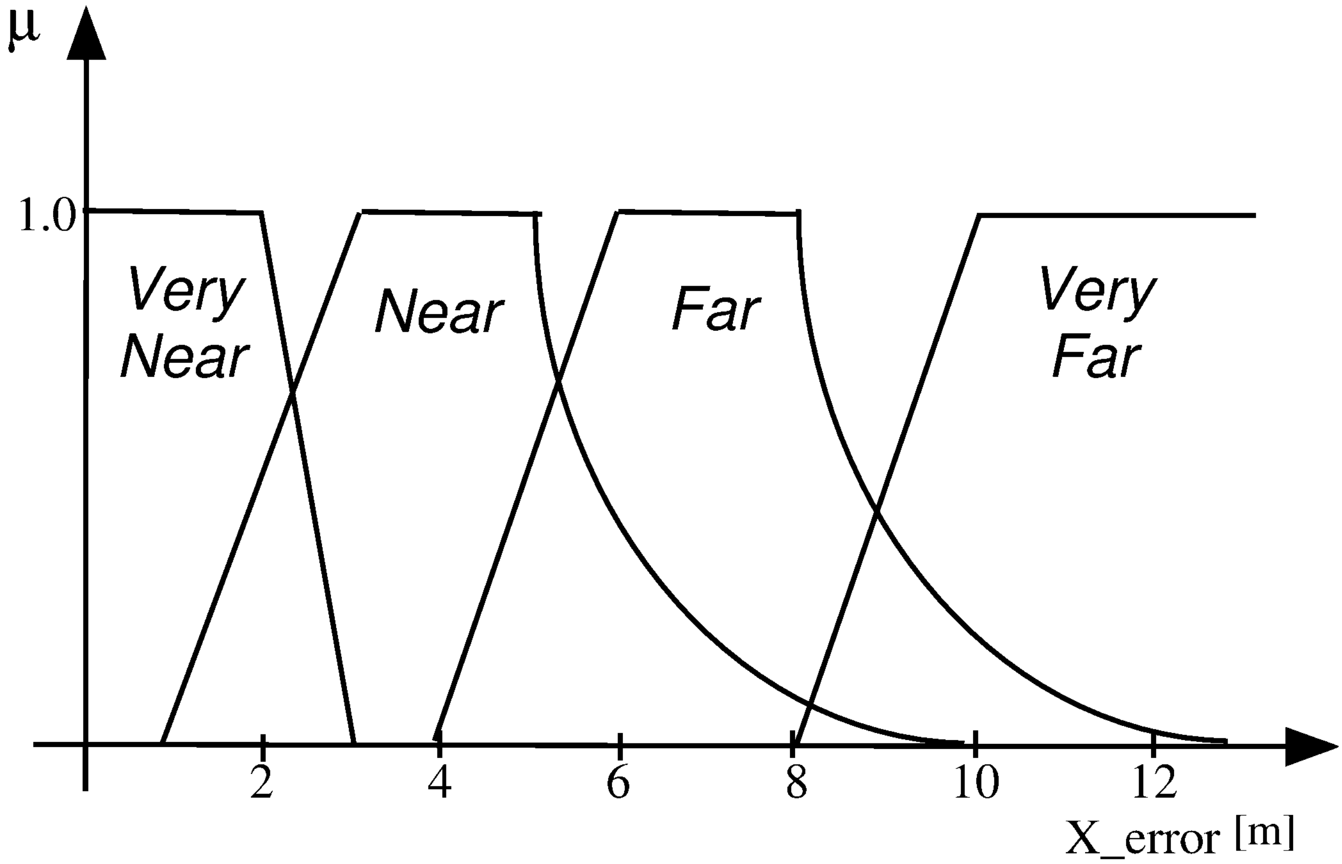

Figure 3: The fuzzy sets for the distance

In the rules two variables are evaluated, one is the error between the current state and the final target in the x coordinate and the other is direction of the current state. These linguistic variables were presented in fuzzy sets: *Very Near*, *Near*, *Far*, *Very Far*,*Horizontal*, *Same direction* and *Counter direction.* (See figure 3 and figure 4).

Using those fuzzy sets the rules are generated as follows:

Rule 1:
IF X_error is *Very Far* AND θ_error is *Same or Counter direction to parking lot*, THEN *Change direction to Horizontal.*
Rule 2:

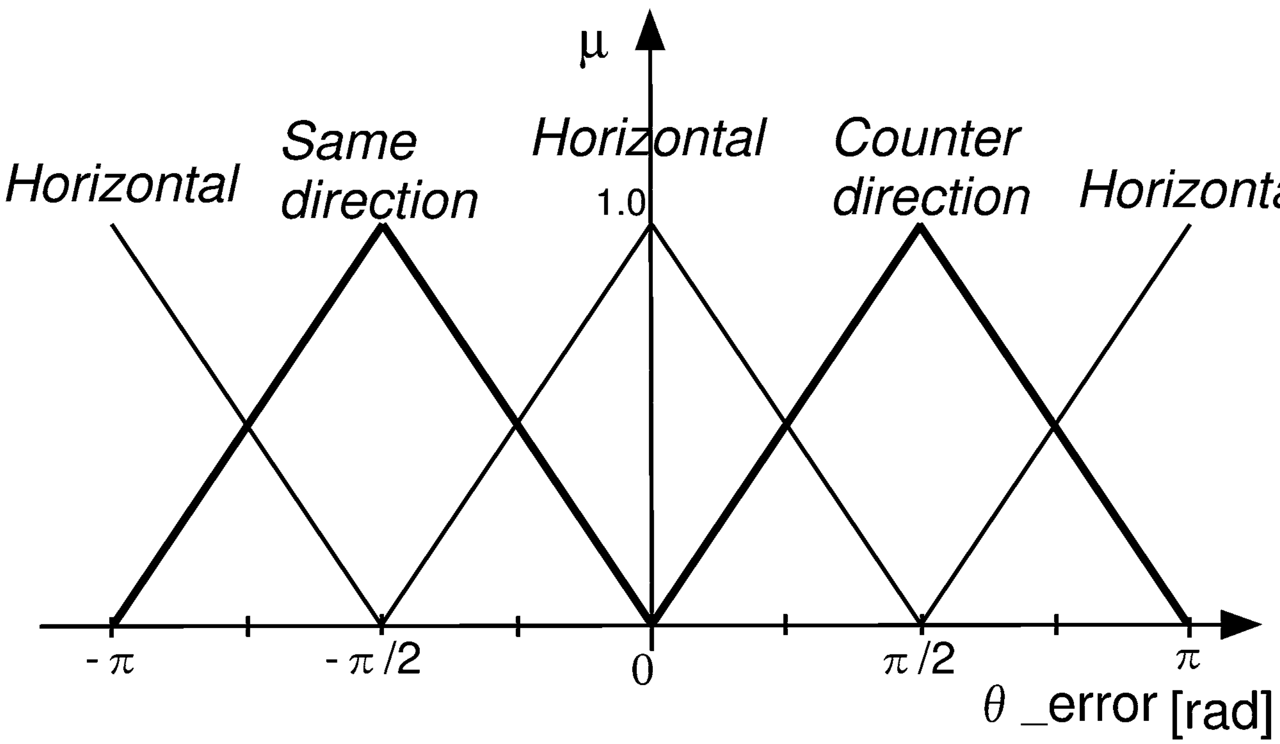

Figure 4: The fuzzy sets for the direction angle

IF X_error is *Very Far* AND θ_error is *About Horizontal*, THEN *Approach the parking lot.*
Rule 3:
IF X_error is *Far* AND θ_error is *Same or Counter direction to parking lot*, THEN *Change direction to Horizontal.*
Rule 4:
IF X_error is *Far* AND θ_error is *Horizontal*, THEN *Approach the parking lot.*
Rule 5:
IF X_error is *Near* AND θ_error is *Same or Counter direction to parking lot*, THEN *Change direction to Horizontal.*
Rule 6:
IF X_error is *Near* AND θ_error is *About Horizontal*, THEN *Enter the parking lot.*
Rule 7:
IF X_error is *Very Near* AND θ_error is *Same direction to parking lot*, THEN *Enter the parking lot.*
Rule 8:
IF X_error is *Very Near* AND θ_error is *Counter direction to parking lot*, THEN *Change direction to Horizontal.*
Rule 9:
IF X_error is *Very Near* AND θ_error is *Horizontal*, THEN *Approach the parking lot.*

Tactical target: the tactical target is needed in order to move the vehicle to reach the strategy target. Firstly, the vehicle is moved approaching the strategy target. Then, the vehicle is moved forward or backward to reach the strategy target. In order to achieve that condition, the tactical target as a stepping-stone is calculated using the equations according to rules applied for each condition. These equations are based on a rough characteristic of the vehicle which tracks the trajectory made using circle. In the rules, two variables are evaluated, one is error between the current state and the tactical target; the other is the direction error between the current state and the tactical target. Those linguistic variable are applied to infere the tactical target such as follows:

Rule 1: if *the distance is small* and *the direction is positive small*, then *approach target line in forward direction.*
Rule 2: if *the distance is small* and *the direction is negative small*, then *approach the target line in backward direction.*

⋮

Rule n: if *the distance is very small* and *the direction is very small*, then *tactical target is equal to final target.*

For example, when the strategy target is ((0,0), +90^o) and strategy target rule 1 is selected, the tactical target is calculated as follows:

Rule 1 :
IF X_error is *Small* AND θ_error is *Positive Small* THEN approach target line in forward direction (state_1).
state_1(see figure 5) is calculated using the equation belows:

$$\begin{aligned} x_1 &= \frac{1}{2}(x_0 + R(1 - \cos(e_0)) \\ y_1 &= y_0 + R(\sin(e_1) - \sin(e_0)) \\ e_1 &= \arccos(\frac{1 - \cos(e_0)}{2} - \frac{x_0}{2R}) \end{aligned} \tag{1}$$

Rule 2 :
IF X_error is *Small* AND θ_error is *Negative Small* THEN approach target line in backward direction (state_2).

⋮

Rule n :
IF X_error is *Very Small* AND θ_error is *Very Small* THEN Tactical target is equal to stratgy target.

Where,
(x_0, y_0) : current position,
(x_1, y_1) : calculated tactical target position,
e_0 : direction error between current state and final target,
e_1 : direction error between tactical target and final target,
R : minimum turning radius of the vehicle.

Automatic Driving Part by Predictive Fuzzy Control

The vehicle is controlled by predictive fuzzy control [5] described in figure 6.

The result of having executed two or more control instruction candidates was given beforehand from the current state prediction by integrating equation 2.

$$\begin{aligned} \frac{dx}{dt} &= v \cos\phi \cos\theta \\ \frac{dy}{dt} &= v \cos\phi \sin\theta \\ \frac{d\theta}{dt} &= \frac{v}{L} \sin\phi \end{aligned} \tag{2}$$

Where,
v is the speed of the vehicle,
θ is the direction of the vehicle,
ϕ is the steering angle,
L is length of the vehicle.

The result of the predicted error to the target and the distance to the obstacle is evaluated. The grade of control instruction candidates is determined by the value of error. The smallest error has the highest grade. The candidate that has highest grade is assumed to be the best control instruction for the current state. The vehicle is controlled according to these control instructions.

In this predictive fuzzy control method, the control based on human prediction can be achieved.

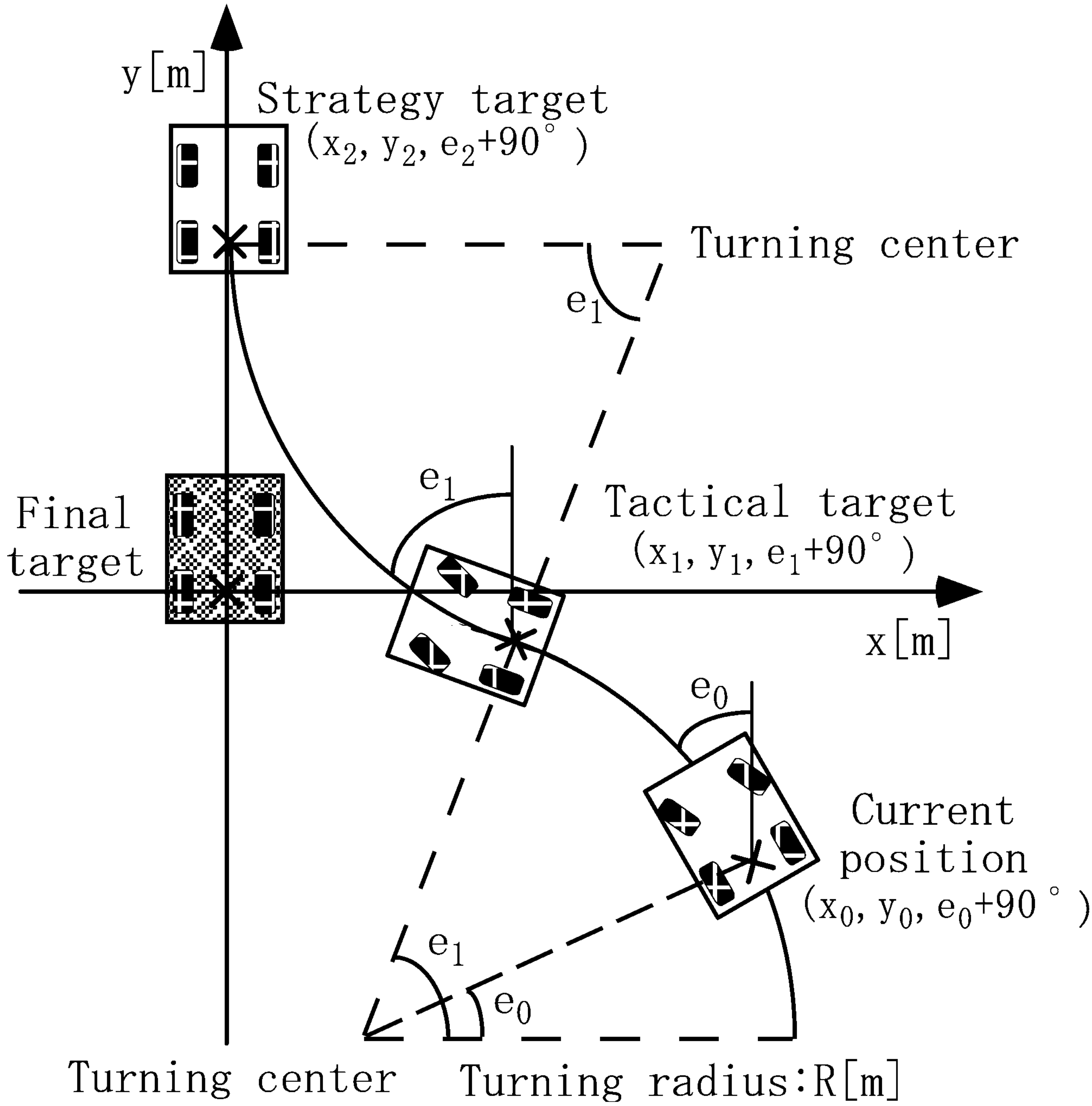

Figure 5: Strategy and tactical target

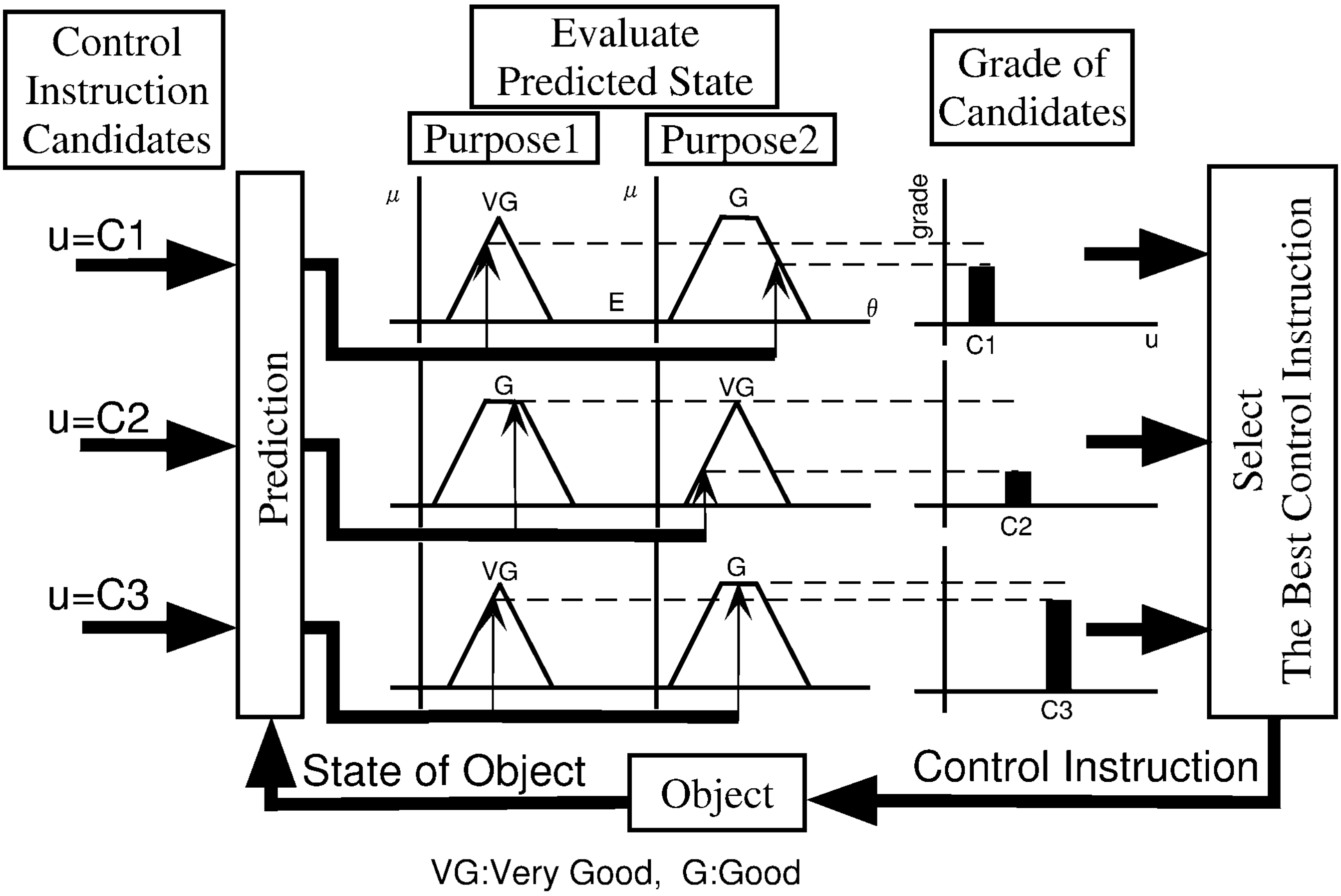

Figure 6: Predictive fuzzy control

4. SIMULATION RESULTS

The characteristic of the vehicle is described in table 1 and the coordinate of the parking site can be seen in figure 7.

Table 1: Characteristic of the vehicle

wheelbase	$2.6m$
distance between axis and bumper	$0.4m$
width	$1.7m$
smallest radius	$6m$
velocity	$0.4m/s$ (foward) $0.0m/s$ (stop) $-0.4m/s$ (backward)

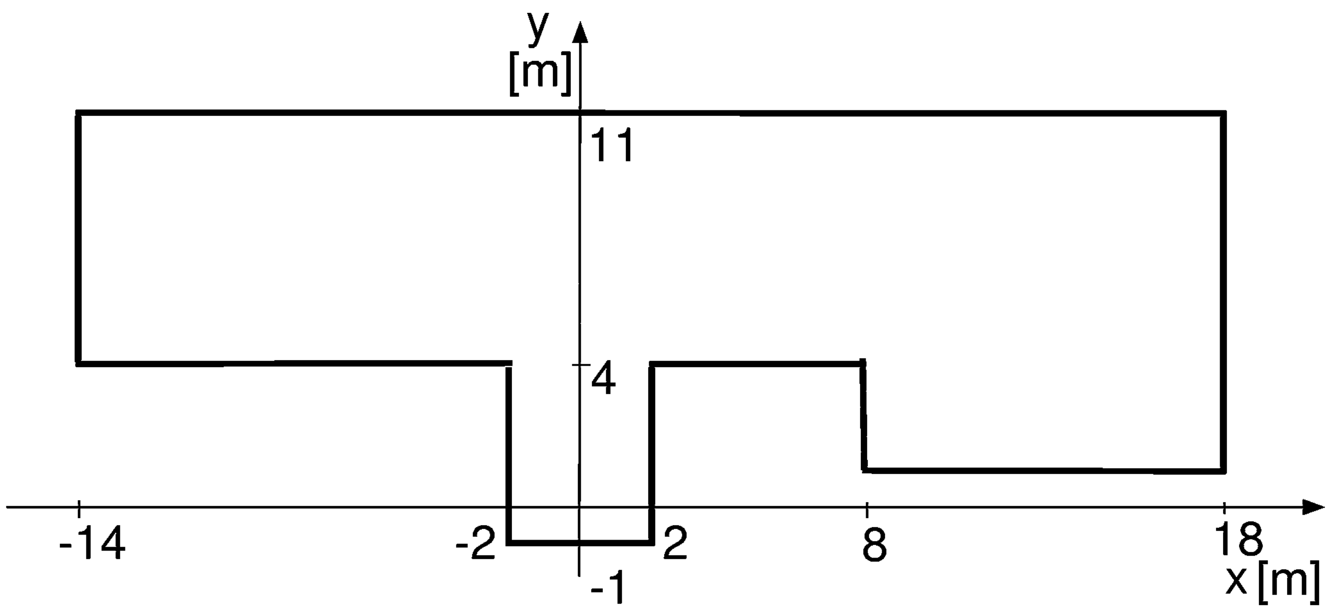

Figure 7: The parking coordinate

The simulation was carried out as follows. Firstly, the initial state is made by driving the vehicle randomly. After that, the intelligent control system start control the vehicle using strategy target and tactical target to reach the final target. The vehicle moved using predictive fuzzy control to reach tactical targets. In this simulation, the entire procedure to park a vehicle from initial state to go to the final target must be less then 200 seconds. If the system take more than 200 seconds to reach the final target, it is defined as failed. There are 1000 different initial states made in this simulation.

Initial state: this state is made by positioned the vehicle in the coordinate $(x, y) = (4, 8)$. Here, the direction of the vehicle was taken at random between 0.75π and 1.25π. After that, the control instruction (steering angle and velocity) is set at random. From this state, the vehicle is driven at random in 20 seconds. The control instruction is change randomly twice, but the velocity ($|V| \leq 1.0m/s$) has probability 20 % to be changed.

Simulation result: the proposed system can park a vehicle from many initial state. Take an example as can be seen in figure 8. In this case, the vehicle start from coordinate (11.83,7.93,-141.7) which is chosen randomly. After that, the strategy target is set to coordinat(5.56,6.00,180) which means change direction to horizontal. Using tactical targets which are calculated using equation (1), the vehicle reached the coordinate (2.47,5.88,180). Because this point is too advance, the vehicle need to make a counter direction by moving backward and reached the coordinate (5.47,5.94,-162.93). From this point, the coordinate (-2.297,7.43,141.83) is chosen as a strategy target. However, the vehicle reached the coordinate (-1.45,6.88,141.83). From here, the nearest point to the final target that can be achieved is (0.00,2.63,90). This point is considered as a final strategy target. Finally, the vehicle parked at coordinate (0.0,0.0,90) successfully.

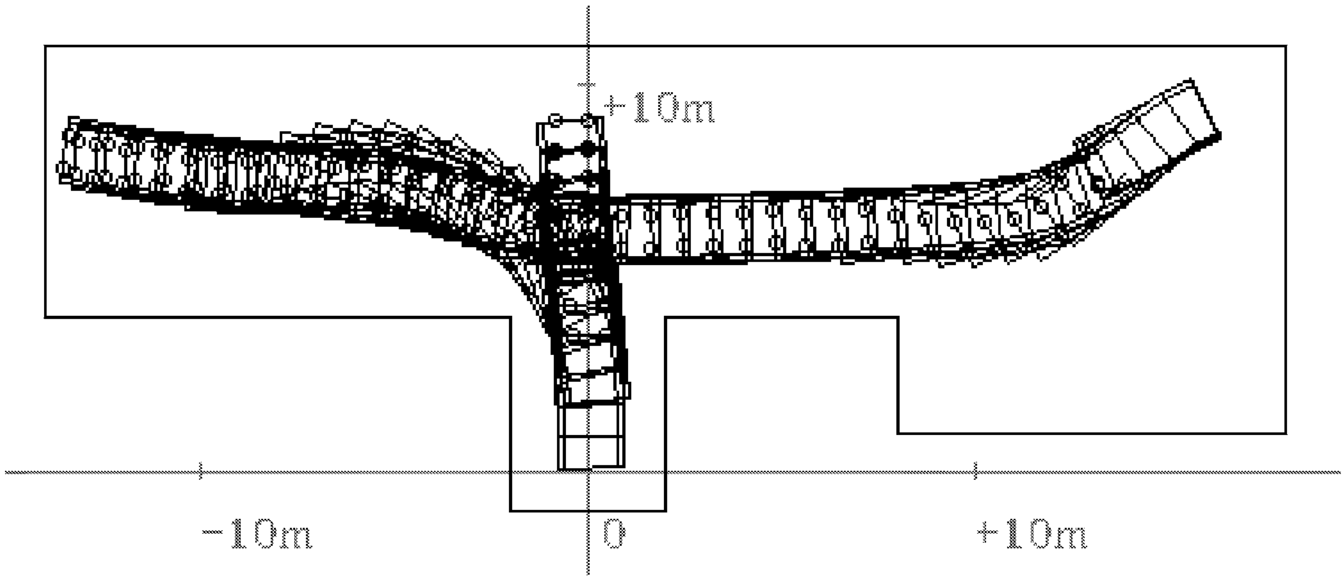

Figure 8: A trajectory of proposed system

The proposed system can park the vehicle from many different initial states. It is observed from the simulation that the system which only use tactical targets, the successful trials are 256 among 1000 trials. However, when the proposed system was done, the succeessful trials are 995 among 1000 trials.

It is demonstrated from this results that the proposed system achieved a flexible control system which is based on human control strategy. The effectiveness of the system based on human control strategy is confirmed.

5. CONCLUSION

The intelligent control system based on human control strategy was designed and applied to the parking control in a narrow area. This system consist of three parts: detector part, target setting part and automatic driving part. The target setting part which is based on human control strategy is a flexible target. In the automatic driving part, the predictive fuzzy control was used. The effectiveness of this system was shown by the simulation results.

In this paper, the vehicle was taken as an example of a non-linear system, and the effectiveness of the control system which used fuzzy control and human control strategies was confirmed.

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