

Intelligent Parking Support System for Four-wheeled Vehicles in Consideration of Human's Operation Error *

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Abstract – It is difficult for unskilled person to park four-wheeled vehicles, particularly when the movable area is restricted. Offering the information about the operation procedure can support their operation. Since human has large operation delay and an operation mistake, it was a problem that the indicated operation and his actual operation are disagreement. In this paper, even if an operation error exists, the system that can support operator safely and efficiently is developed. This system consists of three parts, 1) detect, 2) motion planning and 3) offer information. The support knowledge and heuristics of the high-level expert human are built in using the fuzzy theory. Effectiveness of this system is shown by the results of support experiment for human and simulation experiment using human's operational model. It is shown that this system can support human who has operation error (time constant 0.2 seconds, operation delay 0.7 seconds).

Keywords: Parking support, operation error, fuzzy inference, four-wheeled vehicle.

1 Introduction

Four-wheeled vehicles such as automobile are widely used as a daily movement means. However, it is difficult for unskilled person to operate them. That is because they have a non-holonomic characteristic that the direction of the movement is limited with kinematics constraints[1]. Particularly, when the movable area of vehicles is restricted, it is difficult to select for suitable operation according to that situation. Reducing the parking load is necessary.

There is a research of automatic parking control of the four-wheeled vehicle, which acquires parking knowledge by the method of reinforcement learning[2]. Sensor-based control architecture that realizes parking autonomously also has been proposed[3]. However, fully automatic drive has a serious problem that driver pay attention insufficiency and he feels discomfort.

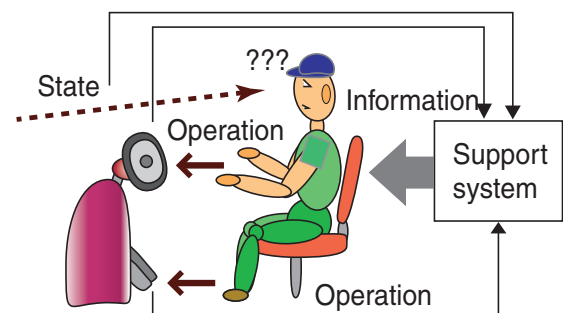


Figure 1: Concept of the operation support

For this reason, the operation of the vehicle carry to human, and the system which guides the operation has been developed. The intelligent parking support system for welfare vehicle offers the running support information by the voice[4][5]. This system has the problem that when the driver's operation delay and operation mistake are large, the support performance decreased remarkably.

In this paper, intelligent parking support system for four-wheeled vehicles that assumes the automobile is presented. The control system that considers the human's operation error is designed in consideration of large running speed. Safe and efficient support is achieved by building in the parking knowledge of the expert to plan motion, and setting the running target flexibly.

The flexibility for the human's operation error is evaluated by the experiment on parking support for human and the simulation using human's operation model.

2 Model of the Four-wheeled Vehicles

A four-wheeled vehicle is modeled as a rigid body moving on the plane. It has two rear wheels and two directional front wheels. The model of a four-wheeled vehicle is shown in Fig. 2. This is called the steer mechanism of *Ackerman* –

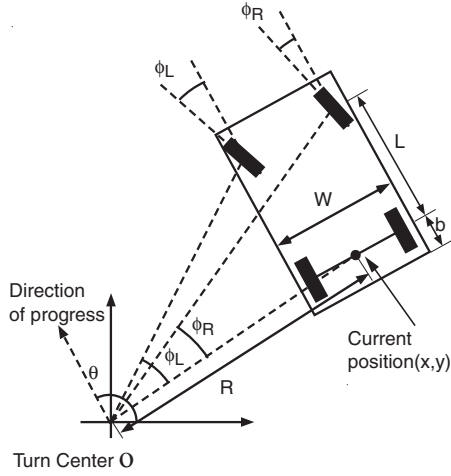


Figure 2: Model of a four-wheeled vehicle

Jeantaud. The motion of the vehicle is described by the following equations.

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

where ϕ is the steering angle, i.e., the average orientation of the two front wheels of the vehicle. v is the locomotion velocity of the front axle midpoint and L is the wheelbase. Since the steering angle of a car is mechanically limited, the following constraint also holds (*maximum curvature constraint*):

$$|\phi| \leq \phi_{max} \quad (2)$$

3 Human's Operation Error

The operation input of a four-wheeled vehicle has accelerator operation and steering operation. Supported person operates according to the offered support information. There is a difference between the operation that the support system planned, and the actual operation of him. This is called human's operation error and in this paper defines it as follows.

- Human's operation error =
Planned operation of the system – Actual operation of the human

3.1 Factor of operation error

Generally, the factors which generate human's operation error are as follows.

- Operation delay
- reaction time, operation time, offset

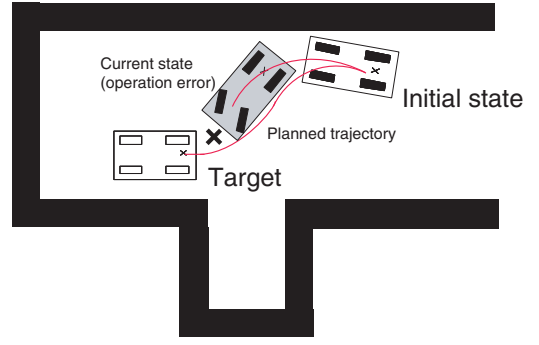


Figure 3: Effect of human's operation error

- Operation mistake
- Operation which was mistaken to the support information

The error of accelerator operation is generated by reaction time and operation time. The error of steering operation is generated according to the all factors of operation delay and operation mistake.

3.2 Effect of operation error

Operation error reduces the safety and efficiency of a support system greatly. Fig. 3 is a example that effect of human's operation error on control. A system forms the operation plan to reach the target by turning the steer to the left and moving forward. However, once steering operation is delayed by the operation error, vehicle's trajectory separates from the planned one and it is impossible to reach the target. In order to reach the target from this state, it is required to go back to the initial position or to carry out an additional counter steering.

Thus, when there is an operation error, it is difficult to carry out operation that follows the planned trajectory completely. Moreover, trajectory following by force requires sudden operation, and operator's burden comes to be very large.

From these reasons, in order to cope with an operation error, it is necessary to consider the running target itself rather than to follow the trajectory.

4 Parking Support of the Human

Following directions of a guidance member can easily complete parking, even if unskilled driver who has an operation error operate. From this, parking support of a guidance member is considered.

1. A guidance member observe surrounding circumstances, the situation of the vehicle and the situation of the operation (Detect).
2. A motion plan is mapped out based on experimental knowledge they have, and the target is set based on it (Motion planning).

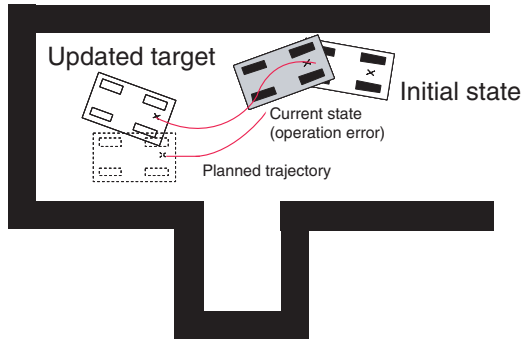


Figure 4: Flexible motion planning of the human

3. It thinks about the best operation to reach the target by predicting the state after a few seconds (Decision of operation candidate).
4. Once operation candidate is decided, the guidance member think about offer information according to the situation of the vehicle and the operation at that time (Decision the kind of offer information)
5. Information offered next is changed by the offer interval, the last offered information and the current operation, so the operator can receive it easily (Decision of support information).

To cope with operation error, human set up a running target flexibly according to the situation at Step 2. That is, even if operation has separated from the planned one, by setting up a suitable control target each time, safe and efficient support which reduce the burden of operation can be realized (Fig. 4).

5 Intelligent Parking Support System

5.1 System Configuration

Intelligent parking support system based on the Chapter 4 is shown in Fig 5. This system consists of the three parts, 1) detector part, 2) motion planning part and 3) offer support information part. By using the fuzzy inference in each part, the inference rule can be made based on human's linguistic knowledge, and a multipurpose evaluation can be done. Flexible language information can be offered by using information that is obtained during the inference. Hereafter, it explains the function of each part respectively.

5.2 Detector Part

In the detector part, the attainment to the target set in the motion planning part and the contact to the obstacle are observed, and it is judged whether a new target is necessary.

5.3 Motion Planning Part

In the motion planning part, a running target is set up in consideration of the characteristic of the four-wheeled vehicle. The set up target needs to satisfy three conditions,

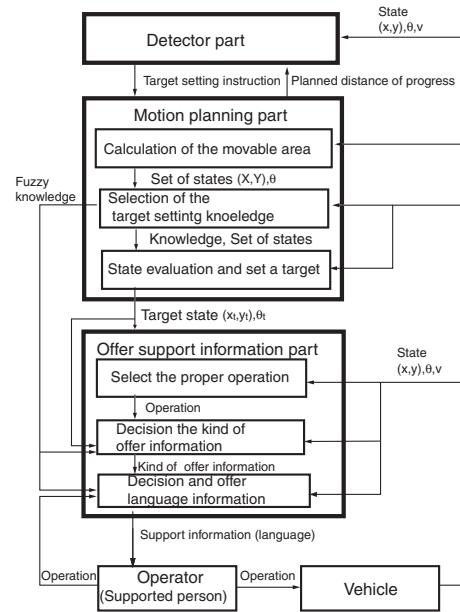


Figure 5: Configuration of intelligent parking support system

Kinematic constraints, Dynamic constraints and No collision constraints. Setting up and changing the target properly as follows can flexibly cope with human's operation error.

Firstly, since human has regarded the target state as a thing with the degree, target setting knowledge (multi-dimension space (x, y, θ) and evaluation value (μ)) is described using the fuzzy set. The knowledge used for parking of human is six, A:"go horizontal", B:"near to the garage", C:"move to a counter steering point", D:"parallel translation", E:"(directly) put into the garage", and F:"control end" (Fig.6). The target is set up using this target setting knowledge.

5.3.1 Calculation of the movable area

In calculation of the movable area, some kinds of steering angles are assumed from the current car state, and the states of the vehicle within several seconds ago (X, Y, θ) are computed using the vehicle model.

5.3.2 Select the target setting knowledge

In select the target setting knowledge, a suitable knowledge is chosen out of the target setting knowledge of A, B, C, D and E that is defined beforehand (Fig. 6).

5.3.3 State evaluation and set a target

In state evaluation and set a target, the decided target setting knowledge and the computed states of movable area are used. If there is a state where the evaluation value is higher than current target, it is updated as a new running target (Fig. 7).

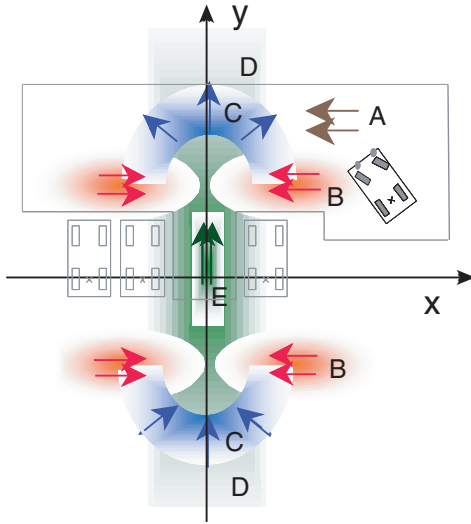


Figure 6: Fuzzy knowledge used for target setting

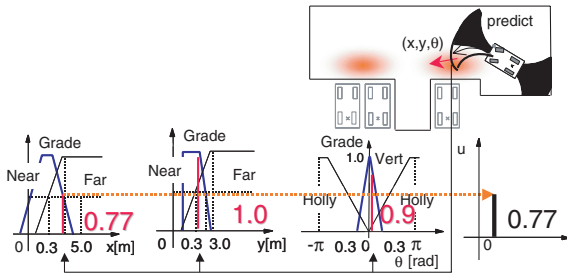


Figure 7: Example of target candidate evaluation "near to the garage"

5.4 Offer Support Information Part

5.4.1 Select the proper operation

In select the proper operation, a predictive fuzzy control is used[6]. The predicted result of each operation candidate (error margin with the target, distance with obstacle) is evaluated from fuzzy multipurpose evaluation, and the operation of the highest evaluation is output.

5.4.2 Decision the kind of offer information

In decision the kind of offer information, the information is decided by a multipurpose fuzzy inference based on the human's knowledge of "if it is this situation at these intervals, it seems to have to offer such information".

The kind of offer information is classified into seven kinds "Don't offer it", "Steering wheel control", "Progress of direction", "The steering wheel is straight", "Attention" and "Stop". . 8.

5.4.3 Decision the offer language information

Offer language information is decided according to the kind of support information and the best operation. Decided support information is offered to the driver by the voice.

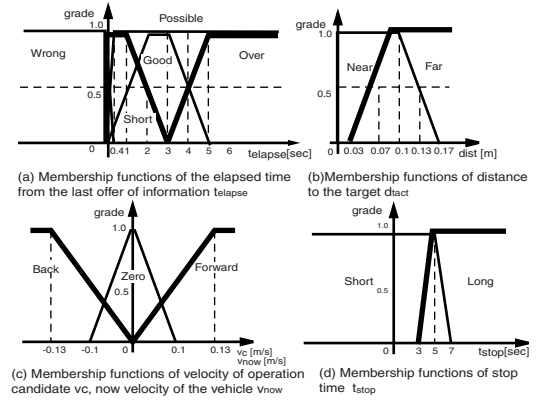


Figure 8: Fuzzy sets used for deciding the kind of information

Offered information is following seven kinds of information.

- Do not offer information
There is no offered information.
- Steering wheel operation
"Return a little", "In addition, right" etc.
- Progress of direction
"Go" and "Back".
- Parking knowledge
"Move to a counter steering point", "(Directly) Enter the parking lot" etc.
- Operation procedure
"Steer right a little and advance" etc.
- Attention "Attention to backward" etc.
- Stop "Stop".

6 Experiment

6.1 Support experiment for human

In order to check up the effectiveness of this support to the human, the experiment which used the game handle controller is conducted (Fig. 9). Support information is offered by sound and the operator is instructed to operate according to that information. Specification of the vehicle in this experiment is shown in Table 1. States of the vehicle ($x[m]$, $y[m]$, $\theta[rad]$) in this experiment is shown next.

- Initial state (12.35, 3.00, 2.34)
- Final target (0.0, $-0.5, \pi/2$)

In this experiment, three trials were carried out on the same conditions. Result of the support experiment is shown in Table 2. About 30 pieces of information is offered, and about 90 sec are spent to complete parking. Fig. 10 is the motion of the vehicle at trial 1. It is having drawn in the state of the vehicle from the support beginning to the parking completion at intervals of 1.5 sec. From these results, the operator was able to park safely and efficiently according to support information. Moreover, even when visual infor-



Figure 9: Support experiment with game handle controller

mation is not given, the operator was also able to complete parking easily.

Offered information in trial 1 is shown below. .

<START (0.0s)>
 "once left and go", "keep", "stop"(9.5s), "keep and go",
 "center", "right a little", "center", "right a little", "keep",
 "center", "stop"(30.5s), "right a little and back", "keep", "re-
 turn a little", "center", "stop"(43.0s), "right a little and go",
 "stop"(48.7s), "keep and go", "stop"(56.0s), "canter and go",
 "keep", "stop"(65.0s), "canter and back", "canter", "keep",
 "stop"(77.5s), "go", "keep", "center", "stop".
 <FINISH (86.2s)>

Table 1: Specification of the vehicle

length	wheelbase	width
4.30m	2.60m	1.70m
velocity	minimum radius of rotation	
0.80m/s	4.90m	

Table 2: Result of the support experiment

	Trial 1	Trial 2	Trial 3
Parking time [sec]	86.2	96.7	83.3
Pieces of offered in-formation	31	33	30
Target setting times	11	13	15

6.2 Quantitative evaluation by simulation

To evaluate support performance quantitatively, human's operation error (steering operation and accelerator operation) is approximated by the model and simulation of parking support is done. When support information is offered, the model

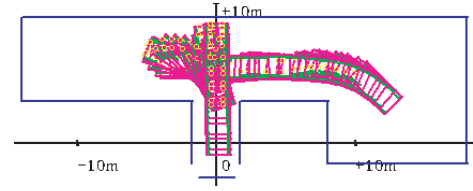


Figure 10: Motion of the vehicle at trial 1.

outputs an operation input and controls the vehicle instead of human. Human's characteristic of response to the information can be approximated by "first delay (time delay τ + time constant T)". Where, the amount of control reference is set to u_i to the kind of information i , human's operation is approximated by the following formula (3).

$$h_i = \frac{1}{1 + T_s} e^{-\tau s} u_i \quad (3)$$

It is found that a driver behavior model in emergency situations has the parameters that τ is about 0.7sec and T is about 0.2sec [7]. Then, the time constant T was made to increase by every 0.1 sec, and it investigated that how long the size of delay time τ could be supportable. The amount of control reference is set into speed $u_v = \pm 0.3m/s$ ("go", "back") and steering angle $u_{str} = \{-0.699, -0.350, -0.214, 0.0, 0.214, 0.350, 0.699\}$ (rad) ("fully left", "left", "left a little", "center", "right a little", "right", "fully right") to that support information. Initial state and final target is same as paragraph 2.1. The distribution of supportable parameters T and τ that satisfy following two conditions, 1) Not collide with a wall and 2) Parking is completed within 200 sec, is shown in Fig. 11.

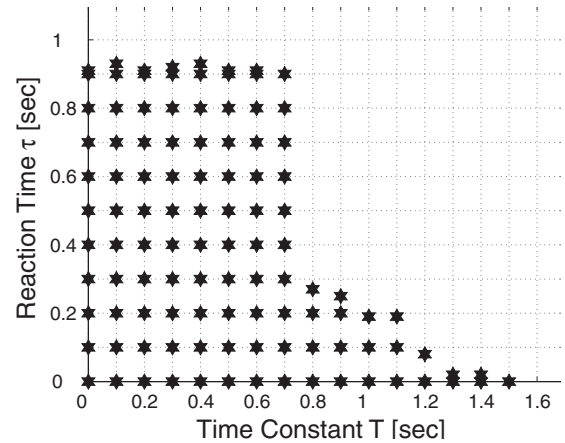


Figure 11: Distribution of supportable operation model parameters

From the simulation result, it finds that the time constant is bigger, the supportable delay time is shorter. At the time velocity: $\pm 0.3m/s$, this system can be support satisfactory at the time constant of 0.2 sec, and the delay time of 0.7 sec.

When the speed of vehicles is smaller, it is possible to cope with larger constant time and time delay.

7 Conclusions

In this paper, intelligent parking support system for four-wheeled vehicles that assume the automobile is developed. In order to cope with human's operation error, the system is considered to human's parking support. Target setting knowledge is embedded into the motion planning part, and flexible target setting like human is enabled.

From the experiment of the operation support for human, it is shown that the developed system can do the safe and efficient support. Furthermore, from the simulation using human's operation model, it is shown that this system can support human who has the operation delay of 0.2sec and time delay of 0.7sec sufficiently.

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