Intelligent Auto-Driving System for a Four-wheeled Electric Cart

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***Abstract*— A four-wheeled electric cart is used as transportation for senior citizens and physically handicapped persons. However, driving operations are difficult for user because of the dynamic characteristic of the four-wheeled vehicle. Therefore, an auto-driving system is effective to support them. Such the system should be able to treat at ease without an unpleasantness for user. In this paper, we propose and develop an auto-driving system that drives flexibly to user's destination by predictive fuzzy controller using human's operation knowledge of a four-wheeled vehicle. The result of experiments shows the effectiveness of the system.**

I. Introduction

A four-wheeled electric vehicle is sold as transportation for senior citizens and physically handicapped persons. Skill and knowledge such as counter-steering are required to drive those vehicles because of the non-holonomical dynamic characteristic of the vehicle [1]. Furthermore, driving operation is tiresome and stressful for users to whom eyesight and muscular power failed.

Thus, an auto-driving system is effective to support them. Such the system should be able to treat without difficulty in consideration of human's riding on the vehicle.

Meanwhile, we developed the intelligent driving system [2] based on human's operation knowledge of the four-wheeled vehicle. This system is based on human's operation knowledge of the four-wheeled vehicle, and able to drive flexibly to a target in various situations. Additionally, a user is able to use the system at ease because the behavior of the system is able to be understood.

In this paper, we develop the auto-driving system by using a four-wheeled electric vehicle on the market, and confirm its effectiveness in experiments.

II. System Configuration

Fig.1 shows the composition of the proposed system. This system is configured by two personal computers (the intelligent controller and the user interface computer), a camera that is set in front of the cart, and a touch panel for setting gates (sub goals).

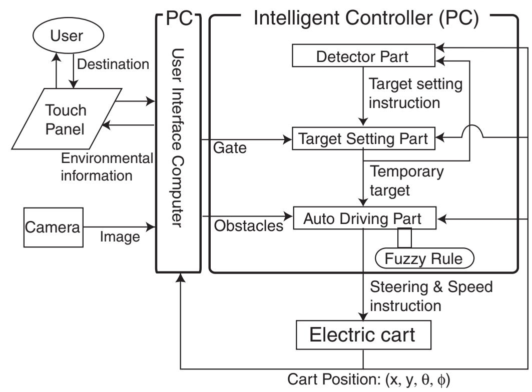

Fig. 1. System configuration.

A. Model of the four-wheeled vehicle

Fig.2 shows the model of four-wheeled vehicle. Slipping of the tire and the generating of the centrifugal force can be disregarded when the speed is very slow in the four-wheeled vehicle of the front wheel steer. As a result, the vehicle does turn movement to turn center O that is on the extension line at the center of each wheel. Parameters of the vehicle are as follows:

(x,y)	: Vehicle's position(Coordinates in the middle of rear wheel)
θ	: Vehicle's angle(angle of direction of progress to x axis)
ϕ	: Steering angle(Average of right and left front wheel steering angle)
L	: Wheelbase
v	: Average speed of front wheel
ω	: Rotational speed of front wheel
R	: Minimum-turning radius

At this time, the equation of motion when turning with the steer mechanism of $Ackerman - Jeantaud$ becomes as follows:

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

The steer angle ϕ and speed v are kept constant. Therefore, the future position (x_t, y_t, θ_t) after t second to current position (x_0, y_0, θ_0) is calculated as follows:

$$\begin{aligned}x_t &= \frac{L}{tan(\phi)}cos(kt) + x_0\\ y_t &= \frac{L}{tan(\phi)}sin(kt) + y_0\\ \theta_t &= kt + \theta_0\\ k &\equiv \frac{v \cdot cos(\phi)tan(\phi)}{L}\end{aligned}$$

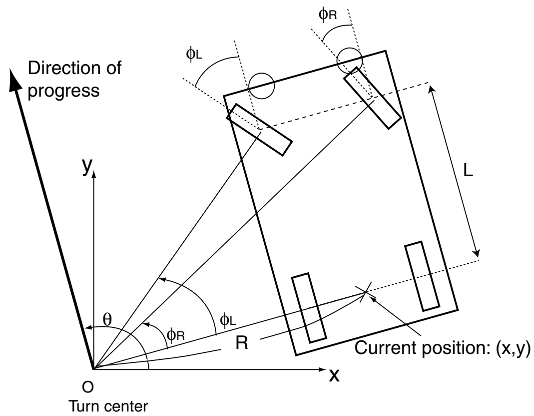

Fig. 2. Model of a four-wheeled vehicle.

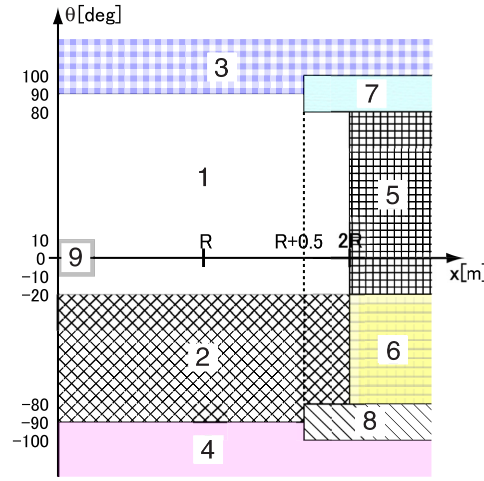

Fig. 3. Area segmentation of $x-\theta$ plane.

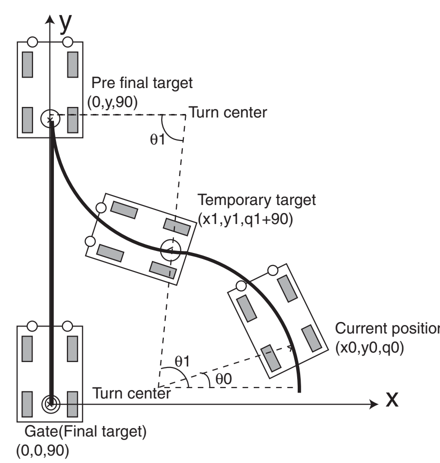

Fig. 4. Example of calculation of a target.

B. Intelligent controller

Intelligent controller is hierarchical fuzzy controller based on human's driving algorithm. This controller is constructed by the detector part, the target setting part, and the auto-driving part.

1) Detector part: One function of the detector part is detecting the current state of the vehicle and obstacle. Another is to observe how the vehicle advance toward a target set in the target setting part. The target setting instruction is sent to the target setting part if the vehicle reaches a target.

2) Target setting part: Input of the target setting part is a target setting instruction from the detector part. This part calculates a temporary target to the final target (provided from a user) by using target setting algorithm that considers the characteristic of a four-wheeled vehicle, and outputs the target to the auto-driving part.

A final target is defined as $(0m, 0m, 90deg)$ at the vehicle's current position (x_0, y_0, θ_0). Similarly, a pre-final target is defined as $(0, y, 90)$ that can reach by the operation of steering angle $\phi = 0[deg]$. A temporary target (x_1, y_1, θ_1) is calculated by using fuzzy rules about the segmentation area1-9 (x-θ area in Fig.3) that consists of x coordinate at vehicle's current position (x_0, y_0, θ_0) and error of the angle in the final target $(0, 0, 90)$. These rules are treated for $x \geq 0$. Whereas, these rules are able to be treated for $x < 0$ by making symmetry for θaxis in Fig.3.

Area 1:
: If x is small and the direction turns to inside, then the temporary target is (x_1,y_1,θ_1) calculated by equation(1) and the speed instruction is to advance by operation of counter steering.

Area 2:
: If x is small and the direction turns to outside, then the temporary target is (x_1,y_1,θ_1) calculated by equation(1) and the speed instruction is to retreat by operation of counter steering.

Area 3:
: If the direction largely turns to inside, then the temporary target is (x_1,y_1,180) and the speed instruction is to advance by operation of steering wheel to the maximum right.

Area 4:
: If the direction largely turns to outside, then the temporary target is (x_1,y_1,180) and the speed instruction is to retreat by operation of steering wheel to the maximum left.

Area 5:
: If x is very large and the direction turns to inside, then the temporary target is (R,y_1,180) and the speed instruction is to advance by operation of steering wheel to the maximum left.

Area 6:
: If x is very large and the direction turns to outside, then the temporary target is (R,y_1,180) and the speed instruction is to retreat by operation of steering wheel to the maximum right.

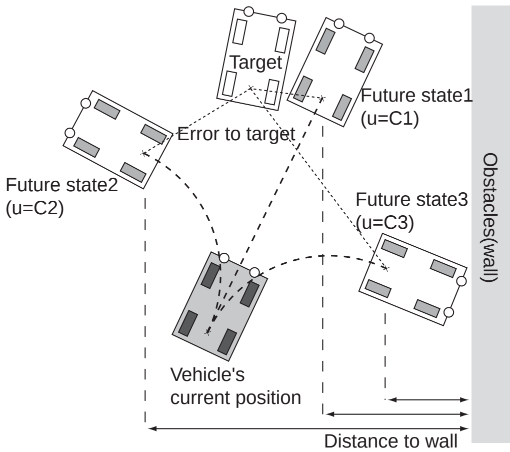

Fig. 5. Operation candidates with prediction.

Area 7:

If x is very large and the direction turns to inside by about 90°, then the temporary target is (R,y_1,90) and the speed instruction is to advance by operation of steering wheel to the straight.

Area 8:

If x is very large and the direction turns to outside by about 90°, then the temporary target is (R,y_1,-90) and the speed instruction is to retreat by operation of steering wheel to the straight.

Area 9:

If x is very small and the direction turns to the front, then the speed instruction is to advance(or retreat) toward the final target.

$$
\begin{aligned}
x_1 &= \frac{1-\cos(\theta_0)}{2}R + \frac{x_0}{2} \\
y_1 &= y_0 + R\{\sin(\theta_1) - \sin(\theta_0)\} \\
\theta_1 &= \cos^{-1}\left(\frac{1+\cos(\theta_0)}{2} - \frac{x_0}{2R}\right)
\end{aligned}
\quad (1)
$$

$$
\begin{aligned}
x_2 &= 0 \\
y_2 &= y_0 + R\{2\sin(\theta_1) - \sin(\theta_0)\} \\
\theta_2 &= 0
\end{aligned}
\quad (2)
$$

3) Auto-driving part: Input of the auto-driving part is a target from the target setting part. Outputs of this part are vehicle's control instruction that is selected by predictive fuzzy control[3] at intervals of 0.1 seconds. The most appropriate steering wheel operation is decided by the predictive fuzzy control. Firstly, attainment forecast time $t(s)$ is calculated by dividing the distance from current position to the target by a velocity candidate. Secondarily, the future state of the vehicle shown in Fig.5 is predicted from integration of vehicle's differential equation by assuming that operation candidates $C_i (i = 1 \cdots n)$ was operated during the t seconds. Thirdly, future states are evaluated by multipurpose fuzzy evaluation (Fig.6) using fuzzy inference with fuzzy set that use membership function of *Good* and *VeryGood*, to accomplish the purpose such as attainment to the target and distance to obstacles. Finally, the operation candidate of highest evaluation is selected as control instruction of steering wheel.

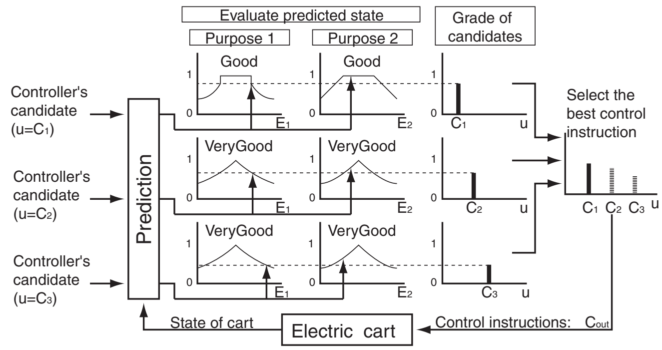

Fig. 6. Overview of predictive fuzzy control.

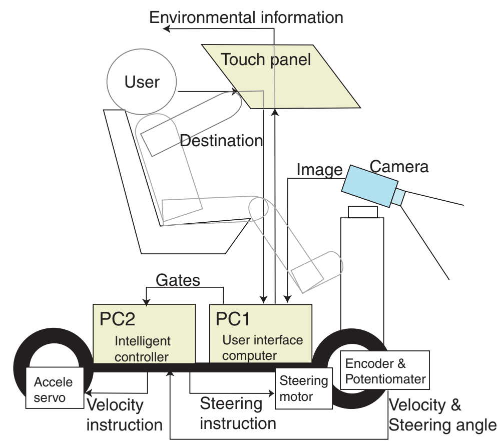

Fig. 7. Hardware construction of the system.

C. User interface

The user interface controller provides the intelligent controller with gates (sub goals) to reach the destination that is specified by a user. Information on gates to the destination[4] had already been provided for the user interface controller, or set from the map on the touch panel display by operation of user.

III. Experiment

A. Hardware

The hardware construction of the system is shown in Fig.7. Table 1 shows the spec of the four-wheeled vehicle "Shoprider" (Pihsiang Machinery Mfg Co., Ltd.) that is base of proposed system. This experiment uses the vehicle that equips personal computers, a camera, a touch panel, and sensors (encoder and potentiometer) to detect the vehicle's position. Fig.8 shows overview of developed system.

TABLE I

SPEC OF THE FOUR-WHEELED VEHICLE

wheelbase		0.80m
tirewidth		0.435m
smallest radius		0.95m
steering angle		50.0deg
velocity	forward	0.35m/s
	stop	0.0m/s
	backforward	-0.19m/s

Fig. 8. Developed system and vehicle.

B. Contents of experiment

The content of experiment is auto-driving from point A(-4m,0m,0deg) to point B(-3m,-5m,0deg) under the environment shown in Fig.9. Gate1, Gate2, and Gate3 (in the Fig.9 and Table 2) are sub goals set by using the touch panel from the user while driving.

TABLE II

GATES COORDINATES IN THE EXPERIMENT

Gate 1	(0.0m,-1.8m,-87deg)
Gate 2	(-0.9m,-4.3m,-91deg)
Gate 3	(-2.2m,-5.6m,9deg)

C. Result of experiment

Fig.10 shows the result of auto-driving by proposed system. At the point A(-4m,0m,0deg), the system drove automatically to the Gate 1 that is set by the user. After the system reached Gate1, it drove to Gate2. Similarly, after the system reached Gate2, it drove to Gate3, and reached near point B of the destination. In particular, the case of the auto-driving from Gate 2 to Gate 3, the system advanced forward for counter steering operation, because the system detected the obstacle. Afterwards, it reached the target by the retreat. In this experiment, gates were provided one by one while auto-driving. In addition, it is possible to provide gates to the system as sets of sub goals of the destination at a time.

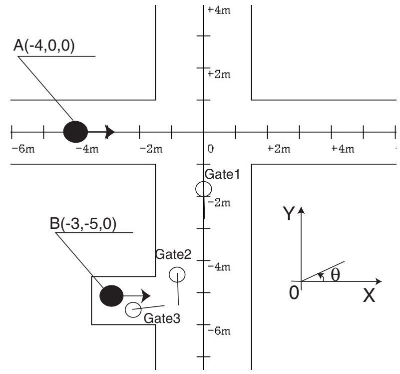

Fig. 9. Environment of experiment.

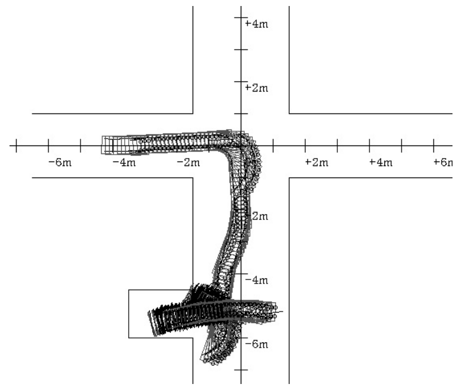

Fig. 10. Result of experiment.

IV. CONCLUSION

In this paper, we developed an intelligent auto-driving system for a four-wheeled electric vehicle on the market. This system sets a target by using human's operation knowledge of the vehicle, and drives to the target by using predictive fuzzy control. From results of experiment, it was confirmed that the system was able to drive to the target in consideration of the vehicle characteristics by using flexible operation such as counter steering. Users are able to understand system's behavior and use the system while relaxing, because this system is based on human knowledge. Therefore, the system is effective for users to reduce stress of driving operation.

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