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Autonomous Deceleration Behavior Model using Multi-Mode Driver Behavior Model based on a Hybrid Dynamical System

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ABSTRACT

This paper presents the multi-mode model of the human driving behavior based on the hybrid dynamical system. We conducted the experiment to collect driving profiles for obtaining the driver behavior model. We have to construct models which considered regenerative brake effectiveness because COMS, that is the experimental vehicle, has that system. The driver behavior model identifying problem was solved by using the data clustering technique and the linear approximation method. The autonomous braking system experiments were performed by the derived driver behavior model. As the results, it has been found that the actual driving behavior and the autonomous driving behavior agree well with each other.

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INTRODUCTION

Recently, although the number of automobiles casualties and traffic accidents has decreased due to advances in various safety technologies, it still remains as a major social problem. As one of the solutions for these problems, autonomous vehicle has been great attracting attention and many researches have been carried out all over the world. However, there are few studies about the driver’s comfort on autonomous vehicle based on the autonomous motion control system. We have proposed a technique to design a motion control system for autonomous vehicle by using driving behavior model identification method based on the hybrid dynamical system (S. Miura. *et al*, 2009). However, the modeling accuracy of the proposed driving behavior model was low, because this driving behavior model was designed with only one action mode. Moreover, because the regenerative brake system on the electric car used in our study operates too hard and the rapid deceleration operation is performed regardless of driver’s intention, we cannot apply the previous driver model as it is.

In this paper, we propose a multi-mode model of driving behavior that can achieve more similar performance to the driver’s driving behavior. We show the results of the verification experiments for the stopping operation by using a autonomous vehicle with the new driving behavior model.

MATERIAL AND METHODS

Experimental Autonomous Vehicle:

Autonomous vehicle is made by modifying the single-seater electric vehicle COMS, shown in Fig. 1. To obtain driving profiles, we attached encoders in the left and right rear wheels and an acceleration sensor under a seat. We also attached the operation amount detecting sensor at the steering wheel, the gas pedal and the brake to enable to collect driver’s driving profiles. We can control the vehicle by the PC with the actuators which used in autonomous driving on steering wheel and brake. There are the PC, the PLC, the AC-DC converter and the UPS in the trunk.

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Fig. 1: Outside view of experimental vehicle

Experimental Conditions:

In order to model the driver's braking operation, we used the experimental autonomous vehicle as a probe car. We had conducted the experiments of the stopping operation against stop line to collect driving profiles. At first, the subject accelerates the vehicle to the 30 (m) away from the starting point. Then, the operator shows the stop position when the vehicle has reached the halfway point. Finally, the subject makes a stop in any one of the stopping point at 15.0, 17.5 and 20.0 (m) away from there. The experiment was conducted under two conditions. The target speed of the vehicle was 15 and 25 (km/h). There were four subjects in this experiment.

Identification of Driver Deceleration Behavior Model:

Within the regenerative braking time, both gas pedal and brake should not be operated. This time is referred to as the operation mode 0. In this mode, the control output is set to 0 and the controller only switches the operating mode to the next mode. In the case of brake operation time, the hierarchical cluster analysis method (H. Okuda. *et al*, 2008) was used to determine the number of operating modes. As results, we decided that the number of the driving mode was 2 in the braking operation time.

Based on the hybrid dynamical system, we derive the driver deceleration behavior model that consists of the decision making part and the operating mode part. At first, we identify the decision making model to switch the modes by using the vehicle velocity v (km/h) and distance to the stop line x (m). A linear approximation method is used for derivation of this condition, and the conditional expression of decelerating determination is following:

$$\alpha v + \beta x + \gamma > 0 \tag{1}$$

where α is a coefficient of the vehicle velocity, β is a coefficient of the distance to the stop line, and γ is a constant term. Each parameter of the model switching determination of deceleration of subject D is derived as shown in Table 1.

Table 1: Switching decision of decelerate action model parameters (subject D)

Decision	α	β	γ
0	1.0000	-1.5422	-2.7501
0-1	1.0000	-1.7590	-4.3011
1-2	1.0000	-4.1438	-0.2359

Then, identify the brake operation model by braking operation output u, distance to the stop line x (m), the vehicle velocity v (km/h) and the acceleration $\dot{v}$ (g). By using the least squares method, each operation model is derived as the following equation.

$$u = ax + bv + c\dot{v} + d \tag{2}$$

Where a is the distance to the stop line's coefficient, b is the velocity's, c is the acceleration's, and d is the constant term. Parameters for each operating mode of the subject D were obtained as shown in Table 2.

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Table 2: Decelerate action model parameters (subject D)

Velocity	Mode	*a*	*b*	*c*	*d*
15km/h	0	0	0	0	0
	1	-6.8340	4.5121	-0.0444	-0.0004
	2	-4.6167	-1.5628	-0.3023	0.7335
25km/h	0	0	0	0	0
	1	0.3296	-0.4694	-0.9451	0.0127
	2	1.4599	-1.8496	-0.4727	0.7028

We performed an evaluation of the brake operation section by comparing its dual-partitioning model and its undivided model using mean squared error between the measured value and the model output, and the results are shown in Table 3. From this result, we found that using dual-partitioning model enable us to reduce error against measured value more efficiently than the other model.

Table 3: Average error between measured values and model output values

Velocity	Partition	Error
15km/h	1	0.0938
	2	0.0527
25km/h	1	0.0703
	2	0.0609

RESULT AND DISCUSSION

Autonomous Control Experiment:

After incorporating derived deceleration behavior model to vehicle dynamics control system, we have conducted a stopping experiment against the stop line by automatic braking system. In Fig. 2, the brake operation amount and vehicle velocity which obtained by the automatic stop experiments under the circumstances of the own vehicle speed of 25(km/h), and also the actual braking operation of the driver and vehicle velocity which used in the model identification are shown. In the Fig., the horizontal axis shows the distance to the stop line (m), the vertical axes shows the velocity (km/h), the acceleration (g) and the amount of brake operation. Also, the blue line represents the behavior of actual braking operation and black, red and green lines represent automatic brake operation. The mode 0 is the regenerative braking section, and the mode 1 and the mode 2 are the driver operation section. The vertical dashed line shows the switching timing of the operation mode which switched by the driver behavior model. As a result, the brake operation by the driver and the brake operation by the automatic braking system are similar, and we can verify the possibility that the derived deceleration behavior model enables the vehicle to realize a similar behavior to the driver's stop.

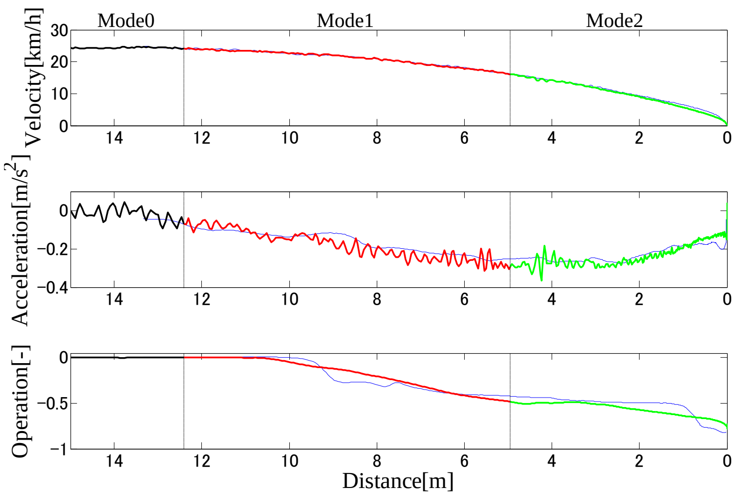

Fig. 2: Experimental result (25km/h)

Conclusion:

We can conclude the purpose of realization of the vehicle motion control system which performs similar driving behavior to the driver, we propose to construct a driving behavior model of a multi-mode structure. Furthermore, we have verified that it is able to perform similar operation to a human brake operation. For the future, it is necessary that we evaluate the confirm using subjective and objective assessment, and then comparative evaluation must be done between the conventional model and its result.

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