Evaluation of Driver Characteristics According to Running Condition Using Driver Model

Ryuta ISHIZAKI*[1], Kazuhiro MORIHARA*[1], and Taichi SHIIBA*[1]
*1 Department of Mechanical Engineering, Meiji University
1-1-1 Higashi-Mita, Tama-ku, Kawasaki 214-8571, JAPAN
ee03088@meiji.ac.jp, ee03158@meiji.ac.jp, shiiba@isc.meiji.ac.jp

Abstract
The aim of this study is to evaluate the driver characteristics according to the running conditions by using a driver model. In order to examine the characteristics of the operation of drivers, the second order prediction model was used as a driver model in this study. For this purpose, we developed a driving simulator. The single lane change tests were conducted to identify the parameters of the second order prediction model. From these tests results, the relationship between the driver characteristics and the running conditions was investigated.
Keywords: driver characteristics, driver model, driving simulator, parameter identification, lane changes

1 Introduction
The characteristics of the operation of a driver depend on running conditions, and it is important to understand the relationship between the operation of a driver and running conditions. As a method to evaluate the characteristics of the operation of a driver, various kinds of driver models have been proposed. In previous research, Sheridan [1] modelled the operation of the driver emphasizing and recognizing a key property of human drivers as looking ahead. Kondo [2] proposed a driver model focusing on measuring the driver sight-point ahead of the vehicle and developed a steering model based on deviations between the sight point and the desired path. Yoshimoto [3] also included the function of the preview among a part of a steering algorithm. These driver models are represented as the transfer function, and require the identification of the parameters according to the running condition in order to imitate the operation of the driver.

In this study, the authors evaluated the driver characteristics according to the running conditions by using a driver model. In order to examine the characteristics of the driving operation, the second order prediction model was used as the driver model. For this purpose, we developed a driving simulator shown in **Fig. 1**. The single lane change tests were conducted to identify the parameters of the second order prediction model. From the results of these tests, the characteristics of the operation of the driver were investigated.

2 Driver model
Various types of driver models have been proposed for the description of the driver characteristics. The concept of the driver model is shown in **Fig. 2**. In this figure, $H(s)$ corresponds to the behavior of a driver to compensate the deviation of the lateral position of the vehicle, $B(s)$ is the function of feedback control by the driver, and $G(s)$ is the transfer function of the vehicle. The parts of the function $H(s)$ and $B(s)$ can be considered as the driver model. In the driver model, the input is a desired path y_{tp}, and the output is a steering maneuvers δ_f. This model can explain the operation of drivers by identified the parameters of $B(s)$ and $H(s)$.

Fig. 1 Driving simulator

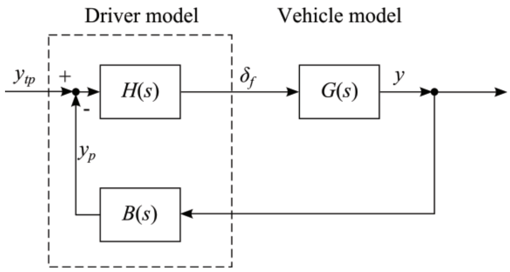


Fig. 2 Block diagram of driver model

As a concept of the prediction of the vehicle motion, Kondo proposed a control theory of look-ahead [2]. He started with the modelling of the driver characteristics, and the model is suitable for the description of the driver characteristics concisely [4]. The concept of the look-ahead model is shown in **Fig. 3**. In this figure, $y(t)$ is the vehicle position, φ is the yaw angle of the vehicle, and y_{tp} is the lateral displacement of the desired path. In this theory, the operation of the driver was represented assuming that the driver operates the vehicle focusing on a point which is at the front of the driver. The point on which driver focuses is called as the prediction point.

The lateral distance of the prediction point is y_p. When the desired path is composed with the straight line and the gentle curve, the longitudinal length between the vehicle and the prediction point is described as the prediction length L [5]. By using the vehicle speed V and the prediction time $T_p = L/V$, y_p can be represented as follows:

$$\begin{aligned} y_p(t) &\approx y(t) + L\varphi(t) \\ &= y(t) + T_p V\varphi(t) \\ &\approx y(t + T_p) \end{aligned} \tag{1}$$

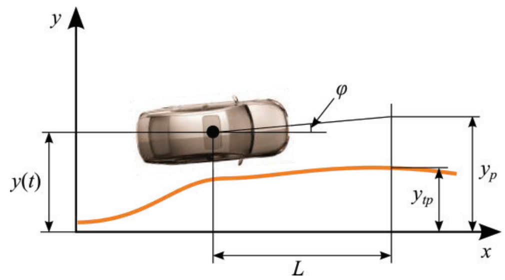


Fig. 3 Concept of look-ahead model

As the extension of the look-ahead model, the second order prediction model was proposed [3]. The concept of this model is shown in **Fig. 4**. In this model, the term $V\varphi(t)$ in equation (1) was replaced by $\dot{y}(t)$. By applying a Taylor serious expansion for $y(t + T_p)$, the second order prediction model is represented as follows:

$$y(t + T_p) = y(t) + \dot{y}(t)\cdot T_p + \frac{1}{2}\ddot{y}(t)\cdot T_p^2 \tag{2}$$

This model includes the term of the predicted lateral position with using the vehicle velocity and the acceleration to the lateral direction (**Fig. 4**). By applying the second order prediction model, B(s) and H(s) in the driver model are represented as equation (3) and (4):

$$B(s) = 1 + T_p s + \frac{1}{2}T_p^2 s^2 \tag{3}$$

$$H(s) = K_s e^{-\tau s} \tag{4}$$

where K_s is the gain of the steering angle, and τ is the time delay. In this study, the parameters of B(s) and H(s) in the second order prediction model were identified by experimental results with a driving simulator described in the following chapter.

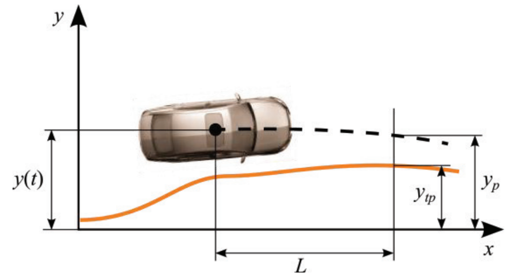


Fig. 4 Concept of second order prediction model

3 System overview of driving simulator

The overview of the driving simulator in this study is shown in **Fig. 5**. When the driver operates the steering wheel, the rotary encoder of the steering torque generator measures the steering angle. The measured data is used as the input data for a real-time full vehicle

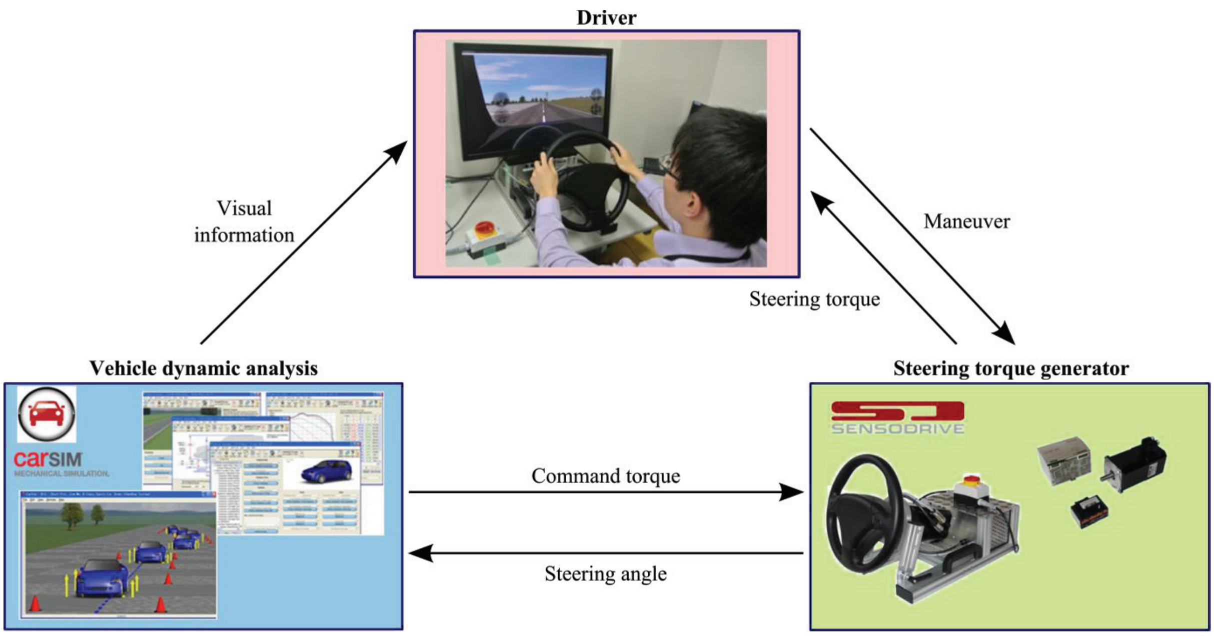


Fig. 5 Overview of driving simulator

simulation. The vehicle dynamics simulation is executed to calculate vehicle state variables by using CarSim [6]. The analysis result of the vehicle position and orientation is used to generate the computer graphics, and the result of the steering torque is used as the command torque of the steering torque generator. Consequently, the operator can feel the steering reactive force and the visual information in this driving simulator.

4 Single lane change test

4.1 Configuration of test course

In order to evaluate the characteristics of the driving operation, single lane change tests were conducted with the driving simulator, and the parameters of the driver model were identified in each condition. The single lane change test can evaluate the transient characteristics of the operation of the driver, and it requires a simple maneuver of the driver. The setting of the test course shown in **Fig. 6** is based on "Lane Change Test Procedure - Passenger Car - Light Trailer Combinations" (JASO C 707-89). In this test course, the gridded ground and the traffic cones and the target path were displayed with computer graphics. This target path which is composed of straight line and the gentle curve described by the clothoid curve [7] was the same as the input of the driver model.

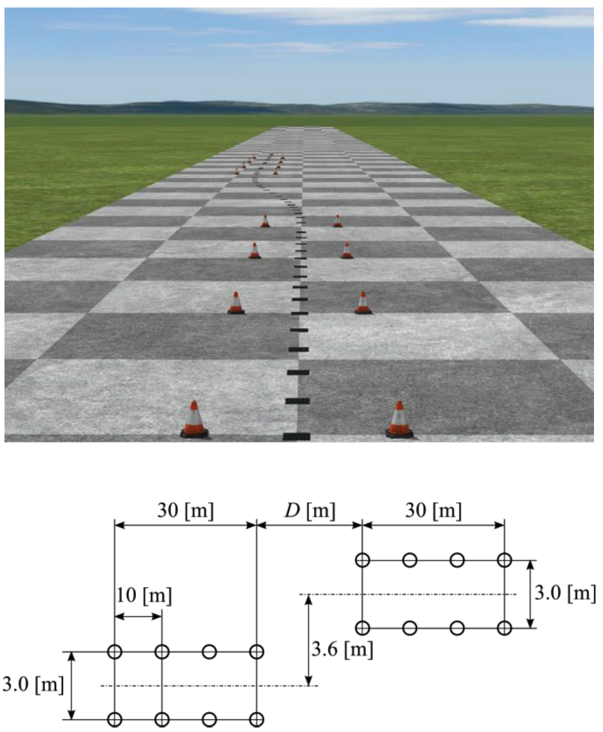


Fig. 6 Single lane change test course.

4.2 Process of evaluation tests in running conditions

In this study, the number of the test subject was three. Every test subjects have a driver license in Japan, and were informed of the test contents including the learning process before the single lane change test. In the test, they were required to give only steering control, in order to evaluate the driver characteristics focusing on the steering control. The conditions of the single lane change tests are shown in **Table 1**. In these evaluation tests, the vehicle velocity and the length of the change section were varied as the driving conditions. Before the single lane change tests in each velocity, the test subjects drove the simulator for 5 minutes in the constant vehicle speed in order to adjust themselves to the vehicle characteristic and the driving simulator environment. The course used for this learning process is shown in **Fig. 7**. After this learning process, the single lane change tests were carried out 5 times with every section length. The section length was changed in descending order. The same procedure was repeated in 60 km/h and 80 km/h.

Table 1 Conditions of single lane change test

Vehicle velocity [km/h]	Change section length [m]
40	50
	40
	30
	20
60	50
	40
	30
	20
80	50
	40
	30
	20

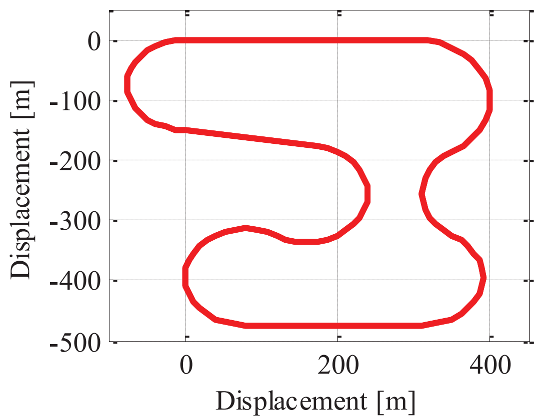
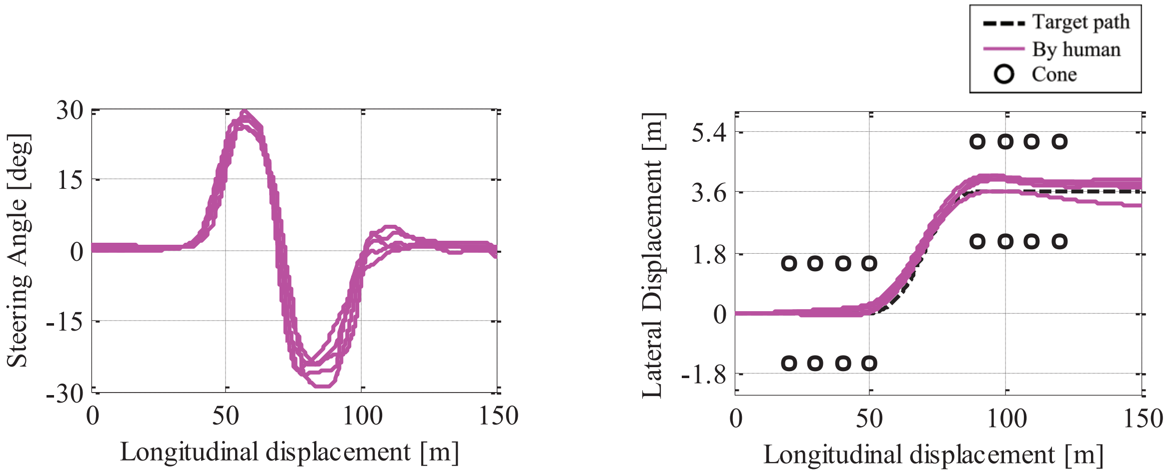


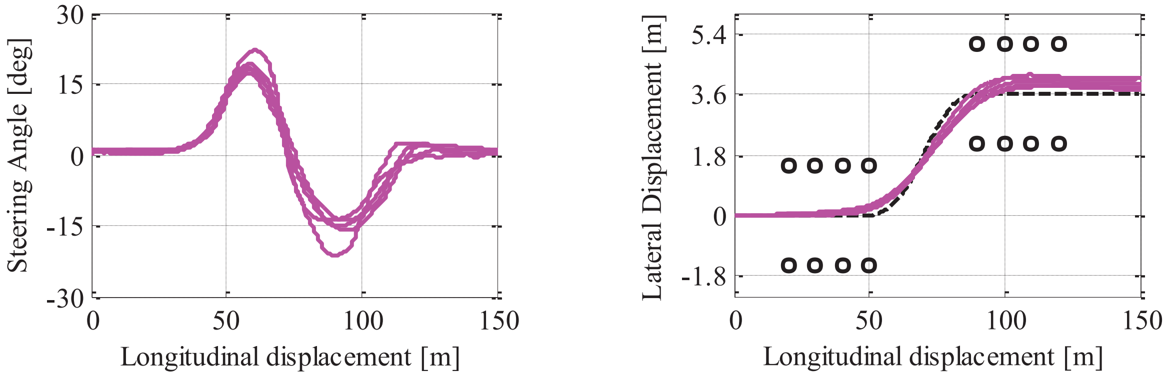
Fig. 7 Course for learning process

4.3 Results of single lane change test

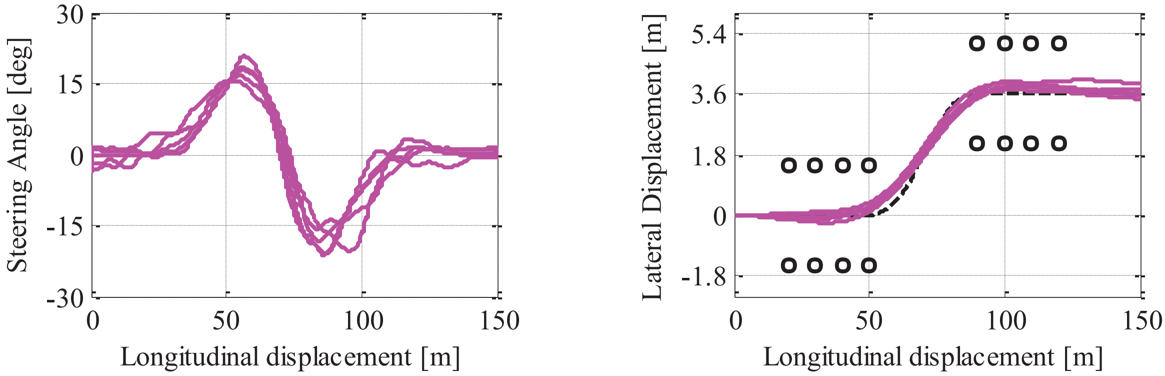
The results of the single lane change test are shown in **Fig. 8**. In this figure, (a) is the result of the driver A, (b) is the result of the driver B, and (c) is the result of driver C with the vehicle velocity was 60 km/h and the lane change section length was 40 m. From these results, the steering angle and the lateral displacement were varied as the driver and each time of the single lane change tests.



(a) Driver A, Vehicle velocity : 60 km/h, Lane change section length : 40 m



(b) Driver B, Vehicle velocity : 60 km/h, Lane change section length : 40 m



(c) Driver C, Vehicle velocity : 60 km/h, Lane change section length : 40 m

Fig. 8 Result of single lane change test

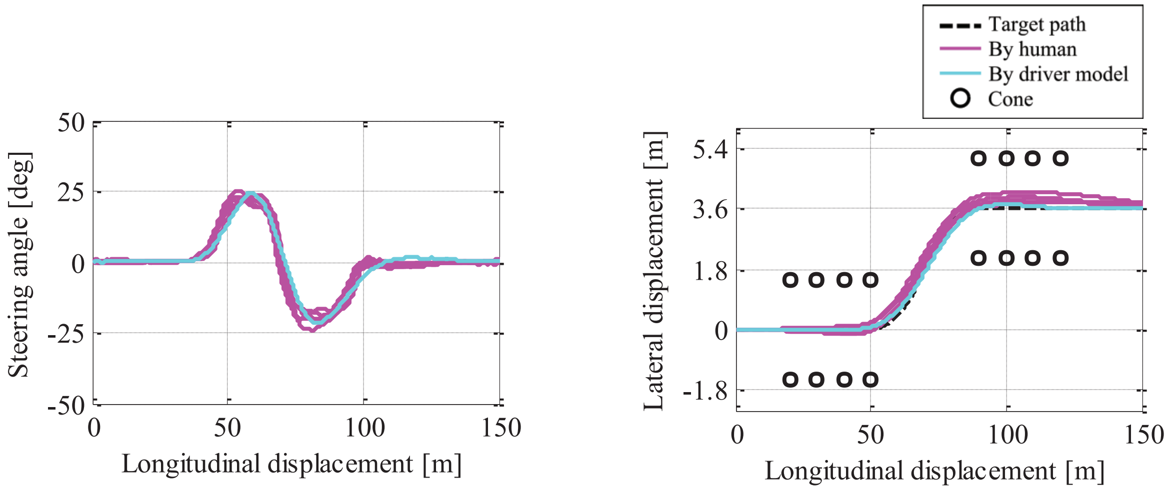
5 Evaluation of driver characteristics

5.1 Identification of parameters for driver model

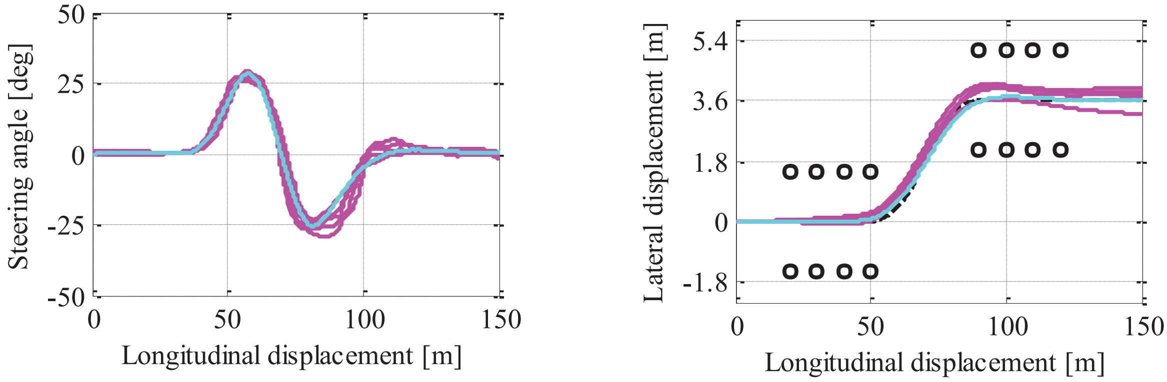
In order to eliminate exceptional results before identifying the parameters of the driver model, the trial with minimum deviation to the average of the five-time trial was selected as a typical result. The parameters for the driver model were identified based on this result. Using the selected data, the steering gain K_s, the prediction time T_p, and the time delay τ in **Eq. (3)** and **(4)** were identified by trial-and-error process.

The results of the identification of the values of the steering gain K_s and the prediction time T_p are shown in **Table 2**. The value of the time delay was identified as 0.1 [s].

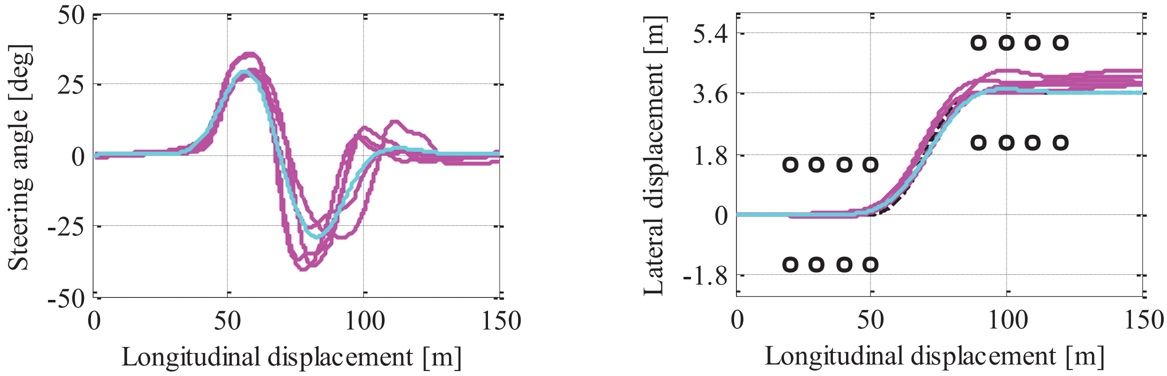
The running simulations with the driver model using these identified parameters were carried out. One of the simulation result of the steering operation and the running path by the driver model is shown in **Fig. 9**. The steering angle and the lateral displacement of the driver model have good agreement with the results of the single lane change tests.



(a) Driver A, Vehicle velocity : 40 km/h, Lane change section length : 40 m



(b) Driver A, Vehicle velocity : 60 km/h, Lane change section length : 40 m



(c) Driver A, Vehicle velocity : 80 km/h, Lane change section length : 40 m

Fig. 9 Identification results and experimental longitudinal results

5.2 Evaluation for operation of driver

From the results of the single lane change test, the relationship between the driver characteristics and the running condition was investigated. In **Fig. 10**, it is observed that the steering gain K_s and the prediction time T_p were changed according to the driver and the length of the lane change section. As the length D of the lane change section decreased, the value of the steering gain K_s increased, and the prediction time T_p decreased for every driver. On the other hand, as the vehicle velocity increased, the steering gain and the prediction time were decreased. However, with the high vehicle speed, the steering gain K_s decreased as the length of the lane change section D decreased.

Table 2 Identified results of the steering gain and prediction time

(a) Velocity 40 km/h

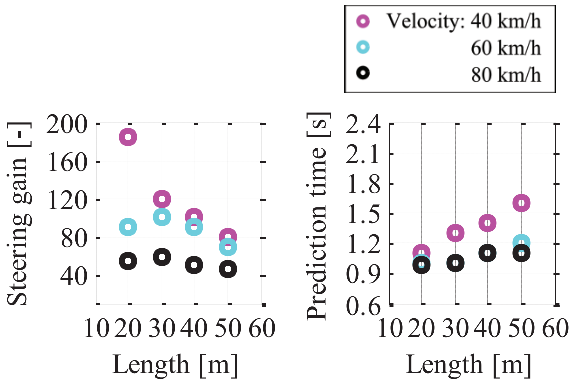
Distance D [m]	Driver A		Driver B		Driver C	
	K_s	T_p[s]	K_s	T_p[s]	K_s	T_p[s]
50	80	1.60	35	2.00	25	2.20
40	100	1.40	40	1.90	30	1.90
30	120	1.30	40	1.80	60	1.60
20	185	1.10	100	1.40	110	1.30

(b) Velocity 60 km/h

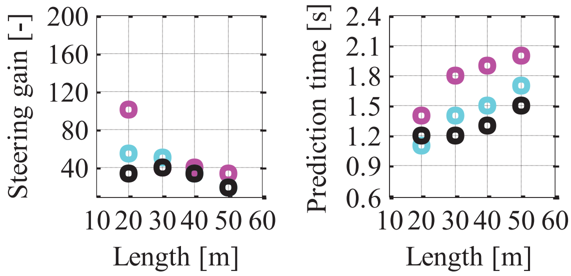
Distance D [m]	Driver A		Driver B		Driver C	
	K_s	T_p[s]	K_s	T_p[s]	K_s	T_p[s]
50	70	1.20	20	1.70	20	1.60
40	90	1.10	35	1.50	22	1.60
30	100	1.00	50	1.40	35	1.40
20	90	1.00	55	1.10	54	1.20

(c) Velocity 80km/h

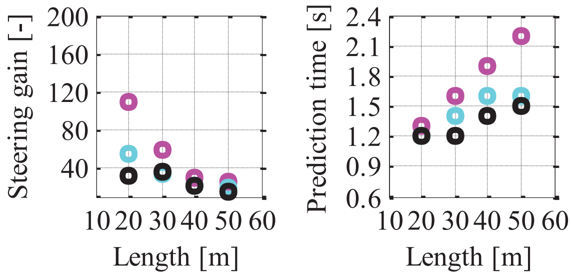
Distance D [m]	Driver A		Driver B		Driver C	
	K_s	T_p[s]	K_s	T_p[s]	K_s	T_p[s]
50	47	1.10	20	1.50	16	1.50
40	50	1.10	35	1.30	22	1.40
30	60	1.00	40	1.20	36	1.20
20	55	0.98	35	1.20	32	1.20



(a) Parameters of the Driver A



(b) Parameters of the Driver B



(c) Parameters of the Driver C

Fig. 10 Identified results of driver characteristics

6 Conclusion

In this paper, the driver characteristics according to the driving conditions were evaluated by using a driver model. In order to examine the characteristics of the operation of drivers, a driving simulator was used to evaluate the behavior of the drivers, and the second order prediction model was used as the driver model in this study. The single lane change tests were conducted to identify the parameters of the second order prediction model. From these test results, the relationship between the driver characteristics and the running conditions was discussed. The single lane change test results show that the steering gain, the derivative steering gain, and the prediction time of the second order prediction model were changed in each driver and the length of the lane change section.

References

[1] Sheridan, T. B., “Three Models of Preview Control”, Proceedings of IEEE Transactions on Human Factors in Electronics, HFE-7, No. 2, (1966), pp. 91-102.

[2] Kondo, M., “Stability/ Controllability/ Maneuverability of Automobiles (3)”, Journal of Society of Automotive Engineers of Japan, (1953), Vol. 7, No. 2, pp. 104-106, (in Japanese).

[3] Yoshimoto, K., “Simulation of Man-Automobile Systems by the Driver’s Steering Model with Predictability”, Journal of Mechanics Society Japan, Vol. 71, No. 596, (1982), pp. 1181-1186, (in Japanese).

[4] Plöchl, M., Edelmann, J., “Driver models in automobile dynamics Application”, International Journal of Vehicle Mechanics and Mobility, Vol. 45, Issue 7-8, (2007), pp. 699-701.

[5] Abe, M., Automotive Vehicle Dynamics: Theory and Applicitions, Tokyo, TDU Press, (2009), Chap. 9, pp. 227-228, (in Japanese).

[6] Mechanical Simulation Corporation. http://www.carsim.com/, November 2013.

[7] Wang, L. Z., Miura, K. T., Nakamae, E., Yamamoto, T., Wang, T. Z., “An approximation approach of the clothoid curve defined in the interval [0, π/2] and its offset by free-form curves”, Proceedings of Computer-Aided Design, Vol. 33, Issue 14, (2001), pp. 1049-1058.

Received on December 28, 2013
Accepted on February 12, 2014