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Cooperative Steering Characteristics of Driver and Lane-Keeping Assistance System

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A Lane-Keeping Assistance System can be expected to use in order to reduce driver workload and assist the driver in controlling vehicle. This paper proposes a design of Lane-Keeping Assistance System that uses steering torque as a control input for cooperative steering between driver and assistance system. The cooperative steering performance is evaluated by computer simulation and experiment using driving simulator under side wind disturbance and lane-keeping on curved road. The weighting function is proposed here to vary amount of assistance level in the evaluation of the system in order to examine the cooperative steering characteristics at different assistance level.

Keyword: ITS, Lane-Keeping Assistance System, Steering Control, Driving Simulator, Cooperative Steering

1. Introduction

Recently many researches about automation of transportation system are being carried out actively as a great tool for improving movement of people or goods more efficient, economical and safety. At this point, the device for implement the concept of ITS can be categorized to infrastructure and in-vehicle systems. This paper deals with the in-vehicle systems for improving active safety of vehicle.

However, at present, it is still difficult to give all of the control operations to the full autonomous driving system because of the problems from reliability of the system and responsibility in case of accidents. Therefore, the driver assistance system seems to be more suitable for practical use than full automatic system in these points. In addition, among all of the driving operation, the lane-keeping operation that requires very high driver's workload can be considered as the most important one. Therefore, this paper focuses on a Lane-Keeping Assistance System that can help reducing in driver workload and unexpected lane departure.

The "automatic" lane-keeping system that uses steering torque as a control input was proposed by H. Mouri and M. Nagai [1]. Steering torque from the motor in electric power steering is used to be a control input of the system instead of steering angle to allow the driver to intervene the system easily [1]. In this paper, weighting coefficient is proposed for a concept of "cooperative steering" system between driver and assistance system to vary amount of assisting torque from the Lane-Keeping Assistance System in the cooperative steering situation.

The cooperative steering performance is evaluated by computer simulation and experiment using driving simulator. Since the Lane-Keeping Assistance System is designed to control the vehicle as human driver in lane-keeping task; interference between driver and assistance system may occur. In this paper, steering assisting torque is varied by using weighting coefficient in order to reduce the interference problem. The effectiveness of weighting coefficient on cooperative steering performance is evaluated. The performance of cooperative steering will be proved under strong side wind disturbance on straight road and a lane-keeping task on curved road.

2. Mathematical model

2.1. Vehicle model

A two-wheel vehicle model as shown in Figure 1 is used to describe vehicle dynamics. The governing equations of the lateral motion and the yaw motion are given as follows:

$$m\ddot{y}_c = 2F_f + 2F_r \tag{1}$$

$$I\ddot{\phi} = 2l_f F_f - 2l_r F_r \tag{2}$$

where, y_c denotes the lateral displacement of the center of gravity, ϕ the yaw angle, $F_f(F_r)$ the cornering force at the front (rear) tire.

A linear tire model is used in this paper, therefore the cornering force at front and rear tires can be calculated as Equations (3) and (4) respectively.

$$F_f = C_f\left(\delta_f - \frac{l_f}{V}\dot{\phi} + \phi - \frac{1}{V}\dot{y}_c\right) \tag{3}$$

$$F_r = C_r\left(\frac{l_r}{V}\dot{\phi} + \phi - \frac{1}{V}\dot{y}_c\right) \tag{4}$$

where, δ_f denotes the front steering angle.

When vehicle travels on a curved road that has a constant curvature, the following relations can be obtained.

$$\dot{\phi}_r = \dot{\phi} - \rho V \tag{5}$$

$$\ddot{y}_{cr} = \ddot{y}_c - \rho V^2 \tag{6}$$

where, ρ is the road curvature and the subscript r refers to the state from the reference line as shown in Figure 2.

The lateral deviation from the sensor equipped on vehicle can be expressed by considering the influence of road curvature as follow:

$$y_{sr} = l_s\phi_r + y_{cr} - \frac{l_s^2}{2}\rho \tag{7}$$

where, l_s is the distance from the center of gravity to front preview point of sensor. In this paper, distance l_s is assumed to be 15m of length [2].

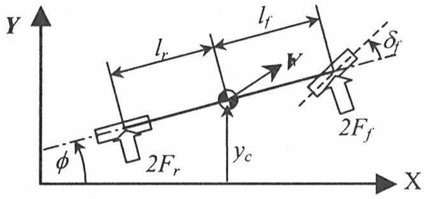

Figure 1. Equivalent two-wheel vehicle model

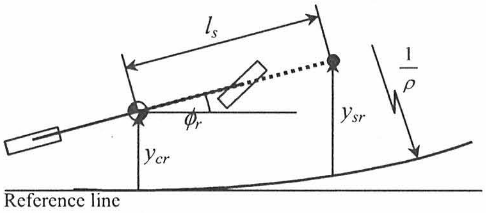

Figure 2. Lateral deviation measurement of sensor

2.2. Steering system model

Steering system of vehicle equipped with steering torque generator is modeled as shown in Figure 3. To simplify this model, the effect from torsional stiffness of steering system and complicated mechanism of power steering system are neglected in this paper. The steering system model can be expressed as follow:

$$\left(I_{sw} + \frac{I_s}{N^2}\right)\ddot{\theta} = -\left(C_{sw} + C_s\right)\dot{\theta} + \frac{T_s}{N} + T_a w + T_d \tag{8}$$

where, T_s denotes self-aligning torque, $T_a w$ assisting torque, T_d driver torque and θ steering wheel angle that equals steering gear ratio times front steer angle, $N\delta_f$. The self-aligning torque can be determined as follow:

$$T_s = -2\xi F_f \tag{9}$$

where, ξ refers to front wheel trail.

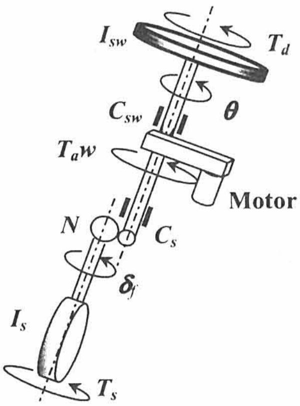

Figure 3. Steering system

Table 1. Vehicle parameters

Definition	Symbol	Unit	Value
Vehicle mass	m	kg	1500
Yaw moment of inertia	I	kgm^2	2500
Distance from CG to front axle	l_f	m	1.22
Distance from CG to rear axle	l_r	m	1.46
Front wheel cornering stiffness	C_f	N/rad	33536
Rear wheel cornering stiffness	C_r	N/rad	50036
Steering gear ratio	N	-	16.8
Moment of inertia of Steering wheel	I_{sw}	kgm^2	0.0322
Equivalent moment of inertia of front wheel	I_s	kgm^2	0.3492
Viscous friction coefficient of steering wheel	C_{sw}	Nms/rad	0.104
Equivalent viscous friction coefficient of front wheel	C_s	Nms/rad	0.330
Front wheel trail	ξ	m	0.0314

3. Lane-Keeping Assisting System

The cooperative steering between driver and the Lane-Keeping Assistance System can be shown by the block diagram in Figure 4. The control system of the Lane-Keeping Assistance System in this paper can be separated into three major parts that are state estimator, feedback controller and weighting coefficient.

In this paper, the state estimator for estimating value of road curvature will be designed and used in order to improve system's efficiency. The state variables that will be estimated are lateral displacement and velocity of the center of gravity, yaw angle, yaw rate, and road curvature. These state variables are estimated from lateral displacement of front preview point from CCD camera and steering wheel angle input to vehicle system. These estimated state variables with two measured variables, steering wheel angle and angular velocity, will

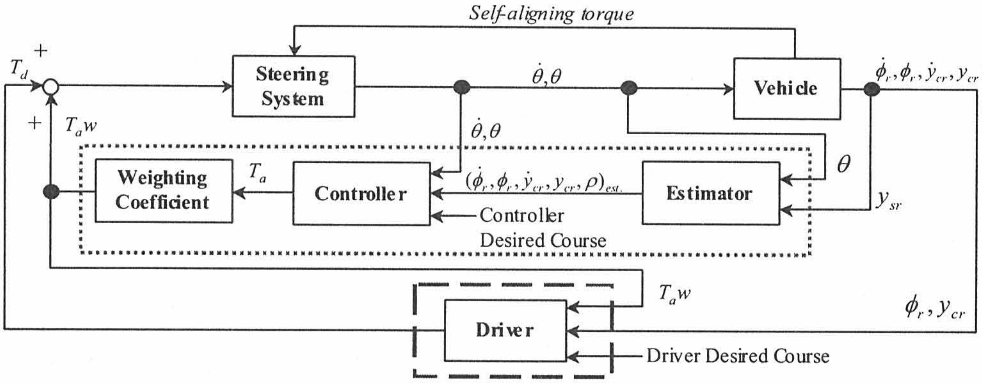

Figure 4. Block diagram of the cooperative steering system

be sent to the controller to provide steering assisting torque to the steering system. Finally, since the Lane-Keeping Assistance System is designed to perform a lane-keeping task as same as a human driver, the weighting coefficient is applied to the system to achieve better cooperative steering performance and reduce interference problem between driver and assistance system. The details of these major parts of the control system are described in the following parts of this section.

3.1. State estimator

Since the road curvature, ρ, will be estimated, the road curvature should be included to be one of the state variables of the control system. In this paper, road curvature's characteristic is assumed to be a Gaussian White Noise in order to use Kalman Filter to design the estimator. The road curvature is assumed to be a first order system as follow [2]:

$$\frac{d\rho}{dt} = -\lambda\rho + \nu \tag{10}$$

where, ν refers to process noise and λ shows the characteristic of road curvature.

Therefore, from the two-wheel vehicle model and the relation in Equation (10), state equation and output equation of the control system for designing the estimator can be obtained as follows:

$$\begin{bmatrix} \ddot{\phi}_r \\ \dot{\phi}_r \\ \ddot{y}_{cr} \\ \dot{y}_{cr} \\ \dot{\rho} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & 0 & b_{12} \\ 1 & 0 & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 & b_{32} \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & -\lambda \end{bmatrix} \begin{bmatrix} \dot{\phi}_r \\ \phi_r \\ \dot{y}_{cr} \\ y_{cr} \\ \rho \end{bmatrix} + \begin{bmatrix} a_{16} \\ 0 \\ a_{36} \\ 0 \\ 0 \end{bmatrix} \theta + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} \nu \tag{11}$$

$$y_{sr} = \begin{bmatrix} 0 & l_s & 0 & 1 & -\frac{l_s^2}{2} \end{bmatrix} \begin{bmatrix} \dot{\phi}_r & \phi_r & \dot{y}_{cr} & y_{cr} & \rho \end{bmatrix}^T + \eta \tag{12}$$

where,

$$a_{11} = -2\frac{l_f^2 C_f + l_r^2 C_r}{IV} \quad , \quad a_{12} = 2\frac{l_f C_f - l_r C_r}{I} \quad , \quad a_{13} = -2\frac{l_f C_f - l_r C_r}{IV} \quad ,$$

$$a_{16} = \frac{2l_f C_f}{IN} \quad , \quad a_{31} = -2\frac{l_f C_f - l_r C_r}{mV} \quad , \quad a_{32} = 2\frac{C_f + C_r}{m} \quad ,$$

$$a_{33} = -2\frac{C_f + C_r}{mV} \, , \, a_{36} = \frac{2C_f}{mN} \, , \, b_{12} = a_{11}V \, , \, b_{32} = a_{31}V - V^2$$

and η is sensor noise. The power spectral intensity of ν and η are Q_0 an R_0 respectively. The values of Q_0 and R_0, in this paper, are set as 10^{-3} and 1 respectively.

3.2. Feedback controller

Next, the feedback controller of the control system will be designed by using LQ control theory. From the two-wheel vehicle model, steering model and assumption of road curvature's characteristic; state equation of the control system for designing the feedback controller to provide steering assisting torque can be obtained as follow:

$$\begin{bmatrix} \ddot{\phi}_r \\ \dot{\phi}_r \\ \ddot{y}_{cr} \\ \dot{y}_{cr} \\ \ddot{\theta} \\ \dot{\theta} \\ \dot{\rho} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & 0 & 0 & a_{16} & b_{12} \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 & 0 & a_{36} & b_{32} \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ a_{51} & a_{52} & a_{53} & 0 & a_{55} & a_{56} & b_{52} \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -\lambda \end{bmatrix} \begin{bmatrix} \dot{\phi}_r \\ \phi_r \\ \dot{y}_{cr} \\ y_{cr} \\ \dot{\theta} \\ \theta \\ \rho \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ b_{51} \\ 0 \\ 0 \end{bmatrix} T_a + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} \nu \tag{13}$$

where,

$$a_{51} = \frac{2\xi l_f C_f}{\left(I_{sw} + \frac{I_s}{N^2}\right)NV} \, , \, a_{52} = -\frac{2\xi C_f}{\left(I_{sw} + \frac{I_s}{N^2}\right)N} \, , \, a_{53} = \frac{2\xi C_f}{\left(I_{sw} + \frac{I_s}{N^2}\right)NV} \, ,$$

$$a_{55} = -\frac{C_s + C_{sw}}{\left(I_{sw} + \frac{I_s}{N^2}\right)} \quad , \quad a_{56} = -\frac{2\xi C_f}{\left(I_{sw} + \frac{I_s}{N^2}\right)N^2} \quad , \quad b_{51} = \frac{1}{\left(I_{sw} + \frac{I_s}{N^2}\right)} \quad ,$$

$$b_{52} = a_{51}V$$

and the other parameters refer to parameters in Equations (11) and (12).

By letting the third term of the right hand side of Equation (13) be zero, the optimum control theory can be applied for the state feedback control system as follow:

$$\begin{aligned} T_a &= -G_{fb}X \\ &= -(K_{\dot{\phi}_r}\dot{\phi}_r + K_{\phi_r}\phi_r + K_{\dot{y}_{cr}}\dot{y}_{cr} + K_{y_{cr}}y_{cr} + K_{\dot{\theta}}\dot{\theta} + K_{\theta}\theta + K_{\rho}\rho) \end{aligned} \tag{14}$$

where, G_{fb} refers to state feedback controller gain and X is state variable of the system as shown in Equation (13).

The feedback gain of controller as shown above can be determined to minimize the performance index, J, in the following equation.

$$J = \int_0^{\infty} \left(q_{\phi_r}\phi_r^2 + q_{y_{cr}}y_{cr}^2 + T_a^2 \right) dt \tag{15}$$

An objective of the Lane-Keeping Assistance System is to design an assistance system to perform a lane-keeping task similar to the human driver. Therefore, in this paper, the feedback controller of Lane-Keeping Assistance System is tuned by choosing weights, $q_{\phi r}$ and q_{ycr}, to give vehicle's responses as same as that of the human driver. In this paper, the values of these weights, $q_{\phi r}$ and q_{ycr}, are given as 1000 and 1 respectively.

3.3. Weighting coefficient

As state above, since the feedback controller designed in last section performs a lane-keeping task as similar to the human driver; therefore, the interference between driver and the Lane-Keeping Assistance System may occur. In this paper, a weighting coefficient as shown in Equation (16) is applied to the control system as shown in Figure 4 in order to reduce the interference between driver and assistance system and achieve better cooperative steering performance.

$$w = w_0 \tag{16}$$

where, w_0 is varied as 0, 0.25, 0.50, 1.00.

The value of w_0 is varied from zero to one to adjust the assistance level of the control system. The computer simulation and experiment using driving simulator were carried out in order to evaluate the cooperative steering characteristic of the driver and Lane-Keeping Assistance System at different assistance level. This will be discussed in the next section.

4. System evaluation

Cooperative steering performance between driver and the proposed Lane-Keeping Assistance System is evaluated by computer simulation and experiment using driving simulator. In the computer simulation, the driver block shown in Figure 4 is replaced with mathematical driver model that was created based on experiment results of a number of drivers. Moreover, in the experiment, the driver block is replaced with human driver by the using of driving simulator. The 6-degree-of-freedom parallel link mechanism driving simulator equipped with a motor that provides reaction torque for steering system is used in this paper. Figure 5 shows the TUAT driving simulator using in this experiment.

Situations used for evaluating the system are lane-keeping under side wind disturbance and lane-keeping on curved road. The result from both computer simulation and experiment will be analyzed based on two performance indexes, Lane-keeping Performance and Driver Physical Workload.

The first part of this section describes about the driver model used in this paper. The detail of performance indexes used for the system evaluation will be explained in the last part of this section.

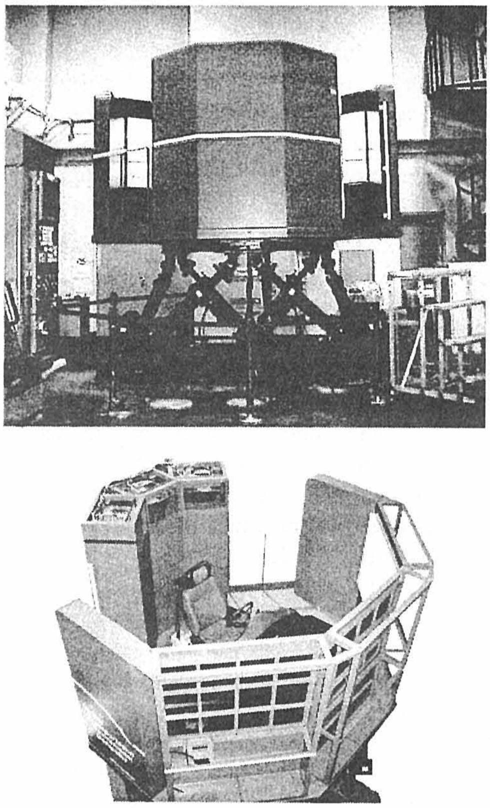

Figure 5. TUAT driving simulator

4.1. Driver model

The cooperative steering characteristic of driver and assistance system is investigated using computer simulation in this paper. The driver model used in the simulation can be shown in block diagram in Figure 6.

The transfer function of the driver model can be expressed as follow:

$$T_d = \frac{1}{1+\tau_I s}\left[G_h e^{-\tau_D s}\varepsilon + K_t T_a w\right] \tag{17}$$

where, K_t describes the effect of assisting torque on the driver as kinesthetic information from the driver assistance system [3], ε denotes a deviation of the driver's front preview point from desired course that can be calculated as follow:

$$\varepsilon = y_p^* - \left(y_{cr} + Vt_p\phi_r\right) \tag{18}$$

where, y_p^* denotes the driver desired course.

In this paper, parameters in the driver model were determined from experiment data using driving simulator. Table 2 shows the values of driver model's parameters used in this paper

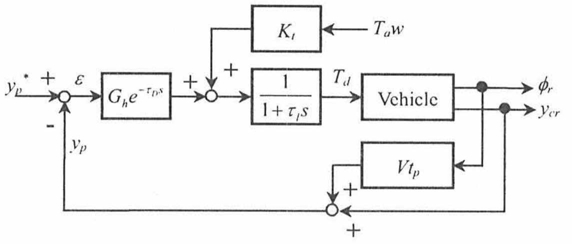

Figure 6. Driver model

Table 2. Parameters of driver model

Definition	Symbol	Unit	Value	
			A*	B**
Physical delay time	τ_l	s	0.20	0.15
Preview time	t_p	s	1.75	1.50
Dead time	τ_D	s	0.20	0.20
Torque gain	G_h	N	1.85	1.65

* Parameters for simulation on straight road
** Parameters for simulation on curved road

4.2. Performance index

The cooperative steering performance will be evaluated using two performance indexes in this paper. First is a Lane-keeping Performance, *LP*, that can be determined as follow:

$$LP = \int_0^t y_{cr}^2 dt \tag{19}$$

where, y_{cr} denotes the relative lateral displacement.

The other one is Driver Physical Workload, *PW*, that can be determined as follow:

$$PW = \int_0^t T_d^2 dt \tag{20}$$

where, T_d denotes the driver torque. The driver workload in this paper means to the driver's muscular workload required to provide steering torque to control the vehicle in lane-keeping task. The Lane-Keeping Assistance System can help reducing in this muscular driving workload so that the driver will not easily get tired.

5. Steering response under side wind disturbance

One of the situations that needs the Lane-Keeping Assistance System can be considered as when vehicle is about to veer away from the lane. The cooperative steering performance is evaluated under side wind disturbance in the computer simulation. Since vehicle is traveling on straight road in this situation, so the estimated value of road curvature will not be used in this section. Therefore, the assisting torque in Equation (14) will be calculated by letting K_ρ be zero in this section.

In this simulation, a strong side wind disturbance will be applied to the vehicle, which is traveling on a straight road at constant speed of 80km/h, during 1.0s to 2.5s of simulation. Moreover, parameter K_t in the driver model is set to be zero in this simulation.

Time response results from simulation are shown in Figure 7. Under a strong side wind disturbance, as the weighting coefficient increases, the lateral displacement and driver torque decreases and the steering wheel will be operated earlier.

The experiment of steering response under side wind disturbance was carried out with 9 subjects who are college student with 20 - 25 years old range of age. Experiment results of steering response under side wind disturbance on the same condition as computer simulation condition of one subject are shown in Figure 8. The graphs in Figure 8 show that experiment result also has a same tendency as simulation result, that is the higher in assistance level the lower in lateral displacement and driver torque.

However, as can be seen from the graph, reduction in driver torque cannot be seen at high assistance level. This may be caused from the interference from assistance system on the driver that can be confirmed by the results of the Lane-keeping Performance and Driver Physical Workload of all subjects from experiment in Figure 9. In case of side wind disturbance, using Lane-Keeping Assistance System well improves lane-keeping performance and reduces driver torque workload even using only 25% assistance level. Moreover, the graph shows that in the experiment, at weighting coefficient higher than 0.5, the assisting torque interferes the driver and deteriorate the driver's workload. In contrast to the Driver Physical Workload, the Lane-keeping Performance in simulation and experiment also has a same tendency that it becomes smaller as the assistance level increases.

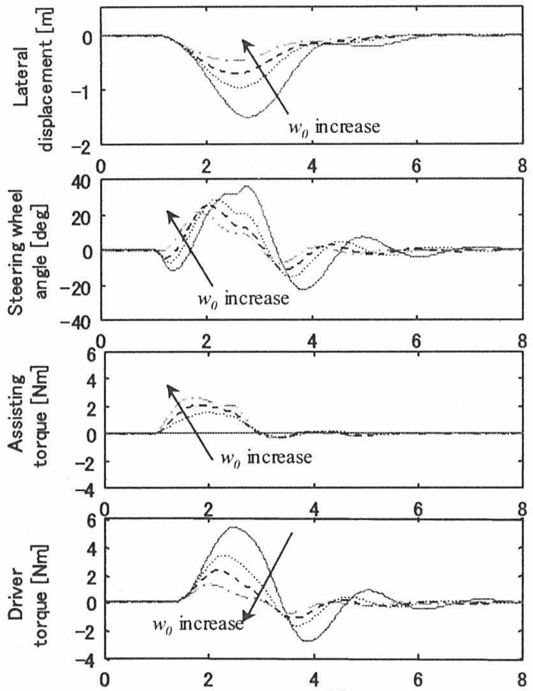

Figure 7. Time responses of steering response under side wind disturbance from simulation

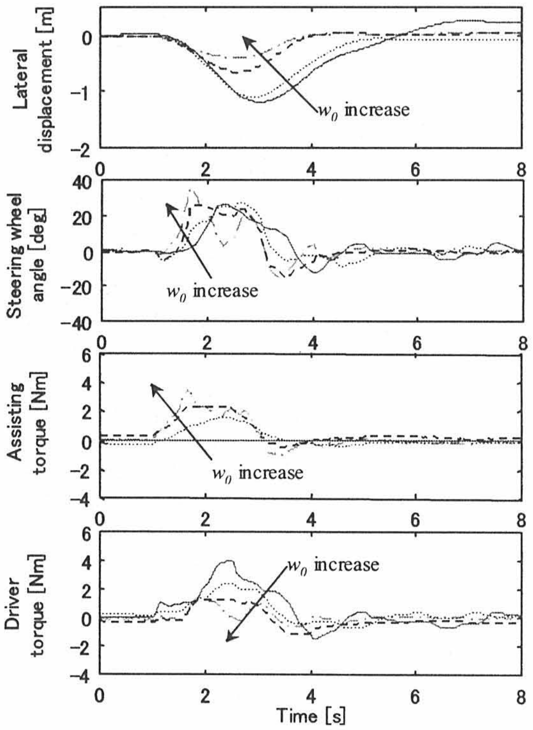

Figure 8. Time responses of steering response under side wind disturbance from experiment

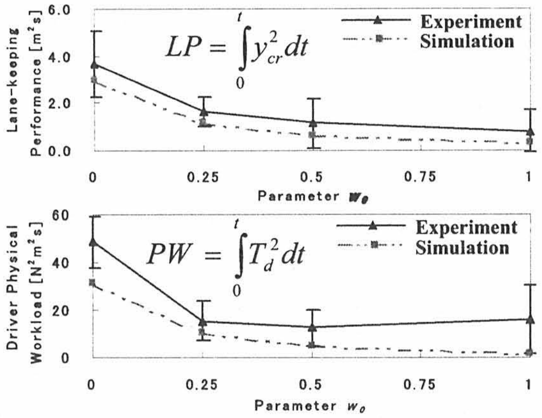

Figure 9. Lane-keeping Performance and Driver Physical Workload from simulation and experime

6. Lane-keeping on curved road

The other situation that needs assisting torque from the Lane-Keeping Assistance System can be considered as a traveling on a curved road. In contrast to the last section, the road curvature has a great effect on this situation, so the road curvature will be estimated and used to calculate the assisting torque in this case.

Similar to the last section, the same weighting coefficient as in Equation (16) will be used with w_0 equal to 0, 0.25, 0.50, 0.75 and 1.00.

In this simulation, parameter K_t of the driver model is chosen for a specific weighting coefficient. In this paper, value of K_t was determined to minimize the Lane-keeping Performance, *LP*, of the cooperative driving. The situation that was used in computer simulation is when vehicle enter to a 500m-radius curve at constant speed of 100km/h. The computer simulation results, Driver Physical Workload and Lane-Keeping Performance, are shown in Figures 10, 11 and 12. The result shows that the Lane-Keeping Assistance System can help reducing in required torque from the driver and improving in lane-keeping efficiency of the vehicle. Moreover, in computer simulation, at high assistance level the Driver Physical Workload can be much decreased because the assistance system will provide a primary torque to control the vehicle and the driver will change his role from the operator who steers vehicle to the supervisor who monitors the operation of the assistance system.

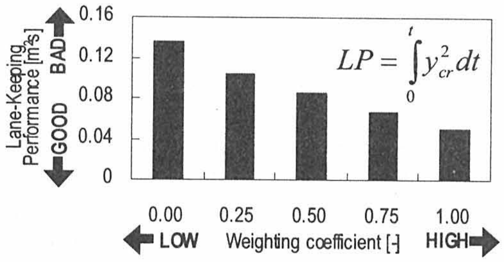

Figure 10. Lane-Keeping Performance *LP* from computer simulation

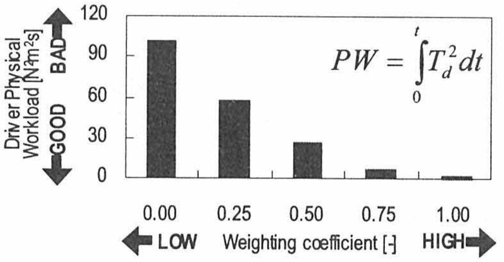

Figure 11. Driver Physical Workload *PW* from computer simulation

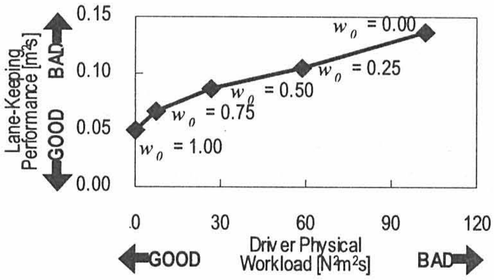

Figure 12. Relation between Driver Physical Workload (*PW*) and Lane-Keeping Performance (*LP*) from computer simulation

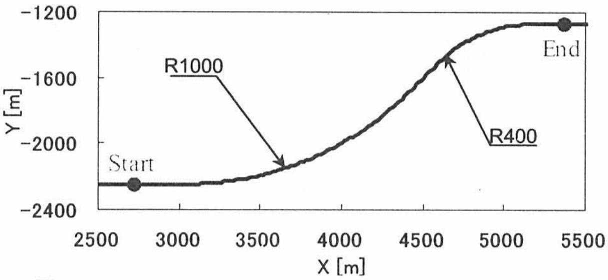

Figure 13. Curved course in driving simulator

Experiment of lane-keeping on curved road was carried out using driving simulator with 11 subjects of same conditions as last section. All subjects were asked to drive on the left lane of two-lane highway road as shown in Figure 13 at constant speed of 100km/h and to perform a lane-keeping task without any side disturbance. The results of Driver Physical Workload, *PW*, and Lane-keeping Performance, *LP*, from experiment of all subjects are shown in Figures 14, 15 and 16. The graphs show that increasing in assistance level can reduce Driver Physical Workload as same as simulation result. However, in contrast to simulation result, the Lane-keeping Performance will not be significantly improved, this is caused from the effect of the driver's uncertainty in the experiment.

Moreover, the variation of the Driver Physical Workload becomes larger at high assistance level. This increasing in variation of the Driver Physical Workload is caused from the interference between driver and Lane-Keeping Assistance System.

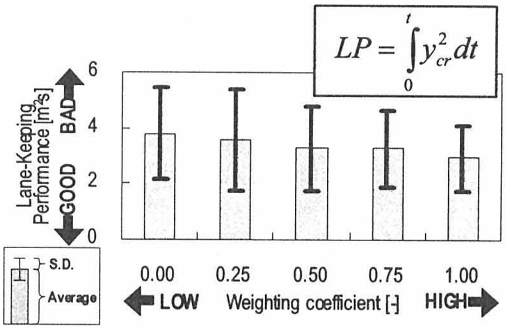

Figure 14. Lane-Keeping Performance (*LP*) from experiment of all subjects

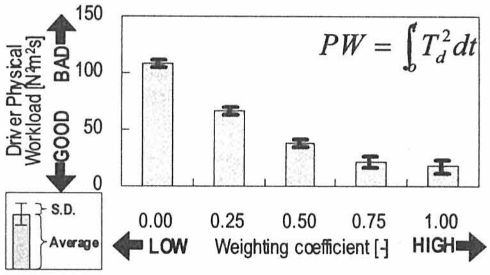

Figure 15. Driver Physical Workload *PW* from experiment of all subjects

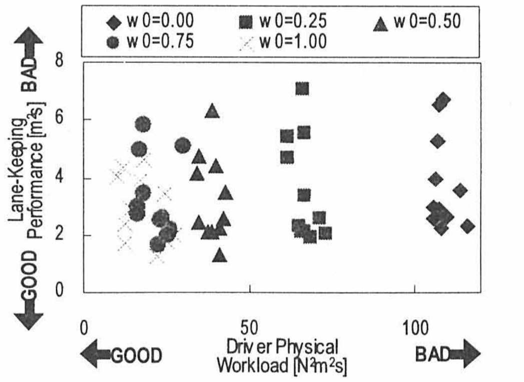

Figure 16. Relation between Driver Physical Workload (*PW*) and Lane-Keeping Performance (*LP*) from experiment

From sections 5 and 6, in normal lane-keeping task that has no strong side disturbance, the driver plays a key role in fine controlling vehicle around middle of traffic lane. Effect of driver's uncertainty is greater than the control system especially in case that vehicle mainly travels in middle of lane. Therefore, the result of Lane-Keeping Performance on curved road in section 6 is also same even assistance level changes. However, the Lane-Keeping Assistance System becomes more important in the case of sudden disturbance as can be seen from the result in section 5 that an unexpected lane departure of vehicle can be suppressed when assistance level becomes higher.

7. Conclusions

This paper proposes the using of Lane-Keeping Assistance System with steering torque input for cooperative steering in lane-keeping task with a human driver. Moreover, the weighting coefficient used for varying assistance level is proposed to use in order to improve the cooperative steering between driver and Lane-Keeping Assistance System. In this paper, the cooperative steering performance is evaluated by computer simulation and experiment using driving simulator under side wind disturbance and lane-keeping task on curved road.

- For Lane-Keeping Assistance System under side wind disturbance, lane departure and driver torque workload are reduced around 50% even using low assistance level ($w_0 = 0.25$). The high effectiveness of the assistance system on side wind disturbance situation is clarified.
- For Lane-Keeping Assistance System when traveling on curved road, a using of weighting coefficient does not well improve lane-keeping efficiency but its effect on improving of driver torque workload is confirmed.

The above conclusions about effectiveness of cooperative steering between the Lane-Keeping Assistance System and driver can be explained as in following statements. Since a driver cannot predict an occurrence of side wind disturbance; therefore, effectiveness of the assistance system is high as can be noticed from the results of lateral deviation of vehicle and driver torque. In contrary, a driver detects the road curvature when steering vehicle through curved road. In this case, vehicle is steered to travel around middle of lane. The effectiveness of the assistance system on lane-keeping efficiency is small but the driver can steer the vehicle with smaller torque resulting in a decreasing of driver torque workload.

8. References

[1] H. Mouri and M. Nagai, "Study on Automatic Path Tracking with Steering Torque Input", Transactions of the Japan Society of Mechanical Engineers, Vol. C No. 66-664, 2001, pp. 3836-3843

[2] H. Mouri, S. Satoh, H. Furusho and M. Nagai, "Investigation of automatic path tracking using an extended Kalman filter", JSAE Review 23 (2002), pp 61-67

[3] S. Horiuchi and K. Sunada, "Synthesis of Driver Assistance System for Lane-Following Using Generalized Predictive Control", Proc. of AVEC'98, 1998, pp 467-472

[4] M. Nagai, H. Mouri and P. Raksincharoensak, "Vehicle Lane-Tracking Control with Steering Torque Input", Proc. of 17th IAVSD Symposium, 2001

[5] M. Ikegaya, N. Asanuma, S. Ishida and S. Kondo, "Development of a Lane Following Assistance System", Proc. of AVEC'98, 1998, pp473-478

[6] K. Naab and G. Reichart, "Driver Assistance System for Lateral and Longitudinal Vehicle Guidance", Proc. of AVEC'94, 1994, pp 449-454

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