

Assistance Method of Obstacle Avoidance Maneuver by Steering Operation

Yukihiro FUJIWARA*
Yasushi SHODA*

Kenichi OHSHIMA *
Mitsuharu KANABOSHI*

ABSTRACT

Assistance types and control methods were studied, in regard to the system to assist driver maneuvers in avoiding obstacles through steering. From the principle that the driver is the focal point of driving operation, a “driver reactive” type of assistance was selected, wherein assistance begins after the driver initiates an avoidance maneuver. Actualization of a four-wheel brake control that equivalently reduces vehicle yaw inertia moment and derivative steering characteristics has enabled the development of a steering reaction torque control system, which reduces driver avoidance operation delay, as a new avoidance assistance control method. Vehicle test results have confirmed that yaw rate gain during an avoidance maneuver rises a maximum of 1.5 times, and that steering delay can be reduced by a maximum of 700 ms; these have led to enhanced driver avoidance maneuvers.

1. Introduction

As a countermeasure to traffic accidents, progress in crashworthiness technology that raises safety in accidents has been remarkable, contributing greatly to the reduction in fatal accidents, though no reduction in the actual number of accidents occurring can be seen. It is believed that systems designed to help prevent accidents would be effective, and accordingly, many automobile manufacturers are developing various active safety and obstacle avoidance systems^{(1) - (3)}.

To actualize such systems, it is necessary to have functions that recognize the surrounding circumstances, using outfield sensors such as radar or cameras, and that assist the driver's driving operation in situations where an accident might occur. However, due to current limitations in outfield sensor recognition capabilities,

the systems implemented so far have been passive safety technologies such as warning systems. On the other hand, by limiting the accident scenarios, there are accident damage mitigating technologies known as pre-crash safety technologies, but accident avoidance assistance technologies using outfield sensors⁽⁴⁾ are still in the research stage.

With this background, the authors have developed a system that assists the steering avoidance maneuver, applying this function with the pre-crash safety system known as collision mitigation braking (CMS)⁽⁵⁾. This research project studied assistance methods, based on the principle that avoidance maneuvers are dependent upon the driver actions. Then, in order to reduce any driver avoidance maneuver delays, studies were made of brake force control reducing the equivalent yaw inertia moment and of steering reaction control system that actualizes derivative handle⁽⁶⁾ with the use of electric power steering (EPS).

* Tochigi R&D Center

For the avoidance scenario, a double lane change on a low friction coefficient road was established, and enhancements of driver's avoidance operation were verified through vehicle testing. The results show that it is possible to reduce the driver's avoidance operation by raising yaw rate gain during avoidance steering, and the control effect which increases steering reaction torque when the steering wheel is returned to the normal position after undergoing avoidance steering.

2. Background to Development

Figure 1 shows avoidance actions taken by the driver when the driver recognizes the danger of an obstacle ahead⁽⁷⁾. It is clear that at least 90% of drivers take avoidance action by braking or steering, or a combination of the two. In addition, in circumstances where the driver does not recognize the dangerous situation and is informed of this with a warning, it has been reported that roughly 70% of drivers will respond after 1 second⁽⁸⁾. That is to say, 70% of drivers, even if they have not recognized a dangerous situation due to inattention, etc., can take avoidance maneuvers after 1 second with a warning.

In contrast, when the road surface friction coefficient is low, such as when there is compacted snow, even if the driver's own avoidance action delay is reduced with a warning as described above, avoidance maneuvers become difficult due to the large delay in the response of the vehicle itself. Moreover, when the avoidance maneuver is carried out through steering, if the maneuvers are inappropriate, the vehicle's path may become unstable (slide or spin, for example).

Vehicle stabilizing systems, such as the Vehicle Stability Assist System (VSA), operate in these kinds of situations, and have been reported as reducing accidents⁽⁹⁾. In addition, a system was made practical, providing assistance before dangerous situations described as above are reached, by proactively stabilizing vehicle motion from the normal use range⁽¹⁰⁾.

However, with this type of system, in an effort to further enhance avoidance performance, there has been no thought given to correcting driver avoidance maneuvers in relation. The reason for this is that in correcting avoidance maneuvers, it would be helpful to have outfield sensor information that fully understands the given avoidance circumstances. Accordingly, to actualize a function that assists driver avoidance operation while maintaining vehicle motion stability, vehicle motion controls that utilize outfield sensor information are necessary.

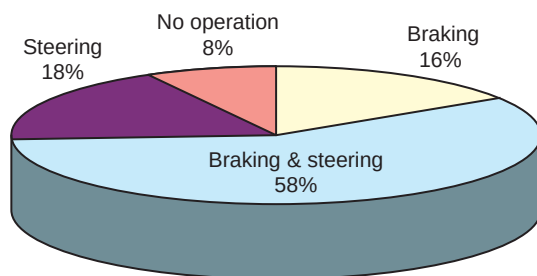


Fig. 1 Driver operation in an emergency avoidance (V=80km/h)

3. Principles of Accident Avoidance Assist Technologies

There are two ways of thinking about how to compensate for the driver avoidance operation delay. The first is a method where, in cases when the avoidance operation delay exceeds the permitted time, the system intervenes and operates before the driver carries out an operation. In this case, the operation delay can be fully compensated for, but the system's environmental recognition capability is required to be as good as that of the driver. In addition, the stronger the system's operation intervention, the greater the operational interference with the driver. This means that there is a limit to the amount of intervention. CMS utilizes automated braking in response to driver avoidance operation delay, but the scope of system operation is limited to scenarios where collisions cannot be avoided. Accordingly, expanding the system's scope of operation to a possible avoidance range will not be possible, as long as the above points cannot be addressed technologically.

Another idea to consider is to detect the driver's avoidance operation, and provide assistance in response to that operation (a driver reactive system). This is an assistance method where the main element of avoidance operation is completely the driver, and there is no means of reliably compensating for driver operational delay. However, required external sensing performance is limited, so compared to the other idea, it is more easily actualized. There are examples of actualization based on this idea⁽¹¹⁾.

In this system, based on the principle that the avoidance maneuvers are dependent upon driver actions, a system was built using the latter idea of a driver-reactive system. The goal is a reduction of collisions with obstacles by taking measures to address operational delays caused by the driver, or by a drop in vehicle dynamic response due to a low friction coefficient road.

4. Outline of the Accident Avoidance Assist System

4.1. System Configuration

Figure 2 shows the system structure diagram. The system configuration was built using existing CMS, EPS and VSA systems. The ECUs of these systems were connected through a Control Area Network (CAN), and data was transmitted.

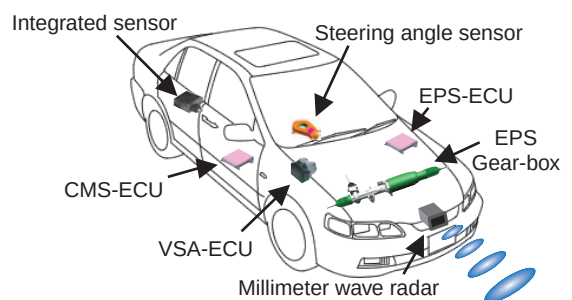


Fig. 2 System structure of obstacle avoidance operation assist system

4.2. System Function

As shown in Fig. 3, the system functions are composed of avoidance target detection, avoidance operation judgment, and avoidance operation assist control blocks.

The avoidance operation judgment block identifies an avoidance operation according to driver steering, in cases where the possibility of collision is high. The criteria value used the linear sum of the squares of steering angle and steering speed, as shown in the equation below.

$$O_t = m \cdot \theta_H^2 + n \cdot \dot{\theta}_H^2 \quad (1)$$

Here, m and n are tuning parameters, and θ_H is the steering angle.

Next, when O_t becomes higher than the specified number, it is judged that an avoidance operation has been carried out, and the avoidance operation assist control block calculates the avoidance yaw rate necessary for avoidance. At this time, if it is judged that

the avoidance operation is complete, the avoidance yaw rate is held at zero, and the avoidance operation assist ends.

4.3. Cooperation with CMS

The scope of this system overlaps with the CMS scope of operation, so it is necessary to ensure the systems do not interfere with each other. Figure 4 shows examples of function cooperation. To give priority to CMS operation, this new system does not operate when the driver takes avoidance action by braking only. However, in situations where the CMS warning braking (pre-braking) operates, when steering avoidance operation is judged, the vehicle shifts from CMS to this system, and accident avoidance operation assist control begins.

On the other hand, in situations where CMS collision mitigation braking operates, because it is not possible to avoid collision even

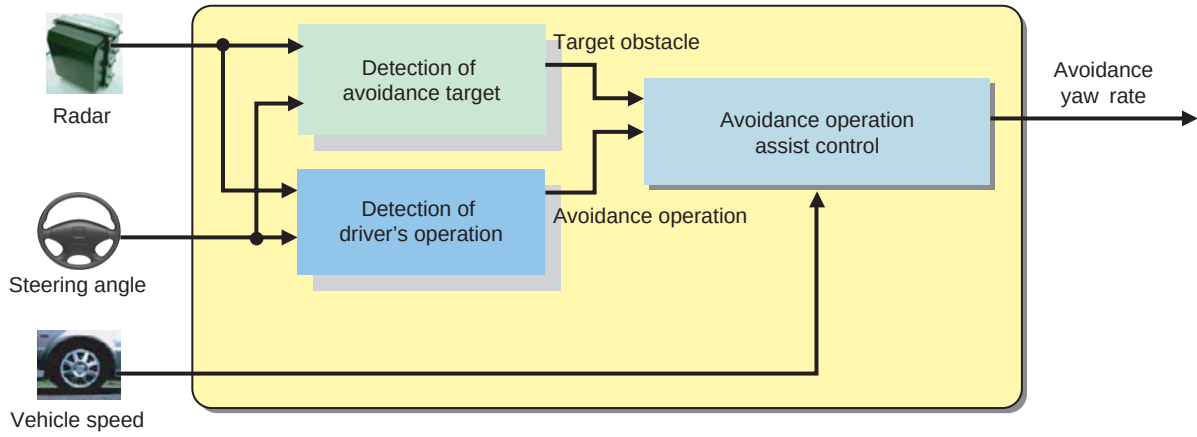


Fig. 3 Structure of obstacle avoidance operation assist function

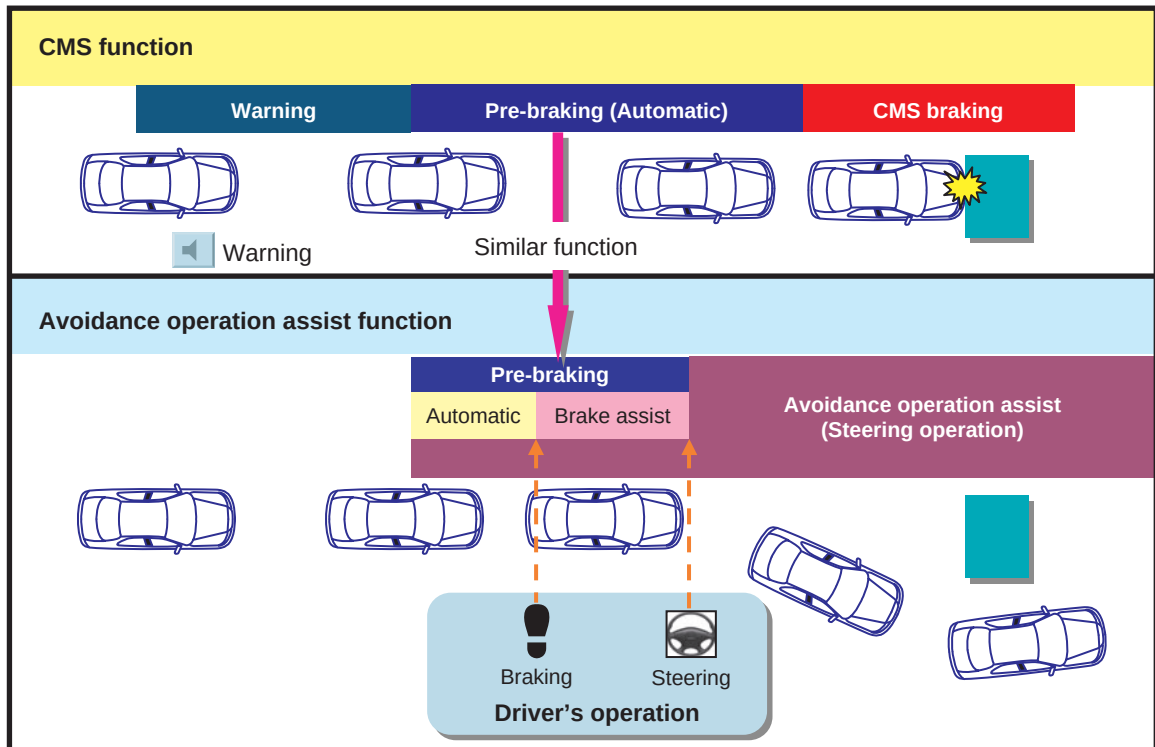


Fig. 4 Assist function comparison with CMS

with steering avoidance, even if avoidance is carried out by the driver under these circumstances, this system does not operate.

5. Design of the Avoidance Operation Assist Control System

A yaw moment control according to steering speed has been reported as a method of reducing avoidance operation delay⁽¹²⁾. In this research, studies were made of yaw moment control through braking force distribution, as a means of actualizing this method.

In contrast, focusing on steering input, steering angle, which is the amount of driver operation, and steering speed, which is the amount of system operation, are combined as inputs to the vehicle. As a result, steering input is phase lead steering (known as derivative handle). Here, studies were carried out concerning steering reaction torque control that actualizes this derivative handle.

5.1. Equivalent Yaw Inertia Moment Reduction Method

This section shows that it is possible to reduce yaw inertia equally, through braking force distribution control.

First, the relationship from yaw moment T_m to yaw angular acceleration $\gamma \cdot s$ is as follows.

$$J_V \gamma \cdot s = T_m \quad (2)$$

Here, J_V is yaw inertia moment, and s is the Laplace operator. Next, control $J_V K \theta_H \cdot s$, which generates supplementary yaw moment from steering speed, is added to Eq. (2). Doing so gives the following.

$$\gamma \cdot s = \frac{1}{J_V} (T_m + J_V K \theta_H \cdot s) = \frac{1}{J_V} T_m + K \theta_H \cdot s \quad (3)$$

In addition, the transfer characteristics from steering angle to yaw rate are defined as follows.

$$\gamma = F(s) \theta_H \quad (4)$$

Here, the following equation is determined from Eq. (3) and Eq. (4).

$$\gamma = \frac{F(s)}{J_V (F(s) - K)s} T_m \quad (5)$$

This means Eq. (5) changes yaw inertia moment as in the following equation.

$$\tilde{J}_V = J_V \frac{F(s) - K}{F(s)} \quad (6)$$

Accordingly, by setting steering speed gain K appropriately, it is possible to make the yaw inertial moment smaller.

5.2. Pseudo Derivative Handle Effect of Steering Reaction Torque

With an ordinary vehicle, it is not possible to change the front tire steering angle, independently of the driver's steering angle. Therefore, it has not been possible to actualize derivative handle unless there is an actuator system such as steer-by-wire.

Therefore, by applying steering reaction torque, derivative handle effect has been actualized by advancing the phase of the driver's steering itself.

First, the following equation is defined from the driver's steering angle.

$$S_{rto} = \alpha \cdot \theta_H + \beta \cdot \dot{\theta}_H \quad (7)$$

This is called the derivative handle ratio, and the range of the provisional value is defined as shown below.

$$-1 < S_{rto} < 1 \quad (8)$$

Here, parameters α and β are setting parameters.

Next, considering the size $d_{\max}$ of the obstacle to be avoided, the amount of lateral movement in the avoidance target is determined as shown below.

$$dist_{ref} = d_{\max} \times S_{rto} \quad (9)$$

Furthermore, if the shortest time to collision TTC that permits the driver's steering avoidance is $TTC_{\min}$, the target amount of lateral movement shown in Eq. (9) can be expressed as the lateral acceleration necessary for avoidance, as below.

$$G_a = \frac{dist_{ref}}{TTC_{\min}^2} \quad (10)$$

In contrast, the yaw rate and lateral acceleration are known to have the following relationship⁽¹³⁾.

$$G_l = V (\gamma + \dot{\beta}) \quad (11)$$

Here, G_l is lateral acceleration, V is vehicle velocity, γ is yaw rate, and β is side slip angle. At this time, assuming that the side slip angle is sufficiently small, the yaw rate required to achieve the lateral acceleration necessary for avoidance is as shown below, according to Eq. (11).

$$\gamma = \frac{1}{V} G_l \quad (12)$$

Accordingly, expressing the lateral acceleration necessary for avoidance G_a as yaw rate becomes the following.

$$\gamma_a = \frac{1}{V} G_a \quad (13)$$

By using the deviation between avoidance yaw rate γ_a obtained in this way, and the actual yaw rate, the system generates steering reaction torque so that the driver's steering amount becomes close to derivative handle characteristics.

5.3. Vehicle Stability Compensator in Avoidance Operation

During avoidance operation on low friction coefficient road surfaces, vehicle side slips tend to occur, and the relationship between the yaw rate and lateral acceleration no longer reaches the approximation of Eq. (12).

According to this formula, when control is carried out that generates a yaw rate, a large side slip angle is generated, and vehicle stability is lost.

Therefore, avoidance assist control is stopped, according to vehicle driving conditions and radar information, and a stability compensator is added to dampen the yaw rate. From the results of preliminary tests using a vehicle, the following conditions are set for the application of the stability compensator.

- When side slip is likely to occur

$$|\gamma| - |G_l| < 0 \quad (14)$$

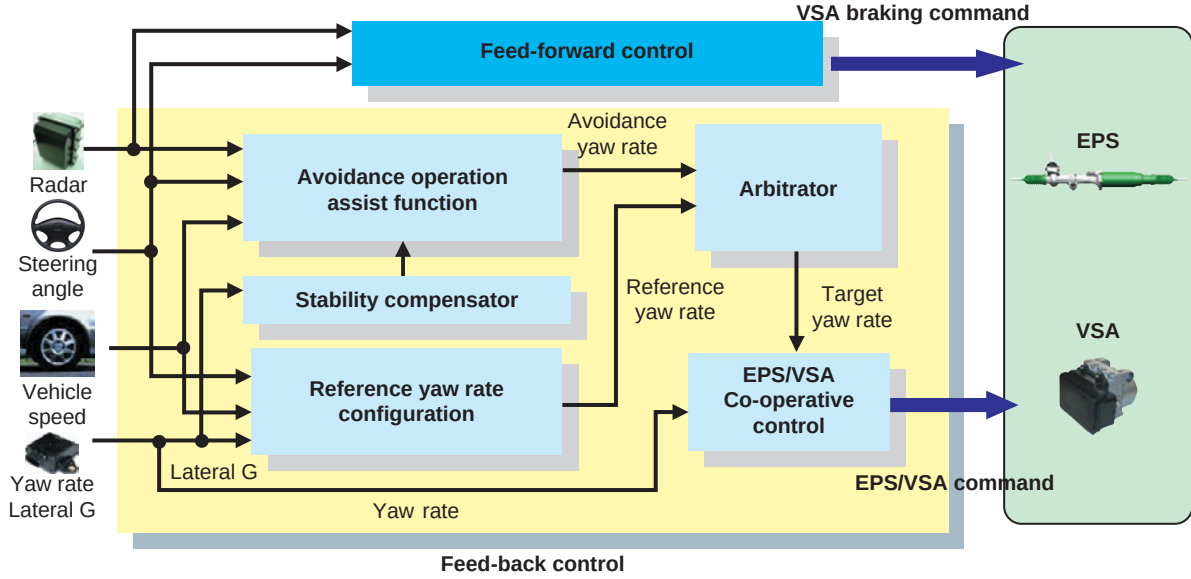


Fig. 5 Control system structure of obstacle avoidance operation assist system

- When obstacle avoidance is certain

$$|d_{ofs}| > d_c \quad (15)$$

- When it is no longer possible to detect an obstacle

$$|d_{ofs}| > L_x \tan^{-1} \theta \quad (16)$$

d_{ofs} is the offset distance detected by radar, d_c is the avoidance possibility judgment value, L_x is the distance to the obstacle, and θ is the radar detection angle. Figure 5 shows the avoidance assist control system structure, based on the principles above.

6. Actual Unit Test Results and Considerations

6.1. Test Conditions

In order to confirm system function and performance, a double lane change course was set up, as shown in Fig. 6. In addition, an avoidance scenario was established wherein the vehicle drives straight forward towards an obstacle in front, recognizes danger due to a collision warning, takes an avoidance action by braking, and then attempts avoidance by steering.

The vehicle used for testing was a 3.0L class passenger vehicle, fitted with studless tires.

Vehicle driving conditions were a road surface friction coefficient of 0.3, straight forward driving at a fixed speed of 60 km/h, and a warning occurring when the time to collision reached 3 seconds, to warn drivers of the pending collision danger. As an avoidance action, the driver took avoidance action with the brakes after the warning, and in this state, avoidance through steering was carried out 22 m (TTC=1.32 sec.) before the obstacle. The test drivers were five men between the ages of 20s and 40s, having ordinary driving skills.

6.2. Test Results

In Fig. 7, the upper row shows yaw rate response and the lower row shows steering angle during avoidance operation. These graphs

are data from the five test drivers, with and without the avoidance operation assist control. Yaw rate responses with the control were enhanced compared to without it, for all test subjects. As the arrow shows in the upper row of Fig. 7, the yaw rate gain peak value was, on average, 1.5 times larger. In addition, concerning steering delay, as the lower row of the figure shows, there were better results for all test subjects, and the time from avoidance action until the steering wheel crossed back to the neutral position was, on average, 700 ms shorter.

In Fig. 8, the upper row shows lateral acceleration response and the lower row shows steering reaction torque. As the arrow shows, there is an average increase of 0.5 m/s² at the lateral acceleration peak. In addition, a characteristic point in steering reaction torque is that, as the part surrounded by the dotted line shows, reaction is large where the steering returns from avoidance steering. This is expressed as an effect suppressing excessive steering by the driver, and an effect assisting return steering. When there is no control,

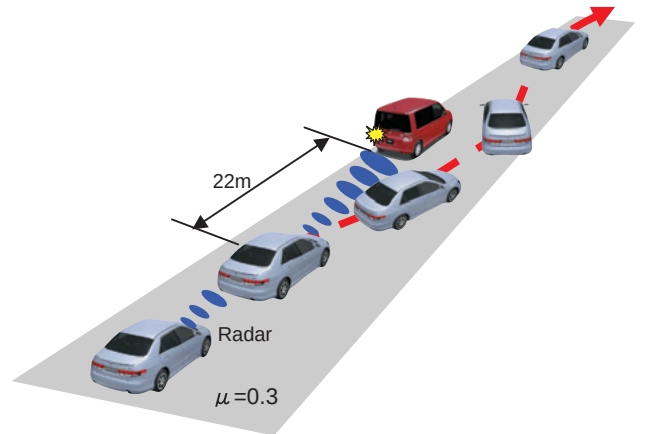


Fig. 6 Control system structure of obstacle avoidance assist system

the steering reaction torque information is not provided, and there is no change to the steering force.

Figures 9 and 10 show the test results for test driver A. These graphs plot avoidance data with and without control, five times each. Test subject A has the largest avoidance operation delay without the control, and almost all attempts at avoidance failed. However, with the control, there were great enhancements in yaw rate responsiveness and in steering delay, and moreover, as shown

by the intersection in Fig. 10, steering reaction torque was large when the steering wheel was turned back, and the reaction information effect was confirmed.

Thus, subject A was able to carry out avoidance operations equivalent to that of other subject drivers. There were no failures in avoidance in these tests.

Figures 11 and 12 show the test results for test driver B. In this case, the driver skillfully avoided the obstacles even without the

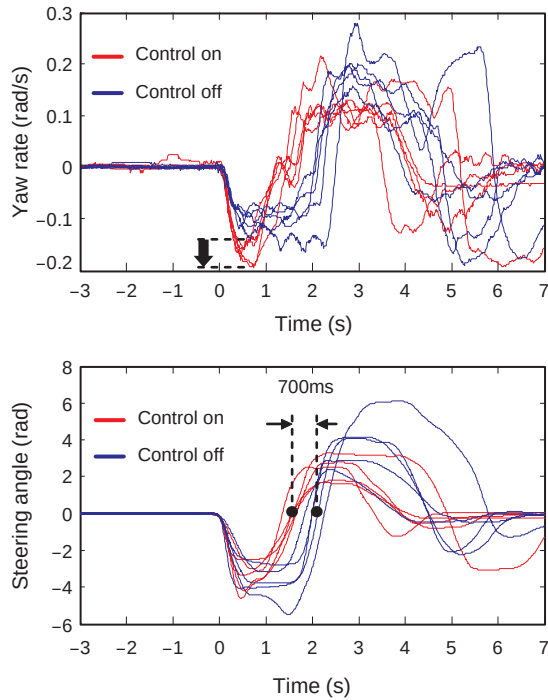


Fig. 7 Test results of total subjects

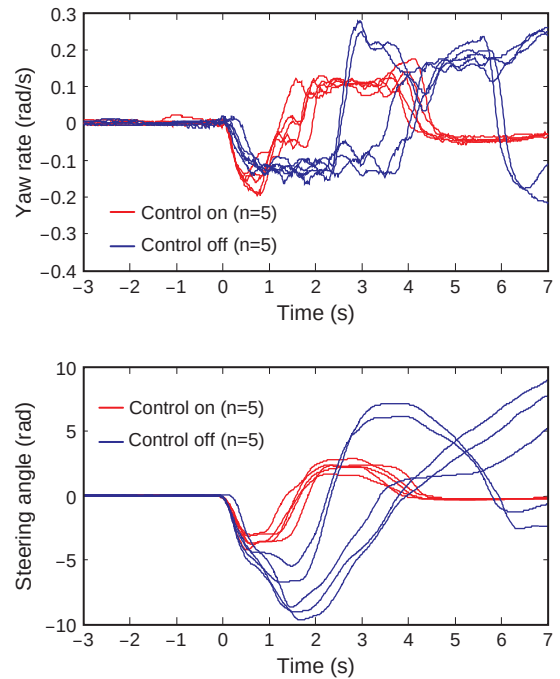


Fig. 9 Test results of subject A

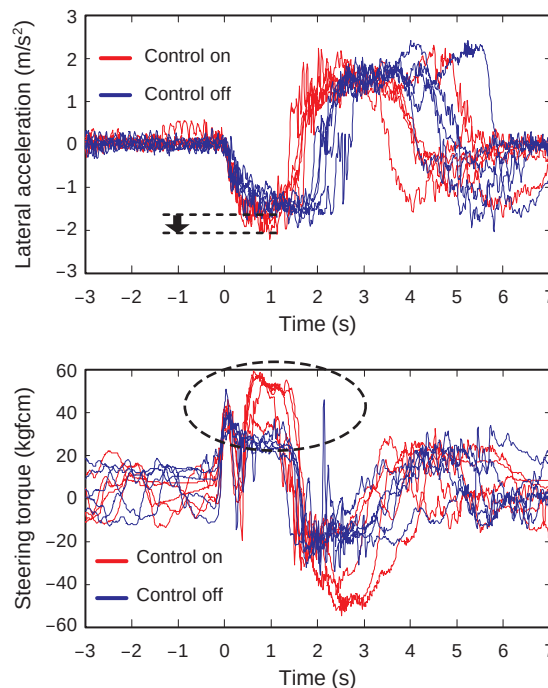


Fig. 8 Test results of total subjects

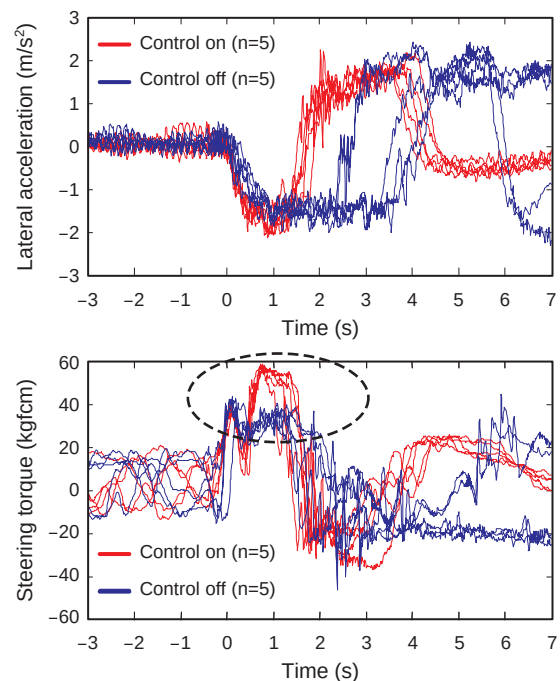


Fig. 10 Test results of subject A

control, and as a result, there was little difference in avoidance when compared to having the control. However, when questioned after the tests, the driver made the evaluation that having the control gave a clear benefit in terms of the ease of operation during avoidance.

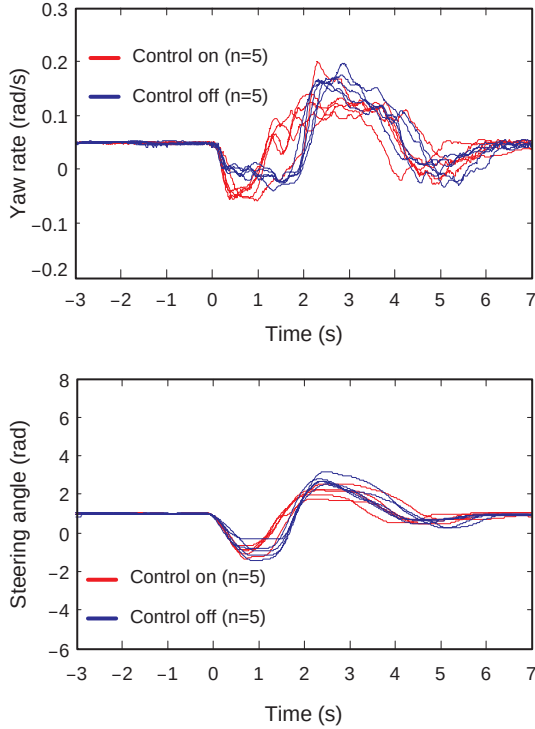


Fig. 11 Test results of subject B

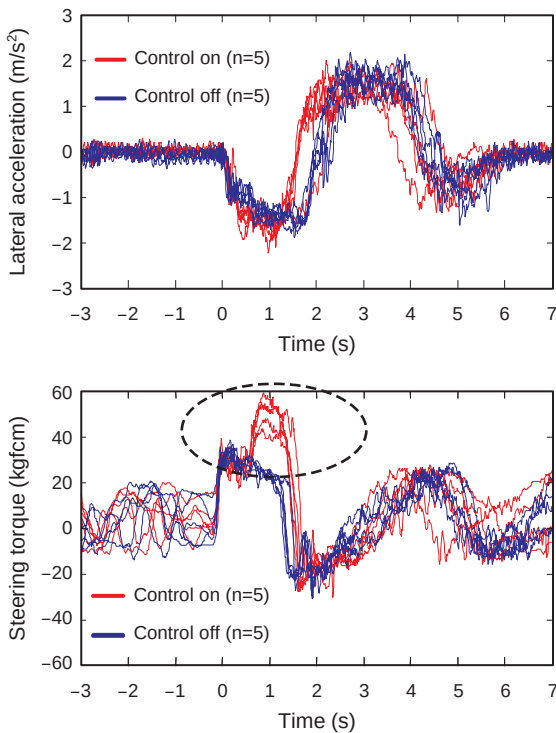


Fig. 12 Test results of subject B

6.3. Considerations

The test results confirmed the following effects.

- (1) Higher yaw rate gain
- (2) A reduction in avoidance steering delay
- (3) Steering reaction torque information against driver operation

Concerning effect (1), in comparison to when there is no control, the yaw rate gain becomes large, even if the steering angle becomes small. Furthermore, during questioning after the tests, all test drivers gave the evaluation that it was easier to steer because the feeling of under-steering was eliminated. Because there is the same effect when a vehicle's yaw inertia moment becomes small, it was verified that the equivalent yaw inertia moment reduction method was appropriate.

In contrast, concerning items (2) and (3), there were beneficial effects on driver steering delay. Here, even test drivers who failed to avoid obstacles without the control, succeeded in avoiding them with the control. This system gave more benefit to those drivers with long steering delays (those with only ordinary skills), than to those with higher skills.

From the above results, it is clear that this system has sufficient benefits as assistance in avoidance operations in the driver-vehicle system. However, there is little difference in the collision avoidance success rate, with or without the control. In order to enhance collision avoidance performance, even more progress is needed in external sensing and in vehicle control devices (for example, steer-by-wire, etc.).

7. Conclusion

This paper has studied systems assisting operations avoiding forward obstacles, and confirms the benefits of the avoidance operation assist function, through vehicle tests. The results of this project are summarized below.

- (1) Generating yaw moment through brake force lateral distribution control, in response to steering speed, enables vehicle yaw inertia moment to be reduced equally, thereby increasing vehicle yaw rate responsiveness during obstacle avoidance.
- (2) An assist benefit was confirmed in reducing driver operation delay by setting the avoidance target yaw rate on the assumption of derivative handle input and using EPS reaction torque control.
- (3) The results of an avoidance test using a double lane change task confirmed that the greater the driver's steering delay (of drivers with only ordinary skills), the greater the system benefit.

References

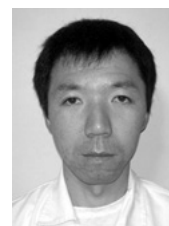
- (1) Mashimo, H., Furukawa, Y., Asanuma, N., Fukumaru, T., Kaseyama, H.: Introduction of Honda ASV-2 for Roadway-vehicle Coordination Systems (Passenger car), Honda R&D Technical Review, Vol. 13, No. 2, p. 1-6 (2001)
- (2) Nonaka, M., Igaki, M., Hori, Y.: Advanced Safety Vehicle TOYOTA ASV-2, TOYOTA Technical Review, Vol.15, No. 1, p. 42-47 (2001)
- (3) Yasuda, T., Obara, H., Matsumoto, S.: Outline of Nissan ASV-2, NISSAN TECHNICAL REVIEW, No. 48, p. 57-60 (2001)
- (4) Suzuki, T., Takahama, T., Kimura, T., Matsumoto, S., Naito, G.: The Development of a Braking Control System for

- Collision Avoidance Assistance, JSAE Annual Congress Proceedings, No. 114-02, p. 13-16 (2002)
- (5) Kodaka, K., Sugimoto, Y., Otabe, M., Ichikawa, S., Urai, Y.: Rear-end Collision Velocity Reduction System, Honda R&D Technical Review, Vol. 13, No. 1, p. 159-166 (2001)
 - (6) Takahashi, J., Sato, M., Horiuchi, S.: Evaluation of New Derivative Steering System using A Driving Simulator, JSAE Kanto Branch Conference Proceedings (2003)
 - (7) Yamamoto, A.: Improvement of Accident Avoidance Performance Considering Driver-Vehicle System, Journal of Society of Automotive Engineers of Japan, Vol. 49, No. 12, p. 10-15 (1995)
 - (8) Kamiji, K., Kodaka, K., Akaba, H.: Development of Honda Precrash Safety Technology, Honda R&D Technical Review, Vol. 16, No. 2, p. 115-120 (2004)
 - (9) Inagaki, S.: Improvement for Active Safety Performance of Toyota VSC (Vehicle Stability Control), Journal of the Japan Society of Mechanical Engineers, Vol. 106, No. 1012, p. 154-155 (2003)
 - (10) Hattori, Y., Koibuchi, K., Yokoyama, T.: Vehicle Dynamics Management by Nonlinear Optimizing of Each Tire Force, JSAE Annual Congress Proceedings, No. 10-02 (2002)
 - (11) Ichikawa, K., Matsuura, M., Tomioka, K.: Development of Preview Controlled VDC, SUBARU Technical Review, Vol. 28, p. 115-120 (2001)
 - (12) Doi, S., Nagiri, S., Amano, Y.: Analysis of Active Safety Performances of Automobile Based on Driving Maneuvers in Emergent Situations, R&D Review of Toyota CRDL, Vol. 33, No. 1, p. 31-38 (1998)
 - (13) Abe, M.: Jidosya no Undou to Seigyo, Second Edition, p. 55 (2003) (in Japanese)

■ Authors ■



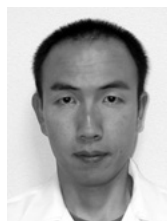
Yukihiro FUJIWARA



Kenichi OHSHIMA



Yasushi SHODA



Mitsuharu KANABOSHI