Research of Minimize Steering Grasping to Take over Driver from System in Advance Safety System

Shotaro Odate
Naohiro Sakamoto
Honda R&D Co., Ltd Automobile R&D Center

Paper Number 19-0039

ABSTRACT

Advances being made today in electronic technology are evolving the processes that make vehicles more intelligent, in addition to realizing safer and more comfortable driving. Lane departure prevention systems are also becoming practical due to millimeter-wave radar and onboard forward observation cameras. The U.S. Department of Transportation has implemented a National Automotive Sampling System Crashworthiness Data System (NASS/CDS) for North America that found 10,743 accidents in 2016 involved departure from the road. There were 12,043 fatalities in these accidents. Lane departure prevention systems are expected to make a major contribution to reducing accidents of this kind. Advances are also being made in the development of systems that will enable autonomous driving, and the system to ensure safe and comfortable vehicle operation is being developed.

These systems embody great potential for reducing the number of accidents caused by road departure. However, the validity of the systems is largely dependent on the level of acceptance by drivers. System validity will be determined by when they provide driving assistance, how much relaxation will be permissible on the driver's side, given that the driver needs to maintain contact with the steering wheel, and the extent of assistance provided by the system.

This paper will discuss research on the minimum necessary contact and contact strength with the steering wheel on the part of the driver when the autonomous system is in operation. Using a six-axis driving simulator employing an actual vehicle, the research conducted tests involving 22 test subjects, and studied the relationship between the status of the driver's contact in terms of steering angle speed and steering angular velocity and vehicle behavior when the system failed. The authors analyzed the influence on avoidance behaviors depending on the state in which the steering is held or not grasped when a person performs avoidance behavior.

When the steering torque activates, such as in a curve, the reaction will be faster if drivers touch the hand. In the case of a straight road with no steering torque activating, the result of the difference in reaction time depending on whether they are gazing at the front, regardless of grasping or non-grasping, has been clarified from this research.

INTRODUCTION

The advances being made in electronic technology today are causing evolution in the processes of making vehicles more intelligent. This is realizing greater safety and comfort in driving. In addition, millimeter-wave radar and forward-mounted cameras for observing the area around the vehicle are making lane departure prevention systems feasible. The US Department of Transportation has implemented a National Automotive Sampling System Crashworthiness Data System (NASS/CDS) that found 10,743 accidents in 2016 involving departure from the road [1]. These accidents involved 12,043 fatalities. It is expected that lane departure prevention and autonomous traveling system recognizing the lane's white line by the camera and performing autonomous operation will greatly contribute to this type of accident reduction (Figure A). Advances are also being made in the development of systems that will enable further automated autonomous driving, and the system to ensure safe and comfortable vehicle operation is being developed [2]. The evolution of this kind of advanced safety system, however, is raising concerns that drivers may feel excessively confident in the safety systems so that they take their hands off the steering wheel and stop paying attention while the systems are providing driving assistance [3]. Furthermore, In the event of a malfunction in a part of the safety system, it is necessary to immediately return the responsibility of the vehicle to the driver, but there is a possibility that the driver may not be able to respond adequately. For this reason, sensors to detect steering wheel operation by the driver are becoming increasingly important. The authors employed a six-axis driving simulator located at the Automobile R&D Center of Honda R&D Co., Ltd., to investigate the situation when an advanced safety system experiences a failure during operation so that responsibility is passed from the system to the driver. The extent of driver hand contact with the steering wheel that is needed in order to enable the driver to operate the vehicle correctly after such circumstances have occurred was clarified, and the least amount of grasp needed on the steering wheel was investigated.

System features

Figure B shows the layout and configuration of the steering wheel system developed for this research. The static capacitance sensor is used to determine whether or not the driver is grasping the steering wheel. Human hands have capacitance like that of a capacitor. By detecting this capacitance, the system can determine whether or not the driver has a hand or hands on the steering wheel (Figure B).

Methods

As far as the authors have ascertained, the driver modeling literature indicates that there are numerous factors involved in driving but sufficient attention in computer simulation [4,5]. There are almost no examples of simulations using complete models, but the existing models are able to be modified by incorporating insights from psychophysical and physiological research. In addition, the advancements that have been realized up to the present are in sensor technologies. Therefore onboard electronics make it possible to develop workable models [6,7].

Test subject

Twenty-two people who have driving licenses participated in the simulation tests. The test subjects ranged in age from their 20s to their 60s. In order to enable investigation of the question of whether there is a relationship between contact of the driver's hand with the steering wheel and the driver's grip strength, each driver's grip strength was measured (Table 1). The data acquired also included vehicle speed, steering angle, amount of braking, amount of acceleration, yaw rate, and steering torque (Figure E).

Data weighting

In order to eliminate the deviation of the measured data, we assumed that the reaction time would be earlier if the grip strength of the subject was high, and weighted the measured data using the normal distribution of Japanese grip strength.

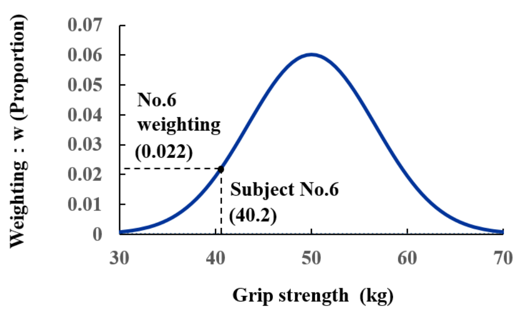
Table 2. Normal distribution of Japanese grip strength [8].

N=72,157

	Grip strength (kg)			
	Male		Female	
Age	Average	Standard deviation	Average	Standard deviation
20-24	48.92	6.83	29.09	4.67
25-29	49.17	6.95	29.51	4.74
30-34	50.33	6.83	30.23	4.56
35-39	50.01	6.64	30.58	4.49
40-44	49.21	6.33	30.47	4.65
45-49	48.07	6.26	29.74	4.74
50-54	46.72	6.05	28.21	4.38
55-59	44.72	6.23	27.12	4.18
60-64	42.24	6.14	25.65	4.14
65-69	38.44	5.84	24.04	4.46
70-74	36.2	5.67	22.8	4.3
75-79	33.53	6.14	21.22	4.32

Assuming that the distribution is a normal distribution in table 2, weighting the individual's grip strength from the grip strength data of the whole country and add it to the result. As a calculation example, calculate with subject No. 6 as an example in the table 1.
Where, W is the weighting data, f is the function of normal distribution.
These are then substituted in the defined equation:

$$
\begin{aligned}
W &= f(Ave, Nomal\ deviation, Grip\ strength\ ) \\
&= f(50.01, 6.64, 40.2) \\
&= 0.022
\end{aligned}
$$



Where, i is the subject, n is the number of subjects, gi is the grip strength of the subjects, W(gi) is the weighting, RTi is the reaction time. RT is the result.

$$
RT = \frac{\sum_i^n \left(W(gi)\right) \times RTi}{\sum_i^n W(gi)}
$$

Simulation apparatus

Data was collected using a full motion simulator located at Honda's Tochigi Automobile R&D Center, an apparatus capable of conducting advanced simulations. This simulator surrounds an actual vehicle with a dome-shaped screen, and allows measurements to be conducted while a projector reproduces video images around the vehicle. In order to realize an environment in which the driver can believe that they are actually operating the vehicle, the system is able to move on six axes to reproduce vehicle behavior. The vehicle employed in the measurements was a 2013 model year Honda legend (powertrain : Hybrid). Test subjects' manual contact with the steering wheel, the steering angle, and steering torque were measured (Figure F). The measured data was obtained using the vehicle's CAN. The vehicle's meters were modified, and warnings were provided to drivers via a liquid crystal panel, to help ensure that they were easy to understand (Figure G). These modified meters alerted drivers with takeover warnings in visual and audio form (Figure H).

Procedure

After having their grip strength measured, test subjects were provided with preliminary explanations and a discussion of informed consent, followed by a presentation explaining test procedure. The test subjects completed a five-minute practice drive on was a high-speed road used for test driving consisting of a straight section, a junction, and a curve. A light volume of traffic was also present on the road in order to allow the test subjects to get used to the simulator environment, but no events involving the safety system occurred during the practice drives. Following the practice drive, the test subjects ran through the test course using five patterns of manual contact with the steering wheel (contact with one finger, two fingers, three fingers, one hand, and no hands), and measurements were conducted of the extent to which the test subjects were able to operate the steering wheel when the request to take over operation came from the system. Although the method of holding the steering wheel is designated, even at the time of one finger, since the evasive behavior after that is avoided in a manner easy for the subject to perform, it is considered that there is no influence. In order to simulate distracted driving, the same tests were conducted with the navigation system in operation. Considering the possibility that drivers would become used to the requests to take over vehicle operation if they always came at the same time, measurements were conducted with requests made randomly, with and without any event having occurred. Each drive continued for approximately 30 minutes. The requests to take over control of the steering wheel are randomised in time with no reference to any external events. Test subjects were instructed to drive normally, observing the speed limits (Figure 8). The vehicle is traveling on a Highway at 100 (km/h), and enters a junction in order to take a new route. The vehicle reduces its speed to 60 (km/h) in order to negotiate the curve. As the vehicle is rounding the curve, automated driving systems suddenly fail and steering control is lost. the driver performs an emergency avoidance maneuver (Figure I).The vehicle is following a preceding vehicle at 100 (km/h) on a highway. The speed of the preceding vehicle suddenly drops, and the distance between the vehicles is reduced. At the same time, automated driving systems suddenly fail, and accelerator and brake control are lost. The driver conducts an emergency avoidance maneuver. In order to regulate the method used to avoid danger, the drivers were instructed in advance to use the steering wheel for this maneuver (Figure J). Even when the operating the navigation system, the same test cases were carried out as in the case of straight running and curved driving (Figure K).

Result

- When driving behind a vehicle ahead, delays were not observed in the reaction time from the termination of autonomous driving until avoidance was initiated, even when the driver's hands were off the wheel, except when the driver was operating the navigation system. Other than that, no differences were seen, including when the hands were not grasping the wheel when driver's hands were in the lap (Figure 1).
- When driving behind a vehicle ahead, the steering angle velocity in steering wheel operation following the termination of autonomous driving tended to be greater when the driver's hands were off the steering wheel than when the hands were touching the steering wheel. When the hands were off the steering wheel, whether they were in the driver's lap or operating the navigation system did not affect the result. In either case, the steering angle velocity grew greater in the same way. When the driver's hands were in contact with the steering wheel, the steering angle velocity exhibited the same tendency regardless of whether the driver was grasping the steering wheel, pinching the wheel with the fingers, or touching the wheel (Figure B).
- The reaction time from termination of autonomous driving until avoidance was initiated when driving through a curve was faster when the driver was touching the steering wheel than when the driver's hands were off the steering wheel. The reaction time grew even faster when the grasp was in the form of pinching the wheel with three fingers or grasping the wheel with one hand (Figure 3).
- When grasping the wheel with one hand or having one finger in contact with the wheel, the reaction curve described a small circle and avoidance was accomplished with minimal steering wheel operation. When the driver was not grasping the steering wheel, that circle grew larger and the driver would operate the steering wheel more than needed for avoidance (Figure 4,5,6).

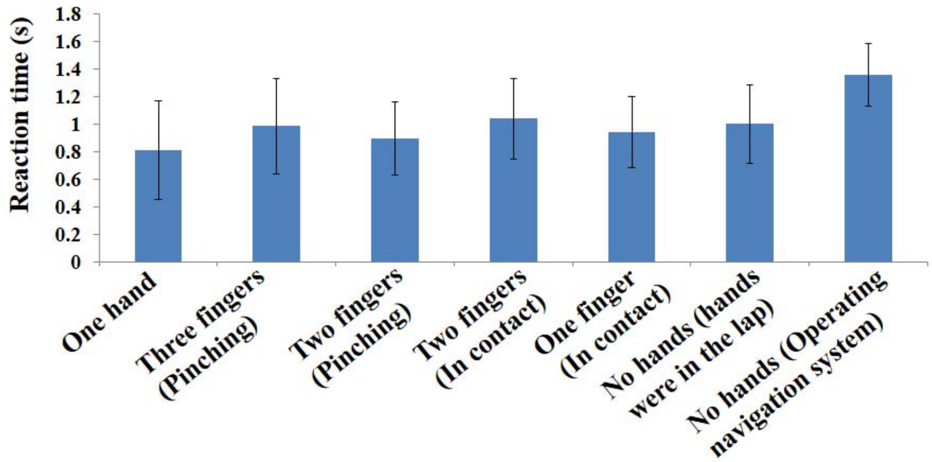


Figure 1. Reaction time from completion of automatic operation to avoidance start

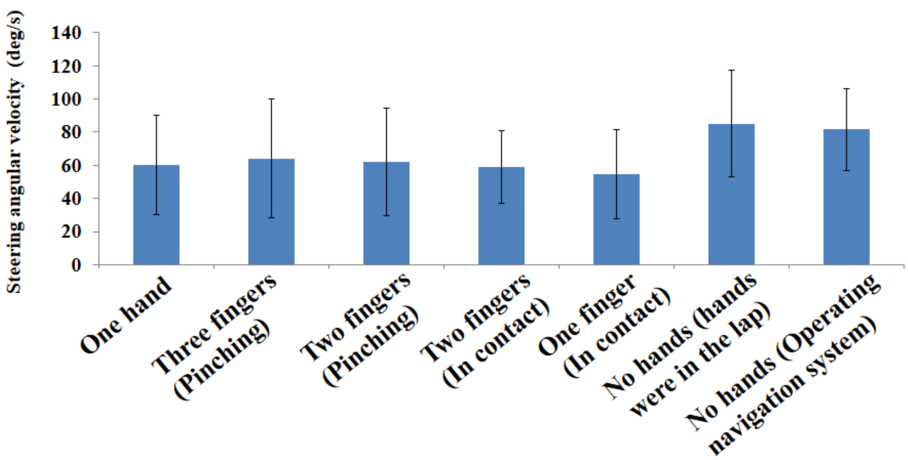


Figure 2. Steering operation during follow-up driving

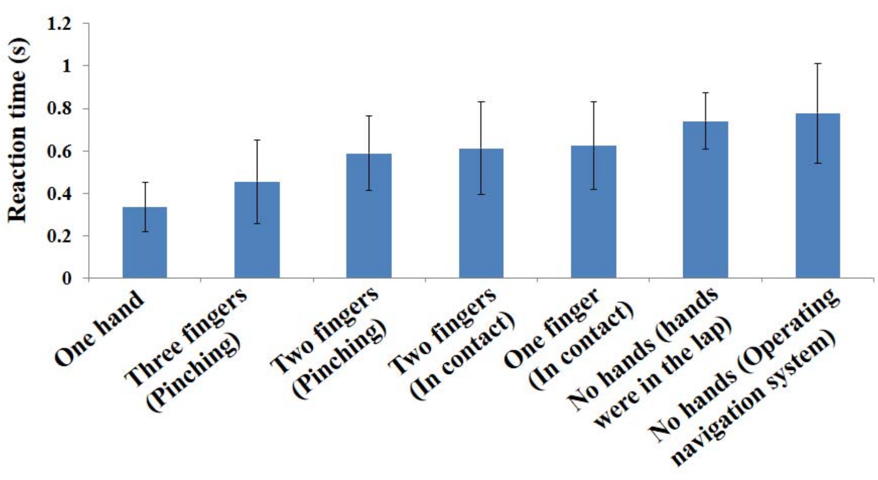


Figure 3. Time from completion of automatic operation in curves to start of avoidance

In order to judge the steering operation amount of the driver, the relation between the steering angle and the steering angular velocity was measured. When the reaction time is early, since the steering operation amount is accurately performed quickly, both the steering angle and the steering angular velocity become small, and the curve also draws a small circle. Also, when the reaction time is slow, the steering operation amount increases and the steering angle and the steering angular velocity show large values, so the curve becomes large.

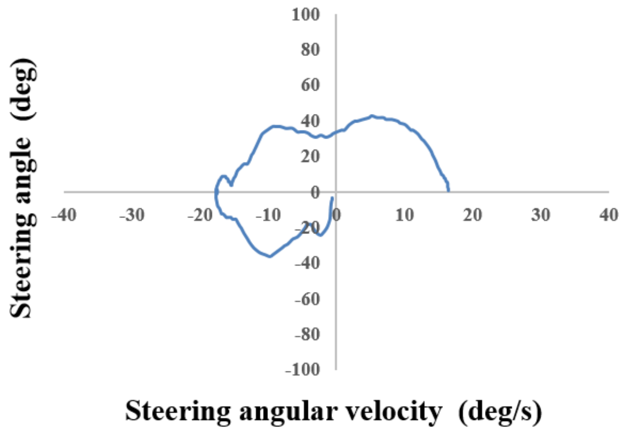


Figure 4. Steering operation when holding with one hand

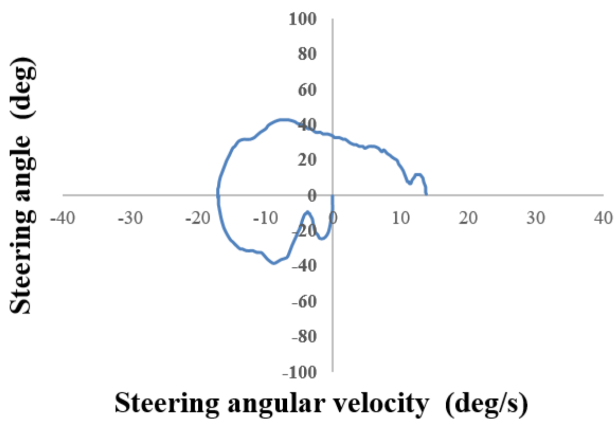


Figure 5. Steering operation at one finger

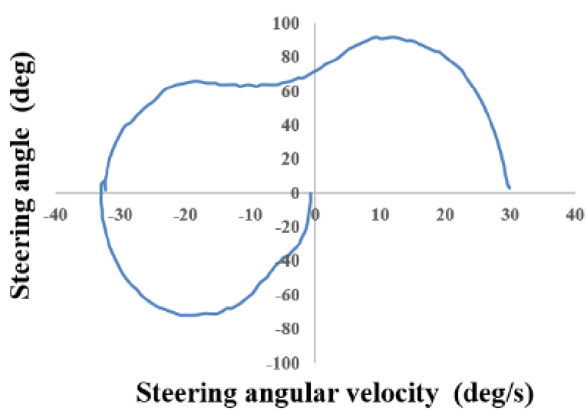


Figure 6. Non-gripping (state where hands are placed on knees)

Discussion

- The reaction time following the termination of autonomous driving when driving through a curve is thought to be faster when the driver's hand is in contact with the steering wheel because the steering wheel reaction force that occurs when autonomous driving cuts out can be felt by the tactile sense, and this enabled faster reaction than to sound or light.
- When driving behind a vehicle ahead, the reaction time from termination of autonomous driving until avoidance was initiated was the same whether the driver's hands were off the steering wheel or simply resting on the driver's lap with the driver looking to the front, and when the driver was in contact with the steering wheel and similarly looking to the front. However, when the driver was operating the navigation system, not only was the driver's hand touching it, but the driver's gaze was also directed toward the navigation system or control panel. This is thought to be the cause of the delay in reaction to the vehicle ahead.
- When driving behind a vehicle ahead and the status of steering wheel operation was suddenly changed from having the driver's hands off the steering wheel to operating the steering wheel, there was a visible tendency for steering wheel operation to become rough or uneven (the steering speed became faster). If the driver had even just a single finger in contact with the steering wheel, then the steering wheel was operated in the same way as when grasping the steering wheel with one hand. This suggested that having even slight contact with the steering wheel means that there is some readiness in the driver's consciousness to engage in operation.
- When the driver's hands were off the steering wheel, resumption of steering for avoidance sometimes involved sudden operation of the wheel. Therefore it appears advisable to provide a period of several seconds for the driver to have contact with the steering wheel before autonomous driving is terminated. However, the testing reported here did not include testing of how many seconds in advance would be desirable or what kind of human machine interface (HMI) should be used to notify the driver. The authors hope to pursue research from that perspective in the future.

Conclusion

Simulation tests were conducted in order to study the effect of the drivers' manual contact with the steering wheel. The following results were obtained ;

(1) The reaction time from termination of autonomous driving until avoidance was initiated when driving through a curve tended to be faster when the driver was in contact with the steering wheel than when the driver was not grasping it. Also, a trend toward even faster reaction times was observed when the driver was grasping the steering wheel by pinching the wheel with three fingers or grasping the wheel with one hand.

(2) The reaction time from termination of autonomous driving until avoidance was initiated when driving behind a vehicle ahead showed delays only when operating the navigation system, even when the driver's hands were off the steering wheel. Otherwise no difference was observed, including when the driver was not grasping the steering wheel (hands resting in the driver's lap).

(3) Steering wheel operation from termination of autonomous driving until avoidance was initiated when driving behind a vehicle ahead tended toward greater steering angle velocity when the driver's hands were off the steering wheel than when they were in contact with the steering wheel. When the driver's hands were off the steering wheel, the result was not affected whether the hands were in the driver's lap or operating the navigation system. In either case, the steering angle velocity grew greater in the same way. Also, when the driver was touching the steering wheel, the steering angle velocity tended to exhibit the same tendency whether the driver was grasping the steering wheel, pinching it with the fingers, or in contact with it.

References

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APPENDIX: TABLES AND FIGURES

Table 1. Subject details

No.	Age	Gender	Grip strength (Right) : kgf	Grip strength (Left) : kgf	No.	Age	Gender	Grip strength (Right) : kgf	Grip strength (Left) : kgf
1	Late 30s	Male	52	54.1	12	Late 20s	Male	45.9	52.1
2	Early 30s	Male	49	49	13	Early 30s	Male	47.4	43.8
3	Early 20s	Male	47.2	53.1	14	Early 30s	Male	48.1	44.1
4	Late 20s	Male	52.3	44	15	Early 60s	Male	35.6	29.3
5	Early 30s	Male	42	36	16	Early 30s	Male	48.2	40.6
6	Late 30s	Male	40.2	35.5	17	Late 30s	Female	26.9	27
7	Late 30s	Male	43.9	38.7	18	Early 30s	Male	48.7	42.6
8	Early 50s	Male	51.2	41.7	19	Early 30s	Male	59	52.8
9	Late 30s	Male	37.9	38.1	20	Late 50s	Male	48.6	54.9
10	Late 20s	Male	36.5	32.8	21	Late 20s	Male	37.5	33.9
11	Early 30s	Male	34.3	35.4	22	Early 30s	Female	33.6	32

Figure A. Image of the advanced safety system recognizes the white line on the road

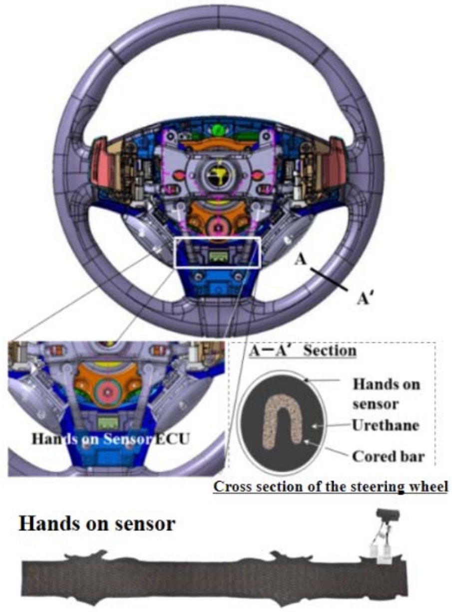

Figure B. Layout of Hands on sensor ECU

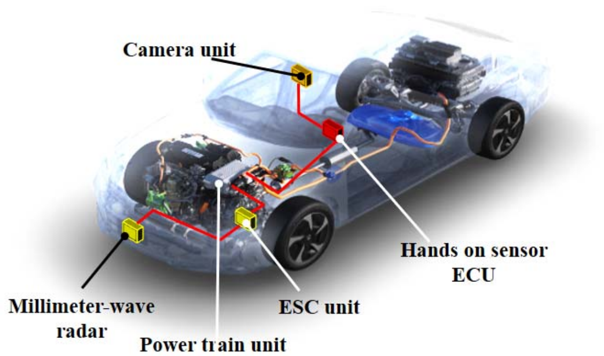

Figure C. Concept diagram of the system operation

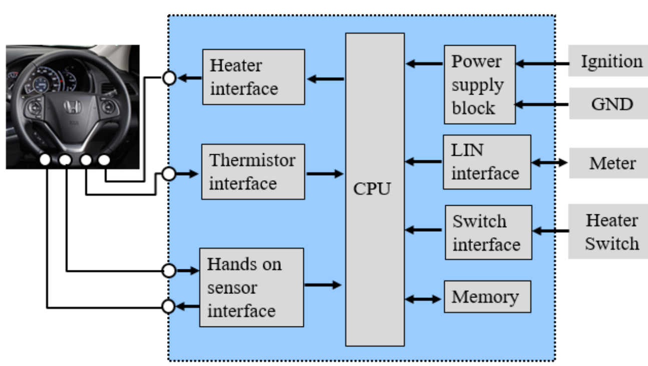

Figure D. System configuration diagram of hands-on sensor

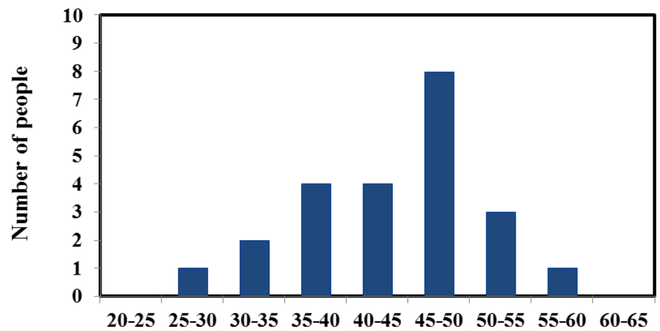

Figure E. Subject distributions

Figure F. Simulation equipment for this study

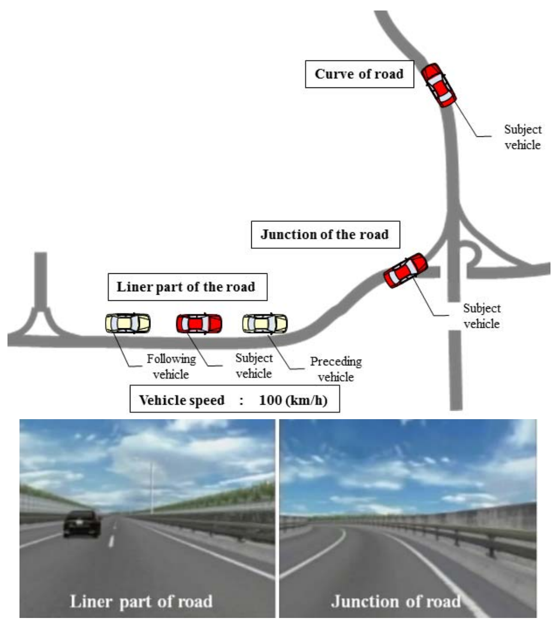

Figure G. Course of simulation

Figure H. Status of assumed steering grasping (The environmental conditions are measured at a temperature of 25 ° C and a humidity of 50%).

Figure I. Simulation with curve

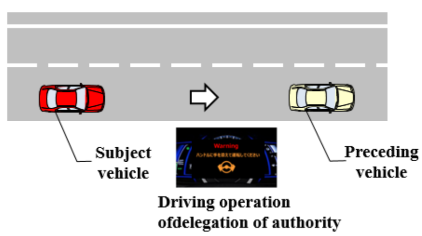

Figure J. Simulation on straight road

Figure K. The driver is manipulating the navigation