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Self-Driving that Keeps Drivers in Peace of Mind – Appropriate Distance from Walls –

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***Abstract*—**We address the satisfactory of the driver who is boarding on a self-driving vehicle. Even if self-driving control is perfectly safe, the driver may take anxiety caused by the duration between a vehicle and a wall. We proposed experimental environment and procedure that are able to reveal the boundary condition of satisfied duration between a self-driving vehicle and a wall. The boundary condition gives an idea to make more robust self-driving against the difference of environments. We conducted a psychological experiment for 21-22 aged 6 male Japanese participants who have Japanese driving licenses using the proposed environment and procedure. In this experiment, the limitation of vehicle's state in that all of the participants do not want to drive a vehicle by himself/herself instead of a self-driving system was examined. As a result, the participants were satisfied when the vehicle is away more than 1.186 m from the wall at the condition of 60 km/h and 3.9 m lane width. The proposed environment and procedure are applicable to many other conditions to reveal the limitation of satisfactory about the distance between a vehicle and a wall. When the all of the limitations will be researched, we can develop a vehicle that satisfies its driver. The driver will not feel to drive the vehicle by himself/herself instead of a self-driving system.

***Keywords*—**Safety, satisfactory, self-driving, psychological experiment, boundary condition.

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I. Introduction

SELF-DRIVING is a big upcoming technology in recent years. In this paper, we address peace of mind in self-driving through psychological experiments.

The system and technology for the safety of self-driving have been improved. Berger *et al.* proposed commercial-off-the-shelf (COTS) architecture [2]. Seo *et al.* developed a lateral-localization image-processing system for the estimation of vehicle's state [11]. Mladenovic *et al.* investigated an agent based vehicle control model [8]. Seo *et al.* realized a highway work zone recognition system that is based on the image processing for the traffic signs on highways [10]. Ximin *et al.* implemented an in-vehicle information system that supports human machine interaction [14]. Intelligent Transport Systems (ITS) is also expected to improve the safety of self-driving vehicles [1]. These researches are focusing on the improvement of the safety of self-driving vehicle on the basis of devices.

In order to assure safety, psychological researches for the drivers are also important. Goodall made a question whether self-driving vehicles are able to have the ethics like human [3]. Yang *et al.* discussed the in-vehicle technology that supports aging drivers including cognitive functions [15]. Howard *et al.* investigated the public opinions about self-driving vehicles [4]. Tanaka *et al.* developed a passenger robot in order to investigate the psychological effect of a car interface [13]. Sümer *et al.* revealed the asymmetric feature between driving and safety skills [12]. Imamura *et al.* developed a psychological experiment device by focusing on driver's workload, mental condition, and skill [5]. Especially, Zhong-hua *et al.* modeled the stress around braking pedal velocity [17]. These researches revealed the safety of driver on the basis of technologies and mental of drivers.

After safety is assured, comfortless and satisfactory are the next problems, although there is a small number of a research currently. Luo focused on comfortable driving [6] and developed a self-driving model that controls an automobile considering the distance from a forward vehicle using model predictive control. Luo's work is supported by several researches too [7,9,16]. However, there has not been any research about satisfactory distance from a wall that is placed at a side of a vehicle.

We propose a psychological experimental environment and procedure that are able to obtain the limitation of the distance between a self-driving vehicle and a wall on the basis of the satisfactory of drivers. In the experiment, 21-22 aged 6 participants drove a self-driving vehicle in a simulator. As an experimental result, the limitation distance from the wall was 1.186 m on the condition of straight road, driving velocity of 60 km/h, and lane width of 3.9 m.

This paper is organized as follows. We propose the environment and procedure in Section 2. The proposed environment and procedure are applied to experiments in Section 3. Discussion is given for the results of the experiments in Section 4. In Section 5, we conclude this study.

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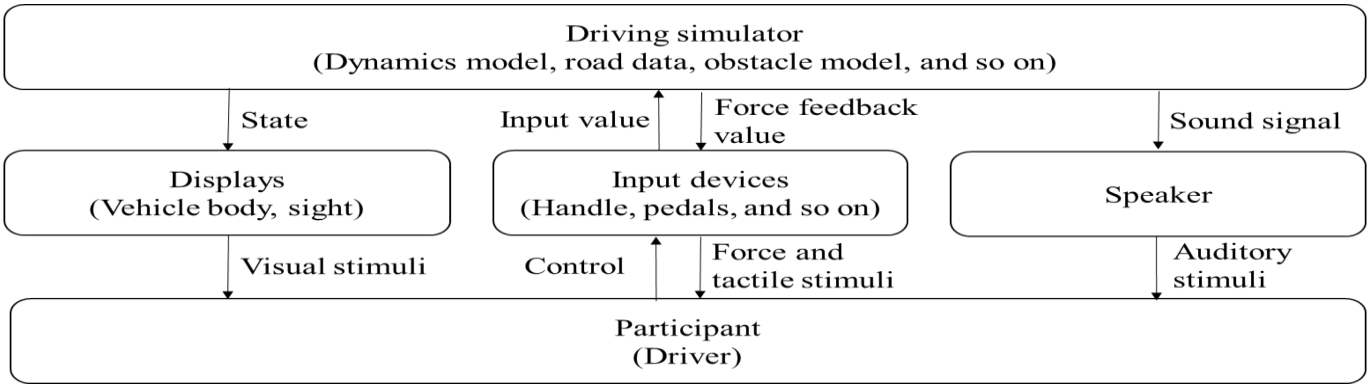

Figure 1 Block diagram of experimental system

II. PROPOSITION

Satisfactory of drivers is an important issue in order to apply self-driving system to actual emvironment. There are many reasons of the anxiety of a driver as listed below:

- Fast driving
- Low visibility (rain, night driving, obstacles, and so on)
- Sudden braking
- Accession to a guardrail or a wall

Even if the drivers know thier vehicles are safe, they might not satisfied under such conditions. Satisfactory is much related to the design of a control system. From the view point of the development for the control system of a self-driving vehicle, we must take into account the above mentioned factors as boundary conditions.

Especially, the anxiety about the accession to a guardrail or a wall decides the width on a load in that self-driving system is accepted by a driver. If accepted width is quite narrow, we might not able to design the rules of self-diving control. In this paper, we use the term satisfactory/satisfy for the state in that a driver does not want to control a vehicle by himself/herself instead of a self-driving system.

We developed an experimental environment on a simulator. On the development of the experimental system and procedure, there are mainly two different methods, a real vehicle or a simulator. The benefit of a real vehicle is a high reality that is related to an actual use. However, the experiment besides a guardrail or a wall using self-driving control has the risk of accidents. We need a much expensive system that is able to avoid the risk. On the other hand, driving-simulator assures the safety while an experiment. Moreover, we can easily obtain data such as the distance from a wall, velocity, control timing, and so on

A. *Experimental system*

We developed an experimental system in **Figure 1**. The main body of the experimental system is a driving simulator that includes dynamics model, road data, obstacle model, and so on. For the simulator, we used CarSimDS developed by Mechanical Simulation Corporation.

In order to give visual stimuli to participants, we used three displays with 40 inch as in **Figure 2**. Visual noise was shut out using a blackout curtain. Input devices were attached on a desk and floor. These devices feedback force and tactile stimuli against the participant. Especially, the handle makes force feedback according to the state of the vehicle through an embedded motor. Also, sound signal was expressed from the computer placed blow the desk.

Figure 2 Overview of experimental system

B. *Proposed experimental environment*

We developed an experimental environment that allows an effective data acquisition from the participants in order to measure the distance from the wall that may give anxiety for a participant.

1) Simulated vehicle moves forward automatically in a constant velocity
2) The vehicle gradually comes close to a wall
3) Participant is able to control the steering in order to avoid the wall (while a participant is controlling the vehicle, steering control is not automated)
4) When a participant gets his/her hands off from the handle, 1) and 2) are applied again

This experimental environment allows an experimenter acquiring the data at the instance that participant's feeling changes from satisfied to unsatisfied. While a participant is not operating the handle, the participant is satisfied about the self-driving of the vehicle. At the instant that the participant touches the handle, the participant is feeling unsatisfied about the self-driving.

TABLE 1 THE BOUNDARY OF THE REGIONS AND THE CORRELATION COEFFICIENT BETWEEN THE POSITION AND VELOCITY ON THE DATA WHEN A PARTICIPANT STARTED TURNING THE STEERING RIGHT

	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6
Length A (m)	0.326	0.341	0.492	0.720	0.259	0.173
Length B (m]	1.078	0.924	1.165	1.186	1.097	0.936
Correlation coefficient	0.198	0.136	0.259	0.365	0.483	0.090

By fixing the velocity of the self-driving, we can measure the exact velocity when the participant feels unsatisfied. Also, slow shifting to the wall allows us the measuring of exact state of the vehicle on that the participant feels unsatisfied. There is a time delay from the time that the participant feels unsatisfied and the time that the participant touches the handle. Fixed velocity and slow shifting cover the problem of the time delay. We can measure almost the same states at both of the times.

For the visual stimuli, we made a road as in **Figures 3** and **4**. If we do not show any objects over the wall or the wall is painted by a plain color, participants might be difficult to feel the velocity of the vehicle. On the other hand, if we place objects that take attention from the participants; they might make noise about the timing when the participant touches the handle. Therefore, frequently sighted simple objects such as houses or trees are suitable for the visual stimuli. We painted the wall using a type of block texture in order to express the velocity more clearly.

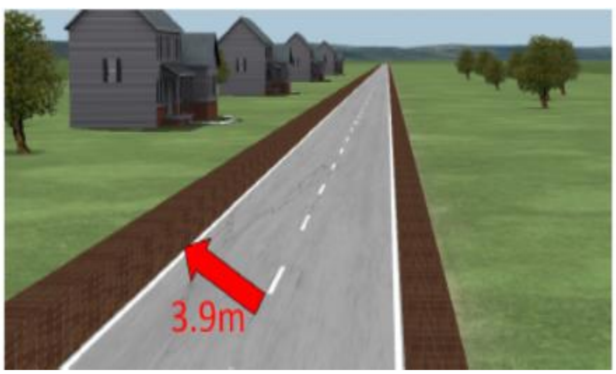

Figure 3 Overview of the road

Figure 4 Sight from a vehicle

C. *Proposed experimental procedure*

The experimental procedure is composed of 4 parts, questionnaire, introduction, test-driving, and driving.

1) Questionnaire part: In order to confirm the gender, experience of driving, age, existence of handicaps, frequency of driving, and so on. We conducted questionnaire.
2) Introduction part: We told each participant the follows:
   - Attention of safety
   - "Do not touch the devices other than the handle."
   - "Let the vehicle moves as it like as far as possible."
   - Agreement of the publication of the obtained data

   Note that we do not tell the fact that the simulated vehicle gradually moves close to the wall.
3) Test-driving part: Every participant drives the simulated vehicle 2 minutes in order to familiar with its control. We used different course than driving part for the test-driving.
4) Driving part: The other input devices than the handle do not receive any input. In order to keep a constant velocity, we cannot allow the participant to control them. The input from the handle is more prioritized than self-driving control.

III. EXPERIMENT

This experiment was conducted under the agreement of the committee of research ethics in Iwate University.

A. *Settings*

Using the proposed environment and procedure, we examined 21-22 aged 6 male Japanese participants who have Japanese driving licenses. Each participant drove the simulated vehicle for 6 minutes. We set the lane width at 3.9 m, vehicle's width at 1.8 m. The velocity of the vehicle was fixed at 60 km/h. Considering Japanese traffic, the handle of the vehicle was set at right-hand drive.

B. *Results*

Figure 5 shows an example of the experimental results of the 6 participants. The line on this figure shows the position of the vehicle in the perpendicular direction against the lane. The vehicle collide against the wall at Y = 2.88 [m]. Initial position of the vehicle is at the center of the lane Y = 1.50 [m]. The red/green triangles show the point that the participant turned steering wheel to right/left using the handle.

We gathered the data at the red triangles to analyze the unsatisfied situation of the participants. Each plots in **Figure 6** shows the position and the velocity against the wall at the time when Participant 1 started turning the steering to right. Region A/B shows the brank areas that do not include any data. Region A shows the area between the position that the vehicle hits the wall and the closest position to the wall that Participant 1 started turning the steering to right. Thus, the position of Line A shows the allowance of Participant 1 against the wall.

Table 1 shows the summery of the lengths (Length A and B) from the colliding position to Line A and Line B and the correlation coefficient between the velocity and position on the plotted data.

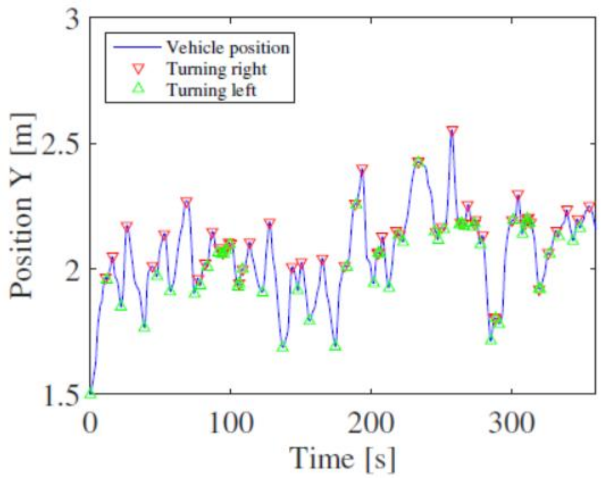

Figure 5 Driving path of Participant 1

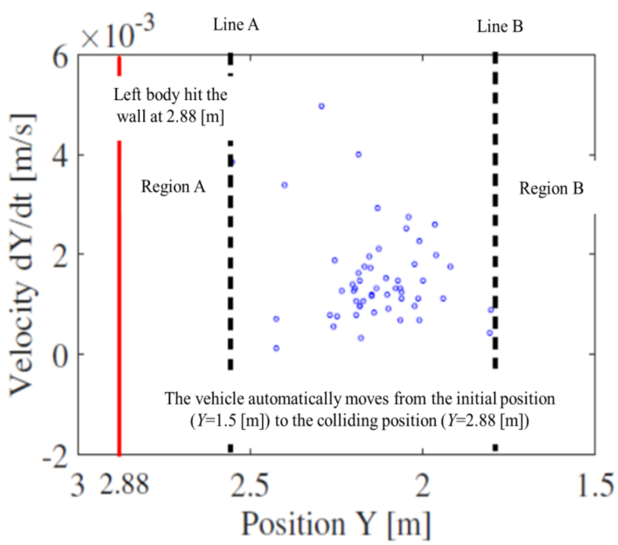

Figure 6 Position and velocity against the wall at the time when Participant 1 started moving steering to right

IV. Discussion

A. Recommended allowance from wall

If we take all of the customers into account, we need to fix the control parameters of self-driving vehicle to the worst case. About the distance from the wall, Participant 4 showed the worst case, because he started turning the steering to right (avoiding the wall) the most far from the wall (1.186 m) among the participants (**Table 1**). If the self-driving vehicle keeps more length than 1.186 m from the wall, none of the participants turned it and all of the participants were satisfied. Thus, we definitely recommend the allowance more than 1.186 m in this environment.

B. Correlation coefficient

In this experiment, correlation coefficients between position and velocity do not show a large tendency (**Table 1**), but all of the values are positive. This means that the participants tended to be close to the wall when the velocity of the vehicle against the wall was high. This may be because of the delay of handle control. In order to obtain data without the delay of handle control, we need to decrease the velocity. However, it decreases the number of data obtained in a trial. So, we need to control this parameter carefully in order to assure the quality and efficiency of the experiment.

C. Allowance in different environment

We may need to define the allowance according to the difference of environment. For example, the required allowance may depend on the driving velocity, size, and open view of a vehicle. Climate, road, and mental conditions may affect the required allowance. We need to examine the dependency one by one carefully.

D. The difference of positive/negative participant

According to **Table 1**, Participant 6 controlled the vehicle closest to the wall among the participants. Participant 4 controlled the vehicle most far from the wall among the participants. We can say Participant 6 is positive about collision, and Participant 4 is negative.

Figures 7 and **8** show the driving paths of the participants. **Figure 8** shows larger vibration amplitude about the position of the vehicle than **Figure 7**. This means that Participant 4 controlled the vehicle precisely than Participant 6. These results may show the characters of the drivers. Participant 4 may be delicate about driving. Participant 6 may not mind small difference. In this experiment, Participant 4 showed the most negative tendency about the collision against the wall, because Length A of Participant 4 was largest (**Table 1**). Participant 6 showed the most positive tendency as same reason. These two facts may have a relationship. The person who is delicate about driving may avoid a wall with a large allowance. The person who does not mind small difference may approach a wall closer.

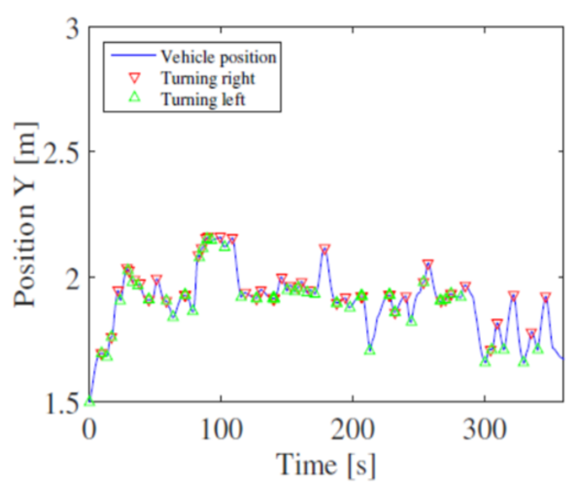

Figure 7 Driving path of Participant 4

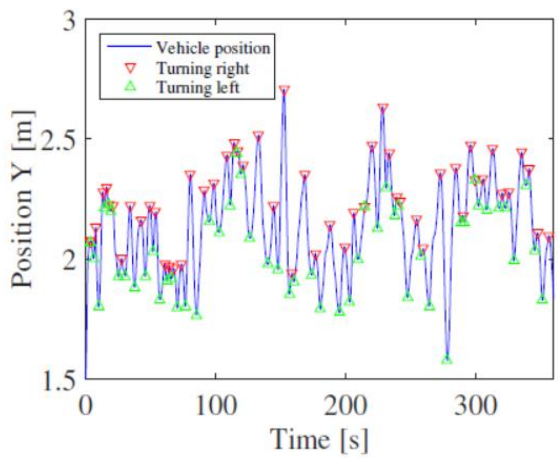

Figure 8 Driving path of Participant 6

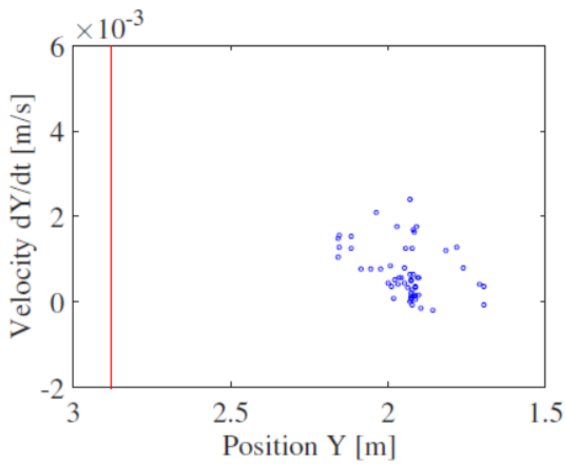

Figure 9 Position and velocity against the wall at the time when Participant 4 started moving steering to right

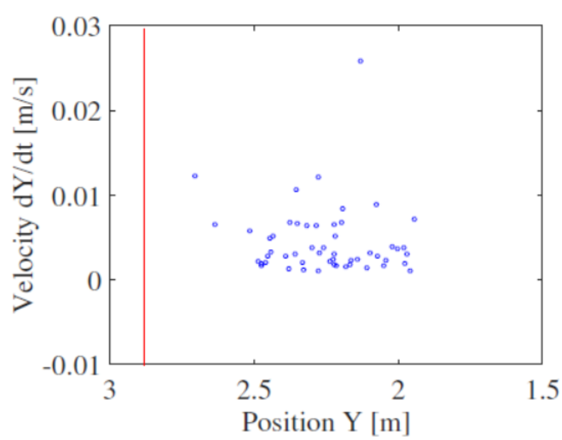

Figure 10 Position and velocity against the wall at the time when Participant 6 started moving steering to right

If this hypothesis is right, we may be able to change the control method of self-driving vehicle according to the characteristics of the driver through an easy psychological test.

Figures 9 and **10** show the position and velocity against the wall at the time when Participant 4 and 6 started moving steering to right. The standard deviations in horizontal axes are 0.102 and 1.778. These results also support the above mentioned considerations.

E. Analysis for visual lines

We may need to take data from the visual lines too. If we take the visual lines of the participants, we may be able to classify the participants in two groups. The person who is watches the wall in order to check the distance and the person who watches the centerline may produce different experimental results.

F. Types of the vehicle

In this research, we conducted the experiment against right-hand drive vehicle, which is popular in Japan. Also, the experimental road was designed as right-hand traffic. We may need to conduct the same experiment for the other combinations (i.e. left/right-hand drive vehicle and left/right-hand traffic) in order to compliment the situations. The proposed environment and procedure that easily modify the condition might make much benefit when we conduct such kind of experiments too.

G. Ideas for additional experiments

Here, we describe the idea of additional experiments.

- Combining the proposed environment and procedure and more realistic driving simulator in order to improve the precision of the experiment
- Obtaining the visual lines of the participants in order to analyze the participants' recognition for the distance around the vehicle
- Changing sheet position of the driver in order to confirm the affection of the position to the satisfactory distance
- Trying the combinations of left/right-hand drive vehicle and left/right-hand traffic in order to complement the combination that happens in actual use.

In order to make a common rule (boundary condition) of self-driving vehicle control, we need much more experiments. However, this kind of activity is important to develop the best vehicle that is appreciated with all of the societies in the world.

V. Conclusion

In this paper, we proposed the experimental environment and procedure for the confirmation of the duration from a wall in that drivers are satisfied about a self-driving control system. As a result of the application of the proposed environment and procedure for a psychological experiment, the participants were satisfied when the vehicle is away from the wall more than 1.186 m at the condition of 60 km/h and 3.9 m lane width. The proposed environment and procedure are applicable to many other conditions to reveal the limitations of satisfactory about the distance between a vehicle and a wall. The limitations give an idea to make the control rule of a self-driving system.

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