Bicycle Collision Analysis Using a Vehicle Driving Simulator "MOVIC-T4"

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ABSTRACT

To investigate vehicle driver maneuvering and visual behavior at small, non-signalized intersections with a narrow field of view, laboratory experiments were conducted using a MOVIC-T4 driving simulation system. First, the drivers' low-speed dynamic view angle, which is the view angle during motion, was measured in experiments using computer generated movies. A dynamic view angle of about 140-150 degrees was found at speeds of 10 km/h or less, indicating the possibility that drivers would not see bicycles on the sidewalk of an intersecting road when driving. Next, we installed a small, non-signalized intersection with a narrow field of view into the virtual reality space of MOVIC-T4; such intersections are common in urban areas of Japan. Furthermore, we developed an artificial intelligence bicycles system to simulate cyclists in the driving conditions presented to the test participants. The participants had a limited view angle due to the limits of the head-mounted display, which created the possibility of an interaction with the cyclists. We then observed differences in driving characteristics caused by structural design, road infrastructure, and traffic situations at the intersection. As a result, we indicated the feasibility of using a driving simulator for investigating bicycle accidents at intersections.

Keywords: safety, bicycle traffic, intersections, oversight, driving simulator

INTRODUCTION

In Japan, the bicycle is an important mode of transportation for short distances. There are over 86 million bicycles in Japan, and the national average of the bicycle's modal share was about 12% in 2003 [1]. One reason for high bicycle use is that cycling on sidewalks is permitted. Although this situation has created serious hazards to pedestrians in recent years, cycling on sidewalks has continued because it is widely believed to be safe for cyclists. In fact, the bicycle accident rate in Japan is higher than in the United States and EU countries.

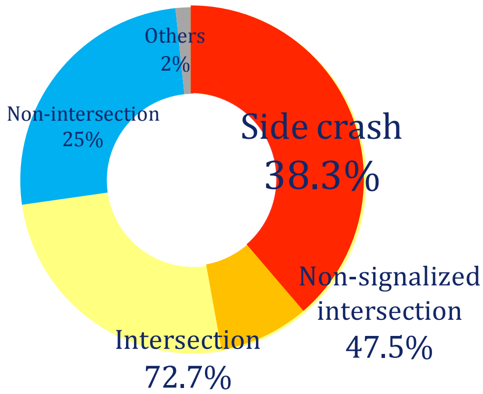
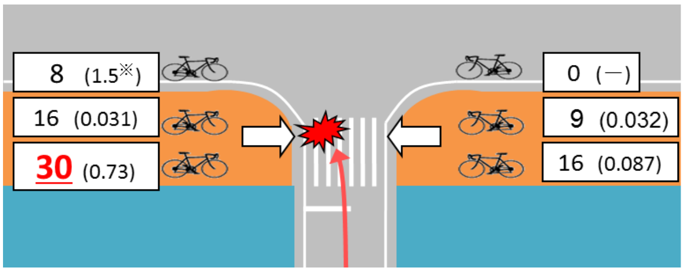


Figure 1 Location and type of accidents during bicycling in 2008 [2]



Number of accidents during 2002-2005
at an intersection in Tokyo
(percentage of the probability of accidents)

Figure 2 Comparison among the cases of side crash at an non-signalized intersection [2]

Around 50% of accidents between bicycles and vehicles occur at non-signalized intersections, and around 80% of accidents at such intersections are side crashes, with the most hazardous case being an accident between a vehicle on a narrow side road and a bicycle on the sidewalk of a wider road. Most accidents occur between a vehicle and a bicycle approaching from the left side, as shown in Figure 2. One reason collisions occur is that vehicle drivers watch the automobile traffic on the merging road and do not focus on cyclists. Because cyclists have the right of way, they approach this type of intersection without slowing down, and driver oversight must be prevented to avoid a collision. Moreover, another factor in collisions is that people are allowed to cycle on sidewalks with two-way traffic; for this reason, cycling on sidewalks is more dangerous than cycling on roads. The statistics of fatality rate show that (see Figure 3). But most cyclists in Japan think the opposite is true because statistics show only the number of bicycle accidents, not the circumstances leading to the accident. In addition, there are vast amounts of that kind of intersections and less serious conflicts routinely (see Figure 3) and it is hard to derive the tendency of accidents from only statistics.

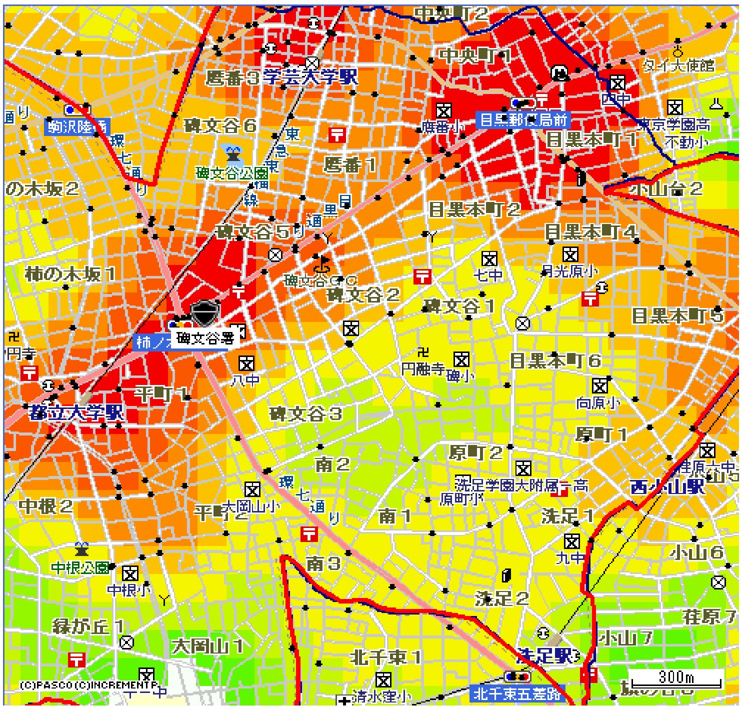


Figure 3 Location of minor injury accidents (black dots) during bicycling in Tokyo (2008) [3)]

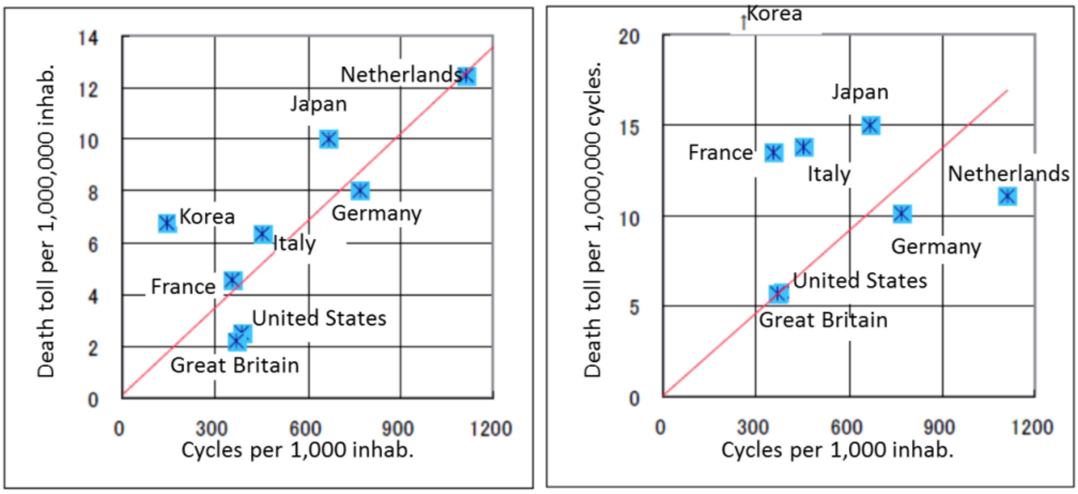


Figure 4Comparison between the Nations of the Death Toll by Accidents During Bicycling [4)]

The literature review of accident analysis at intersections in Japan is shown in Table 1. There are many studies about the accidents between vehicles and some studies about that between a vehicle and a bicycle; however there are few researches about that focused on driving behavior, road structure, and visual behavior between a vehicle and a bicycle. Furthermore, the situation that people bicycle two-way at sidewalks is original in Japan. There are very few studies about that situation using a simulator because of reproductive difficulty.

In this study, laboratory experiments on vehicle drivers using the MOving VIrtual Cockpit by Tokyo Tech and Trion for Tokyo highway (MOVIC-T4) [6)] driving simulation system were conducted to investigate the feasibility of using a driving simulator to investigate bicycle accidents and to ascertain the characteristics of vehicle drivers' maneuvering and visual behavior at small, non-signalized intersections with a narrow field of view.

Table 1 Literature review of accident analysis at non-signalized intersections in Japan

<table>
<tr><td colspan="2">Accident type</td><td colspan="3">Bicycle to motor vehicle</td><td colspan="3">Motor vehicle to motor vehicle</td></tr>
<tr><td colspan="2">type of analysis</td><td colspan="2">Except DS</td><td>DS</td><td colspan="2">Except DS</td><td>DS</td></tr>
<tr><td rowspan="5">attributes</td><td>direction position</td><td>Hamaoka (2009) Takeda (2008) Masuoka (2007)</td><td rowspan="2">Sasaki (2007)</td><td rowspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td>velocity</td><td>Kitazawa (2007)</td><td colspan="2"></td><td></td></tr>
<tr><td>driving behavior</td><td colspan="2">Yoshida(2007) Kakihara(2007)</td><td rowspan="3">This study</td><td>Washitani (2003)</td><td rowspan="2">Hagita (2006) Itou (2003) Tanaka (2001)</td><td rowspan="2"></td></tr>
<tr><td>road information and structure</td><td colspan="2"></td><td>Hagita (2004) Kihira (2000)</td></tr>
<tr><td>visual behavior</td><td colspan="2">Watanabe(2009)</td><td colspan="2">Hatanaka (2007) Hamaoka (2004)</td><td>Arizumi (2006) Munehiro (2007)</td></tr>
</table>

DEVELOPMENT OF DRIVING SIMULATION SYSTEM

General Outline of MOVIC-T4

MOVIC-T4 is a small, portable simulator made up of a small motion base with two degrees of freedom, and a head-mounted display (HMD) with a 114 degree view angle and an eye tracker for the visual system. Microsoft Visual C++ is the programming language used to develop the three-dimensional (3D) virtual environment, along with "WorldToolKit" by SENSE8 for real-time 3D simulation. The simulator has an average frame rate of 30 Hz which varies depending on traffic conditions such as the number of surrounding vehicles. Hardware components include an HMD, a head orientation tracking sensor, vehicle control devices, and a two-degree-of-freedom motion base. The state of the control vehicle is calculated from the user's driving control input and the road geometric structure database. The motion is then based on the state of the control vehicle. This simulation system allows around six surrounding vehicles to be generated; these vehicles are set to run automatically, with initial attributes including starting position, desired running speed, desired headway distance, judgment criteria in changing lanes, and vehicle type. In addition, the HMD currently used in MOVIC-T4 has a 114 degree horizontal field of view, and a resolution of 1280 × 1029 pixels. Coupled with the head tracking sensor, the effective field of view can reach 360 degrees. Compared with traditional projector-based driving simulators, the HMD-based system can achieve a high level of realism by immersing the user in a virtual space that recreates a road; the view angle and cost of HMD-based systems may be lower due to the reduction in the size of the physical display equipment and the graphics requirements.

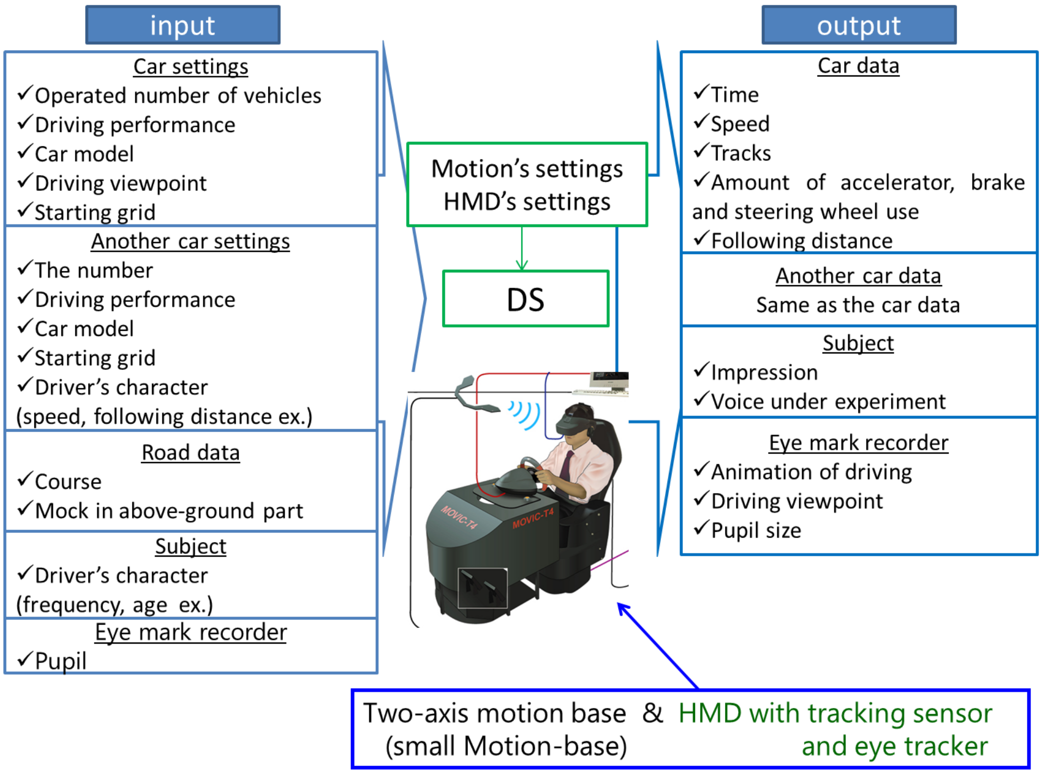


Figure 5 Overall system components of MOVIC-T4

Measurement of View Angle during Left Turn at Intersection

As found in the experiment with a 114 degree HMD, there may be a possible delay in perceiving a bicycle due to sight limitations, and so we need to develop a virtual reality system in which a bicycle can be recognized naturally within the drivers' limited field of view.

Driving requires perception, judgment, and handling ability, and the sense of sight is the most important part of perception. The causes of most traffic accidents are perceptional mistakes by drivers, and thus reproducing the qualities of sight accurately in the MOVIC-T4 driving simulator is one of the highest priorities. Therefore, we designed road structures and surrounding traffic situations in the virtual reality space to be compatible with the 114 degree view angle of the drivers. The details of the arrangement to the virtual reality system are shown below.

The view angle with a fixed target is from 180 to 210 degrees [7]. In contrast, the situation under investigation involves movements of both a driver (the participant) and a bicycle (the object), creating a "dynamic view angle" [8]. We measured the view angle in an experiment using a movie using CG (Computer Graphic) taking into account the factors that affect the dynamic view angle of drivers that collide with bicycles: the "vehicle speed", the "bicycle speed", and the "point of gaze".

<u>Methodology of dynamic view angle measurement</u>

A participant sat 40 cm in front of a screen to create a view angle of about 170 degrees (see Figure 6). A CG movie depicting a speed of 10.0 km/h or less (the driving speed approaching a non-signalized intersection) was displayed on the screen. The participant was instructed to look at a dot on the screen and push a button when they recognized a moving object approaching 3.0 m from the left side of the dot. In addition, we calculated their dynamic view angle and their reaction time.

We conducted the experiment according to the following conditions.

1) Three levels of vehicle (participant) speed: 5.0 km/h, 10.0 km/h, and 15.0 km/h.

2) Five levels of bicycle (object) speed: from 5.0 km/h to 15.0 km/h.

3) Two levels of driver (participant) concentration: with or without concentration to gaze at the dot.

The subjects were 7 students (6 males and 1 female) whose average age was 24.7.

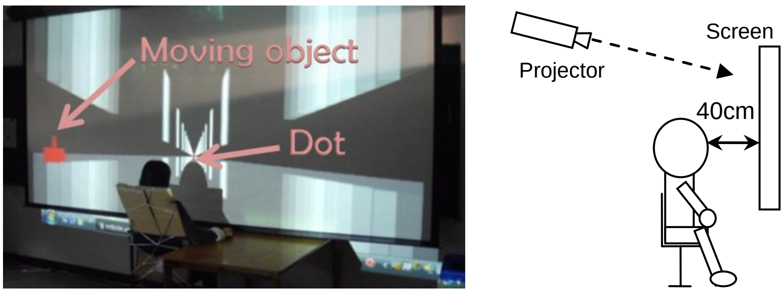


Figure 6 Photograph and schematic of dynamic view angle measurement setup

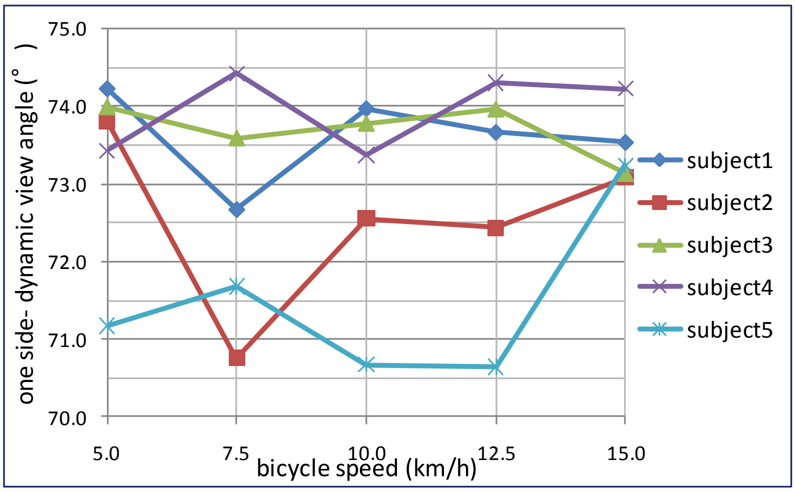


Figure 7 One-side dynamic view angle versus bicycle speed (5 samples)
(Average measured three times per scenario)

The relationship between the moving object's speed and one-side dynamic view angle in the condition of the "10.0km/h participants' speed" and "gazing at the dot" is shown in Figure 7. They didn't reveal a correlation in the all subjects' data, and other factors follow a similar pattern. We found the following results: 1) there is not always a connection between vehicle speed, bicycle speed, and the concentration level of drivers; 2) the view angle characteristics differ depending on the participant; and 3) the dynamic view angle was about 140-150 degrees, narrower than the peripheral visual field, but wider than the 114 degree view angle of the HMD in all cases. The results show that there is a possibility that drivers do not see bicycles on the sidewalks of the intersecting road while they are driving in the MOVIC-T4 virtual reality space.

Developing Artificial Intelligence (AI) Bicycle System and Intersection in Virtual Reality Space

In order to have an effective test setup, we need to design an intersection that realistically produces a high rate of accidents between vehicles and bicycles in a virtual reality space. Therefore, we considered the structural design of an intersection and the traveling characteristics of AI bicycles that automatically set their speed in the virtual reality space.
We need to meet the following requirements: 1) an AI bicycle approaching an intersection is assumed to go through the intersection without reducing its speed, in accordance with its right of way; 2) the road structure is typical of urban areas in Japan, and in compliance with the Government Order on Road Design Standards; 3) for a bicycle to approach the intersection at the same time as a vehicle driven by the participant, a bicycle is generated in the virtual reality space; 4) at the moment a cyclist and driver meet at an intersection, a driver (whose view angle is 114 degrees) cannot see the bicycle because of road structure obstructions; and 5) bicycle speed is determined in response to vehicle speed to ensure that the vehicle and the bicycle reach the intersection at the same moment.

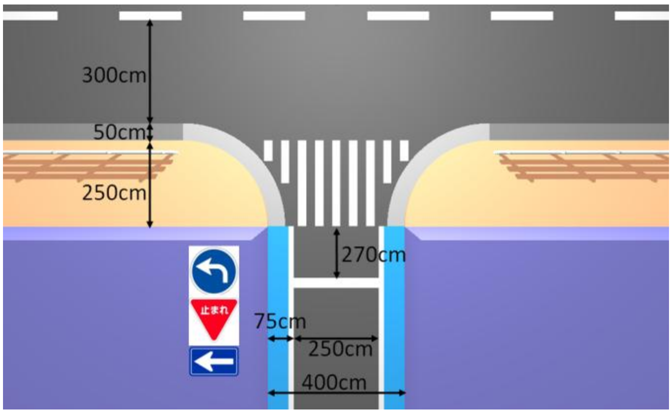


Figure 8 Road structure used in the experiment

Table 2 Data on bicycles and vehicles at an intersection in Tokyo

	Location 1	Location 2	
	Vehicles	Vehicles	Bicycles
Number	36	53	102
Average Time (sec)	1.14	1.12	1.96
Average Speed (km/h)	7.18	7.73	12.4
Max Speed (km/h)	11.4	11.2	16.1
	5.24	5.90	10.1

Through preliminary experiments, we found an adequate test condition that causes an AI bicycle at 9 km/h to come into sight when a point on the vehicle's bumper reaches a distance of 2.6 m before the intersection for the road structure shown in Figure 8; a collision occurs if the vehicle's speed is between 5.5 km/h and 10.3 km/h. The condition is based on realistic data measured at 2 intersections in Minato Ward and Shinagawa Ward of Tokyo (see Table 2).

As a result, it is shown that we can efficiently generate conflicts in the virtual reality space with a high degree of realism.

Development of HMD Supporting Device

The HMD weighs around 2.0 kg and is top-heavy when placed on a user, which causes them to be unable to move their head freely when wearing only the HMD. Therefore we developed the HMD supporting device shown in Figure 9. With the supporting device, the HMD is well-balanced, somewhat flexible, and feels as if it weighs only about 300 g.

EXPERIMENTS ON DRIVING SIMULATOR PERFORMANCE

We examined the MOVIC-T4 performance during the experiment to determine driving characteristics at a non-signalized intersection. The participants were 8 male university students whose average age was 22.0.

In the experiment, a participant drove the on narrower road and turned left at the intersection shown in Figure 8. Among the factors we observed were the participants' driving

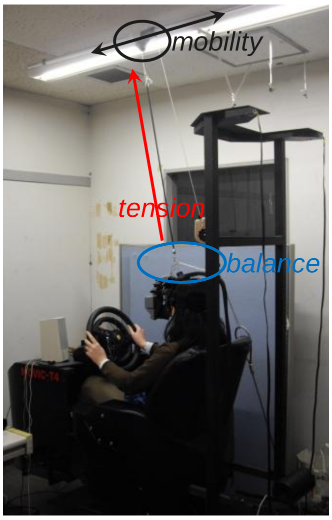


Figure 9 MOVIC-T4 driving simulator and HMD supporting device

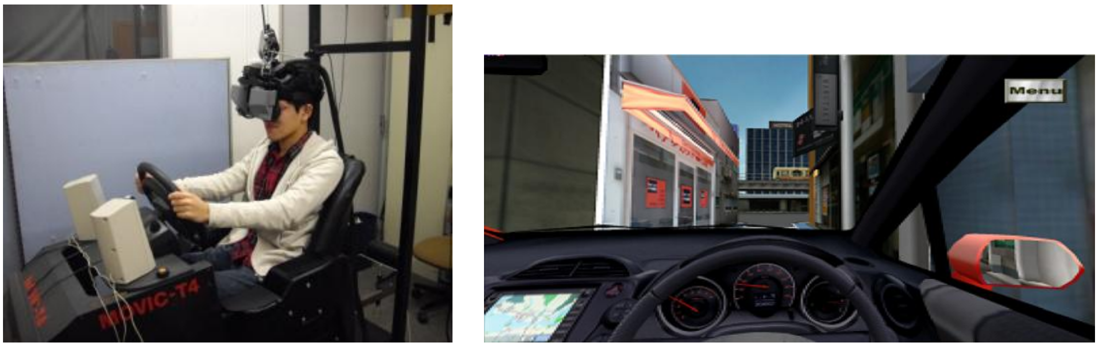


Figure 10 Appearance of MOVIC-T4 and virtual driving view

Table 3 Road structure conditions in the driving simulation experiments

Pattern	bushes	STOP mark	Width of sidewalk	A leading vehicle	Traffic volume of pedestrians	Bicycle on sidewalk
A	×	×	2.0 m	×	few	×
B	○	×	2.0 m	×	few	×
C	×	○	2.0 m	×	few	×
D	○	×	3.5 m	×	few	×
E	×	×	2.0 m	○	few	×
F	×	×	2.0 m	×	large	×
H	○	×	3.5 m	×	few	From the left side
I	○	×	3.5 m	×	few	From the right side

* A bicycle approaching the intersection were generated in the Pattern H and I courses.

characteristics and gaze points. The factors we took into consideration were "bushes side of sidewalks", "STOP road surface marking", "width of sidewalk", and "leading vehicle on the narrower road", and thus prepared the 6 courses (pattern A-F) shown in Table 3 for the experiments to validate driving simulator feasibility.

Methodology of Driving Simulator Experiments

First, we allowed the participants to test drive the simulator to learn how to operate the accelerator and brakes during low speed driving. Next, we instructed them to drive the five pattern courses shown in Table 3 (Patterns A-E) in a random order, and observed their driving characteristics and gaze points.

Results of Driving Simulator Experiments

Driving simulator feasibility results

Table 3 shows the vehicles' speed characteristics of 3 zones; i) 2.7 m before the stop line, ii) 2.7m after the stop line, and iii) 2.7m after the zone B) at the intersection shown in Figure 7. They were reasonable data and it was revealed that the steering wheel, accelerator, and brake were learned in the tutorials to some degree, but further improvement is necessary. In addition, the driving simulator feasibility experiments, it was revealed that 1) the HMD supporting device reduced the burden on the participants, but the tightness of the device caused participants to become tired after wearing it for a long time; and 2) participants drove more safely than usual, but no participant reported that either the driving simulator operation or the virtual reality space felt unreal.
We conclude that the driving simulator feasibility is verified for the experimental situation.

Driving characteristic results

As the result of Table 4, it is revealed that 1) the vehicle speed is down before the stop line (zone i)) only when the volume of pedestrians are large (Pattern F), and 2) the vehicle speed is fast during turning left (zone iii)) only in the case with bushes (Pattern B) and a leading vehicle (Pattern E). The slowing down in Pattern F is because it is obviously hard to turn left smoothly. And the speed-up in Pattern B and E is because the drivers tend to turn left in short order when being timed nicely in the hard-to-see the merging road situation. So, it is possible that the most dangerous situation is the moment of being timed nicely to confluent at the hard-to-see the merging road situation.

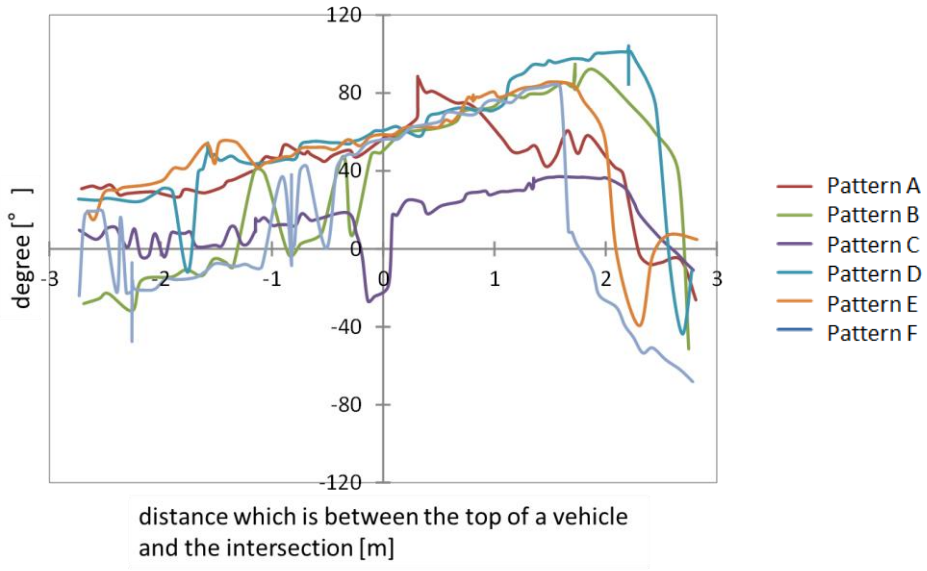
Figure 11 and 12 shows the participants' view position during the driving experiments. As the result, it is revealed that the most subjects see the right side during approaching the intersection of

Table 4 Vehicle speed characteristics

	Zone i)	Zone ii)	Zone iii)
Pattern A	7.90 (5.60)	3.95 (1.17)	1.78 (0.703)
Pattern B	6.15 (4.39)	4.96 (2.86)	2.65 (0.959)
Pattern C	4.49 (1.29)	4.27 (2.04)	2.14 (1.04)
Pattern D	9.00 (6.04)	5.58 (4.53)	4.29 (3.26)
Pattern E	5.77 (3.44)	4.68 (3.55)	2.42 (1.01)
Pattern F	3.91 (0.857)	1.95 (0.755)	1.52 (0.864)

Average [km/h]
(standard deviation [km/h])

Sample number = 8



* The vertical axis is a degree scale. (The positive is in the right and the negative is in the left.)

* The horizontal axis is a distance scale which is between the top of a vehicle and the intersection.
That is, when the top of the vehicle is the position of the stop line it is -2.7, and when it is the position of border of a building and a sidewalk it is 0.)

* An AI cyclist can find see a bamper of a vehicle's bumper at the moment when a the driver is 1.65 m short of the intersection (because the length of baumper is 1.65 m).

Figure 11Examples of View contactsgaze points during while driving (Subject who gaze the right side during driving)

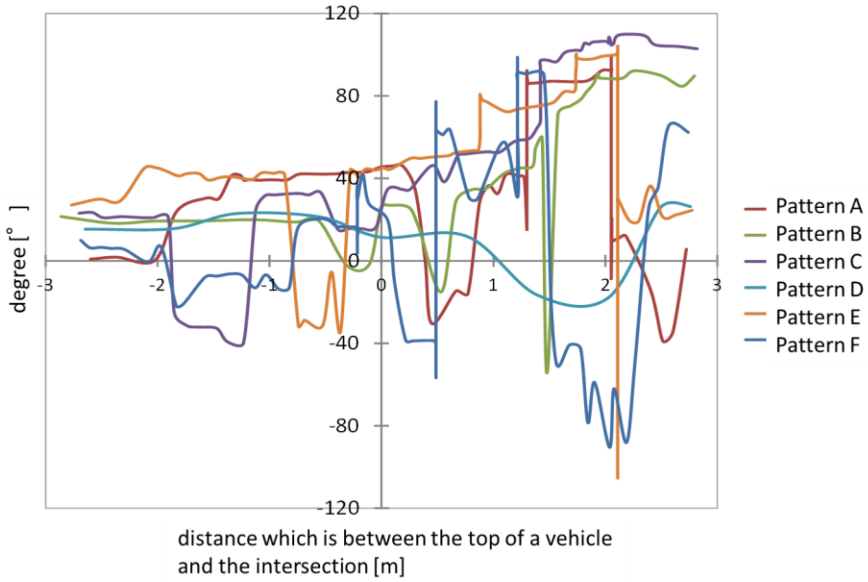


Figure 12 Examples of View contactsgaze points during while driving (Subject who gaze the left side at Zone iii))

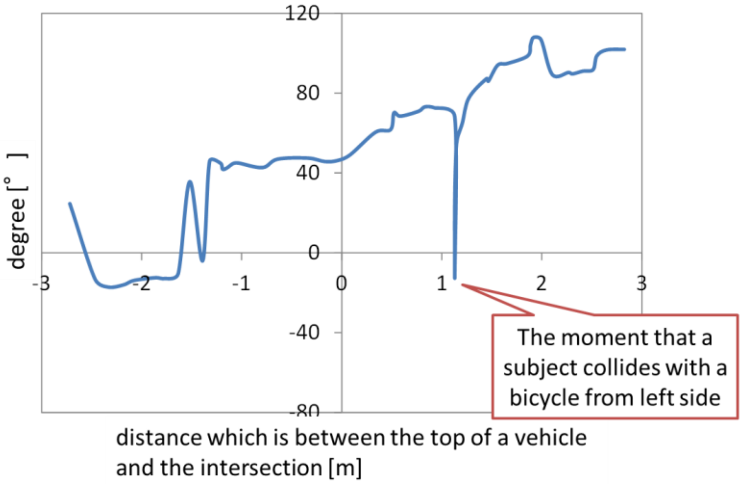


Figure 13 Gaze point of a subject while driving in Pattern H

the all road structures and they looked the left side only when they watched the side mirror. Especially after passing the position of the border of buildings and the sidewalk (the horizontal axis is from 0 to 1.6 in Figure 11 and 12), the most drivers saw the right side. Furthermore, the 3 subjects out of 4 collided with bicycle in Pattern H, and the 1 subject out of 4 collided with bicycle in Pattern I. We may need more samples to show the generality, but we can observe the stakes of oversight in left side at the intersection (See Figure 13).

In addition, the driving characteristic results show that 1) the “STOP” road surface marking didn’t have any effect in reducing vehicle speed before the intersection (and it is fit to the observation data at Tokyo) ; 2) the presence of a leading vehicle had some effect in making participants look toward the left while turning left, but it did not prevent conflicts with bicycles because most participants looked toward the right at the moment of turning left into the intersection; 3) there were great differences among the gaze points of the participants; and

4) in nearly all the samples, a driver glanced around slightly from right to left while turning left at the intersection. It was confirmed that a bicycle approaching from the left side toward a blind, non-signalized intersection might not be seen by a vehicle driver.

CONCLUSIONS

We examined the adaptability and the realism of the DS system in depicting collisions at blind, non-signalized intersections, and the results are as follows: 1) the sight limitation of the HMD was measured by examining the dynamic field of view; 2) the AI bicycle system was developed in the virtual reality space of the dynamic simulation; 3) experiments show that drivers tend to look to the right when approaching the intersection; and 4) the HMD supporting device makes drivers more comfortable. In addition, we could observed some driving characteristics by 8 subjects data, and it is showed that the oversight in left side during turning left at the intersection is occurred it is possible that the most dangerous situation is the moment of being timed nicely to confluent at the hard-to-see the merging road situation. We need to validate them by more number and attributes of subjects.

Although the number of participants in the present study was small and new problems with the DS system were found, it was shown that realistic experiments will be possible with further improvements.

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