# Study on Improving Angular Acceleration Feel of the Driving Simulator and its Effects on Drivers' Behaviors

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In recent years, studies on the motion and human interface of the vehicle have been performed. Due to the rapid advancement of computer technologies, it becomes possible in driving simulators to display detailed scenes and provide realistic motion feels of the vehicle driving. Driving simulators are widely utilized in the research and development of vehicles that account for the driver behavior in a virtual traffic environment. However, some drivers feel sick during and after the driving. It could be caused by deep immersion of visual and motion feels. The driver feels the difference between the real driving and the virtual one. This paper presents about the development of the turning table in the driving simulator. It can provide yawing motion which is approximately same as actual one. It is shown in this paper that the use of the turning table leads to more realistic drivers' feel for the steering actions. Furthermore, the effect of the angular accelerations on the drivers' behaviors is demonstrated using the turning table installed in the driving simulator.

***Keywords: Driving Simulator, Turning Table, Simulator Sickness, Driver Behavior***

## 1. Introduction

In recent years, the research on intelligent transportation systems (ITS), has been actively performed the motion and human interface of the vehicle using a driving simulator. With the advance in computer technologies, it becomes possible to display fine scenes of roads, streets, and vehicles in real time. The uses of driving simulator for experiments have become more effective and efficient [1]–[3]. At present, the use of a driving simulator is extended to the development of ITS technology, for instance, the research and development of vehicles, design and evaluation of the road, and traffic controls [4]–[9]. On the other hand, there is a problem in driving simulators in which operators feel sick easily due to the deep sense of immersion in the virtual environment [10], [11]. It can be considered that the problem is caused by the differences between actual and virtual driving environments, especially in the quality of the image displayed and the linear and angular accelerations obtained using the driving simulator. There have been various studies on motion perceptions [12],

[13]. As a subjective evaluation of the sickness due to the simulator, Kennedy et al classified the symptoms into three types; "nausea", "fatigue of the eyes", and "dizziness" [14].

Conventional shaking equipment with 6 D.O.F. enables various combinations of motions such as pitch, role, yaw, back-and-forth, left-to-right, and up-and-down motions. However, linear and angular accelerations are limited by the range of the motions and are not exactly the same as those of actual vehicles. For this reason, accelerations are generated by multiplying a scale factor. In addition, the gravitational effect of the tilted driving seat is used as a continuing acceleration. The center of rotation is also shifted. However, despite of these techniques, simulator sickness often occurs in turning motions at intersections. This is attributed to the fact that, there are differences in the visual feel caused by scene updating while turning and motion feel created by yaw angular and sideway accelerations. Asano et al developed a driving simulator with the mechanism that enables the driving seat to rotate. With the simulator, they studied the flicker in the displayed scenes when the

seat rotates rapidly and found the effects of a turning driving seat on the eye movement [15].

The motion feel due to yaw angular acceleration is discussed in our experiment. We aim at selecting the scale factor as realistically as possible. We first develop the turning table mechanism and combine it with a sophisticated driving simulator that has six D.O.F. This paper describes the experimental results of the effect of the angular acceleration caused by lane changing and turning on drivers' behaviors.

## 2. Universal driving simulator

### 2.1. Visual systems

A visual system is the most important part of a driving simulator because the driver grasps the distance to the car in front and behind, the position of the car in a lane, and sees traffic lights. Thus, we introduced the latest system as shown in Fig. 1 while the specifications of it are tabulated in Table 1.



Fig. 1 Omni-directional Visual System

Eight screens are set up 2.5 meters away from the driver's view point. When the 6 D.O.F. shaking platform is in its neutral position, the angle of the vertical field of view (FOV) is ±15 deg and the one of the horizontal FOV ±45 deg. A projector and screen are mounted on the 6 D.O.F. platform to simulate door mirrors. The FOV is fixed irrelevant to the motion.
Each screen is equipped with a simulated scene generator (PC based) that can display XGA (1024×768 pixels). The visual system can display 100 vehicles on a high way with 60 Hz.

Table 1 Specifications of Visual System

| Items | Specifications |
|---|---|
| FOV | H: 360 deg, V: 30 deg |
| Number of Projectors | 10 |
| Resolution | XGA/ screen |
| Luminance | 2100 |
| Screen size | 100inch x 8 screens(On Floor)<br>60inch x 1 screen(On MTN)<br>20inch x 1 screen(On MTN) |

### 2.2. Motion system with a turning table unit

A turning table is mounted on the 6 D.O.F. shaking platform as shown in Fig. 2. The 6 D.O.F. shaking facility has Steward parallel link structure with a combination of 6 linear motor actuators. The rotation center of the 6 D.O.F. shaking facility coincides with the rotation axis of the turning table. A driver's head on the driving seat is located along the rotation axis. Table 2 gives the list of performance of Turning Table.
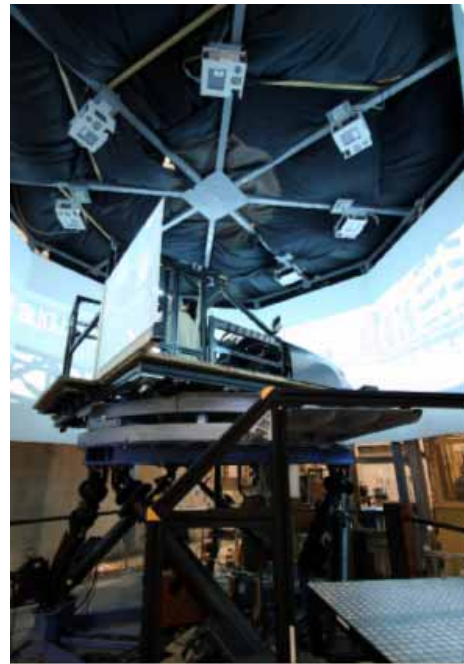


Fig.2 Motion System
(6 DOF Parallel Link Mechanism and Turning Table)

The turning table is controlled by a turning table computer that receives the heading angle from the main computer. The motion of the vehicle is computed by the main computer. The turning table computer controls the AC servo motor and decelerator at the rate of 60 Hz via RS232C. The angular resolution is less than or equal to 0.05 degree. Table 3 shows the scale factors of the motion system used in this experiment. With the turning table, the scale factor for the yaw angle is 1.0. Without

the table, the scale factor is 0.0. The rotation center of the shaking unit is the floor of the simulator body.

Table 2 Specifications of Turning Table

| Items | Specifications |
|---|---|
| Actuator | AC servomotor |
| Max. Angular Acc. | 300 deg/s$^2$ |
| Max. Angular Vel. | 80 deg/s |
| Range of Rotation | ±540 deg |

Table 3 Scale Factor of the Motion System

| Items | Scale Factor |
|---|---|
| Pitch Angle | 1.0 |
| Roll Angle | 1.0 |
| Yaw Angle | 1.0 or 0.0 |
| Surge Acceleration(X) | 0.08 |
| Sway Acceleration(Y) | 0.1 |
| Heave Acceleration(Z) | 0.6 |

## 2.3. Steering systems

The motion of the vehicle is computed by the main computer. The self-aligning torque is computed according to the steering angle of the front tires, and simple assisting torque is added. The total torque is sent to a steering computer at the rate of 60 Hz. According to the torque received, the steering computer calculates the axial torque at the 4.5 KHz sampling rate. The torque is generated by an AC servo motor. The specifications of the steering system are shown in Table 4.

Table 4 Specifications of Steering System

| Items | Specifications |
|---|---|
| Actuator | AC Servomotor |
| Torque | Max 50N m |
| Range of Rotation | ±720 degree |
| Adjustable Items | Control Logic |
| | Height of Steering |
| | Tilt Angle of Steering |

Meanwhile, the steering wheels and operation reaction generator unit are connected via a universal joint, and it is possible to change the tilt angle of the steering wheel and the height of it.

## 3. Experiments

Two male adults with the regular driver's license were selected as test drivers. They drive a car regularly. One test driver has no experience in driving simulators, and the other has some experience. Each test driver

conducted experiments for lane changing and turning using the driving simulator with the turning table first. Three days later, they repeated the same experiments using the driving simulator without the turning table. The test drivers were interviewed after each experiment about the levels of their "nausea", "fatigue of the eyes" and "dizziness".

## 3.1. Lane changing

In the experiment, we used the double lane changing test course described in Technical Report: TR3888 (ISO/TC22/SC9) (Fig. 3). The feature of this course is that the test driver has to perform a quick lane change continuously. The test drivers drove at the speed of 100 km/h. To make the analyses easy, the maximum speed is set at 100 km/h by software. The test drivers drove once as a practice and experimental data were collected at their second driving.
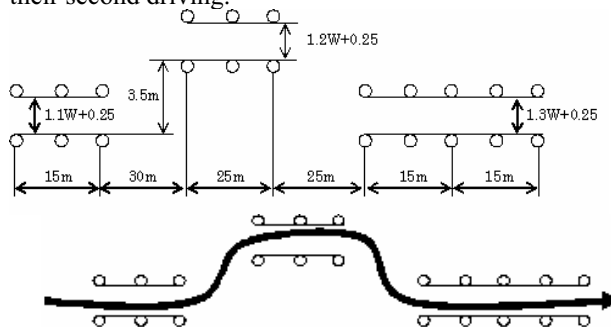


Fig.3    Cone Allocation in Double Lane Changing Experiment

Fig. 4(a) shows the trajectories of the vehicle without the turning table, while Fig. 4(b) shows the trajectories with the turning table. The abscissa indicates the position in the Y direction, and the ordinate shows the position in the X direction. The trajectories corresponding to the road sections that are surrounded by color cones are highlighted with shades, which are referred to as Section 1, Section 2, and Section 3, respectively. In the case without the turning table, for example, Section 2 and Section 3, drivers tended to enter the road section surrounded by color cones from the closer edge. By contrast, in the case with the turning table, the drivers entered the sections in parallel to the rows of the color cones. Fig. 4(c) shows the yaw angular speed without the turning table, whereas Fig. 4(b) shows the yaw angular speed when the turning table was used. The abscissa shows the yaw angular speed, and the ordinate shows the time. While driving in Section 2 (inside the circles), the yaw angular speed with the turning table is more stable (Fig. 4(d)).

(a):Position of the Vehicle without Turn Table



(b): Position of the Vehicle Applied Turn Table



(c): Yaw Rate without Turning Table
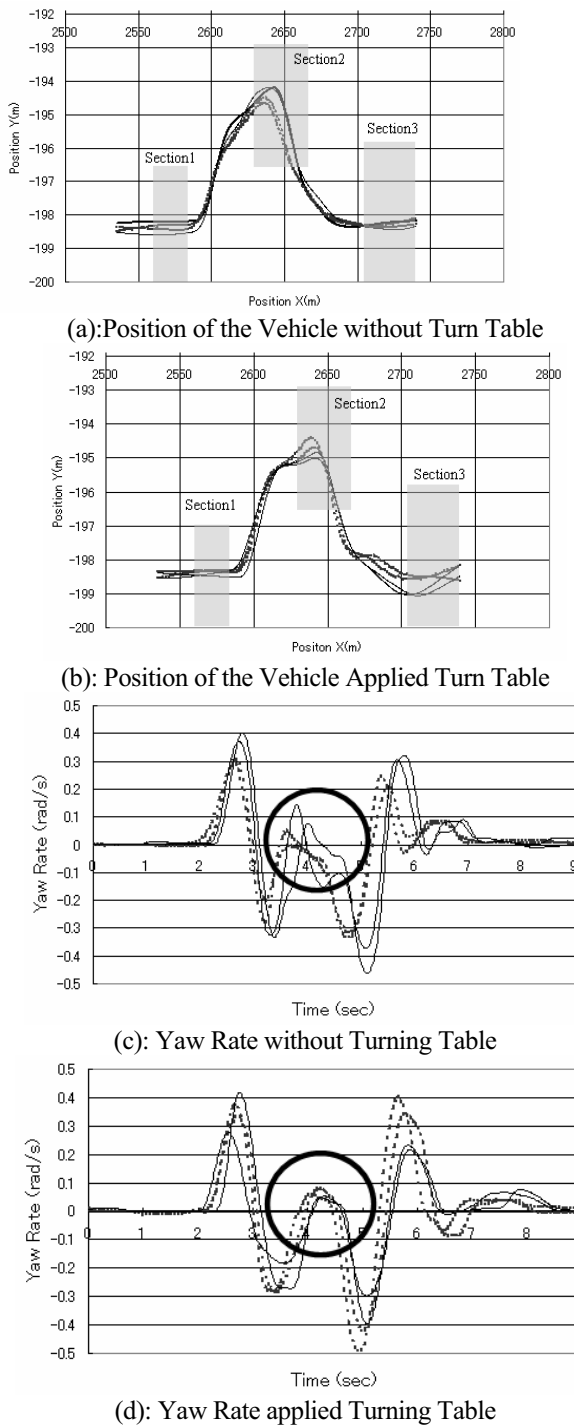


(d): Yaw Rate applied Turning Table

Fig.4  The Results of the Double Lane Change Experiment

The steering angle had the similar tendency. This indicates that the test driver can feel the yaw motion of the vehicle more easily using the turning table. As a result, the steering control is made easy. Furthermore, the post-experiment interviews also showed that "nausea", "fatigue of the eyes", and "dizziness" was less when the turning table was used.

## 3.2. Turning motion

Figure 5 shows the intersection model used in our experiment. There is one lane in one side of the road whose width is 3.5 m. Color cones are arranged where curbs and center lines are present.
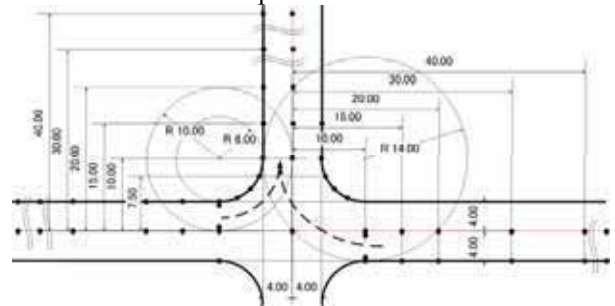


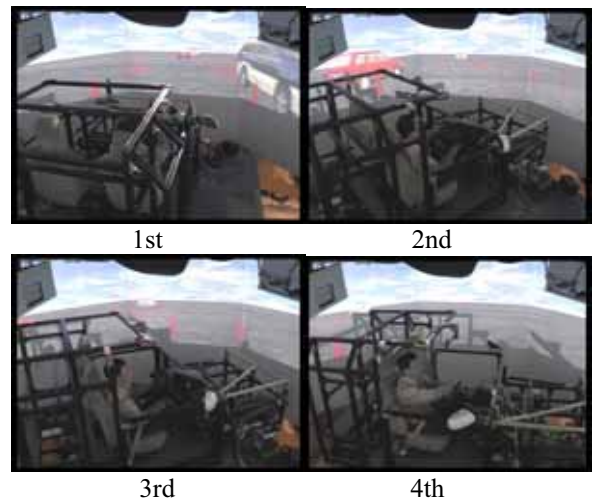Fig.5    Intersection Model in Experiment



| 1st | 2nd |
| 3rd | 4th |

Fig.6  Motion of the Turning Table during the Experiment of Turning in the Intersection

The test drivers enter the intersection at the speed of about 20 km/h and perform right or left turning. To make the analysis of the experiment, the speed is limited to 20 km/h by software. Figure 7 shows the results of the experiment. It can be seen that the peak of the yaw rate in Fig. 7 (above) is sharp, while the one in Fig. 7 (lower) shows a gentler slope and is more symmetric. These results indicate that the test drivers could perform smoother turning due to the feel of yaw rate aided by the turning table. Post-driving interviews also verifies that they suffered from less car sickness when the turning table is used.
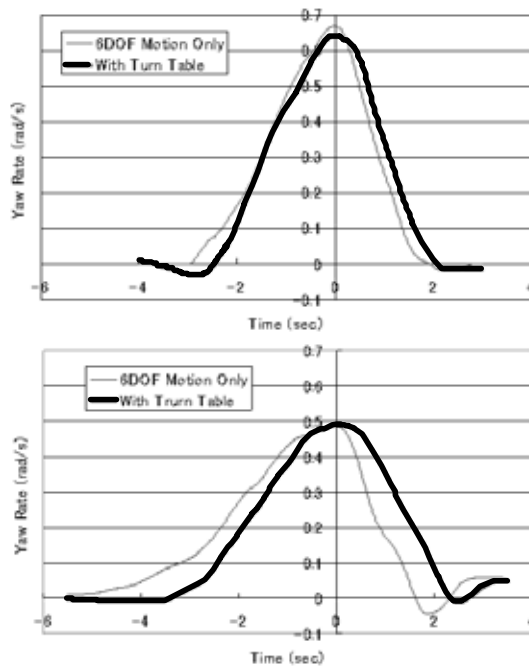
Fig.7    The Results of Turning in the Intersection
Experiment

## 4. Discussions

In the experiment of lane changing, the test drivers performed smoother steering operations when the turning table is used. This can be interpreted that the drivers could feel the orientation of the vehicle continuously owing to the turning table, making steering easier.  The experiment for turning also showed the similar effect of the turning table, in which the profile of the yaw rate is more symmetric about its peak. This can also be considered as a positive impact on a smooth driving. As a result of the experiment, we can state that the direct feel of the vehicle motion enhances the ease of steering operations. In the subjective evaluation about the effect of using a turning table, the drivers have less car sick when the turning table is used. Similar, but more apparent, results were also obtained in the experiment of turning. This indicates that car sickness of the drivers is alleviated thanks to more realistic visual scenes and motion feels. Meanwhile, there was a comment that the driver could have the feel of turning, but at the same time, he felt the rear tire was slipping. This indicates that the rotation center of the turning table should coincide with hat of the actual vehicle more accurately. From the experimental results, we can state that a turning table is a useful device, especially for the simulators that provides a deep sense of immersion with a 360° panoramic vision. As future work, we will work on the alleviation of the car sickness caused by simulators by increasing the number of test drivers and introducing biometrical measurements.

## 5. Conclusions

The simulator described in this paper was developed through the collaboration between Ikeuchi Lab. specializing in image information engineering and Kuwahara Lab. specializing in transportation engineering at Institute of Industrial Science, Collaborative Research Center for Advanced Mobility and Center for Collaborative Research, The University of Tokyo, Sustainable ITS Project. The simulator provides a "mixed reality space" that combines virtual reality and actual spaces. It is a novel universal driving simulator for research purposes, which enables the driver to feel and evaluate the motion of any vehicle under various conditions. Combined with a tire testing machine, it is also possible to test the properties of the tire and study the interaction between the driver and simulated traffic environments and the infrastructure. We continue to work on the development of a mixed reality driving test space for more accurate analysis of human factors, including the analysis of driver's motion and motion of a vehicle, the mechanism of human perception, and mental work load evaluation.

## 6. Acknowledgements

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