

Development of High-Performance Driving Simulator

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ABSTRACT

A number of active safety systems are already developed to support drivers' decision and action to help avoid accidents, but further enhancement of those active safety systems cannot be accomplished without increasing our understanding on driver behaviors and their interaction with vehicle systems. For this reason, a state-of-art driving simulator (DS) has been developed that creates very realistic scenarios as a means of realizing these requirements.

The DS consists of a simulator cabin, turntable (inside the dome), a 6-DOF hexapod system, shakers (vehicle vertical vibration actuators), and a motion system capable of moving 35 meters longitudinally and 20 meters laterally. The system is also capable of projecting images of actual city streets and highways onto a 360° spherical screen inside of the dome. As a result, the DS is able to reproduce a driving environment that is very similar to real driving.

Utilizing the DS also helps us to evaluate the effect of driving without proper attention such as while drowsy or drunken, and to reproduce near miss scenarios that are impossible to perform in actual traffic environments or on test courses because they are dangerous and against the law. We believe the results obtained through these experiments should help significantly to contribute to the development of active safety systems.

1. INTRODUCTION

To accomplish the aim of eliminating traffic casualties, activities are required to reduce traffic accidents based on a three-pillar approach that considers people, vehicles, and the traffic environment. As a part of this approach, driving behavior is being analyzed to promote the development of active safety technologies. In addition, driving simulators (DS) capable of realistically simulating accident-prone city streets in Japan have been developed as a means of verifying the effect of these analyses and technologies. Generally speaking, a DS can simulate changes in vehicle speed by adjusting displayed images and motion devices. Such devices are known to be effective for tests that would be dangerous for actual vehicles on test courses and for tests where a vehicle must be driven under certain environmental conditions.⁽¹⁾ The DS described in this paper aims to achieve top of the world performance by producing a test environment as close to the real traffic as possible while preventing the driver from realizing that the driving is simulated in order to get a clear understanding of driving behavior. This paper describes this DS technology and its application.

2. THE IMPORTANCE OF DS

Active safety systems aim to prevent accidents. As shown in Fig. 1, 56% of accidents in Japan occur at intersections, and errors in driver recognition or judgment account for 92% of the accidents that occur in the country. It is therefore necessary to find out what sort of recognition/judgment errors occur at intersections,

how they result in accidents, and develop technologies to help prevent them.

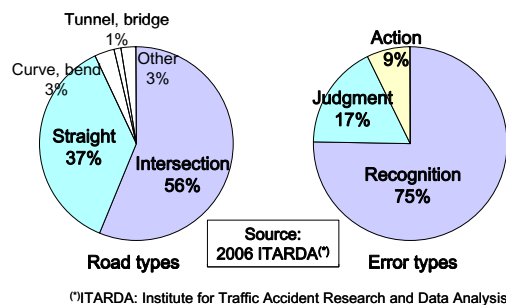


Fig. 1 Traffic Accident by Road and Error Type

An index for active safety performance evaluation, corresponding to passenger injury criteria for collision safety performance given in Fig. 2, can be regarded as the accident reduction rate or amount of near miss incident reduction. How to evaluate the index is an extremely important issue. However, as shown in Fig. 3, it is difficult to evaluate the index with test-course experiments because realistic complicated traffic scenarios cannot be reproduced and putting real drivers under drowsy or fatigued condition is not appropriate. A DS that can simulate virtual environments where traffic accidents occur is therefore required.

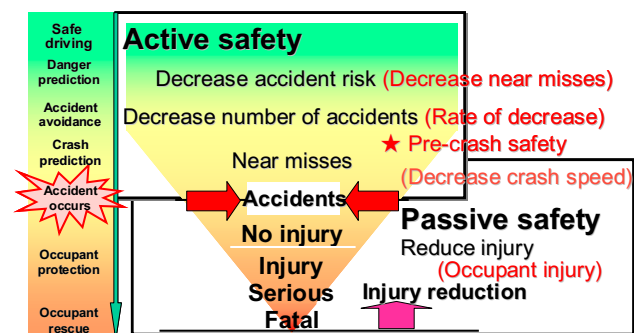


Fig. 2 Active Safety Performance

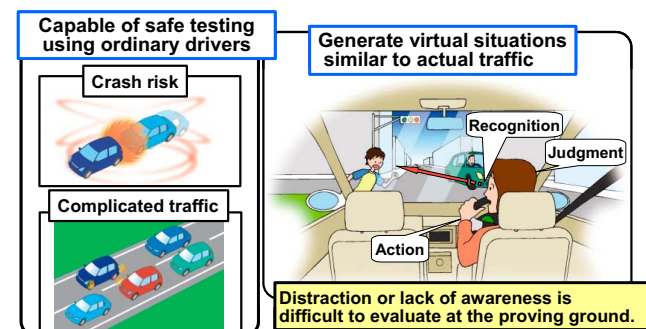


Fig. 3 Active Safety Evaluation

3. DS DEVELOPMENT TARGETS

As shown in Fig. 4, the application and performance of DS differ according to the scale of the vehicle motion system and image display. Types vary from small fixed screens for driving education to the world's largest driving simulator developed by the National Highway Traffic Safety Administration (NHTSA). This is the National Advanced Driving Simulator (NADS), which is equipped with a 360° image and a 6-DOF hexapod system and an XY-axis translational motion system. ⁽²⁾

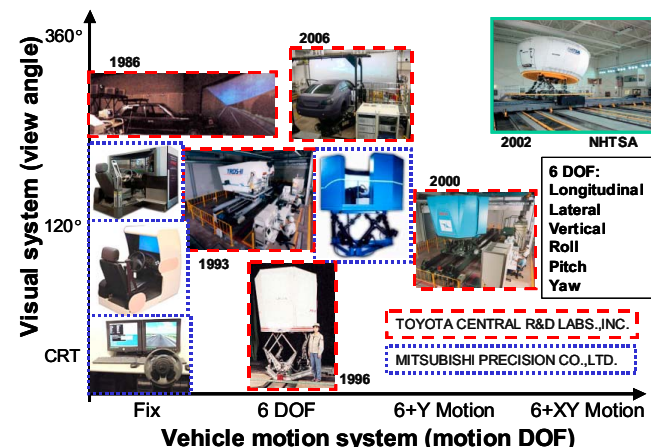


Fig. 4 Driving Simulator Types

Considering the environment in which traffic accidents occur in Japan, we must simulate driving at intersections where accidents frequently occur, as indicated in Fig. 1. The scale of the vehicle motion system depends on to the degree of acceleration is reproduced. As shown in Fig. 5, a system capable of generating 0.3 G longitudinal and lateral acceleration was targeted as this range can cover 80 to 90% of ordinary driving. It is well known that XY motion is effective to reduce motion sickness while braking and turning at intersections, but not clear how long their travel will be needed. Therefore, NADS ⁽³⁾ was used for its investigation at the very first stage of Toyota's DS design (Fig. 6). From the test runs in NADS, it was realized that a DS capable of moving 35 meters forward and backward and 20 meters to the side would be needed to generate 0.3 G of longitudinal and lateral acceleration (Fig. 7).

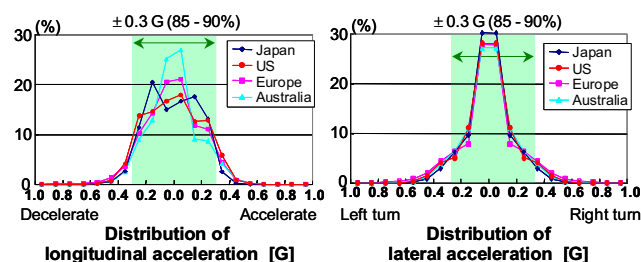


Fig. 5 Acceleration in Ordinary Driving

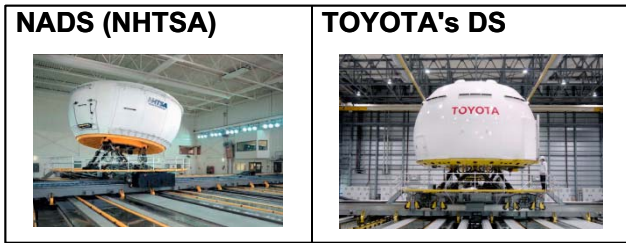


Fig. 6 NADS and Toyota's DS

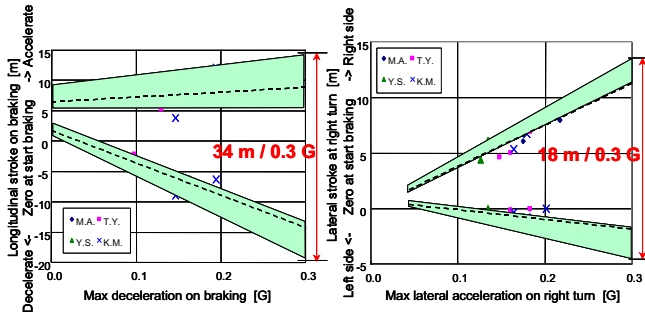
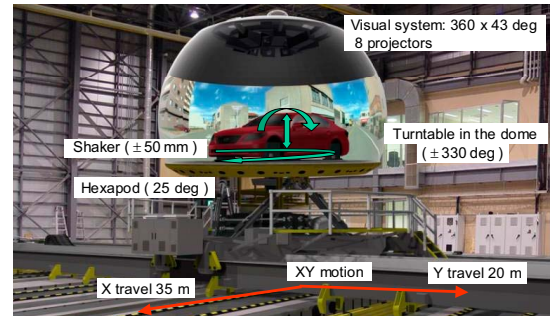


Fig. 7 Dynamic Performance of NADS XY Motion

4. DS CONFIGURATION AND PERFORMANCE

4.1 VEHICLE MOTION SYSTEM - The DS consists of a vehicle motion system to simulate acceleration, a visual system to produce a virtual traffic environment, and a simulator cabin for driving operation. This section first explains the vehicle motion system, which is the most important component of the system. As shown in Fig. 7, the most important feature of the DS is its translational motion system, which is based on NADS. A particular feature of the system is its 35-meter translational distance capability to enhance realism when braking (i.e., the sense that the driver is able to stop at the intended position). The system is equipped with a turntable ⁽⁴⁾ inside the dome that can turn $\pm 330^\circ$ to reproduce left/right turns at an intersection. The driving simulator is supported by four shakers on the turntable to faithfully reproduce the sensation of driving at low speed on city streets.

The DS should achieve the dynamic performance to faithfully represent the vehicle motions on the real world. Therefore, the data for the frequency response characteristics of longitudinal acceleration, brake pedal stroke, steering angle and lateral acceleration were collected under ordinary driving on public roads (Fig. 8). As a result, development began on the premise that lateral acceleration would require response characteristics of at least 2 Hz and longitudinal acceleration would require at least 4 Hz. Table 1 gives the response characteristic of the motion system developed; response of at least 4 Hz is realized for all response characteristics.



Aim	Method	Specifications
Improve braking feel	Wide X travel range	35 m x 20 m, 0.5 G, 6.1 m/s
Decrease motion sickness	Turntable in the dome	± 330 deg, 0 to 5 Hz
Simulate ride comfort	Long stroke shaker	± 50 mm, 0 to 5 Hz

Fig. 8 Toyota's DS

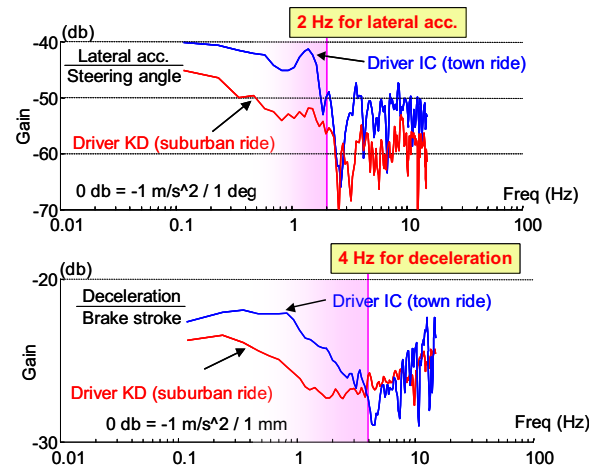


Fig. 9 Frequency Response on Ordinary Driving

Table 1 DS Motion Dynamic Performance

		Max stroke	Max velocity	Max acceleration	Frequency response	Natural frequency
XY motion	X	± 17.5 m	± 6.1 m/s	± 4.9 m/s ²	19 Hz	4.9 Hz
	Y	± 10 m	± 6.1 m/s	± 4.9 m/s ²	14 Hz	4.6 Hz
Hexapod	X	± 0.7 m	± 1.0 m/s	± 4.9 m/s ²	8.9 Hz	8.1 Hz
	Y	± 0.66 m	± 1.0 m/s	± 4.9 m/s ²	9.4 Hz	8.1 Hz
	Z	± 0.6 m	± 1.0 m/s	± 9.8 m/s ²	12 Hz	13.7 Hz
	Pitch	± 25 deg	± 45 deg/s	± 120 deg/s ²	8.6 Hz	3.7 Hz
	Roll	± 25 deg	± 44 deg/s	± 120 deg/s ²	8.5 Hz	4.6 Hz
Turntable	Yaw	± 25 deg	± 44 deg/s	± 120 deg/s ²	10.5 Hz	6.1 Hz
	Yaw	± 330 deg	± 60 deg/s	± 120 deg/s ²	7.6 Hz	21.3 Hz
Shaker	Z	± 50 mm	± 0.16 m/s	± 4.9 m/s ²	30.5 Hz	25.0 Hz
	Pitch	± 2.0 deg	± 2.0 deg/s	± 197 deg/s ²	28.9 Hz	16.2 Hz
	Roll	± 3.88 deg	± 3.88 deg/s	± 381 deg/s ²	33.4 Hz	23.0 Hz

As shown in the block diagram of Fig. 10, the method of simulating longitudinal and lateral acceleration with translational motion and tilt systems ⁽⁵⁾ involves generating acceleration by slow tilting in a low frequency range by the tilt system to prevent the driver from sensing the tilting motion, and then generating the remaining target acceleration by the translational motion system. Figure 11 shows the distribution in actual