

Consideration of Critical Cornering Control Characteristics via Driving Simulator that Imparts Full-range Drift Cornering Sensations

Hiromichi Nozaki
Kogakuin University

Masayuki Shimizu and Makoto Sakuno
Mitsubishi Heavy Industries, Ltd

Copyright © 2009 SAE International

ABSTRACT

A driving simulator capable of duplicating the critical sensations incurred during a spin, or when a driver is engaged in drift cornering, was constructed by Mitsubishi Heavy Industries, Ltd., and Hiromichi Nozaki of Kogakuin University. Specifically, the simulator allows independent movement along three degrees of freedom and is capable of exhibiting extreme yaw and lateral acceleration behaviors. Utilizing this simulator, the control characteristics of drift cornering have become better understood. For example, after a J-turn behavior experiment involving yaw angle velocity at the moment when the drivers attention transitions to resuming straight ahead driving, it is now understood that there are major changes in driver behavior in circumstances when simulator motions are turned off, when only lateral acceleration motion is applied, when only yaw motion is applied, and when combined motions (yaw + lateral acceleration) are applied. Therefore, it is now understood that drivers responded chiefly to yawing and lateral acceleration by providing feedback to the motion, thus clarifying the characteristics of counter steering. From observations of the driver's eye-tracking and perspiration levels, it is further understood that drivers are strongly influenced by motion feedback in the yaw motion when compared with the drift lateral acceleration motion at the time of cornering.

INTRODUCTION

Large scale driving simulator is "NADS" of NHTSA and Toyota driving simulator [1] of the type same as NADS. These driving simulators was equipped with a real vehicle cockpit, a visual 360-degree spherical dome screen, a turntable system, a vehicle vertical vibration system and a XY-axis motion system with a movement range of about 35m by 20m. But, it is not a general purpose driving simulator because it is large scale. On the other side, general-purpose driving simulators that offer up to six degrees of freedom, and which utilize parallel motion linkage, etc., are currently on the market. Even though such simulators impart some movement in the designed multiple degrees of freedom, it is difficult to accurately synchronize the simulation and impart the sensations a driver can be expected to receive during cornering, braking, etc., due to restricted movement capabilities of the simulator hardware. As a result, such simulators are incapable of imparting the sensations incurred during drift cornering, especially during moments of large slip angle and counter steer. Because of this, a specific degree of freedom was incorporated into a separate simulation method and an apparatus capable for providing great freedom of movement was fabricated and tested.

During drift cornering, (1) strong lateral acceleration behavior is normally accompanied by (2) extreme yawing behavior. For our simulator, the sensations produced by extreme yawing were imparted by installing

an independent rotation mechanism. Furthermore, accurate movement can also be imparted to produce steady state lateral acceleration sensations that simulate those experienced during roll movement (including transitional lateral acceleration sensations that simulate those experienced during lateral movement). This means that the movements of our driving simulator correspond to drift cornering events in a way that allows test subjects to experience the actual sensations of extreme yawing and lateral acceleration. This was accomplished by developing a method that allows the three degrees of freedom to operate independently of each other. Furthermore, examinations of the drivers identified the body sensation parameters that were used to control feedback-related steering during drift cornering. Such examinations also provide useful information on the drivers' actual condition.

EXPERIMENT DEVICE

DRIFT CORNERING DRIVING SIMULATOR

Mitsubishi Heavy Industries, Ltd. and Nozaki (Kogakuin University) jointly developed the drift cornering driving simulator used during this research (Figure 1). The concept behind the simulator was not just to replicate the motions of the vehicle during grip cornering, but also to replicate every motion of a vehicle engaged in drift cornering as closely as possible. Therefore, there is a necessity for constructing the motion device which can simulate the bodily sensations of drift cornering due to its ability to produce (1) large lateral acceleration behaviors, and (2) large yawing behaviors. It is assumed that if structural limitations to the simulation instrument were removed, infinite rotation would be possible and yawing behavior could be more accurately simulated. The result was spin behavior that imparted sensations that were as near to reality as possible. However, the yaw angle velocity was assumed to be a maximum ± 40 deg/sec due to the weight restrictions, etc. of general-purpose driving simulators, and this scale factor dropped to about 0.6 when compared with actual vehicle behavior. However, the sensations related to spin, drift cornering and counter steer were considerably closer to those that would be imparted by an actual vehicle. The effects of normal lateral acceleration could be reproduced using the simulator's roll function while momentary lateral acceleration was reproduced by the simulator's lateral movement. In total, regular lateral acceleration reproduces about ± 0.4 G (Momentarily about maximum ± 0.7 G). And, this scale factor assumes about 0.6-0.7. Moreover, although a regular value for lateral acceleration is provided by the component force of the gravity acceleration by applying the roll angle, drivers do not appear to perceive the rotation easily when the movement axis applied to imitate lateral acceleration is near the vicinity of the driver's ear (where equilibrium sensations are centered). For that reason, the roll rotation axis, which was set at the driver's

shoulder vicinity, has been altered by means of a timing belt though the servo motor and its location is now simulated as the vicinity of the side of the driver seat in this device. Table 1 shows the parameters and performance of the simulator while Figure 2 shows a schematic diagram of the device. In these experiments, in order to induce sensations on the subject that were as realistic as possible, the driving simulator was enclosed behind a blackout curtain and the driving subjects operated the steering wheel based on the driving situation projected on the display panels. The reflection of the driving situation was simultaneously monitored on the control side during the experiments. There is no influence because the delay of the display system is extremely small. In these experiments, the following items are measured.

(1) Vehicle drive state data: steering angle, steering torque, vehicle velocity, positional data, body slip angle, yaw rate, yaw angle, roll angle, pitch angle, lateral acceleration, the steering angle of each wheel, etc.

(2) Human body response data: gaze point, amount of perspiration.

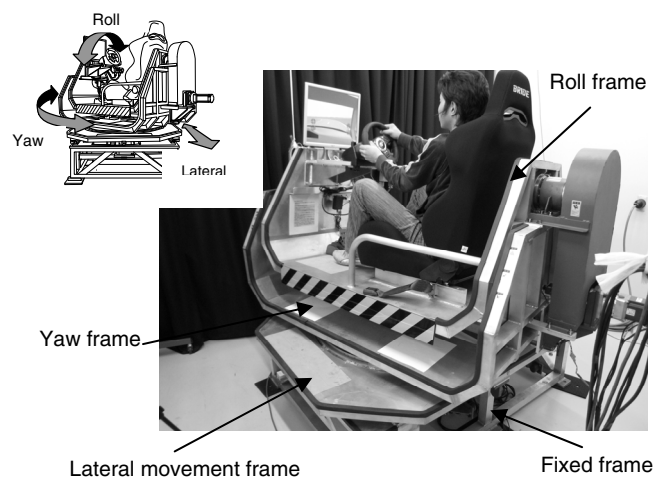


Figure 1: Driving simulator

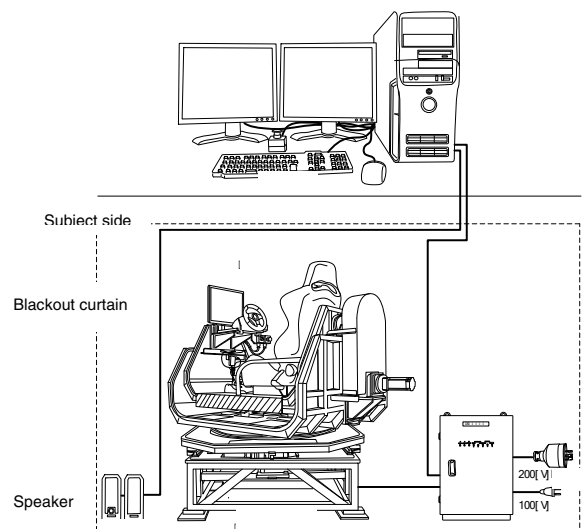


Figure 2: Schematic diagram of the driving simulator

Table 1: Parameter and performance of driving simulator

Item	Performance
Actuator	AC servomotor
Control method	Three-axis control method for roll, yaw, and lateral movement (feedback control by potentiometer)
Main specifications	Shake & Rotation frequency 0 ~ 3 Hz Roll motion Max. angular ± 20 deg Max. angular velocity ± 50 deg/sec Yaw motion Max. angular ± 90 deg Max. angular velocity ± 40 deg/sec Lateral movement Max. displacement ± 200 mm Max. velocity ± 240 mm/sec Lateral acceleration ± 0.7 G
Size of device	Width 1,525 mm $\times$ Length 2,037 mm $\times$ Height 1,800 mm
Weight of device	About 400 kg
Power supply	Single phase AC 200 V and, single phase AC 100 V

GAZE DETECTION DEVICE

Figure 3 shows the appearance of a driver wearing the sensor goggles, which are the detection component of the gaze detection device. In this experiment, the eye movement of the driver was monitored using the gaze detection device Free View-HMS (Takei Equipment Ind. Corp.). The gaze detection device photographs the driver's eye with a camera located in the detection section, and image processing is used to determine the driver's gaze position in real time. The sight result can be viewed since because the gaze point is overlaid on the reflection view that the driver sees and that is monitored with the view camera in the detection section. The gaze can be monitored in real time, even when the driver's head and body move. The reflection data together with the view information on the eye movement is sent to a personal computer and is recorded using a video conversion machine, and the reflection data and various sight information is compared and analyzed (Figure 4).

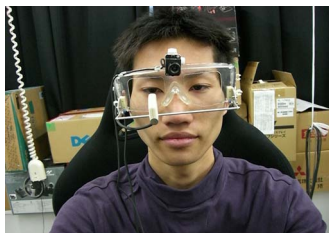


Figure 3: Driver wearing sensor goggles

Frame number of camera

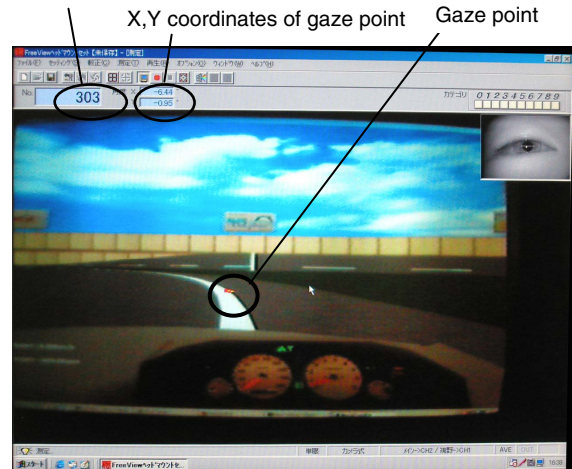


Figure 4: Visual display seen by the driver of the simulator

PERSPIRATION METER

Figure 5 shows the capsules which perform as sensors for the perspiration meter; these are attached to the palms of the hands. The two channel type perspiration meter used in the experiment is measured with reference to a capsule in an environment of ventilated room air. As in previous models, neither dry air nor N_2 gas are needed, but a new method was used to supply room air to the capsule.



Figure 5 Capsule sensors of perspiration meter attached to palms of hand

DRIVING SIMULATOR VEHICLE MODEL

The driving simulator is based on CarSim (Version 6.06) (Mechanical Simulation Corp. (USA)), which is a full vehicle movement simulation software package. Figure 6 shows a schematic diagram of the vehicle model. Table 2 lists the main components in the vehicle together with the number of degrees of freedom associated with each component. For example, the rear axle is rigid and has two freedom degrees: vertical