Improvement of Driver’s Feeling by Turning Cabin Driving Simulator

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Abstract

In order to improve feeling (e.g. simulator sickness symptoms) of driving simulator when a left or right turn maneuver at an intersection, the prototype driving simulator whose cabin can turn with simulated yawing angle was manufactured. Main computer calculate mainly vehicle dynamics of translation (longitudinal and lateral movement) and yawing movement. Then the calculated translation is projected to cylindrical screen (horizontal view angle; 237 degrees) as an image. On the other hand, computed yawing movement is used for driving command in order to turn the simulator’s cabin itself.

Eighteen subject drivers participated in the experiment that was required to a left/right turn maneuver at eight intersections using two types of driving simulators (fixed-base/turning-cabin driving simulator). In the fixed-base simulator driving, many subjects reported serious image flicker and simulator sickness symptoms. Furthermore, large movement of sight direction that exceeds an image flow was observed. That is to say, the phenomenon means inconsistency of both movements of driver’s line of sight and image flow, and it suggests one of cause of impairing driving feeling regarding visual sensation. In the turning-cabin simulator driving, however, quite less the report and the phenomenon ware observed. Moreover, drivers moved their line of sight to far point, over their moving direction much earlier than the fixed-base driving simulator case. This sight behavior has been also reported in a real-world test, which used an actual test vehicle.

These results suggest that the turning-cabin driving simulator improve the driving feeling, and it can make driver’s sight behavior as close to real-world case as possible.
INTRODUCTION

Increasing “simulator sickness (SS)” when performing right or left turns has become a problem in driving simulators (DS) since a larger viewing angle was adopted. This sickness like car sickness, is commonly explained as a sensory conflict.\(^{(1)}\) The theory explains that a conflict occurs between the vestibular, visual, and bodily senses based on past experiences and remembered sensations. In the DS, the difference between the perceived acceleration and remembered sensation of motion in a actual vehicle induces SS. Images on the DS differ from those in a moving vehicle in resolution, blurred image, sense of distance and so on, so there are conflicts with the sense of vision as well. A larger angle of view on the DS probably increases the SS caused by visual conflicts with DS motion.\(^{(2)}\) Moreover, in order to clearly perceive driving direction at an intersection, it is considered that image quality is important as well as DS motion.\(^{(3)}\)

These discrepancies in the vestibular, visual, and bodily senses based on past experience and remembered sensations from a actual vehicle will be called a “sense of incongruity.”

This study focuses on a method to reproduce the yaw movement of real scale vehicle movement in order to reduce the sense of incongruity on the DS. In a fixed-base DS, reproduces the yaw movement as an image in the reverse direction of a right or left turn. Resulting images move on the screen in lateral direction at a high speed, causing blurred image. Therefore, we produced a prototype DS equipped with a mechanism to turn the cabin by yaw movement, improving the vestibular, visual, and bodily senses while reducing this blurred image. We also confirmed the improvement in the sense of incongruity in right or left turns and the effect of movement on visual direction.

TEST EQUIPMENT

Simulated images of yawing movement generate the flicker sensed caused by blurred image by the driver. Therefore, our “turning-cabin DS” reproduces yawing movement by literally turning the DS cabin, using AC servomotors instead of images (upper right corner of Fig. 1).

The left side of Fig. 1 shows the components of yaw and translatory motion to represent vehicle movement in a right turn within a microperiod. In the turning-cabin DS, we can reduce the blurred image because the components of translatory motion in the vehicle’s movement are reproduced by images but the yawing movement is reproduced by rotating the DS cabin itself. By adopting this system, we can expect concomitant improvement in the vestibular and bodily senses.

The lower right corner of Fig. 1 shows the method of image reproduction on the fixed-base DS. We used images to reproduce the components of both translatory motion and yawing motion of the vehicle. Both the turning-cabin DS and fixed-base DS have a
mechanism for concurrent use of the same equipment, so we can switch from one to the other arbitrarily. Table 1 shows the basic performances common to both types of DS.

![Diagram](image)

Fig.1 Difference of simulation method between turning DS and fixed-base DS

<table>
<thead>
<tr>
<th>DS Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vehicle model</strong></td>
</tr>
<tr>
<td>3-DOF, 4 wheels, Load shiftable model</td>
</tr>
<tr>
<td>(2000cc class passenger car)</td>
</tr>
<tr>
<td><strong>Tire model</strong></td>
</tr>
<tr>
<td>Map data based on Magic Formula Tire model</td>
</tr>
<tr>
<td><strong>Steering</strong></td>
</tr>
<tr>
<td>Microsoft force feedback steering system</td>
</tr>
<tr>
<td>(Steering gear ratio : 4)</td>
</tr>
<tr>
<td><strong>Horizontal view angle</strong></td>
</tr>
<tr>
<td>237° (Include curved surface screen 150 °)</td>
</tr>
<tr>
<td><strong>Vertical view angle</strong></td>
</tr>
<tr>
<td>34°</td>
</tr>
</tbody>
</table>

### TEST METHOD

#### Test Course and Conditions

We formed a database of images from an urban area containing intersections (Fig. 2) where we set a course of eight alternating right and left turns. The right-turn and left-turn intersections we analyzed had a single lane in each direction and a road width of 3.5m. Signal controls were disabled, to record pure eye tracking data while turning. We ran the test course for drivers as both a turning-cabin and a fixed-base DS. We analyzed the recorded data for both right-turn and left-turn intersections from the 20m sections before and after the center of each intersection.

#### Test Procedure

Test subjects (drivers) first received an explanation of the contents of the test. Next, they made a practice run on the same course as that used for the full-scale test. We used a simplified simulator equipped with three, 15-inch, LCD monitors to convey a sense of
steering and speed. Each driver performed this practice run once or twice depending on degree of ability.

To measure the direction of visual movement at right and left turns, each driver wore an eye-tracker made by Nac Co. (EMR-8) and performed this test as both fixed-base and turning-cabin DS. The visual movement data recorded by that device did not include head movement. Therefore, as shown in Fig. 3, we mounted two LED lamps on top of the driver’s head and measured the head-turning angles by taking pictures with a CCD camera installed above the head. We later analyzed the images to measure the head-turning angles. We instructed the drivers to run at the same speed as in daily driving and that signal controls were not operating. While running, we gave drivers sufficient notice of right or left turns before reaching the pertinent intersections. To offset the effect of the repetitious order of conditions, we varied the order of operations from one driver to another. We gave any driver who became SS a sufficient rest time to recover between fixed-base, turning-cabin, DS testing.

Drivers

We could not obtain measurement data from the eye-mark recorder due to the reflection of light caused by glasses or deformed eyeballs in some of the original 18 drivers participating in this test. We therefore excluded such drivers from analysis.

Our final driver list consisted of five females aged 29 to 53 (average age 38.6, standard deviation 11.1 years) and seven males aged 29 to 56 (average age 44.2, standard deviation 11.4 years).

EVALUATION INDEXES

Subjective Evaluation

After they completed the tests, we asked drivers to evaluate the feeling of flicker on image quality as compared with that in an actual car, using scoring from 5 to 1, assigned to “strong flickering,” “slight flickering,” “average,” “reduced flickering,” and “No flickering.” We also asked them to evaluate symptoms of SS, such as dizziness, nausea, headache, and cold sweat, using scoring from 4 to 1, assigned to “Severe,” “Average,” “Fair,” “None.” After they completed all tests, we asked drivers to evaluate their
preference of DS systems using scoring from 3 to 1, assigned to “Fixed-base DS is better,” “No difference,” and “Turning-cabin DS is better.”

**Image-Following Indicator**

We investigated influence of visual-direction behavior by DS type. Figure 4 shows an example of the pattern of visual-direction behavior for right turns in the turning-cabin DS. The saw-tooth waveform in the figure represents movement of visual direction on the head-coordinate system. The driver obtains visual information by repeating saccadic eye movement to forward image of the running direction (line a-b) and following to image flow by yaw (line b-c).

To investigate the changes in visual direction in relation to the flow of images, we calculated the variation of visual direction on the vehicle coordinate system by adding up the variation of head-motion angle from point b to point c and the variation of visual direction on the head coordinate system. We divided the variation in visual direction by the variation in yaw angle within the pertinent time range and defined this quotient as the image-following indicator.

\[
\text{Image-following indicator} = \frac{\sum \Delta \text{Variation of visual direction angle} + \sum \Delta \text{Variation of head motion angle}}{\sum \Delta \text{Variation of yaw angle}}
\]

When images are completely followed by visual movement, the absolute value of the indicator is 1. As the absolute value deviates from 1, the degree of the following decreases. In this test, we can divide the direction of visual movement into the following three sections based on its features (Fig.2 and Fig. 4). In concrete terms, we can see from the images on the eye-tracker that drivers paid attention to specific sections of a turn.

During the first phase, drivers pay attention to inside the running course (near point) of right and left turn, up to 10m. During the middle phase, they moved their visual direction from the near point to a long distance ahead of a turn (far point), from 10m to nearly 17m. During the last phase, after 17m, they gaze on the far point ahead of a turn. We decided, therefore, to calculate the image-following indicator for each of these three

![Fig.4 An example of visual direction behavior and measured yawing angle](image-url)
**Yaw Velocity When Visual Behavior Stabilizes**

In the last phase shown in Fig.4, the driver operates a vehicle heading straight. During in the phase, the driver gazed on the far point ahead of a turn. Point A, however, indicates the point of beginning to the gazing, and Point B indicates the end point of a turn. The gazing was continued between Point A and Point B without saccadic eye movement. We measured the point and yaw velocity at the point A for each driver. However, the gazing deviated remarkably at the far point, the Point A was replaced with the point where the visual direction accorded again with the far-point with stability.

**TEST RESULTS**

**Subjective Evaluation**

*(1) Preference for the DS type*

The comparison between the turning-cabin and fixed-base DS upon completion of the test showed that 10 of the 12 drivers preferred the turning-cabin DS. The remaining two drivers had no preference.

*(2) Feeling of Flicker on images*

As shown in Fig. 5, for all three phases, the drivers felt the fixed-base DS contributed “more flickering than in a moving vehicle” or “a little flickering” in more cases than the turning-cabin DS.

*(3) Symptoms of simulator sickness*

Figure 6 depicts a subjective evaluation of the symptoms of SS reported after completion of each portion of the test. All symptoms of SS except headache appeared more frequently in the fixed-base DS. The three evaluations of the “severe” in the figure were the same subject. The evaluations of the “average” in the turning-cabin DS were the same subject as well.

![Subjective evaluation of feeling of flicker](image)

Fig.5  Subjective evaluation of feeling of flicker
Image-Following Indicator

Figure 7 presents the measurements from the image-following indicator in right and left turns. In both the turning-cabin and fixed-base DS, the absolute value of the image-following indicator in the first and middle phases was less than 1. We believe this is because the first and middle phases, where the visual direction of the driver adjusts to the inside course and the point near the vehicle, decreases the lateral movement of the images watched by the driver as compared to the yaw angle. In the last phase, where the driver watches a point far ahead of a right or left turn, the absolute value of the image-following indicator approached 1 in both right and left turns in the turning-cabin DS. In the fixed-base DS, however, the absolute value of the image-following indicator exceeded 1 in both right and left turns, showing a significant increase compared to the turning-cabin DS (p<0.01). The fact that the indicator exceeds 1 in the section where drivers watched a far point means that the movement of visual direction exceeds the flow of images in connection with the yawing movement in the fixed-base DS. This trend was particularly remarkable for left turns.
**Yaw Velocity When Visual Behavior Stabilizes**

Based on the results in the previous section, the driver probably cannot clearly watch the image at a far point in the latter phase of a right or left turn in the fixed-base DS.

Therefore, we studied the vehicle position (Point A in Fig. 4) and the yawing angle velocity at the point of time when we began the image-following with the visual direction fixed on a far point. In right or left turns in the turning-cabin DS (top of Fig. 8) the driver begins image-following with visual direction fixed to the far end before ending a right turn. In the fixed-base DS, however, the point where attention is fixed on the far end is delayed compared to the turning-cabin DS. For a right turn in the fixed-base DS (bottom of Fig. 8) the yaw velocity is much less than in the turning-cabin DS (p<0.05). In other words, the visual direction cannot stably follow the far point until the moving velocity of the image decreases sufficiently.

![Diagram of vehicle position and yawing angle velocity](image)

**Discussion**

Drivers exhibited a clear preference for the turning-cabin DS type in their subjective evaluation, and SS was aggravated in the fixed-base DS. The three evaluations of the “severe” in the figure 6 were the same subject. The evaluations of the “average” in the turning-cabin DS were the same subject as well. These two subjects who evaluated SS was high in turning-cabin DS operated the fixed-base DS at the first. Furthermore, the subjects who operated fixed-base DS at the first, they did not evaluate higher SS in the turning-cabin DS than in fixed-base DS. These subjective evaluations indicate that the experiment has an order effect. It is considered that the cause of bad evaluation such as “Severe” and “Average” in turning-cabin DS were affected by the order effect. Subjective evaluation of the flickering feeling on images was also aggravated in the
fixed-base DS. The turning-cabin DS thus proved effective for reducing the visual sense of incongruity.
In the fixed-base DS, we found that a discrepancy occurred between the visual direction and the images in the last phase of the intersection so that the movement of visual direction exceeded the movement of the image watched.

We predict that this visual information about the far point is insufficient for useful input due to this discrepancy. It is possible that the visual sense of incongruity is a large factor in the fixed-base DS.

Furthermore, a previous study analyzing visual-direction behavior patterns for right turns in an actual vehicle driving reported that gazing to the road ahead in a right turn becomes dominant during and after the last phase of the turn (at a vehicle-yaw of 45 degrees or greater).\(^{(4)}\) This suggests that stable gazing to a far point beginning earlier in the turning-cabin DS simulates the visual behavior in a actual vehicle driving more closely than in the fixed-base DS.

**CONCLUSIONS**

After noting the blurred image as a factor in the sense of incongruity for right or left turns, we manufactured a prototype DS that turns the cabin itself to reduce the effect. We compared the subjective evaluations and the analysis of visual-direction movement patterns for right and left turns in the fixed-base and prototype turning-cabin DS. We acquired the following information.

1. The feeling of flickering on images decreased and the subjective Simulator Sickness decreased as well in the turning-cabin DS as compared to the fixed-base DS.
2. In the fixed-base DS, the movement of visual direction exceeded the movement of the scenes in the last phase of right or left turns and may be a factor in the visual sense of incongruity.
3. In the fixed-base DS, unlike the turning-cabin DS, the visual direction stably followed the far point ahead of a right or left turn only after the yaw velocity decreased sufficiently.

As our results show, the sense of incongruity in making right or left turns in a simulator can be reduced by using the turning-cabin DS.

**REFERENCES**