Whole-View Driving Simulator For Measuring Driving Behavior In Town Environment

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Abstract

A hi-fidelity driving simulator with the 300 degree screen and an actual vehicle cabin on hexapod motion platform has been developed in order to measure driving behavior, including visual behavior, in town environment. For measuring the driving behavior, various driving parameters were recorded. The eye glancing direction was detected by combining the eye-tracking system and the head-tracking system. The eye glancing direction on the ground coordinates system was computed by transferring eye-movement data onto the eye-tracking screen coordinates. An experiment with ten subjects was conducted to investigate the characteristics of driving behavior for the repeated drive for about 5 km in the town with several left and right turns.The eye glancing behavior while turning left at intersections was analyzed in this paper. The tragectory of the eye glancing points differs driver by driver, but the tragectory showed a certain goemetrical form. This suggests that each driver follows imaginary leading line to perform the turning maneuver.

Résumé

Introduction

Clarifying individual driving characteristics become important because of recent development of Intelligent Transportation Systems (ITS). The timing of presenting the message from an ITS is basically based on physical parameters, such as the distance to the obstacle and the vehicle speed. However, the drivers are not uniform. The timing and the way of presenting messages should be adapted depending on the driving skill (e.g. beginners vs. experienced drivers) and the driver's condition such as age, gender, fatigue level, concentration level, and so on. Therefore, in order to adapt ITSs to individual drivers, it is important to know the characteristics of the driver's behavior. However, it is difficult to analyze driving behavior in a real traffic environment. To overcome this problem, we have developed a driving simulator to measure driving behavior as a part of the government project "Behavior-based Human Environment Creation Technology".

There is a great advantage to use the driving simulator for measuring the driving behavior because we can control the traffic situation (behavior of other vehicles and pedestrians) and the road environment that are crucial factors to the behavior. Not only controlling the situation and environmental factors but also recording of various behavioral measures is a great advantage when using the driving simulator. In the real road environment, sometimes it is difficult to obtain all the measures that we would like to have. For example, the precise vehicle position is difficult to obtain in the real environment. In the next section, the system structure of the driving simulator is described (see in detail Akamatsu et al 2001). In the third section, the eye glancing object detection system that is installed to the simulator in order to analyze driver's visual behavior. In the fourth section, the visual glancing characteristics while turning left at intersections obtained in the driving simulator experiment is described.

Hi-Fidelity Driving Simulator For Measuring Driving Behavior

Hardware configuration

The hardware configuration of the driving simulator is illustrated in Figure 1. The motion system had a 6-axis (Hexapod) electromechanical motion platform for rendering motion perception and vehicle vibration. The fully instrumented 2-box vehicle cabin is fixed on the motion platform. The cabin on the motion platform was surrounded by display screens that were fixed on the ground. A 180 degree cylindrical screen was located 3.0 meters in front of the driver. For the right-rear view, a 40 horizontal degree flat screen was attached to the right side of the cylindrical front screen. A 200 inches flat screen was located behind the cabin. The size of image covers the views of the room mirror and the door mirrors on both sides.

Four speaks were installed inside the cabin to auditory sensory cue. It represented the sound of the horn, the turn signal, the crash sound, the engine and exhaust noise, the road noise, the wind noise, the slip, skid sounds, and the sound from other vehicles was also presented. The steering wheel had a servo system to give the natural feeling obtained during

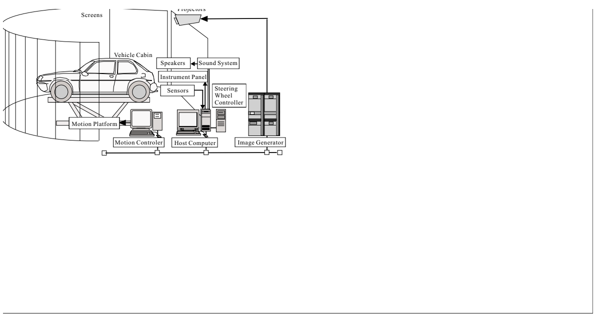


Figure1. Driving simulator system configuration

Photo1. Simulated driving environment

driving. The steering torque and force change as a function of the velocity, the load on the front wheel, and the road friction. The amplitude and frequency of vibration also appeared on the steering wheel as a function of the speed and the engine revolution. The motion platform was also use to give the vibration of the body.

The Windows 2000 computer was used as the host computer to calculate the vehicle dynamics and the traffic flow. Another Window-NT computer was provided to the servo system of the steering wheel. For the image generator, the SGI Onyx2 with Infinite Reality2 engine was used. With this image generator, images were updated in 60 or 30Hz.

Vehicle dynamics model

The vehicle dynamics model was based on the magic formula tire model with a single body. The tires were connected to the body with a four wheel independent suspension. The engine torque was converted into the driving force via the torque converter model. With the magic formula tire model, the longitudinal and the lateral force of the tire was calculated according to the slip ratio and the slip angle. Then, the resultant force vector of the tire was obtained.

The acceleration and deceleration of the vehicle were rendered by movements of the motion platform. The calculated longitudinal and lateral acceleration was fed to a low-pass filter and a high-pass filter. The output of the low-pass filter was used as input for the roll and pitch angular motion of the platform. The output of the high-pass filter was used an input to the X and Y directional motion. The calculated yaw motion was fed to a high-pass filter to

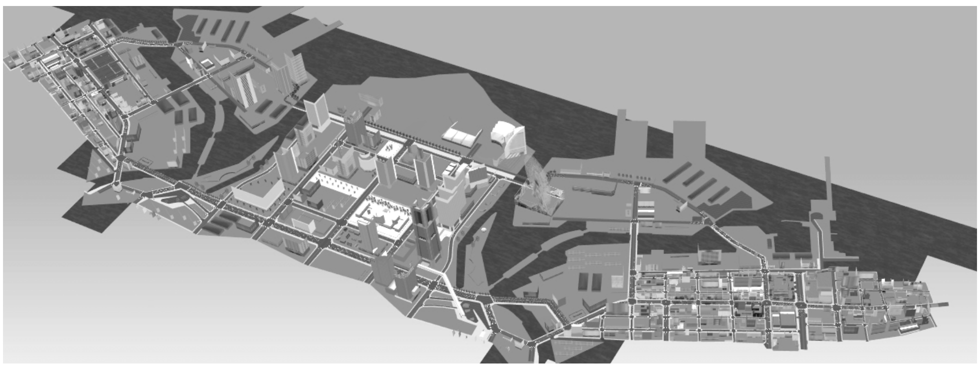


Photo 2. Birds-eye view of the town environment.

generate the yaw motion of the platform. Motion washout filters were used to adapt actual vehicle motion characteristics into the limited range of the motion system.

Visual image of road environment

The visual database includes a wide range of objects on the road environment. Area size for the road network was about 1.2kmx5.0km. A part of the area represents the actual road environment of Yokohama. It contains various current traffic control devices (400 regulatory signs, 31 traffic signals, and 40 guide signs), high density road side buildings (more than 500), vegetation. There was multiple lane traffic interacting with user-driven vehicle, including 82 and 76 pedestrians. The image projection on the screen was vertically rotated and laterally shifted depending on the pitch, roll, and yaw angle of the motion platform to compensate the movement of the platform to avoid the driver being aware of the platform movement for the rendering.

Eye Glancing Object Detection System

Procedure to obtain glancing vector and glancing object

Combining the driving simulator system, we have developed a system to detect the visual object presented on the screen that a driver is looking at. Inputs to the system were the driver's eye and head movements, that were measured by the RK-426PC Pupil/Corneal Reflection Tracking System (ISCAN Inc.) and IS-600 Precision Motion Tracker (InterSense Inc.) respectively. Tracking orientation and position of his head were realized by an inertial navigation system with acoustic range measurements, so that the driver had ultrasonic transponder beacons and a inertial measurement unit on his cap and L-shaped bar with ultrasonic receivers was attached in the vehicle cabin, behind driver's head.

Outputs of the eye tracker system and the head-motion tracker system were fed to the host computer with other records about the driver's driving. After an experimental session, a time series of the eye glancing vectors on the ground coordinates were computed by using records about the cabin motion. The glanced object was determined by comparing its position on the screen and the intersection between the glancing vector and the screen.

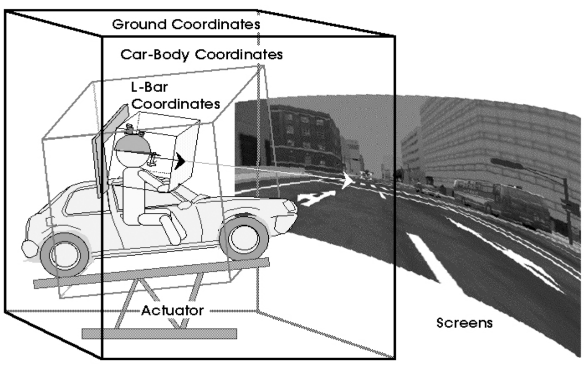


Figure 2 Coordinates transformation in the eye glancing object detection system.

General characteristics of eye glancing vector during town driving

Figure 3 show the temporal modulation of the yaw angles on the glancing vector, on the eye and on the head recorded during the town drive experiment described in the next section. The temporal modulation of the glancing vector on the ground coordinates was realized by the co-operative movements of the eye and the head. High frequency components were caused by the eye movements and low frequency components were by the head movements. In this driving situation, it is not the case that the low inertia eyes lead the way and the heavier head follows more slowly, that was previously studied (Bizzi et al 1971). This means that the head movement was actively controlled to obtain spatio-temporal of visual information for the turning maneuver.

Figure 4 shows the magnitude of rotation of the steering wheel and the yaw angle of the glancing vector. Figure 5 show the correlation between the steering magnitude and the yaw angle of the eye or the head. In turning left or right, driver's head always turned in the same direction as the steering wheel, but the eye did not move dependently from it. This suggests that the visual behavior during the turning was composed of multiple visual tasks. There must be at least two tasks; the object detection task and the turning negotiation task. In order to analyze more in detail, in the next section, we focused on changes of the glancing vector during the left turn maneuver at intersections.

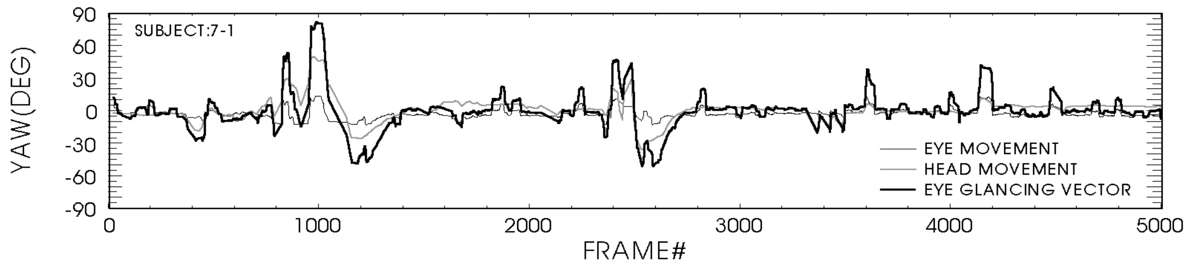


Figure 3 The temporal modulation of the yaw angle on the glancing vector, the eye and the head.

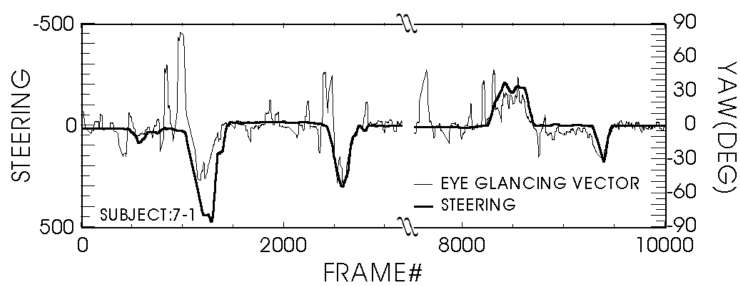


Figure 4 The magnitude of rotation of the steering wheel and the yaw angle of the glancing vector.

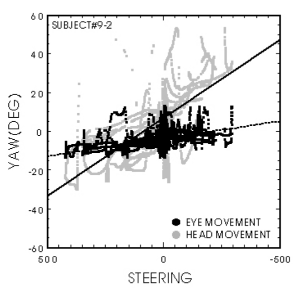


Figure 5 Correlation between steering angle and eye yaw angle or head yaw angle

Town Driving Experiment

Experimental procedure

The driving scenario in the experiment consisted of the several task elements such as “starting”, “stopping”, ”right turning” and “left turning”. The average driving period was about ten minutes and the route distance was about 4.5 km. During the trip, about 20 vehicles and several pedestrians appeared around the driver’s vehicle. An example of the simulated traffic situation is shown in Photo 1.

The subjects were asked to drive the route repeatedly for 12 times (3 times per a day). The first two trips were for the training to accustomed to the driving environment. The driving behavior during the repeated trips has been analyzed to investigate the variability of the driving maneuver (Okuwa and Akamatsu. 2001). For the 13th and 14th drive on the 4th day, we asked the subjects to ware the eye tracker system to record the visual behavior during the trip. From the data obtained from the Eye Glancing Object Detection System, we can analyze various visual behavior such as the vehicle following task, curve. In the rest part of this paper, the analysis of the visual behavior during the left turn maneuver is described.

How glancing vector changes during the left turn

Data analysis

In the simulator drive experiment, there were five left turn during the trip. The left turn maneuver consists of “object inspection task” when entering into an intersection to avoid collision, and “turn negotiation task” which change the direction of vehicle and align the vehicle heading to the direction of the road to go. While the former task might be omitted depending on the road and traffic condition, the latter is definitely necessary. Since one of the main objectives of the project is to discover patterns in driving behavior, we focused on the turn negotiation task, attempting at discovering relationships between the vehicle position and glancing direction.

Representing eye movement data

Figure 6 shows driving maneuver and visual behavior while left turning, plotted along the driving distance as the horizontal axis. The smooth line shows the vehicle heading direction and the other bumpy line plots glancing direction. The rectangle indicates the duration when the vehicle changing its direction. In Figure 7, the thick line represents the vehicle trajectory, and the string of small open circles shows the envelope of glancing direction 15 meter ahead of the current car position. Figure 6 is useful for isolating the object inspection task from the turning negotiation task. The glancing angle changed to the right once and then to the left twice. It began just before the vehicle started turning and terminated at the early stage of turning. It corresponds sweeping eye glancing before and right after onset of direction change of the vehicle in Figure 7. After glancing rightward, the glancing vector moved leftward and then complex movements were observed. Finally, the glancing vector returned to the vehicle

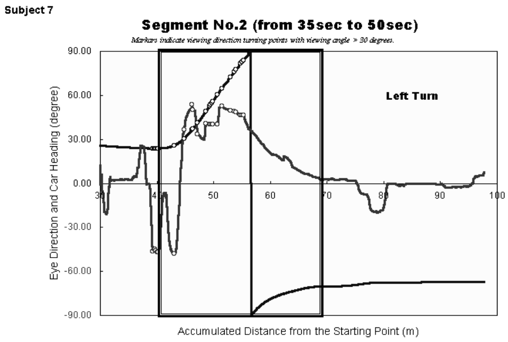


Figure 6. Vehicle heading and eye glancing as a function of vehicle distance

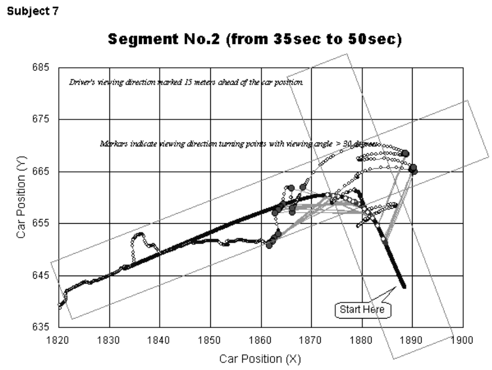


Figure 7. Vehicle trajectory and eye glancing vector on the ground coordinate.

heading direction gradually as the vehicle heading aligns to the new direction. In this example, the subject performed the object inspection task twice by looking far right at the beginning of the left turn. After entering the intersection, the subject performed the turn negotiation task. The last stage of the turning maneuver was "turn completion task" with gradual movement of the glancing to the heading of the vehicle. In the next section, we analyze the complex glancing behavior that might correspond to the turn negotiation task at the middle stage of the turning.

Visual behavior during the turn negotiation task

We made further analyses in order to infer the glancing point when negotiating the left turn. For this purpose we calculated intersections (geometrical cross points) of two glancing vectors at time T and T + 100msec, that estimate the glancing point at time T approximately. Figure 8 shows a series of intersections as open circles connected with glancing vector from corresponding vehicle positions in every 100msec. Grey lines emanating from the vehicle positon show glancing directions for which no intersection (glancing point) was found in this procedure, which might correspond to a transitory eye movement from a certain glancing point to another.

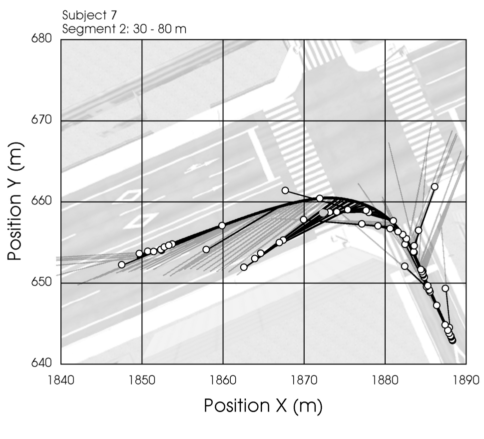


Figure 8. An example of vehicle trajectory and eye glancing vectors.

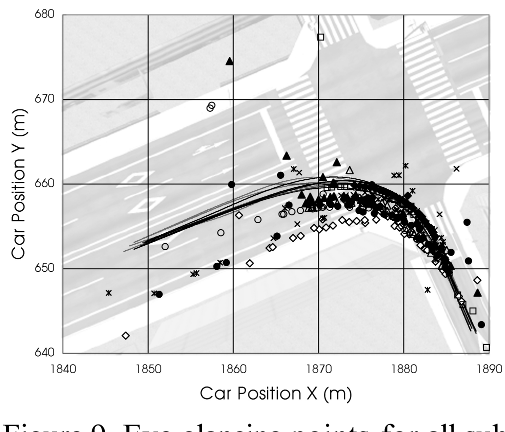
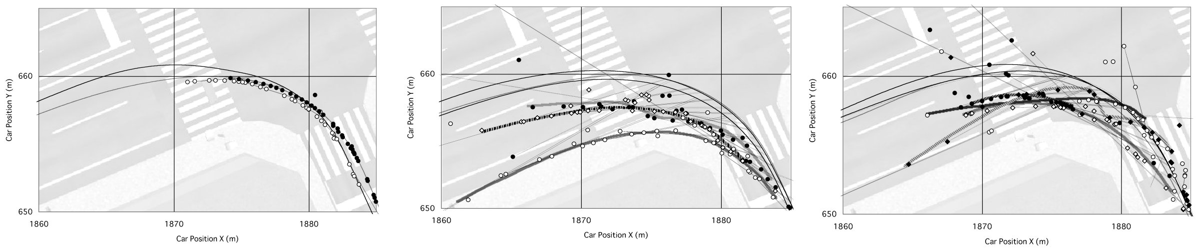


Figure 9. Eye glancing points for all subjects.



a (sub 6 and 10) b (sub 5, 8 and 9) c (sub 1, 3, 4 and 7)

Figure 10. Three types of changes of eye glancing point

Figure 9 shows the glancing points, along with the vehicle trajectories for all the subjects. From this figure, although there were fluctuations or noise, we could see that the glancing points moved along lines that were in between the inner side of the vehicle trajectory and the sidewalk of the left corner of intersection. The changes of the glancing points can be classified into three types. The glancing points of subject 6 and 10 moved almost along or slightly inner side of the vehicle trajectories (Fig. 10a). This means that they glanced the predicted vehicle position a few meters ahead. For subject 5 and 8, the glancing points moved along the roadside edge of the sidewalk for a while. Then, the points left from the edge to the line between the lanes (Fig. 10b). The glancing point of subject 9 moved along a line between the roadside edge and building side edge of sidewalk, and then they aligned to the edge of sidewalk (Fig. 10b). For subject 1, 3, 4 and 7, the glancing points moved along a line between the vehicle trajectory and the edge of sidewalk (Fig. 10c).

For the cases, the subjects glanced along the edge of the sidewalk, it is similar to the "gazing tangent point" phenomenon observed in the curve negotiation (Land and Lee 1994). However, the most common case for the subjects examined here, the glancing points did not follow any remarkable cues. This suggests that the drivers used unseen lines somewhere inside the predicted vehicle trajectory as the cue for the turning. There were two subjects who glanced along the predicted vehicle trajectory. In this case, they might not pay attention to the inner side of the vehicle. This happened may be because of the drivers moved the vehicle to the center-line lane of the two lane road. For such a turning negotiation, it was not necessary to care about hitting a wheel to the edge of the sidewalk.

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