OCULAR MOVEMENT DURING CURBSIDE TURNS AT INTERSECTIONS

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We conducted a driving experiment and measured and analyzed the data on eye movement in order to understand ocular movement during curbside turns at intersections. We used a driving simulator equipped with a system capable of measuring the direction of a subject's glances relative to the heading of their vehicle. By analyzing this data, measured at three intersections, we identified three tasks commonly observed in curbside turns: 1) object inspection; 2) turning; and 3) aligning. During the first task, the measurements showed variable swinging patterns. There was a consistent pattern of looking at targets along the curb in the second task, presumably for guidance while turning the vehicle. During the third task, measurements showed a coherent pattern of returning the glance from turning to the subsequent driving maneuvers.

INTRODUCTION

The purpose of this paper is to describe new findings we obtained by analyzing the data collected in a driving simulator experiment. This paper focuses particularly on ocular movement during curbside turns at intersections, a critical part of driving because of the cognitive and motor demands on the driver. In order to investigate coordination of ocular movement with driving maneuvers, Land and Lee (1994) analyzed these movements by comparing the driver's view and gaze points using an eye-tracking system. They found that subjects gazed at the tangent point while performing a curve negotiation task. However, we wanted an accurate understanding of the coordination of cognitive and motor activities while turning at intersections since there are many accidents at intersections. Land and Lee's finding concerning curve negotiation could be valid for curbside turning but no research has yet proven it. Our research challenges this issue through detailed analyses of ocular movement, using experimental data from a state-of-the-art driving simulator.

This paper starts by describing the driving simulator, the experiment, and the data obtained. We then show three steps commonly observed in curbside turning. We conclude the paper by summarizing the characteristics of these tasks in terms of ocular movement.

DRIVING SIMULATOR

Hardware Configuration

We used a dynamic driving simulator with a hexapod motion platform and projected the visual image on three screens. The first, a cylindrical screen with a 180-degree field of view, is fixed on the floor surrounding the motion platform. The second, a flat screen with a 43-degree field of view, is connected to the cylindrical screen at the driver's side for the side view. The third, a 200-inch flat screen, shows the images of the rear-view and door mirrors. The vehicle cabin is fixed on the motion platform, and the subject can control the vehicle using the steering wheel, brake, and acceleration pedal as if driving a normal car (Figure 1).

The audio system presents various sounds that can be heard while driving; including engine and exhaust sounds from the vehicle, road noise, and exhaust sounds from other vehicles. Vibration, added to the steering wheel and the cabin floor, simulate vehicle movement.

The driving simulator consists of three computer systems. A Windows 2000 computer system serves as the host computer, which calculates the vehicle dynamics and the traffic. A Windows-NT computer system controls the servo system of the steering wheel. An SGI Onyx 2 system with Infinite Reality2 generates images at update speeds of 60 or 30Hz.

The parameters of driving behavior, such as vehicle speed and pedal stroke, are recorded in data files at a rate of 30 Hz.

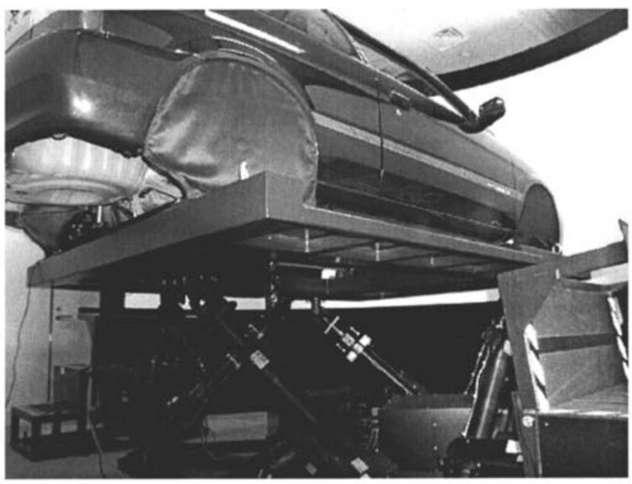

Figure 1. Appearance of the driving simulator.

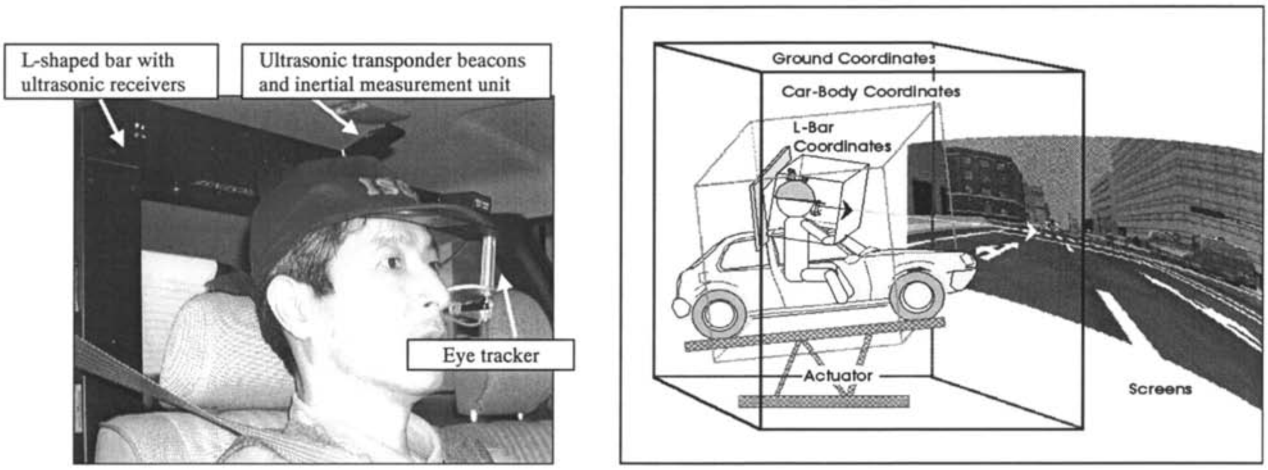

Figure 2. *Left* – Equipment for measuring driver's eye and head movements. *Right* – Coordinates transformation in the eye-glance direction detection system.

Visual Image of the Road Environment

The visual database includes a wide range of objects in the road environment. The size of the road network is about 1.2 km x 5.0 km. A part of the area represents the actual road environment of Yokohama, Japan. It contains 400 regulatory signs, 31 traffic signals, 40 guide signs, more than 500 closely spaced roadside buildings, and vegetation. Multiple-lane traffic, including 82 vehicles and 76 pedestrians, interact with the subject's vehicle.

Glance-Direction Detection System

We developed a system that detects the direction in which a driver is looking and added it to an existing driving simulator (Figure 2). The system detects the looking direction by measuring the eye movement and head movement of the driver. An RK-426PC Pupil/Corneal Reflection Tracking System (ISCAN Inc.) measures the driver's eye movements, and an IS-600 Precision Motion Tracker (InterSense Inc.) measures head movement. An inertial-navigation system with acoustic-range measurements tracks the orientation and position of the driver's head. The system consists of ultrasonic transponder beacons with an inertial measurement unit attached on the driver's cap, and an L-shaped bar with ultrasonic receivers attached to the vehicle cabin behind the driver's head (Figure 2, left). As shown by the photo, the cap and the miniature camera the subjects wore were minimally obtrusive and did not significantly restrict their head movement or driving ability.

Outputs of the eye-tracker system and the head-motion-tracker system are fed to the host computer and stored in data files, then converted into a time series of the eye-glance vectors on the ground coordinates using the data on the cabin motion (Figure 2, right).

TOWN-DRIVING EXPERIMENT

Experimental Procedure

A driving scenario was defined as a 4,500-m driving route consisting of several task elements such as starting, stopping, driver's side turning, and curbside turning. A complete trip, driving normally according to the scenario, took about 10 minutes. During the trip, about 20 vehicles and several pedestrians appeared around the subject's vehicle.

There were three curbside turns in the scenario, and these will be the focus of this paper:

- First curbside turn at 10 m from the starting point: Exits a parking place, stops at the curb, and turns to the passenger's side onto a narrow one-lane road.

- Second curbside turn at 40 m from the starting point: Travels along a narrow one-way road, stops at the red light, turns to the passenger's side when the light changes to green, and follows the jammed traffic along a wide two-lane road.

- Third curbside turn at 2,260 m from the starting point: Travels along a one-lane road, stops at the STOP sign, and turns to the passenger's side onto a wide two-lane road.

The subjects were asked to drive the route 14 times, three times a day for the first four days and twice on the fifth day. The first two trips were for training, in which the subjects became accustomed to the driving experiment. The following ten trips measured driving behavior. See Okuwa and Akamatsu (2001) for a detailed analysis on this segment of the experiment. The two trips on the fifth day measured eye-glance directions. In this paper, the data from one of these two

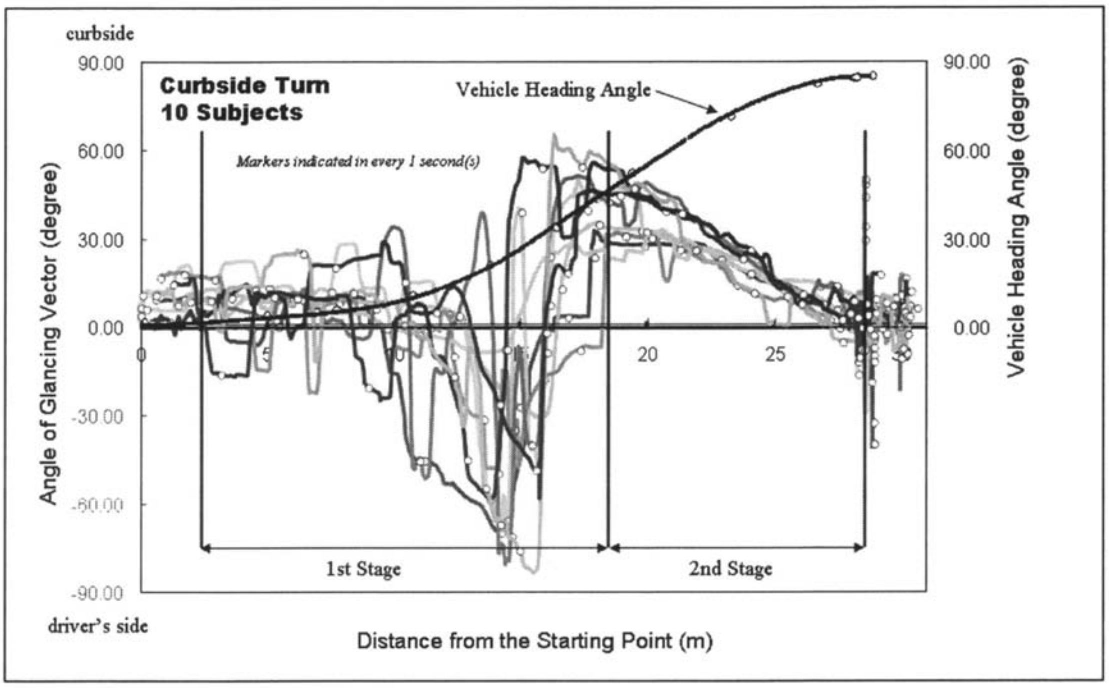

Figure 3. Overlay plot of glancing directions at the first curbside turn from ten subjects.

trips analyzed ocular movement. NASA TLX tests to examine workload showed that the subjects' workload reached a stable state on the second day of the experiment. At that time, the eye-glance direction data would not have been affected by fatigue or vigilance.

Subjects

Ten male subjects participated in the experiment. Their average age was 30.3 years old, ranging from 22 to 38. They had 10.8 years of driving experience on average, ranging from 3 to 19.6 years. Their average driving distance a year was 16,151 km.

OCULAR MOVEMENT WHILE TURNING

Results and Preliminary Analysis

Figure 3 illustrates an overlay plot of the data from ten subjects, of eye-glance direction relative to the vehicle's heading at the first curbside turn. The glance direction is plotted along the ordinate (Y axis), and the accumulated driving distance is plotted along the abscissa (X axis). The smooth line shows the vehicle's direction from one of the subjects relative to a predetermined direction, indicating the progress of the turn.

A pronounced feature of this plot is that there are two substantially different stages in the turn. We argue that the second stage should be further separated into two sub-stages.

The first stage begins before the vehicle starts turning and ends at the middle of the turn. This stage is characterized by the variability in the pattern of glance direction.

The second stage is characterized by a coherent pattern of glance direction. It starts at the middle of the turn and ends at its completion. As seen in the plot, the glance directions are approximately 30 to 50 degrees towards the curbside, relative to the direction of the vehicle's heading at the middle of the turn. The glance angles start to decrease monotonically and converge in a single decreasing line at the second half of this stage of the turn.

The same two stages were also observed in the overlay plots for the second and the third turns.

A Closer Look at the Glance-Direction Data

We devised a procedure for detailed data analysis of the second stage. Figure 4 schematically illustrates this method. We calculated the intersection (geometrical cross points) of two glance vectors at time T and $T+\Delta T$. This intersection, if it exists, provides an estimate for the glance point at time T (Figure 4, top). However, there are situations where no intersection is present along the direction of the vehicle movement, yet a virtual glance point exists behind the current vehicle position (Figure 4, bottom).

Figure 5 illustrates the result of applying this procedure to the data from one of the subjects at the third curbside turn. Circles show the positions of the vehicle on the vehicle trajectory in one-second increments. The new method was not applied to Segment 1, which corresponds to the first stage of

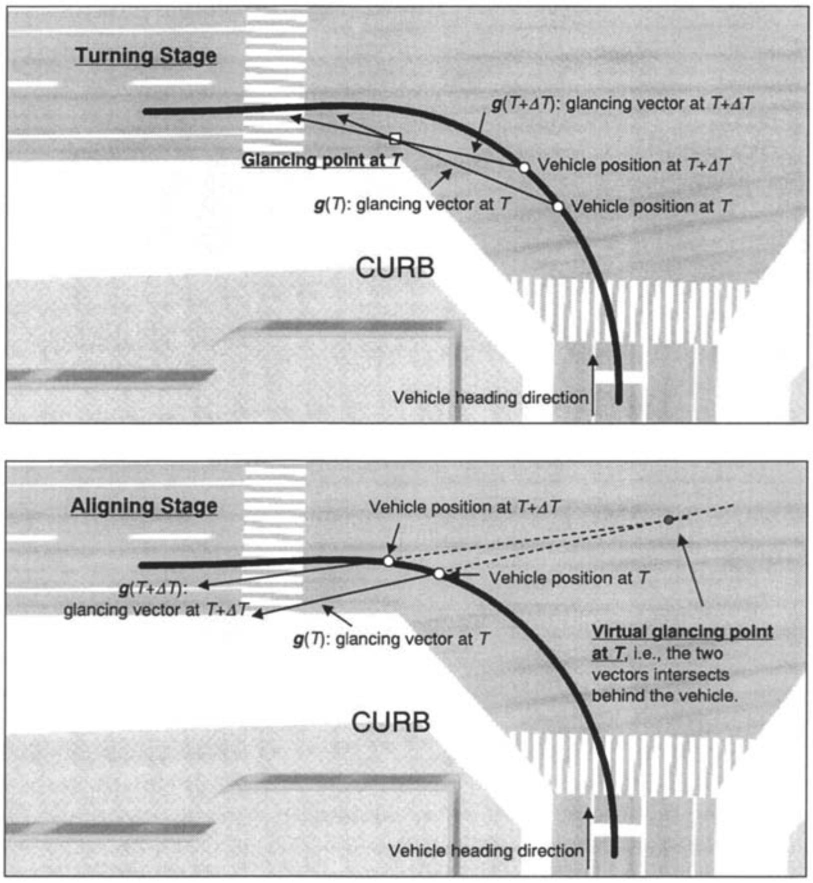

Figure 4. The method for estimating glance points. In this figure, ΔT demonstrates a larger value than the one we used for the analysis, 100 msec. Remark – Since the figure uses the actual driving trajectory from one of the subjects (subject 7), the "curbside turn" appears as a "left turn." This is because the traffic keeps left in Japan. For those with the opposite traffic condition, a mirror image of the figure should be used.

Figure 3. The points along the glance vectors indicate the glance directions. In the figure, dots show these points at every 1/60 second. They represent the characteristic swinging pattern of this segment. In segment 2, a series of glance points are shown as squares connected by glance vectors from the corresponding vehicle positions. By superimposing the CG image of the simulator as seen by Figure 5, we confirmed that these squares align along the curb of the intersection. In segment 3, we obtained no real glance points, but a number of virtual ones following the direction of the vehicle's movement. The dotted lines emanating from the vehicle positions show glance directions during this period.

Elements of Turning

We created plots like Figure 5 for each subject, and then confirmed all plots had the same features consisting of the three segments described above. Based on these findings, we suggest that a curbside turn maneuver should consist of the following three tasks corresponding to the three segments.

Task 1. **Object inspection** for avoiding collision when entering into intersection. In this task, the subjects' glance directions showed variable swinging patterns.

Task 2. **Turning** for driving the vehicle along the curb in the intersection. In this task, the glance directions in Figure 3 showed consistent patterns with only slight variability. This indicates that the subjects looked at different targets along the curb as guidance for controlling the vehicle. This is consistent with the expectation that the drivers would have different targets, i.e., the guiding line inside the curb, the edge of the curb, etc., when turning the vehicle along the curb in the intersection. Indeed, Akamatsu, et al. (2001b) reported that the subjects could be divided into three types in terms of the curbside targets they used in turning, by comparing the plot in Figure 5 for all the subjects. However, since they have not developed an objective method for identifying these types, their findings must be rigorously examined by further analysis of the data. This also suggests that Land and Lee's (1994) findings concerning curve negotiation might not be completely valid for curbside turning.

Task 3. **Aligning** for changing direction and aligning the vehicle to the direction of the road. In this task, there were no real glance points but there was a series of virtual glance points, corresponding to the driver's behavior of moving his eyes from the curb to the direction of the vehicle. No individual differences were observable, as shown by the second half of stage 2 in Figure 3, suggesting that this behavior is governed by a mechanism independent of drivers' characteristics and traffic conditions. This pattern differs from that caused by saccadic eye movements that are normally observed when the driver observes and recognizes real objects in the driving scene while driving a straight road.

CONCLUSION

We analyzed data on eye movement for ten subjects from a town-driving experiment measured with a driving simulator in order to understand ocular movement during curbside turns at intersections. We devised a method for estimating glance points and applied it to the glance data to find three tasks commonly observed in accomplishing the curbside turns: object identification, turning, and aligning. These tasks had significantly different features in terms of ocular movement. Variable swinging patterns characterized the object inspection. Turning demonstrated a consistent pattern with slight variability in the ocular movement associated with controlling the vehicle along the curb by looking at nearby objects as targets. Aligning showed a consistent pattern that might be

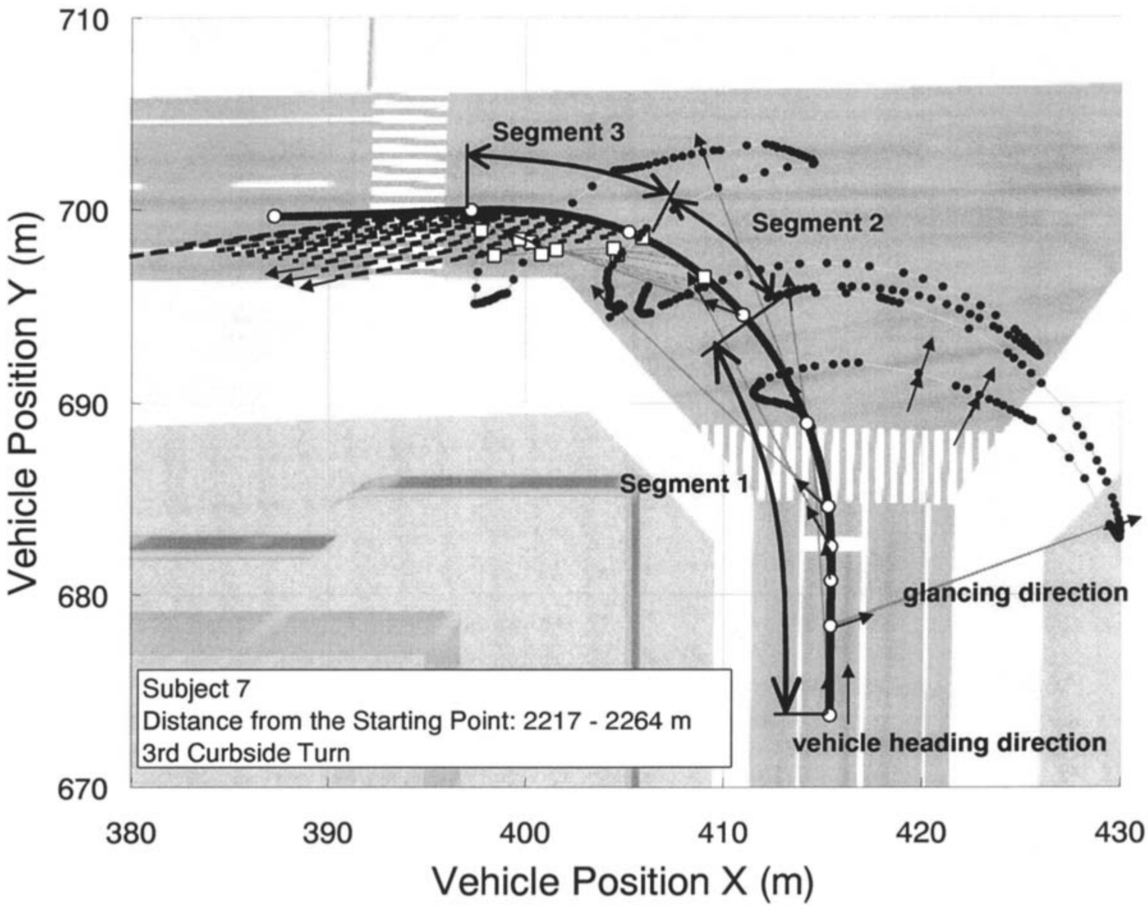

Figure 5. Three segments during a curbside turn (left turn in Japan). Segment 1, Swinging pattern of glancing direction vectors, followed by Segment 2, a series of real glancing points, and Segment 3, a series of virtual glancing points.

governed by an unknown mechanism necessary for returning the glance from finishing the turn to continuing the other driving maneuvers. The number of subjects we tested is not large enough to generalize for all drivers, but we believe these findings demonstrate a part of drivers' behavior during curbside turns at intersections.

The finding that turning and aligning are not accompanied by saccadic eye movements could have important implications for safe driving at intersections. During these tasks, drivers' eyes are engaged mostly in the tasks for controlling the vehicle direction and are not used effectively for checking safety procedures.

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