Steering Behavior Model of Drivers on Driving Simulator through Visual Information

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Abstract—A driver is regarded as a system that receives visual information and that controls the steering wheel. To identify the system, we conducted experiments to get input-output data using a driving simulator and confirmed that the focus of expansion of optical flow has sufficient information to predict steering behaviors.

I. INTRODUCTION

Driving behavior prediction is essential to develop an advanced driver assistance system (ADAS) or even automatic driving system since they should know how surrounding vehicles move in the next step [1]. To avoid collision with surrounding vehicles, a driver mainly takes one of the two actions. One is to reduce the speed using the brake and the other is to move laterally using the steering wheel. While the former is rather easy to predict [2], the latter is more difficult since the driver has to take the traffic of other lanes into account [3]. On the contrary, even how a driver behaves during a curve driving is still unclear [4], [5], [6], [7].

A driver perceives the road ahead and controls the steering wheel so that the vehicle trace the line the driver plans in mind. However, modeling the driver’s strategy is controversial since the line is unseen and there are mainly two features to be considered, the tangent point (TP) and the future path (FP) [4], [5], [6]. TP is the point in the driver’s visual field at which the gaze direction coincides to the tangent line of the inside lane edge (Fig. 1). TP had been considered the tracked point by a driver for a long time but drivers showed different behaviors when asked to look at TP during driving [6]. FP is the trajectory of a vehicle in the future time points (Fig. 1). However, FP does not appear and has no visual information to be perceived by a driver. This fact may be a cause of controversy.

One idea to cope with this difficulty is to skip the feature extraction, that is, to use optical flow directly [7] since most of the dynamic visual information is given as optical flow (Fig. 2). In fact, if we regard a driver as a system that receives visual information and that controls the steering wheel, the problem of behavior prediction results in the system identification from input-output data, which are given by perception-action cycle in case of driving [8].

To identify the system from real data, we first measured the driving behaviors of subjects using a driving simulator as well as their gaze using a glass-type eye tracker (see III.A Measurement). Then, we applied the steering model based on optical flow and the optimal control theory in [7] (see II. Steering model) to our data and compared the model outputs with the real steering behaviors. As a result, they agreed very well and the usefulness of optical flow and its focus of expansion (FOE) was confirmed.

II. STEERING MODEL

The steering model based on optical flow [7] is twofold. The first part is to regard the gaze point as the target of a driver while FOE is in the actual direction of self-motion [9]. This fact means we need not calculate FOE from optical flow since...
TABLE I
PARAMETERS OF THE VEHICLE DYNAMICS.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>vehicle velocity [m/s]</td>
</tr>
<tr>
<td>ks</td>
<td>steering wheel gear ratio</td>
</tr>
<tr>
<td>β</td>
<td>sideslip angle [rad]</td>
</tr>
<tr>
<td>γ</td>
<td>yaw rate [rad/s]</td>
</tr>
<tr>
<td>δ</td>
<td>steering angle [rad]</td>
</tr>
<tr>
<td>Kf, Kr</td>
<td>cornering stiffness of the front and rear tires [N/rad]</td>
</tr>
<tr>
<td>l_f, l_r</td>
<td>distances from COG to the front and rear tire axles [m]</td>
</tr>
<tr>
<td>m</td>
<td>vehicle mass [kg]</td>
</tr>
<tr>
<td>I</td>
<td>yaw moment of inertia [kg m²]</td>
</tr>
</tbody>
</table>

The direction of self-motion is derived from the car data. The second part is to nonlinearly control the steering to approach the target using a quadratic Lyapunov function [7].

A. Vehicle Dynamics

To make the steering model, the vehicle was modeled using a single-track model [10], that is, the dynamics is described as

\[
\frac{d}{dt} \begin{bmatrix} \beta \\ \gamma \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} \beta \\ \gamma \end{bmatrix} + \begin{bmatrix} E \\ F \end{bmatrix} \frac{\delta}{k_s},
\]

where

\[
\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} -\frac{2(K_f + K_r)}{mV^2 + 2(l_f K_f - l_r K_r)} & \frac{mV^2 + 2(l_f K_f - l_r K_r)}{IV} \\ \frac{2(l_f + l_r)}{mV^2 + 2(l_f K_f - l_r K_r)} & \frac{2(l_f + l_r)}{IV} \end{bmatrix},
\]

\[
\begin{bmatrix} E \\ F \end{bmatrix} = \begin{bmatrix} \frac{2K_f/(mV)}{2l_f K_f/I} \\ \frac{2K_r/(mV)}{2l_r K_r/I} \end{bmatrix}
\]

according to [7]. See Table I for the notations.

The parameters in the vehicle dynamics were fixed to one of the two sets so that each corresponds to a big car or a small car (concrete values are omitted here).

III. EXPERIMENTS

Eleven healthy subjects were recruited (M/F: 9/2) in Kyoto University. Informed consent was obtained from all the participants prior to the experiments. The experiment procedure was approved by the ethical committee of Nara Institute of Science and Technology (H27-1548).

A. Measurement

1) Driving Simulator: The driving behavior of each subject was measured using a driving simulator developed by one of the authors (Fig. 3), where the parameters were set to the values determined in the steering model (see II.A Vehicle Dynamics). The collected data were the steering wheel angle and other driving behaviors, as well as car conditions such as the position, the velocity, and the yaw angle.

2) Eye Tracker: The gaze of each subject was measured using a commercial eye tracker (Tobii Glass, Tobii, Sweden). The eye tracker indicates the gaze position in the movie recorded with a camera therein (Fig. 4).

B. Procedure

Each subject was instructed to drive a vehicle as usual with the eye tracker on face. S/he drove around the course one time with the big car for habituation and three times with the big car and three times with the small car, where the course included two kinds of curves, large and small radii (Fig. 5).

IV. RESULTS

Three of the eleven subjects were excluded from the analysis below because one failed in recording behaviors due to equipment trouble and the other two went out of the course during the experiment. To compare the predicted steering angle sequence with the observed one for each trial, we calculated the correlation between the two sequences. The correlation for gradual curves was 0.74 ± 0.23 (Average ± S.D.) and that for sharp curves was 0.96 ± 0.06 (Figs. 6, 7).

V. DISCUSSION

The correlation values of 0.74 and 0.96 for gradual and sharp curves were very high, indicating the steering model
based on FOE explains steering behavior very well. The reason of the higher correlation for sharp curves may result from larger changes of the steering angle (Figs. 6, 7).

The difference of the sequences is mainly due to some spikes in the predicted sequences, which do not appear in the observed sequences (Fig. 6). These spikes seem to result from eye movements (saccades) of the driver because the target changed discontinuously while the steering wheel angles continuously.

Including this phenomenon, visual information induces eye movements of the driver. However, this steering model does not explain eye movements at all although the gaze information is important to understand the driving behavior. This is the next step of this study.

VI. CONCLUSIONS

We regarded a driver as a system that receives visual information and that controls the steering wheel and showed that the important feature of visual information is FOE, the focus of expansion of optical flow using the real data collected by a driving simulator. The steering model based on FOE output a sequence that has the correlation of 0.80 with the observed sequence on average.

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REFERENCES


Fig. 7. Predicted and observed steering wheel angles of Subject 1 on the small car.