STREET: A novel simulator for driver assistance system evaluation

Masami Aga
Shin Tanaka
Hideki Sakai,
Toyota Motor Corporation
Japan

Tetsuo Kurahashi
Takashi Machida
Hiroko Mori
Hironobu Kitaoka
Toyota Central R&D Labs., Inc.
Paper Number 09-0144

ABSTRACT

In order to evaluate the impact of driver assistance systems under various situations, researchers have attempted to reproduce accurate traffic situations and accidents by traffic simulations. Here, we propose a new simulator STREET (Safety & Traffic REaltime Evaluation Tool) that has a driver model with a cognition model and a decision-making model in it. This paper mainly describes the aim and the architecture of this novel driver model.

In the cognition model, there are three stages: 1) detecting objects in the field of view, 2) classifying such objects like a lead vehicle or oncoming vehicle, etc., and getting information, and 3) setting the driver’s gaze direction. In the decision-making module, there are two stages: the first stage is to decide a maneuver for each recognized object by using “a decision rule with maps” expressed as the status space region defined by object’s parameters such as distance and velocity as axes. The second stage is to decide the most appropriate maneuver among the combinations permitted in the acceleration/deceleration ranges for each object in succession to the first stage. The driving maneuver is switched in sequence based on the decision-making model output and the vehicle motion is then consequently calculated. When the traffic participants are added in the scene, decision-making rules are added for them, allowing STREET to correspond to complex traffic situations.

Two benefits are expected by using STREET. One is that users can evaluate and understand system activation under the target situations. Another is that the system can be evaluated under various traffic situations beyond the target situations so that the users can assess the limitations of the system. Some preliminary results using STREET and further development plans for the system are also discussed.

INTRODUCTION

For the purpose of evaluating traffic safety systems, traffic simulators have been developed. Most conventional simulators have implemented “average” vehicle motion for a traffic circumstance prepared for the evaluation. These have been very useful for estimating “average” performance. However, the upcoming driver support systems are expected to comprehend each driver’s behavior influenced by external situations and his/her internal conditions, and to automatically adapt their properties. It will become very difficult for conventional traffic simulators to evaluate such adaptive support systems.

So, a traffic simulator, called STREET (Safety & Traffic REaltime Evaluation Tool) [1] has been developed. This paper describes the concept of STREET and its driver model in detail, in which a driver recognizes his/her surrounding and decides the most appropriate maneuver. By allotting a variety to the parameters to each traffic participant based on his/her characteristics and his/her abilities measured under actual traffic circumstances or DS experiments, it becomes possible to assess the system benefit comprehensively.
OUTLINE OF A DRIVER MODEL IN STREET

Figure 1 shows the structure of STREET. Traffic participants such as car, motorcycle, bicycle or pedestrian, are called mobility objects in the simulator. Each mobility object recognizes each other, decides its next operation and puts it into practice.

Each mobility object is generated from “Mobility generation module (b)” and is given its properties based on mobility dataset that define not only origin, destination and route, but also driver or pedestrian characteristics and abilities.

Roads are generated from “Road generation module (a)” using a road element dataset that possesses road network data defined by node and link and roadside commodities such as traffic signals, stop signs and also obstacles.

The generation, disappearance and movement during the period of each mobility object are managed under “traffic environment module (c)”. Each one obtains surroundings from the Traffic Environment Module, recognizes its situation and then decides the next operation. As the result, the location and velocity of each are updated and the changes are reflected in the data in the Traffic Environment Module and new interactions between the objects are yielded. If “Active Safety System (d)” is equipped to the objects such as information service, warning or intervention, they work to influence drivers’ cognition, decision and/or behavior.

Figure 1. Structure of STREET

Figure 2. Execution screen (STREET)

When collisions happened during simulations, STREET outputs accumulated data such as process of the cognition, decision, operation and driving situations and the collision diagram after the simulations were
completed. Two examples are shown in Figure 2. Active safety systems are designed to either help reduce collisions or mitigate human injuries as a result of decreased collision speed. For the purpose of evaluate mitigation benefit, “Injuries Estimation Module (e)” is attached to calculate a probability of fatality, serious injury and less severe injury in collisions.

A DRIVER’S COGNITION MODEL

Cognition itself is the composition of visual, auditory and tactual sensation etc. Among all, visual is the most important to be modeled because it is closely related to traffic accident cause. Central visual field allows drivers to be aware of the location and speed of objects while peripheral visual field allows drivers to be aware of just the existence of them. Therefore, cognition status depends on the direction of eyes. When there are many objects, the order of cognition is one of the important factors that drivers must decide.

Figure 3 is a simplified model of human’s memorizing procedure. Sensory memory holds instantaneous iconic information within driver’s visual field. The sensory information is segregated in this process. Selected information that is considered to attract a driver will be stored in memory while the unselected one will be forgotten.

Memory process model in STREET models sensory memory and short-term memory as shown in Figure 4. Objects such as cars, passengers etc. that exist within driver’s visual field are inputted to sensory memory, and selected ones among them are copied in short-term memory with location and velocity information.

STREET uses the fan-shaped visual field with visual distance and angle as parameters for both central visual field and peripheral field as shown in Figure 5. The parameters are varied between individuals because they depend on their ability.

The location and velocity of each object in short-term memory are used to classify whether it is a lead vehicle, an oncoming vehicle, a vehicle coming from right or etc. Such definitions are expressed in Figure 6 and 7. The process is essential to estimate a surrounding risk and to decide the priority to direct the eyes.
Figure 6. Classifying objects

<table>
<thead>
<tr>
<th></th>
<th>Classifier</th>
<th>Speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Leading</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Right Leading</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Left Leading</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Right</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Left</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Oncoming vehicle/Straight</td>
<td>30</td>
</tr>
<tr>
<td>7</td>
<td>Oncoming vehicle/Turn right</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>Oncoming vehicle/Turn left</td>
<td>20</td>
</tr>
<tr>
<td>9</td>
<td>Crossing vehicle from right/Crossing</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Crossing vehicle from right/Turn right</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Crossing vehicle from right/Turn left</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Crossing vehicle from left/Crossing</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Crossing vehicle from left/Turn right</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Crossing vehicle from left/Turn left</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Pedestrian/Crossing(near)</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Pedestrian/Crossing(far)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 7. Classified objects in the field of view

Traffic light: Blue
Oncoming vehicle/ Turn right: 0 [mph]
Oncoming vehicle/ Straight: 30 [mph]
Pedestrian 1 [mph]
Right Leading vehicle: 35 [mph]
Oncoming vehicle/ Turn left: 20 [mph]
A DRIVER’S DECISION-MAKING MODEL

The driver’s decision-making model is the core of the simulator. In actual traffic, a driver’s decision is influenced not just by recognized objects, but also by their complex combinations. However, it is rather impractical to implement such combinations one by one.

So, we propose a new driver’s decision-making model that consists of a bundle of rules like a production line shown in Figure 8. It is a concrete example which simulates that a driver recognizes five objects, that is, a traffic signal (green), the vehicle in front (brake light lit), a vehicle on the right (not close), a vehicle on the left (not close), and an oncoming right-turning vehicle (stopped). All the while, the driver is following a vehicle and approaching to an intersection.

The decision-making model has two steps. The first step (Step1) is the decision of candidate of maneuver and its level using “a decision rule with maps” for each recognized object. The map establishes the correspondence from one point in the state space region defined by the object’s and driver vehicle’s information to one maneuver. Wiedemann’s model [2] for the vehicle in front and the Gap Acceptance model [3] for an oncoming vehicle are considered adequate to be applied. They propose appropriate maneuver zones enclosed by kinematics conditions and also by the driver’s abilities and characteristics. Figure 9 shows the modified Wiedemann’s model in STREET for an average driver while following a vehicle. Each region has an allowable range between the maximum deceleration and the maximum acceleration to avoid a collision and maintain the driver’s safety margin (usual gap time, acceptable deceleration, and so on). The range of course should pay attention not to break any traffic rules. Various maps are prepared according to the driver’s abilities and characteristics.

In the second step (Step 2), the most appropriate driving maneuver within the smallest allowable acceleration range among the candidates is selected. Then, a target location and a target velocity are identified.

The model has three benefits: First, it is based on the information processing model for a human. Second, it expands easily to complex traffic situations simply by piling up new decision rules with maps for added object. Third, the development of a decision rule with a map is easy, for one can deal with a decision rule with a map respectively. We have developed almost 1,500 rules so far that are related to intersection driving. As the number of rules increase, the model can cover more traffic situations.
Figure 9. The map of decision rule for an average driver in LVD scene

EXPERIMENT AND RESULT

We confirmed the capability of traffic flow reproduction of the simulator. The traffic conditions used for validation are shown in Figure 10. Vehicles are generated at the rate shown in Figure 10(1) and the signal timings are set as shown in Figure 10(2).

Figure 10. Traffic conditions used for the validation

Figure 11. The distribution of a gap time to a leading vehicle

LVS: Lead Vehicle Stopped

LVD: Lead Vehicle Decelerating

LVM: Lead Vehicle Moving
The indexes related to the lead vehicle were validated. The distribution of gap time to a lead vehicle while passing through an intersection during the signal is green is shown in Figure 11. The simulator shows the mode value of 2.0 sec while measured data shows that of 1.8 sec. The graph indicates that the distribution of simulation coincides well with that of measured data [4]. The 50 percentile TTC (time to collision) at the onset of braking to a lead vehicle is compared in Figure 12. It can be seen that the 50 percentile TTC in simulation coincides well with that of measured data [5], except for LVM scene. The difference may suggest that actual drivers are more sensitive to the lead vehicle’s deceleration than the modeled driver. Further investigation will be needed to understand these differences.

CONCLUSION

To evaluate the performance of safety systems, a traffic simulator with a detailed driver model, named STREET has been developed. Its cognition model possesses sensory memory and short-term memory so as to emulate human visual behavior. The characteristic of its decision-making model is that it consists of decision rules with maps so as to ensure expandability and easy development. The capability of traffic flow reproduction of the simulator was confirmed. In the future, we plan to validate both the macro- and microscopic traffic flow levels and evaluate the effect of driver support systems.

Reference


