

Verification of ASSTREET Driver-Agent Model by Collaborating with the Driving Simulator

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ABSTRACT

This paper proposes a novel method of verifying comprehensive driver model used for the evaluation of driving safety systems, which is achieved by coupling the traffic simulation and the driving simulator (DS). The method consists of three-step procedure. In the first step, an actual driver operates a DS vehicle in the traffic flow controlled by the traffic simulation. Then in the next step, the actual driver is replaced by a driver model and the surrounding vehicle maneuvers are replayed using the recorded data from the first step. Then, the maneuver by the driver model is compared directly with the actual driver's maneuver along the simulation time steps. For example, while turning right (in front of the oncoming traffic), the proposed verification method was applied to our driver-agent model of traffic simulation system ASSTREET (The Advanced Safety System & Traffic REaltime Evaluation Tool) to demonstrate that the proposed method provides a straightforward way of verifying the driver-agent model capability to reproduce the driving behavior including the subtle driving behaviors, such as safety confirmation, that can have significant impact on driving safety. The scheme of interactive connection of ASSTREET and a driving simulator is also described.

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INTRODUCTION

In the development of advanced driving safety systems, it is necessary to evaluate benefits of driving safety systems before their introduction by applying appropriate simulation techniques. At present, there are two main approaches for the evaluation of these systems, one utilizing traffic simulation and the other employing driving simulator (DS).

The traffic simulation approach typically involves calculation and comparison of the surrogate safety measures such as distributions of time-to-collision, post encroachment time, headway distance, average speed, speed variations, etc., for the cases with and without the safety systems [1,2]. Some latest research work utilizes simulation of collision between vehicles according to the implemented error model of the driver, such as our latest work proposing a sophisticated evaluation method of pre-crash safety system using "ASSTREET" (The Advanced Safety System & Traffic

REaltime Evaluation Tool) [3,4]. The reconstruction of real world collisions in the simulation can also be included in this approach, where the comparison is made between the simulated real collision scenario and the predicted collision scenario using a virtual prototype of the driving safety system [5,6].

On the other hand, main purpose of the DS approach is to investigate the effect of the driving safety systems on driving behavior of human drivers. A number of studies have been executed with this goal. For this approach, as stated in [7], it has been recently recognized that the impact of the driving safety systems on the behavior of individual driver can be analyzed through the driving simulator only if the surrounding vehicles in a driving scenario could move autonomously by taking into account the effect of the same system under evaluation. Therefore it is necessary to combine

traffic simulation and driving simulator, using the traffic simulation to control the surrounding vehicles in DS [7,8,9].

The success of these simulation-based evaluations of the driving safety systems depends on the fidelity of the driving behavior and the traffic flow produced by the comprehensive driver model in the simulation. Thus the verification of driver model is a significant issue to be addressed in this research area. The conventional verification of driver models is usually based on the comparison between macroscopic and statistical indexes like the traffic volume or the gap acceptance for right/left turn in the intersection calculated by the simulation and those observed in actual traffic. The necessity of the conventional verification remains important, however, it is insufficient for the evaluation of driving safety system benefit because all the necessary driving behaviors, including non-normative or abnormal driving behaviors, are not accurately and/or fully reflected in these conventional indexes. It is desirable that the time-series data of driver's control inputs and/or vehicle state variables are directly compared to more precisely capture the difference in the driving behavior between the human driver and the driver model.

Recalling here the concept of collaboration of the traffic simulation system and the driving simulator, the DS environment enables drivers directly to interact with the driver model and allows such model to be tested and analyzed (e.g., visual validation), especially against non-normative driving behavior [7]. Furthermore, the DS environment will also provide us the opportunity to collect the data for the verification of the driver model by means of the direct comparison of time-series data obtained during driving. In other words, the other significance of the collaboration concept is that it is complementary to the conventional verification of the driver model stated above. Yet the procedure for this collaborative verification of driver model should be established in order to receive meaningful feedback on improvement of the driver model from the DS environment.

From these points of view, this paper proposes a novel method of verifying driver model, which is achieved by coupling the simulation and the driving simulator. The method consists of three-step procedure. In the first step, an actual driver operates a DS vehicle in the traffic flow controlled by the traffic simulation. During the driving, all information, including actual driver's behavior, such as accelerator/brake pedal and steering operation, and surrounding vehicles position and speed, etc., is recorded. Then in the next step, the actual driver is replaced by a driver model and the surrounding vehicle maneuvers are replayed using the recorded data from the first step, meaning that the same traffic situation as to what the human driver was facing is presented to the driver model for making decisions on their driving. Then, the maneuver by the driver model is compared directly with the actual driver's maneuver along simulation time steps. To the author's best knowledge, such time-series-based comparison of driving behaviors of human driver and

driver model for specific scenes on the road (e.g., turn right/left at an intersection) have not yet been reported. The proposed method is applied to the simulation system ASSTREET and its driver-agent model.

This paper is organized as follows. First, the driver-agent model of ASSTREET is introduced in Section 2. Subsequently, the scheme of interactive connection of ASSTREET and a driving simulator is presented in Section 3. Then in Section 4, our novel verification method of direct comparison of the driving behavior will be described in details, followed by the results of the application of the method to the right-turn (turning in front of the oncoming traffic lane) driving behavior in Section 5. Finally, Section 6 concludes the paper.

DRIVER AGENT MODEL OF ASSTREET

The ASSTREET is a multi-agent traffic simulation system, meaning that the traffic flow is generated from the results of the movement of the vehicles driven by driver agents that can perceive and recognize surrounding traffic environment and decide their actions suitable for recognized traffic situations. As shown in Figure 1, the driver-agent model consists of four main modules: perception, recognition, decision making, and control. The details of the modules are described below.

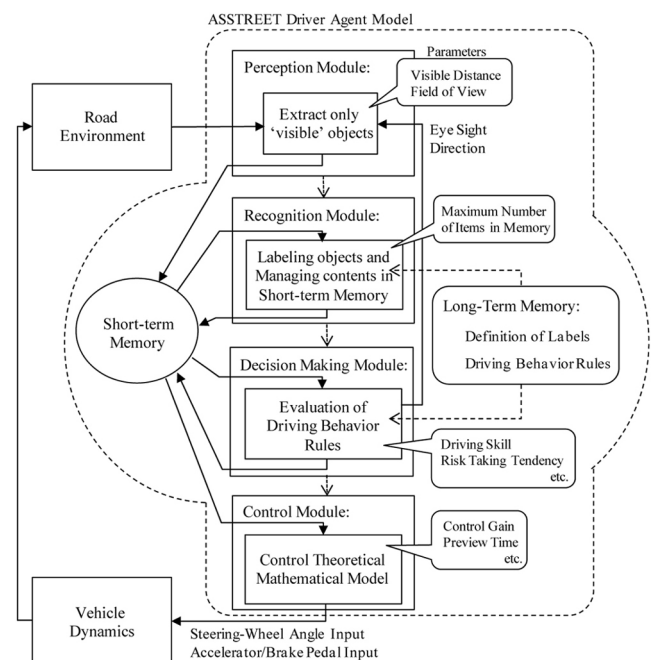


Figure 1. Structure of ASSTREET Driver-Agent Model

Perception Module

The perceptual process is included in the ASSTREET driver-agent model. The environment of the driver agent is sampled at regular intervals to receive the information of other agents, buildings and obstacles in the field of view of

the driver agent. The objects behind and hidden by other objects are rejected from the perceptual information. The field of view and visible distance are parameters of the perception module to reflect driver's individual characteristics. The resultant perceptual information is stored in short-term memory of the driver agent.

The direction of driver agent's view and the gaze time are controlled by the decision making module depending on traffic situation and goal of the driver agent. For instance, to make lane-change maneuver, the decision making module commands the perception module to view the side-mirror to gain information behind the subject vehicle.

Recognition Module

Using production rule-based knowledge in long-term memory of the driver-agent model, the recognition module put a recognition label, such as 'Preceding Vehicle', 'Oncoming Vehicle' and so on, to the perceived object that is stored in the short-term memory. The surrounding traffic situation can be defined and expressed by using combinations of statements using the recognition labels. Note that a recognition label for a object can be determined only using observable state variables of the object and road environmental data. It is important when linked with the driving simulator that the driver agent should not access to other agent's internal state data (i.e., items in the short-term memory).

There is a limit to the number of objects stored in the short-term memory of the driver agent. Thus the selection is executed in this module among perceived objects and memorized objects according to their potential hazard level, for example, the object regarded to be potentially hazardous should remain in the memory.

Decision Making Module

Figure 2 illustrates functional diagram of the decision making module. The decision making module consists of four sub modules: planning of lane-change, safety confirmation, longitudinal control planning and lateral control planning. Each sub-module contains driving behavior rules, which can be expressed by the logic trees.

The "planning of lane change" sub-module operates a flag for starting lane-change maneuver in the short-term memory if the recognized surrounding traffic situations compel to do so. The "safety confirmation" sub-module commands the perception module where and how long to see. The sub-module also judges the recognized current traffic situation to be safe or not to perform intended driving task, and the evaluation result of safety is stored in the short-term memory so that the different modules can refer to it. The "lateral and longitudinal control planning" sub-modules determine reference values of the control modules that is best suited to the traffic situation.

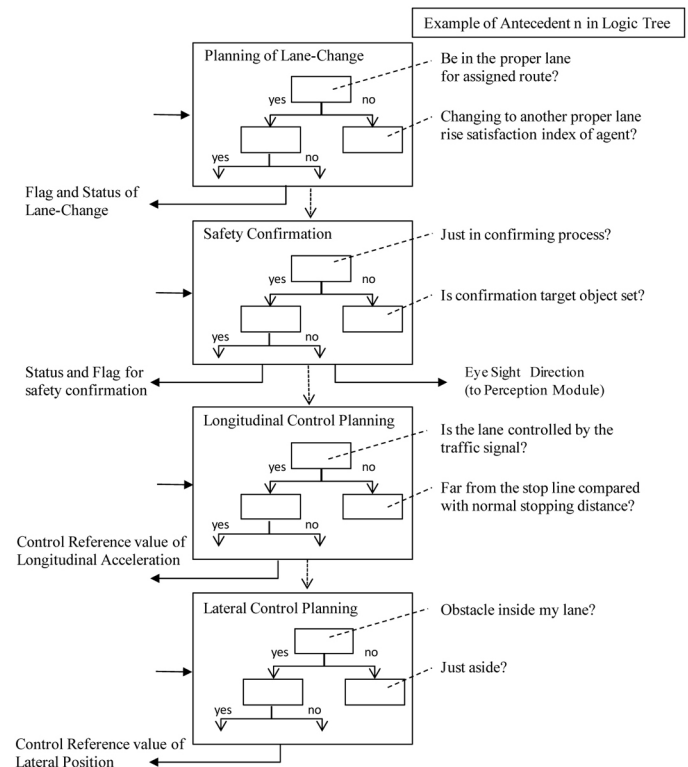


Figure 2. Functional Diagram of Decision Making Module

Figure 3 shows an example of the decision logic for longitudinal control. In the ASSTREET driver-agent model, desired acceleration commands for each perceived objects are firstly evaluated using the decision rules specified for the objects, and then the minimum of those accelerations is selected as acceleration command to the control module.

Some parameters representing driver's driving skill, risk taking tendency, and so on are included in the driving behavior rules so that the variety of the driving behavior appears by changing these values. The driving behavior rules implemented in the decision making module dominate the simulation fidelity of driver behavior. Thus the accuracy and/or modification of the driving behavior rules will be a key issue in the verification of the driver model.