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An Integrated Framework for Real-Time Interaction of Vehicles with Human

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Abstract

As technologies for full self-driving automation in vehicles progress rapidly, human factors become more complicated, and it is more difficult to predict driver's behaviour on the road, especially under the mixed-traffic condition. In this paper, we introduce an efficient framework for research on the interaction between human-driven physical vehicles and autonomous vehicles by integrating a traffic simulator and a driving simulator with a human driver into one system through standardized V2V communications, as a form of HILS. We demonstrate that the implemented system is capable of real-time processing under realistic traffic scenarios.

Keywords:

Hardware-in-the-Loop Simulation, Interaction, Human factors.

Motivation for Integrated Real-Time Interaction Framework

As we move to full self-driving automation, we are going through a period of transition before legitimately implementing and deploying fully autonomous vehicles on the public road. During this period of transition, there will exist different and mixed traffic situations, consisting of both autonomous vehicles and non-autonomous vehicles. Non-autonomous vehicles are referred to as human-driven vehicles in which the control still lies in the hands of a human driver. In the mixed-traffic environment, autonomous vehicles need to coexist safely and efficiently with manually driven vehicles, and their passengers should be comfortable as much as each individual driver of non-autonomous vehicles, but it is not easy to achieve. This is because it is difficult both for drivers to anticipate the behaviours of autonomous vehicles and for autonomous ones to predict unexpected behaviour of a human driver. Unless a strong cooperative capability is provided to both types of vehicles, unexpected crashes may happen involving autonomous cars complying strictly with transportation rules. For example, a driver crashed his car into the back of Google's self-driving car at an intersection on July 1, 2015, and three Google employees had been injured in this accident [1]. To deal with a problem of coexistence, we propose a novel integrated framework for research in real-time interaction of autonomous vehicles with human, including the capacity of V2V (Vehicle to Vehicle) communications between human-driven vehicles and autonomous ones.

The interaction of vehicle automation with human is referred to as human factors in general. Prior research mainly deals with human factors in terms of driver adaptation to automated vehicles and considers them as part of vehicle automation (combined function automation, limited self-driving automation and full self-driving automation in [16]). Hence, it focuses on how to orchestrate the impact of automated vehicles on human. Specially, several attempts to study human factors are associated with the development of the human machine interface/interaction to provide warning information for only a driver or passengers in autonomous vehicles, including the types of feedback automated vehicles should provide for the drivers, how to notify warnings and useful messages to drivers and passengers efficiently such as auditory, tactile, or visual presentation, and timing to transfer information [2]-[5]. Some of the previous work investigate human factors with respect to driver's trust and acceptance of the automated vehicles by identifying critical situations and various factors that have a positive or negative effect on driver's trust [6]-[9]. Several efforts try to seek an adequate solution to driver's engagement with limited automated vehicles during the trip by analysis and assessment of the impact on the performance (related to fatigue, disengagement, confusion and distraction) of drivers experiencing the automated driving vehicles [10], [11]. Unfortunately they all do not adequately cover how the driver intention and reaction related to a real driving environment affects the behaviour of autonomous vehicles, especially under the mixed traffic. The relationship between autonomous vehicles and non-autonomous vehicles becomes more complex owing to the uncertainty about what should happen whenever a human-driven vehicle encounters autonomous vehicles in an unspecified area. It is worthwhile to focus on the interaction of human-driven vehicles with autonomous vehicles under the mixed-traffic condition as it is not yet known how each driver in non-autonomous vehicles reacts to the appearance of autonomous vehicles on the road.

This paper aims to provide a new and efficient framework for interaction study by integrating a traffic simulator and a driving simulator with a driver through standardized V2V communications. We demonstrate that our implementation is capable of real-time processing under realistic traffic scenarios. The proposed framework is scalable for multiple driving

simulators due to the use of V2V communications. Thus, multiple drivers can experience the same traffic scenario with their own manipulation of vehicles at the same time. Our approach to the integrated real-time interaction framework is tailored for cost-effectiveness and identification of safety risks.
We start with the overall concept of the integrated real-time interaction framework for both human-driven vehicles and autonomous vehicles. We then discuss how to implement the main components in the proposed framework which is integrated among a traffic simulator, a driving simulator and a driver with reality, and evaluate how well the implemented framework is working in real-time.

Overall Concept of an Integrated Framework

We propose and construct an integrated real-time interaction environment enabling a V2V communication mechanism, as a form of Hardware-In-the-Loop Simulation (HILS). Our integrated framework enables autonomous vehicles to communicate with each other as well as a human-driving real vehicle on the same road. The integrated environment provides realistic traffic scenarios with immersive rendering of sensory information. Since a typical traffic simulator itself cannot provide user experiences regarding the simulated traffic scenarios, the integration of a driving simulator and a traffic simulator is necessary. As depicted in Figure 1, the integrated framework consists of three parts: 1) a traffic simulator for vehicle movements and traffic signal control, 2) a driving simulator for realistic driver behaviour, and 3) a physical vehicle for a driver.

The traffic simulator creates virtual autonomous vehicles and construct the identical road networks of specific GPS positions taken from the Internet map services (e.g. OpenStreeMap). It also controls the route and the behaviour of autonomous vehicles as well as manages the information of the human-driven vehicle received from the driving simulator. Virtual autonomous vehicles also need to exchange information with other vehicles in order to travel more safely by itself in a virtual world. Since the driving simulator is in charge of the realistic drive of the physical vehicle controlled by a human driver, it directly connects to the physical vehicle, and reflects driver intention and reaction obtained from the physical vehicle. In other words, as a virtual vehicle corresponding to a physical vehicle is created in the driving simulator, the status of the virtual vehicle depends on human factors (driver’s intention, perception, and reflexes) of the physical vehicle. The driving simulator, which has certain messages received from the physical vehicle, may periodically broadcast the status of the human-driven vehicle to its own neighbours for the interaction with virtual autonomous vehicles generated by the traffic simulator. The driving simulator also recognizes traffic condition corresponding to messages received from the traffic simulator and renders the appreciate 3D scenes by deploying objects (the object of a virtual car corresponding to a physical vehicle as well as objects of autonomous vehicles driving near a human-driven vehicle), weather, and etc., onto the screen. Finally, intention or behaviour of a driver is delivered from the physical vehicle to the driving simulator in a timely manner while a driver of the physical vehicle can virtually travel on the road by pressing his/her foot down on a brake pedal and an accelerator pedal, using gears, and turning a steering wheel.

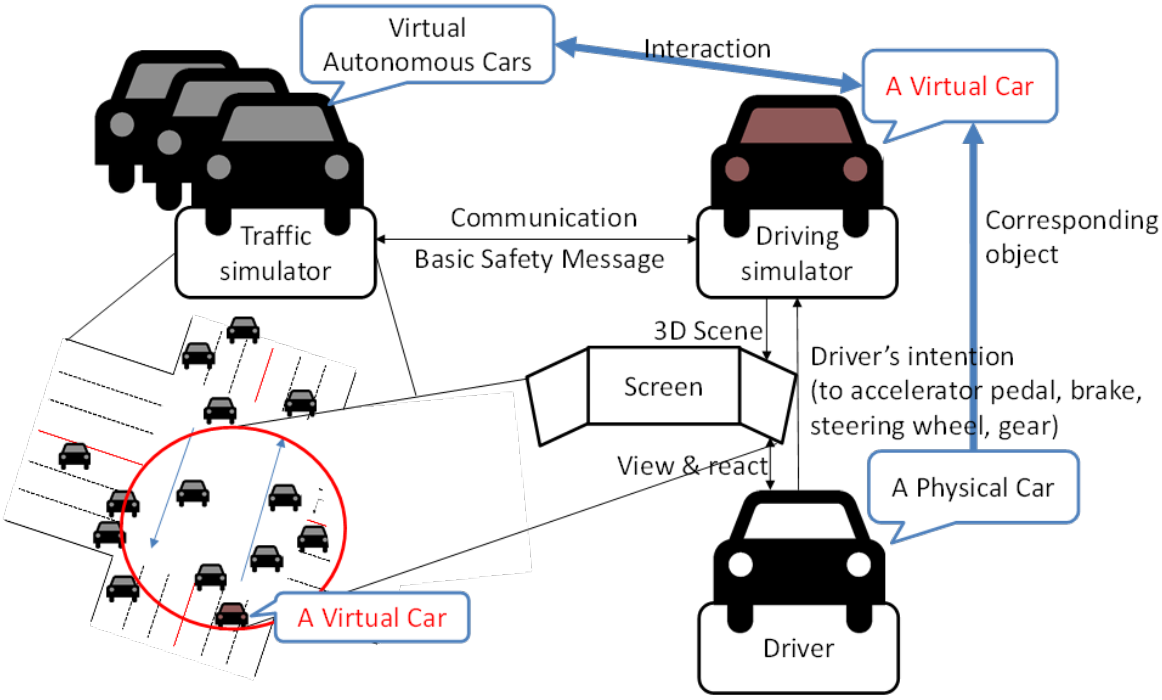


Figure 1 – A concept of an integrated real-time interaction framework

Implementation and Performance of the Integrated Framework

As previously described, the presented framework targets for an integrated system of a traffic simulator with autonomous vehicles and a driving simulator connected to a human-driven vehicle. Implemented components for the integrated system (see Figure 2) are presented in this section. There are two main concerns while the integrated system is implemented. First, a traffic simulator needs to be synchronized with a driving simulator automatically, in order to ensure both all vehicle movements and 3D visualization with reality are available to a driver and virtual objects during runtime. Second, it supports the real-time processing and interaction between them without major performance degradation over time. We discuss its performance for the real-time interaction in detail in the next section.

Traffic simulator for vehicular control

We implement and fully exploit a traffic simulator for real-time performance of our framework. It is capable to support intersection protocols without collision, control vehicular movements, visualize traffic conditions, and provides the capability of V2V communication for all of the virtual vehicles. It is an extensively modified version based on the structure and operation primitives of AutoSim which is one of microscopic traffic simulators [12]. The modified traffic simulator transfers simulated traffic status and received vehicles status associated with the road condition by broadcasting a message as the form of the basic safety message (BSM) specified in standard SAE J2735, which defines the transmission time interval of BSM as every 100 ms [13]. A transmission range (radius) of all vehicles in the integrated system is 150 m and they transmit BSMs by using a simple broadcast method to only neighbouring vehicles. BSM contains the status of vehicles such as GPS coordinates, speed, and heading. Each autonomous vehicle follows the predefined intersection protocol [14]. It also visually displays the movement of virtual autonomous vehicles, the human-driven vehicle, and the road topology.

Figure 2 – An integrated system

Driving simulator for a realistic drive

The driving simulator integrated in our system is open source Java based simulator OpenDS [15]. Although we put the communication capability with BSM in OpenDS in order to share and synchronize traffic information, it turns out that both the interval (100 ms) and potential failure of transmission of BSM cause visual flickering of virtual vehicles, and significantly degrade driver's recognition of the reality. We compensate it by rendering 3D scenes continuously to provide reasonable frequency (30Hz or 60Hz) of synchronized updates of nearby vehicles using sparsely received status of each vehicle. It was achieved by estimating the vehicle status based on the ego-motion. It significantly improved the capability of a driver to recognize the current traffic condition and conform to realistic driving scenarios. The traffic simulator and the driving simulator are connected using Ethernet for V2V communications in an ad-hoc environment. Through this connection, the proposed framework supports scalability when many driving simulators with individual drivers concurrently connect with a traffic simulator, considering the reliable transfer of safety messages among them.

Physical vehicle for driver intention

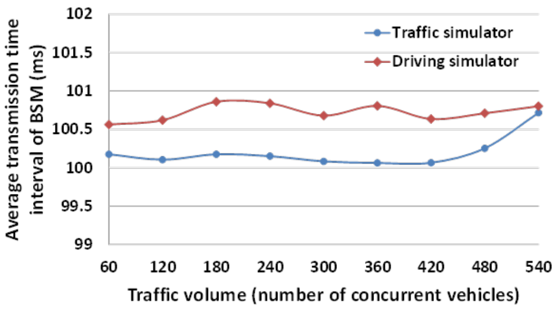
A physical vehicle is directly connected to the driving simulator using both serial cables and CAN (Controller Area Network) cables. The integrated system uses these interfaces in order to deliver certain messages represented by driver intention to the driving simulator, whenever a driver controls the individual part (e.g., steering wheel, brake, accelerator, and gears) of the physical vehicle. Especially, it periodically reports the driver's intention related to the steering while, even though the angle of the steering wheel is not changed.

Enhanced Performance of the Proposed Integration System

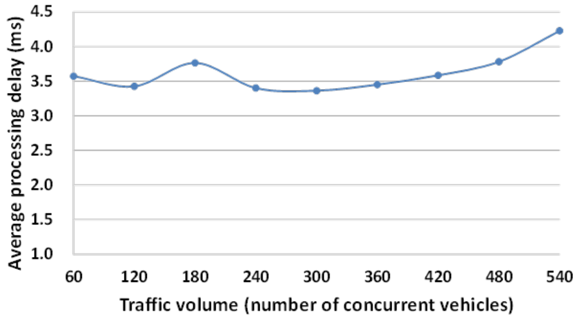
A serious drawback in microscopic traffic simulation is high computation time because microscopic simulators model every object independently. This feature makes it difficult to support real-time management and processing in response to a certain situation when it deals with lots of objects simultaneously. Therefore, one important requirement is the interaction between main components at runtime in our integrated system. To support the robustness and real-time performance of our integrated system, we need to demonstrate that it is capable of real-time processing with the increase of the traffic volume until the road is saturated.

In our experiments, we assume that the road is saturated when the traffic volume is close to about 1900 vehicle/hour/lane, which has six lanes and one intersection on the road [16]. Autonomous vehicles travel along the specified path up to the maximum speed of 20 m/s. We obtained road networks from OpenStreetMap for streets in Pittsburgh. The traffic simulator generates up to 540 autonomous vehicles moving along predefined paths without collision. A driver is seated on the physical vehicle and drives a vehicle in 3D traffic environment provided by both the traffic simulator and driving simulator.

The results of the experiments in terms of an average transmission time interval of BSM at the traffic simulator and the driving simulator, and an average processing delay are shown in Figure 3(a) and (b), respectively. BSM is repeatedly sent to neighbours at 100 ms intervals over the following 5 minutes when a transmission range of each vehicle is 500 m. From Figure 3(a), it is clear that the average transmission time interval of BSM follows about 100 ms. Consequently, they comply with the rule for transmission in order to share the information such as traffic, road condition and driver intention even though traffic volume constantly increases.



(a) Average transmission time interval of BSM as the number of vehicles increases



(b) Average processing delay as the number of vehicles increases

Figure 3 - Experimental results

Figure 3(b) presents the average processing delay which is the sum of transmission time between the traffic simulator and driving simulator and the total amount of time spent to process jobs of the traffic simulator and driving simulator for the duration of 5 minutes. We consider that our framework is capable of processing and managing the associated jobs in real-time if the average processing delay stays below 100 ms in order to achieve the periodic transmission of BSM. As shown in Figure 3(b), there is certainly a tendency for the average processing delay to increase if the number of vehicles is increasing over time because of the nature of microscopic simulation. However, it demonstrates that our framework achieves the real-time performance.

Conclusions and Future Work

In this paper, we present the design and implementation of a tool to study the interaction of human-driven physical vehicles and autonomous vehicles, as a form of HILS. The framework provides a traffic environment of autonomous vehicles and non-autonomous ones. Using the tool, the driver can experience a visually immersive traffic environment with autonomous vehicles. According to the experimental results, the proposed integrated system processes inner functions in real-time through the enhanced performance of the microscopic traffic simulator and the V2V communication capability. As automation in vehicles progresses rapidly, the associated human factors become more complex and it is difficult to predict driver's behaviours on the road. It is worthwhile to provide an environment for investigating the interaction between autonomous vehicles and human drivers under the mixed-traffic conditions. While there has been earlier work in this subject, such interactions have not been studied extensively, and it is not yet clear what should happen and what should change. Our approach to integrated real-time interaction framework is a step to provide a useful tool for the researcher who are interested in such important subject.

We expect that the proposed framework will be utilized for human factors research, and with necessary extensions, it may enable the drivers to experience the diversity of vehicle automation and how the automation functionality should interact with humans in physical vehicles. We intend to put a wireless channel model mimicking one of the wireless technologies (WAVE/DSRC or cellular for connected vehicles) in our integrated system. Other possibility is to combine a distinct network simulator with our integrated system, so that V2V communication will be more realistic. We plan to extend our framework to provide a realistic alternative solution to evaluate the functionality of V2V safety services prior to field operational tests for cooperative intelligent transportation systems (C-ITS) with vehicle automation. If that works out, our efforts will be counted as one of the serious attempts to provide facilities to perform human in the loop tests for various situations.

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