A Networked Multi-Drivers Simulation Platform for Interactive Driving Behavior Study

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Abstract – Traffic simulations are becoming increasingly important to acquire dynamic interaction behavior of drivers. To improve the fidelity and realistic experience of driving behavior studies, research as advanced from single- to multi-driver simulations. In this paper, several existing models were discussed in the context of interactive driving behavior. Recent studies and their applications relevant to multi-driving simulation were also reviewed. A concept framework of interactive behavior model was postulated in which all the influence factors were comprehensively considered during the interactive process between two vehicles. Based on this framework, we have established a Networked Multi-Drivers Simulation Platform. This new simulation platform engaged multiple drivers interacting on in common virtual environment. Performance data and psycho-physiological measures of individual drivers can be collected by the system and transmitted among subjects in real-time. Using this configuration, a virtual traffic simulation was established by including multiple participating drivers for a real-life scenario. Therefore, we propose that conclusions drawn from behavior studies under such simulation and thus based on comparable performance data is more realistic and meaningful than before.

Key words: driving simulator, driver interactive behavior, cognitive state, psychophysiological measures, multiple driver simulation.

1. Introduction

A driver on the road shares the same traffic environment and thereby has to interact with other drivers. Several studies have indicated that the perception of other ambient traffic subjects would likely change a driver's performance or behavior; meanwhile, each driver also influences the behavior of other drivers. Current research focuses on representative behavior of drivers but overlook the individual differences, and the interactive behavior among other drivers and road users and their impact on each other are less discussed. But the probability and severity of traffic accident depends on the driving variations between different drivers [Yas1].

Driving simulators have been widely used in traffic simulation and driving behavior study. Despite the many advantages that driving simulators can provide better than field study, such as safer, more controllable, repeatable and low cost. An important question, however, is whether driving simulators can provide a realistic impression like driving in real life with high validity. Furthermore, it is difficult to account for human feelings invoked on a simulator, such as stress, haste, anxiety and anger and mimic the complex of real-life traffic situations. Unlike an experiment that runs with real drivers on the road, relying on a single-user driving simulator or standalone systems only devote limited contribution on the analysis of interaction processes between multiple drivers. Meanwhile, with the rapid development of computer graphics and human-computer interaction technologies recent years, it becomes apparent that the emulated "human-like" behavior for more complex phenomena such like dynamic human-will-motivated interaction are open to more possibilities than in the past. Compared with the vehicles operated by real drivers, simplified autonomous vehicles (e.g. preprogrammed and randomly triggered) lack human judgment, intention, adaptability, flexibility, and logic, even though they may have realistic 3D representation in virtual environment [Cai2].

In this paper, we present how a better understanding of the interaction process among individual road users can be achieved. To further study the complex interaction behavior between each driver, we developed a high fidelity driver-to-driver interaction platform by replacing driver models with real human drivers to conduct the interactive behavior studies. A new driving simulation platform was built up for the interactive driving behavior studies based on a networked multi-users virtual environment. It provides a laboratory environment to investigate driver behavior in case of different traffic events.

2. Interactive drivers' behavior framework

Traffic danger can be effectively reduced starting from the perspective of individual roadusers. It is convinced that two points overwhelmingly determine an individual's risk in traffic: the individual's behavior and the behavior of other road users [Eva3]. The individual's behavior has been widely discussed before. On the scope of the interactive behavior between individual vehicles, the knowledge of drivers' behavior in such situations was gathered. Our current study focuses on the microscopic Psycho-Physical modeling approaches. This modelling idea establishes on perception-reaction characteristics or psycho-physiological indicators of human beings. Such ideas include Weidemann's Psycho-Physical Car-Following Model [Wie4], Van Winsum's psychological knowledge-based math model about car following behavior [Van5], Andersen's visual angle (DVA) model [And6], and "ARCHISIM" from the French National Institute for Research in Transportation and Safety (INRETS) [Mor7]. These models are centered on single-driver and widely used in the traffic flow simulation software. They take the human factors into consideration and can describe the interaction between adjacent vehicles. Meanwhile, there are few theoretical frameworks focused on driver-driver interaction. Houtenbos et al. [Hou8] proposed an interactive behavior model on a cognitive level to describe the interaction process between drivers with a central role for the concept of expectancy. The main idea of the model is that all road users involved in the interaction perceive the environment through a "window", which is a filtering process that takes place outside the road user, physically selecting what information from the environment can be processed. Ba and Zhang [Ba9] proposed a perception-cognitionemotion behavior framework, which contains attributes and influence factors to interaction process between drivers. These works, together with previous research from our lab [Cai10, Cai11, Lin12, Lin13], form a basis for multi-driver studies.

We have in the past proposed an interaction framework for drivers, which focused on the interrelationship between two single "driver-vehicle" units. It combined physiological measures to provide a comprehensive representation of behavioural performance with the interactive process (Fig.1). The factors that influence the behavior of a driver can be categorized into two parts: individual factors and external factors. Individual factors include personality, further divided into age, experience, gender and education, and driving style, which can be achieved from Driving Behavior Questionnaire (DBQ). The external factors include traffic environment, social norms, public policy, traffic rules, culture, target context and car conditions [Ba9, Zai14, Bjö15]. All of these factors can provide a comprehensively context of the driver as well as affect a driver's decision and manipulation. Drivers' state measures (e.g. eye movement, facial expression and psycho-physiological factors) and performance indicators will reflect the interaction process over all the interactive behaviors. Each couple of interacted vehicles can be regarded as a basic unit on the road and numerous units form a whole traffic platoon.

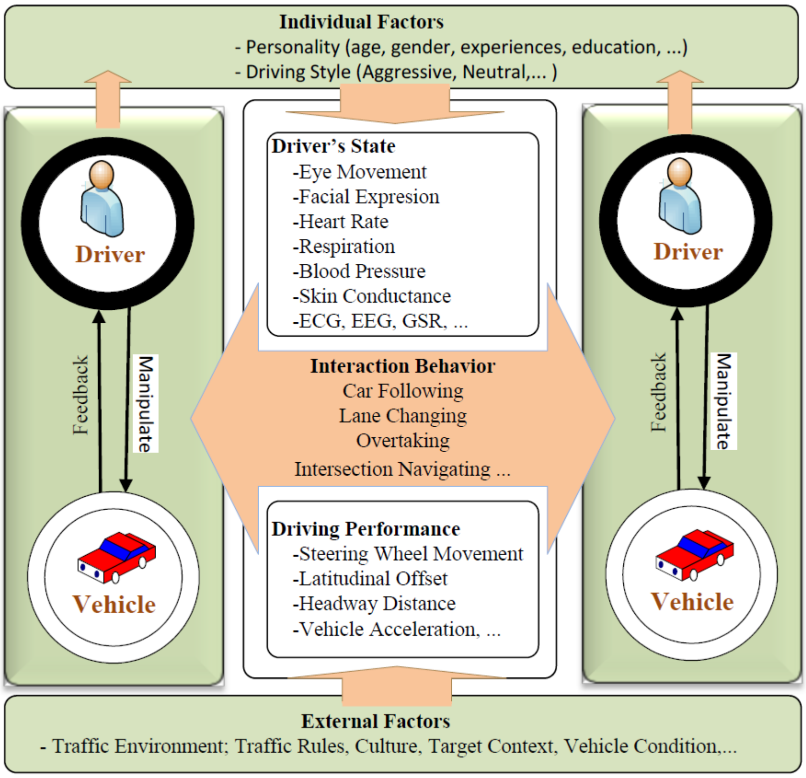

Fig.1 The Framework of Drivers' Interaction Mod

3. Approaches to study interactive driving behavior

There are two approaches to study the individual drivers' behavior. The first one is driving on the real road with infrastructures and real people. This method can enable studying authentic driving behavior on real life. However, uncontrollable conditions make the realization of test situations in real-life traffic very challenging and limited. This becomes especially difficult in safety-critical situations that will lead to seriously ethical problems and might endanger test drivers [Maa16].

A second approach is driving on a simulator with driving models. The movementbased simulators are more precise than other fixed simulators that can give drivers feedback from the steering wheel and chair about how virtual car moved in the environment [Ree17]. However, whichever type of driving simulator is, low fidelity may lead to imperfect replication of real driver behavior and real driving performance. It is relatively easy to use real steering wheels, cabin, moving feedback seat and high quality virtual environment to improve the fidelity of interactive interface and drivers' perception.

Such type of simplified machine driver may lead to some drawbacks as we summarized in our previous work [Cai2]. For example, the weird movement can't convince test drivers that they are driving with real driver; too perfect (or ideal) to produce 'human-like' errors or turbulence that make test drivers feel easily predictable; no active motivation to interact with the neighboring vehicles. Commonly, all the drivers' interaction is either pre-programmed or randomly triggered which are seem not natural.

The majority of currently available simulators are single-user stand-alone systems; traffic engineers cannot easily analyze more complex phenomena, such as the interaction between multiple human drivers or pedestrians [Nak18]. Therefore, we combine the feature of both simulations to establish a novel approach involving multiple real drivers on interconnected simulators under the same virtual environment.

3.1. Multiple-user driving simulation

In recent years, there is an increasing demand for test methods in traffic engineering and drivers' behavior research that involve the dynamic interactions between vehicles. The topic of driver-driver interaction and multipleuser driving simulation has therefore attracted great attention from the US, Germany, China, Japan and Sweden. Examples of these studies show the possibilities and applications by using multi-driver simulation systems to improve driving safety as shown on Table 1.

Table 1. The Recent Studies on Multi-driver Simulation

Country	Literature	Software Platform	Hardware	Parameters	Application
US	[Cai2, Cai19]	OpenGL, VC++	Logitech MOMO game wheel/pedal	-	Drivers' emotion; Traffic flow simulation
Japan	[Nag20]	Java 3D VC++	FBBW and $^{SC}ha_{i}r^{e}$; Rotary motion platform; 2 stations	-	Double-driver fire-truck simulation.
Sweden	[Yas1]	-	Game wheel/ pedal 4 stations	Conflict Indicating Variables: TTC, PET.	Voice based command GPS; traffic lights influences
China	[Wan21]	UC-windroad	UC-windroad; 2 stations	Velocity, acceleration, steering angel, brake.	Driving tendency recognition
Germany	[Maa16, Müh22]	SILAB multi-driver simulation system	FBB steering wheel; 5 stations	Data of longitudinal control, lateral control, …	Driving Assistant System: Emerging Assistant, intersection, traffic light assistant, …
Japan	[Ban23]	SIGVerse	Game wheel/pedals	E.g. inter-vehicle distance; acceleration, steering angel, brake.	Lane changing Training
Germany	[Hee24]	DLR Multi-driver simulation MoSAIC	G27 game wheel/pedal; 2 stations	Lane change, acceleration, brakes.	Cooperative lane change assistant

Most of simulations in Table 1 use commercial 3D software or traffic simulation software to build up the system (SILAB, Java3D/VC++, UC-windroad, SIGVerse, etc). Four or five driving simulators were connected to form a whole driver group that describes the behavior of the entire traffic platoon. The remaining simulations use two networked simulators to evaluate the interactive affects between two vehicles. In terms of the application, they use multiple-driver system to form a platform. This platform can study the effects of ADAS, IVS, AmI, C2X, ICT systems on different interactive traffic situations. Such representative situations include merging assistant, hazard warning and traffic light assistant in intersection, rubbernecking and even collision. Other than the driving performance data (acceleration, steering angel, brake, lateral control, etc.), the indicating variables such as inter-vehicle distance, TTC (time to collision), PET (Post Encroachment Time), variation, coherence are also introduced to quantitative describe the interactive behavior between two cars or whole platoon.

Similarly, current research that induces a drivers' individual differences and physiological and psychological characteristics into the interactive driving behavior study is limited. One study obtains driving data of different drivers through the interactive parallel driving simulated experiment, and using this data to testify their driver tendency recognition model [Zha25]. The headway distance on car following process is the only recognition indicator in this project. In our previous study [Cai2], we suggest the virtual traffic flow of driving simulators be realistic rather than perfect. Therefore we updated our standalone simulator and presented an extended human-in-loop simulation framework. It supports multiple driving terminals that can be used to improve the fidelity of driving simulators. Realistic driver-driver interaction is also essential to investigate the emotional behavior of certain drivers. Provoking the emotion by traditional ways (e.g. watching movies, hearing stories or recalling personal experiences) is inefficient in driving experiments, as it is only a short-term state. In order to investigate the influence of a driver's emotion on performance, we also induced two kinds of emotional states (anger and excitation) through realistic driver-driver interaction by using networked driving simulators [Cai19]. The result indicates that multiple networked driving simulators are feasible for inducing the psychophysiological parameters changes, which can be used as the indicators of emotions.

4. Multi-drivers simulation platform

According to our theoretical framework of drivers interaction model shown as Figure 1, the prototype of the multi-user driving simulation system satisfies three features. First, at least two human drivers participate the simulation by which one driver controlling one driving simulator. Second, all drivers simultaneously in one simulated environment in which they can share same scenarios, follow same task rules, as well as can see and react to each other. Three, drivers' performance information can be transmitted between vehicles synchronously via network; drivers' state can be measured on real-time.

4.1. System Implementation

Our networked multiple-drivers simulation system (Fig.2) is located in the Intelligent Human-Machine Systems Laboratory at Northeastern University. Each simulation terminal contains separate input and output devices. They appear as autonomous vehicles in each other's virtual scenarios and can behave like exposing human drivers to specific traffic situations. For simulator 1, a racing seat is mounted on an AC servo actuator at the center of the cylindrical screen. The projector was connected to the computer, projected the scenarios on the cylindrical screen. Simulator 2 comprised a workstation, a high-fidelity steering system (ECCI TracStar 6000), and three LCD screen. Two Macintosh Computers with NVidia GeForce 8800 GT graphics cards are used here.

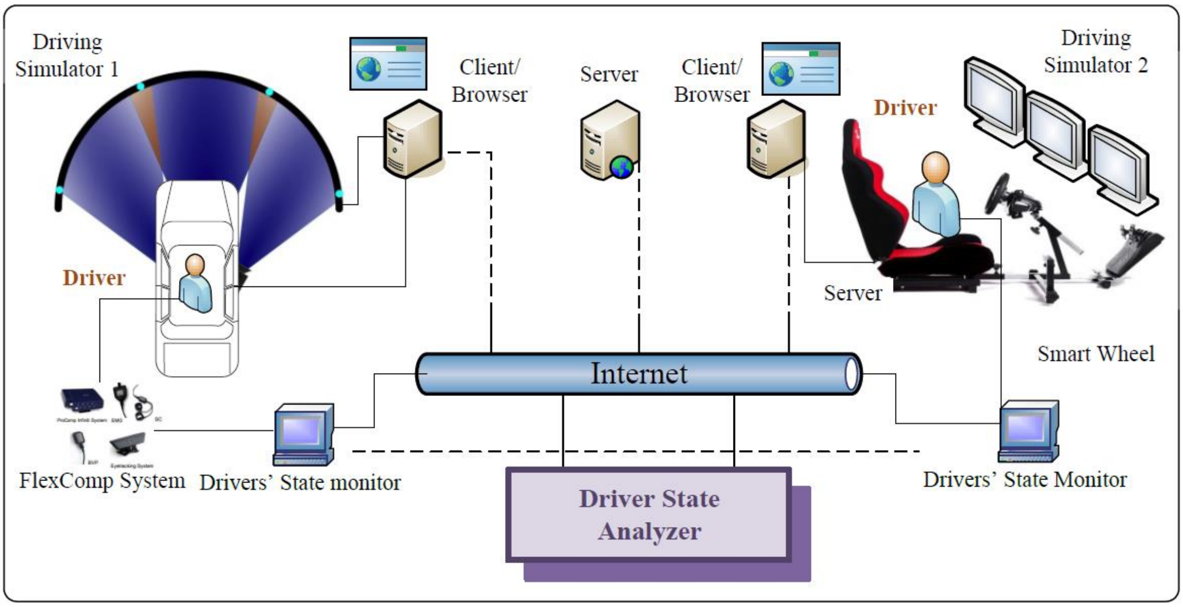

Fig.2. The Prototype of Networked Driving Simulation System

4.2. Network communication module

Because of the concern that data exchange in our multiple driving simulation applications, the simplicity and efficient need to be considered for real time effect satisfactory. Here we implemented the server-client protocol by Java Script and Unity 3D Network Manager Component. A separate network server was set up in a single computer. It calculates computer and clients' state based on the signals received from clients. The clients provide interfaces for driving, which obtain operation signals from drivers and create the real-time updates of virtual scenario. The Driving performance data (position, heading direction and speed) can be recorded by any terminals, which will benefit for the different locations among different driving terminals.

4.3. Data Acquisition Module

As we mentioned above, the following performance data can be calculated and transmitted among any simulation terminals: speed (S), headway distance between two cars (HD), steering wheel angel (SA), gas throttle (GT), operational reaction time (RT), and lane position deviation (LD).

To achieve drivers' psychophysiological response on interactive process, we employed two psychophysiological data acquisition system for both driving simulators. A FlexComp Infinity Biofeedback system is implemented for Simulator 1. We also adapted our previous work -"smart wheel", which has been validated in the laboratory environment for Simulator2 [Len26]. Four types of sensors were embedded into the steering wheel to perform real-time non-intrusive measurements of the physiological states. The parameters including: heart rate (HR), respiration (RR), skin conductance (SC) and the Heart rate variability (HRV) were then derived. In addition, a Tobii X50 Eye-tracker and a low-cost commercial eye tracker were planned to detect the drivers' eye movements and to collect eye fixation positions and durations for interactive cognitive engagement estimation. These subjects' cues can help to understand drivers' mental workload, attention and emotion during the interactive process. Moreover, combined with the individual/external contextual factors shown in Fig. 1, we can input all these information into the Data Analyzer as the context of inference or prediction, or provide the information or suggestion to drivers.

4.4. Virtual Environment Module

A low-cost but high efficiency, flexible and practical graphical interface (3D physics engine powered by Unity3D) was introduced to create simulation systems. The Unity3D is well suited for building environments, external data exchange, and controlling target objects, as well as Graphic User Interface as well as human-machine interaction with scripting [Hig27]. Other than the basic city infrastructures such as buildings, city and rural roads, intersections, traffic lights, pedestrians and cyclists with movement as important road users were also simulated in our traffic environment. They can help to create some hazard traffic situations on the road. Each driving terminal appears as an autonomous vehicle in each other's virtual scenarios and can behave like exposing human drivers to specific traffic situations (Fig.3). Three driving interaction conditions are considered: car following, lane changing and overtaking. With this configuration, multiple subjects' simulator experiments can be conducted and thus comparable performance data can be obtained to draw meaningful conclusions for interactive driving behavior study.

Fig.3. The virtual scenes of Networked Multi-drivers Simulation System

5. Discussions and Future Study

A main objective of this project is to achieve a better understanding of the interaction process between road users and interrelationship between individual behaviors. This paper provides an overview of the interactive driving behaviors' study. It has also expanded the development of recent research based on of multiple-drivers simulations. Based on our knowledge from the literature, we proposed a driver's theoretical interaction framework and built a new networked multiple drivers' simulator system. High fidelity driverdriver interactions were achieved by replacing driver models with real human drivers. Our simulation can provide detailed information about the behavior of the driven vehicle, in relation to the environment and to other vehicles. Other than the driving performance data, it combined with specific physiological measures to each driver that can provide a detailed and comprehensive representation of interactive behavioral performance. In future research, experiment should be conducted to examine the validation of our simulation system. The validation work will focus on ensuring that the drivers can expose their behaviors naturally, and co-drivers can evoke each other's emotion and performance changes in a valid way. Also, future studies on this platform should be demonstrating more feasibility of using multiple driving simulators to investigate driver's performance and cognitive states.

In this work, we take into account the need for different user requirements, as well as for flexibility and extensibility in configuring the networked driving simulation system. In future, with the support of software platform, our simulation software can be easily published to be an application on Windows, Mac OS, Linux, Android, and IOS etc. Different level of end-users from the public such as researchers, innovators, and game players, can enter to the system via internet/intranet and cloud collaboratively. The interface of input devices can be easily extensible to different ways, such as driving simulators, commercial game joysticks, keyboard and mouse, and strokes on a Smartphone (currently named WebDriver). It is easier to extend this platform from traditional client/server (C/S) model to Browser/Server (B/C) model that end-users can use to access the platform online and exchange information. In addition, different levels of driving participants can be recruited into the framework: the autonomous vehicles, the WebDriver, the low-cost game joystick and the high fidelity simulator (Fig.4). The autonomous car models can be used to build up the basic traffic flow; the random web drivers and low-cost simulators can be anyone or located in other places, join the platoon under certain rules to enhance the realistic effect of the traffic. The features of crossplatforms can make the cross-regions become easier. Users could come from different locations, different environment and different interfaces, which even can provide a way to study the differences of the drivers' behaviour across countries, cultures, driving habits, etc.

AIDE's report [AID28] mentioned the future effort on a more personalized behaviour and dynamic adaption is needed to make the ADAS more intelligent. This approach can allow studying the individual driving behavior, which might make improvement in prediction or inference of human state and behavior. It can expand the possibilities to able to represent individual differences in cognitive state and behavior as well as the personalized drivers' behavior study for ADAS. Recently, American Feds also plans to mandate that newly manufactured cars include "vehicle-to-vehicle" communication technology. The V2V communication is an expanding technology that has great potential of becoming the mainstream equipment on car. The car and driver can talk to each other will not only about the information of ambient car or public infrastructures. Imaging if the concise, effective but necessary ambient driver's state can be conveyed to others as the reminder of potential danger, this would benefit from the use of networked multi-driver simulators.

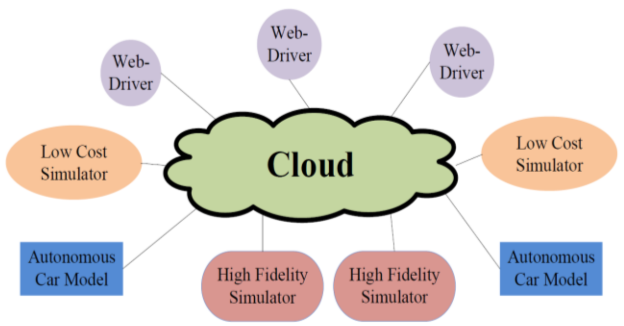

Fig.4. The Extended Networked Multi-drivers Simulation System

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