

Study on Driver Emotion in Driver-Vehicle-Environment Systems Using Multiple Networked Driving Simulators

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Abstract

Driving simulators have been widely used to investigate driver behavior and psychophysiological responses. In this paper, we proposed to use multiple participant-operated driving simulators which communicate with each other so the platoon formed by the simulators can demonstrate realistic effects of driver-driver interaction in simulation scenarios. In our preliminary experiment, three driving simulators were connected through Northeastern's campus network. One was a fixed-based high fidelity driving simulator with an actual automobile cabin and large curve screen in our Virtual Environments Laboratory. The other two are relative low cost simulators housed in the Intelligent Human-Machine Systems Laboratory. With this configuration, we investigated emotional behavior (anger, neutral, and excitement) of drivers by collecting driving performance data, psychophysiological responses and eye movement data. The results demonstrated the feasibility and efficiency of using multiple networked driving simulators to study driver emotional behavior, e.g., road rage.

1. Introduction

1.1 Importance of a realistic driver-driver interaction in driving simulation

Driving simulators have been widely used to investigate driver behavior and psychophysiological responses. To obtain accurate investigation results, high fidelity is usually required for driving simulators. Greenberg [2004] conducted an extensive review on the physical fidelity of driving simulation, from real people in real cars on real roads to sampled people, virtual cars and virtual roads. In everyday driving, drivers/vehicles in the same platoon interact with each other and finally everyone's behaviors are affected. Therefore, in driving simulation, the realistic effects of driver-driver interaction should also be of concern if high fidelity is desired.

Our previous study has shown using autonomous vehicles to enhance the effect of vehicle-vehicle interaction [Al-Shihabi and Mourant, 2003]. Autonomous vehicles need to have a realistic appearance and realistic behavior. However, we found that autonomous vehicles are appropriate to build traffic density on the macro level, but still unnatural for interacting with neighboring vehicles on the micro level. Due to the attached imperfect driver model, the autonomous vehicle has challenges to emulate a vehicle operated by a real human driver. Our *first research aim* is whether the realistic effects of vehicle-vehicle / driver- driver interactions can be achieved by using multiple driving simulators in which the imperfect driver model is replaced by a real driver.

1.2 Driver emotion study through realistic driver-driver interaction

Realistic driver-driver interaction is essential to investigate certain driver behaviors, e.g. emotional behavior. Traditionally, emotion is usually elicited through watching movies, memorizing personal experiences, and hearing stories [Lisetti & Nasoz, 2004]. One of our studies has also shown the relationship between physiological responses and emotion [Leng et al., 2007]. However, these methods may be inefficient in driving experiments because emotions, unlike moods, temperaments or personalities, are thought as short-term state [Picard, 1997]. The effect of emotion elicitation cannot last long enough to survive the whole simulated driving process. In addition, acting and naturalism are two concerns in induced emotion [Cowie et al., 2005]. Take road rage as an example, this kind of aberrant driver behavior is common in daily driving [CNN news, 2006] but difficult to be investigated through simulated driving. The major methods used in previous studies are personal interviews and telephone polls, e.g. introduced in [Parker et al., 2002] and [Smart et al. 2005]. Therefore, our *second research aim* is to investigate the influence of driver emotion on performance through platoon driving simulated with multiple simulators.

1.3 Emotion vs. driving performance

First we review the theoretic relationship between emotion states and driving performance. Intuitively, emotion does play roles in driving, although emotion was not

listed as a direct factor of traffic accidents [NHTSA, 2005]. However it has reported that 16 million people might have road rage disorder [CNN news, 2006]. In daily driving, a neutral emotion state usually occupies the biggest portion of time. Intuitively, some strong emotion states, e.g. rage and extreme excitement have potential to endanger driving safety because of prolonged reaction time.

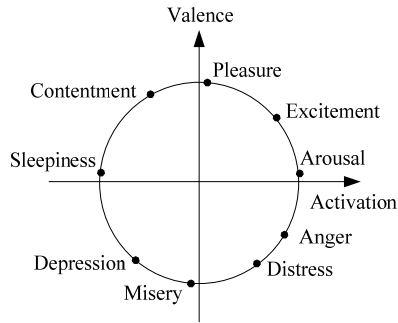


Fig.1 2-D Emotion Model
[Russell, 1980]

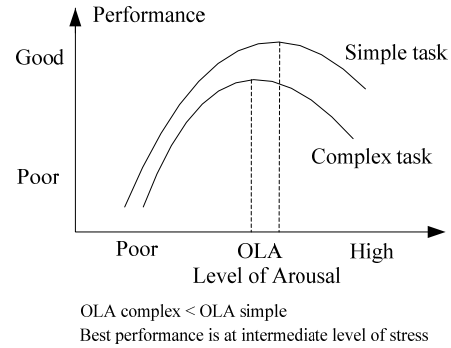


Fig.2 Performance and Arousal
[Kroemer et al. 2001]

The relationship between emotion states and driving performance can be examined through the 2-D emotion model (Fig. 1) and the Yerkes-Dodson Law (Fig. 2). Yerkes-Dodson Law indicates that performance and arousal level has an inverted “U” shape relationship implying appropriate arousal improves operator’s performance. Hence, theoretically strong emotion affects driver behaviors due to very high level of arousal.

2. Implementation of networked driving simulators

2.1 System architecture

The autonomous vehicles contain both driver models and vehicle models. The vehicle model takes the output of the driver model as inputs and then calculates the next status of vehicle dynamics. Vehicle models are well developed and readily available, e.g. bicycle model, 3 degree of freedom model, and high order model [Smith & Starkey, 1995; Hernandez & Kuo, 2004] while driver models are still under development due to their complexity [Lin et al., 2005]. When a real human driver replaces the driver model, the autonomous vehicle becomes a human operated vehicle with real driver behavior (Fig. 3).

Balling et al. [2002] introduced a dual-location high-end driving simulator at Iowa state university

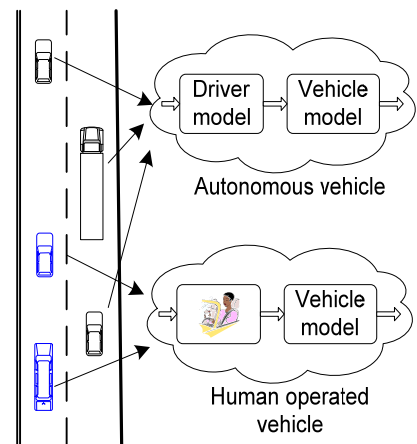
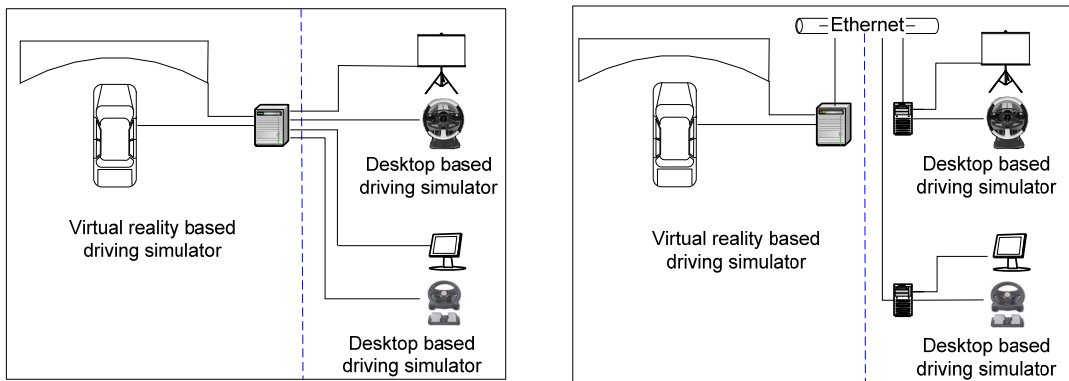


Fig.3 Vehicle platoon comprised of Autonomous Vehicles & Human Operated Vehicles

which could use for experiments involving collaborative or competitive maneuvering. We tried to construct multiple connected simulators with quick steps (Fig.4). In Fig.4 (a), there is only one copy of the simulation software running on the powerful workstation, and each simulator has its own steering wheel input and display output. To support multiple screen output, an extraordinary high performance graphics card has to be used; however its expandability is restricted because of heavy computation load. In Fig.4 (b), all simulators run the same independent simulation software. The static data are replicated for all simulators. Dynamic data for all moving objects are exchanged in real time through a high speed network. The Fig.4 (b) is our preferred configuration.



(a) Multiple Simulators Supported by One Powerful Workstation (b) Multiple Simulators Connected through Network

Fig. 4 Structures of Multiple Connected Simulators

2.2 Vehicle platoon

Even when multiple human operated simulators are connected together to create a vehicle platoon in driving scenarios, autonomous vehicles are still necessary to build realistic traffic flow. Our previous study [Al-Shihabi & Mourant, 2003] has discussed how to build more realistic driver behavior models for autonomous vehicles. The driver model is comprised of four fuzzy logic based units: Perception Unit (PU), Emotion Unit (EU), Decision-making Unit (DMU), and Decision-implementation Unit (DIU). These units work concurrently to implement a driving decision. Both the autonomous vehicles and human operated vehicle adopted a 3-DOF vehicle dynamics model to compute the vehicle dynamics parameters. Steering wheel angle, gas throttle, and brake force are the concerned parameters of the vehicle dynamics models. To achieve high fidelity interactive effects, the human-operated simulators form a platoon to interact with each other. The subjects use the simulators with the highest fidelity, and co-players (experimenters) use the low cost simulators with compromised fidelity.

2.3 Network communication protocol

For most simulator displays, the screen refresh rate is limited to 60 frames per second (fps). Therefore, only when the data exchange rate between simulators is higher than 60

times per second, is the real time effect satisfactory. A dedicated network is better for reducing time delay but it is infeasible when the simulators are distributed remote geographically. Because of the concern that data exchange is a kind of data broadcasting in our applications, User Datagram Protocol (UDP) was adopted in our programming for simplicity and efficient. For virtual reality related programming, the largest portion of CPU time is usually occupied by graphics processing. To make sure the CPU allocates time slices to process network communication just in time, the tasks of sending and receiving should be launched in two separate threads with relative high priority.

2.4 System implementation

Presently, three driving simulators have been connected through our campus network. Each simulator runs the same simulation software. One high fidelity driving simulator, with a fixed base, realistic automobile cabin, and curved screen is located in the virtual environment (VE) laboratory. The other two low-cost driving simulators are located in the intelligent human machine system (IHMS) laboratory. One simulator uses a projector for video output and also has a high fidelity steering system (ECCI TrackStar 6000). The other one is a desktop computer with a large LCD screen and a game wheel (Logic MOMO). The OpenGL based simulation software was initially developed by the VE lab for a single user and then upgraded by the IHMS lab for multiple users.

3. Experiment on driver emotions

3.1 Experiment settings

The driving scenario used was a two-way suburban road, including T intersections, crossings, curves, and traffic intertwined areas. Traffic signs and moving traffic objects were presented at proper locations to simulate a realistic road environment. The subjects used the high fidelity simulator and two experimenters used the other two low-cost simulators. In this configuration, the subject's emotional behaviors were monitored by collecting performance data, psychophysiological parameters, and eye movement data. Totally, 15 subjects (mean age: 28, SD: 5.8) participated in the preliminary experiment. Each subject spent about 8~10 minutes in the simulation driving depending on personal driving speed.

3.2 Emotion elicitation methods

Three emotion states: neutral, anger, and excitement, were induced in the preliminary experiment.

Neutral: Participants were asked to stay calm before taking an easy simulated driving. A leading car was presented in the scenario to guide the participant with moderate speed. No time pressure was implied during the experiment.

Anger: Participants were asked to recall personal angry experiences to stay in an angry mood before a time-pressured simulated driving, e.g. experience of road rage. Then this angry mood was reinforced by further irritations with audio and visual stimuli. The experimenter deliberately demonstrated the following rude behaviors through the

networked driving simulator: flashing headlights, sustained horn-honking, weaving in and out of traffic, and preventing the driver from passing.

Excitation: Participants were asked to play racing games before driving. This warm up process makes the driver very alert. During the subsequent racing scenario, the experimenter deliberately demonstrated high competence so that the participant would drive in the same manner.

3.3 Data collection

To calculate driving performance, the following performance data were collected through the simulation software in real-time: distance to lane center, steering wheel rotational angle, gas throttle, brake force, and vehicle speed. Then the SD of lateral offset (SD-LO), the SD of steering-wheel rotational movement (SD-STW), and time-to-line crossing (TLC) were derived based on the known time stamp. These parameters have been found to be sensitive performance measures [De Waard, 1996; Ma & Kaber, 2005; Bouchner, 2006].

To analyze a driver’s visual attention allocations, eye movement data were collected through the Tobii eye tracker: time stamp, and gaze coordinates on screen. Then the frequency of mirror checking (FMC, in times per minute), and the chance of missing signs (CMS) were summarized. Eye fixations, traffic sign locations, vehicle speed, pedal movements, and number of traffic violations (NTV) were analyzed.

To assess psychophysiological responses, heart rate (HR), skin conductance (SC), skin temperature (ST), and respiration rate (RR) were recorded through the FlexComp Infinity Biofeedback system. Heart rate variability (HRV) was then derived.

4. Results and discussion

The experimental data are shown in Tables 1, 2, and 3. In Table 1, the psychophysiological parameters reflect different emotional responses. Compared with the neutral state, anger and excitation speed up heart rate and respiration rate; and raised skin conductance. This tendency is consistent with previous research [Healey, 2000]. That indicates that multiple networked driving simulators are feasible for inducing driver emotional behaviors, i.e., realistic driver-driver interaction.

Table 1. Psychophysiological Parameters

Emotion state	HR (BPM)	HRV (BPM/M)	SC (Siemens) (mean/SD)	ST (°C) (mean/SD)	RR (TPM) (mean/SD)
Anger	82.6	3.6	2.8/0.6	31.6/0.09	16.2/4.2
Neutral	71.2	3.2	1.3/0.4	31.5/0.08	12.5/3.3
Excitation	86.1	3.7	3.0/0.8	31.8/0.09	15.6/4.0

Tables 2 and 3 show the relationships between emotion states and driving performance. Compared with a neutral state, drivers showed larger deviations of lane offset, larger deviations of steering wheel angle, and shorter times to lane crossings in

anger and excitation. This implies that drivers had poorer lane control capability in the anger and excitation scenarios, compared with in the calm state. Lane control capability directly relates to driving safety. When comparing driving performance between the anger and excitation conditions, the lane control capability under excitation was poorer.

Table 2. Driving Performance Data

Emotion state	SD-LO (cm)	SD-STW (degrees)	TLC (seconds)
Anger	24	2.0	2.5
Neutral	18	1.1	5.6
Excitation	26	2.2	2.1

Table 3. Visual Attention Pattern

Emotion state	FMC (T/M)	CMS	NTV (T)
Anger	4.5	0.25	4.5
Neutral	6	0.06	2.3
Excitation	3.8	0.28	5.3

5. Conclusions

In this paper, three driving simulators were connected through a high-speed campus network. Autonomous vehicles and human driver operated vehicles were simultaneously presented in driving scenarios to form a platoon. High fidelity driver-driver interactions were achieved by replacing driver models with real human drivers. In the experiment, we successfully induced two kinds of emotion states (anger and excitation) through realistic driver-driver interaction by using networked driving simulators. Drivers' psychophysiological parameters changes were the indicators of emotions. The relationships between emotion states and driving performance were investigated by recording driving performance and eye movement data. In the anger and excitation states, drivers showed poorer lane control capability. This study demonstrated the feasibility of using multiple driving simulators to investigate driver emotional behaviors, e.g., road rage.

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