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Development of a driving simulator for virtual experience and education on drunk driving

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Abstract

The aim of this study is the development of a driving simulator for the virtual experience of drunk driving and education on its dangers. Towards this end, visual effects specially designed via a real-time image generation engine were implemented in the graphic database for distorted-vision generation, space perception ability impairment, and downscaled peripheral-vision scope. A steering wheel and brake model were tuned to simulate delay in the driver's decision making, muscular control, and perception reaction time.
The simulation participant can choose the blood alcohol content (BAC) level that he/she wants to experience through a selector button in the center fascia, and can experience the dangers of drunk driving in a virtual environment. Different driving scenarios on an urban road, a rural road, and an expressway were developed for a more comprehensive experience. Each driving scenario was designed to include various visual effects and vehicle dynamics simulations of drunk driving. Through these contents, the participant can indirectly experience the physical and physiological changes that occur in the human body during drunk driving, and can develop alertness in the event of a traffic accident caused by drunk driving.
An instructor monitoring and control system was developed to simultaneously control and monitor multiple driving simulators. This system can record and replay the road situation and the driving behavior of each participant, and can finally report the training result.
This study is expected to contribute to prevention of traffic accidents caused by drunk driving by offering education on dangers of drunk driving in a safely controlled environment. The future work should include implementation of more realistic visual effects and vehicle dynamics simulations of drunk driving on training contents, and broad application in the field of driver training.

Keywords – driving simulator, drunk driving, blood alcohol content, perception reaction time

1. Introduction

Driving under the influence of alcohol (DUI) impairs a wide range of driving skills necessary for carrying out driving tasks successfully. Drivers with high blood alcohol content (BAC) are at a much higher risk of causing traffic accidents and consequent casualties. According to the estimates made by Insurance Institute for Highway Safety [1], the relative risk of fatality in single-vehicle crashes for drivers with a high BAC is 385 times that of a sober driver, and for male drivers, the risk is 707 times.

In South Korea, despite the growing public awareness that “drunk driving is a serious crime and is unacceptable,” the number of traffic accidents caused by drunk driving is hardly ever abated. Above all, over 30% of DUI offenders have been arrested twice or more. The number of habitual drunk drivers tends to increase [2]. Moreover, considering the number of potential drunk drivers who have not been arrested, the problems related to repeated habitual drunk driving are more serious.

According to a survey jointly conducted by Kanagawa Prefectural Police Headquarters and National Hospital Organization Kurihama Alcoholism Center in Japan [3], 76.8% of all people have a history of drunk driving while 56.1% do not have an arrest history related to drinking. The results of the Alcohol Syndrome Screening Test (AUDIT) conducted for people with a history of drunk driving indicate that 41.4% of the people who took the test were suspected of being alcohol-dependent. The percentage of persons with dangerous drinking habits was 32.6%, and thus, about 70% of them had alcohol-related behavioral problems.

In 2004, 16,694 traffic deaths and 248,000 injuries in the United States were related to alcohol-impaired driving (AID) [4]. Over the past decade there has been little change in the number of alcohol-related deaths, although alcohol’s contribution as a percentage of all motor vehicle deaths has decreased slightly [5]. The economic impact of alcohol-impaired crashes in the United States in 2000 was estimated to be $51 billion [6]. The risk of a crash increased when drivers were under 40, were driving at night, and were driving on less traveled, as well as among people who engaged in heavy and/or binge drinking [7]. Hingson and Winter [8] estimated that drivers take more than 82 million DUI trips per year at blood alcohol concentrations (BACs) of 0.08 or higher, representing perhaps 10% of all trips where at least some driver alcohol use is present.

Legal sanctions, such as driver’s license suspension, license revocation, and court-ordered alcoholism treatment, have been designed to deter drunk driving. Driver’s license suspension and license revocation seem to be the most effective deterrents among the general driving population. The most effective means of reducing the cases of DUI and crashes, however, was a combination of license suspension and interventions, such as education, psychotherapy counselling, and specific follow-up schemes like Ignition Interlock and Driver Alcohol Detection System for Safety (DADSS). According to Sadler et al. [9], a DUI conviction should serve to identify problem drinkers and to guide or coerce them into alcoholism treatment. The alcoholism treatment for DUI offenders can range from short-term educational sessions to therapy programs lasting for at least one year.

Korea National Police Agency (KNPA) and Korea Road Traffic Authority (KoRoad) gave directions to all the branches of KoRoad to set up a special class for the drunk drivers in the course who have been penalized. In 2006, a special course about drinking was organized in all the branches of KoRoad. In the course, a lecture and an important training session related to the dangers of drunk driving were conducted. In 2012, a special class for habitual drunk drivers will be added to the new curriculum, in which they have to experience simulated drunk driving using a driving simulator, and in which they will receive intensive education about the dangers of drunk driving through indirect experience. It will be mandatory for a driver with more than 40 point black marks from drunk driving.

Various devices have been developed for simulation of the drunk-driving experience. For example, drunk goggles simulate the effects of impairment, including reduced alertness, slowed reaction time, confusion, visual distortion, alteration of depth and distance perception, reduction of peripheral vision, poor judgment and decision making, and lack of muscular coordination.

They represent a different simulated BAC of approximately 0.04-0.25%. A similar device is the simulated-drunk-driving-experience vehicle, which is a battery-powered mini-vehicle that reacts with delayed steering, braking, and acceleration, simulating the effects of a vehicle being driven by a distracted or impaired driver.

This study was conducted to develop a driving simulator for virtual experience of and education on the dangers of drunk driving, named DUI-DS. DUI-DS was developed by combining the advantages of the drunk goggles and the drunk-driving-experience vehicle. To accomplish this, specially designed visual effects using a real-time image generation engine were implemented in a graphic database for distorted-vision generation, space perception ability impairment, and downscaled peripheral-vision scope. The steering wheel and brake models in vehicle dynamics were also tuned to simulate delay in the driver's decision making, muscular control, and perception reaction time (PRT).

2. Driving simulator

2.1. How alcohol affects drivers

It is not the direct effect of alcohol on driver performance or driver behavior that makes it so crucial in traffic safety, but the changes in crash risk that flow from these changes in performance and behavior.

Moskowitz and Fiorentino [10] reviewed literature on just one aspect, namely, how alcohol affects skills related to driving, identified 1,733 titles. These include cognitive tasks, critical flicker fusion, divided attention, driving on simulators, drowsiness, perception, psychomotor skills, reaction time, tracking, vigilance, and various visual functions. Strong evidence showed performance declines for some driving-related skills at any measured BAC > 0. Performance declines were reported by the majority of studies for BAC ≥ 0.05%, and for 95% of studies for BAC ≥ 0.08%. Alcohol has major effects on behavior, including reducing inhibitions and caution, and increasing aggressiveness and risk taking. Impairment has been defined as a statically significant decrease in performance under alcohol treatment from the performance level exhibited under placebo treatment.

Alcohol is a type of tranquilizer that can be easily acquired in daily life. Drinking a small quantity of alcohol (BAC ≤ 0.03%) will not have a conspicuous effect on the body, but drinking more than a certain quantity (BAC=0.05%) will affect the central nervous system and will impair the PRT, space perception ability, sense of equilibrium, saccadic eye movement, fixation eye movement, and accuracy of motion, as well as the concentration, wariness, attention, and emotional control, which may lead to irrational driving behaviors. The effects of alcohol drinking on the body can be divided into the following steps:

Step 1: The visual perception ability is impaired (BAC≥0.05%).
Step 2: Judgment is impaired (BAC ≥ 0.07%, about 50% of the value before drinking alcohol).
Step 3: Operation errors begin to occur (BAC ≥ 0.15%).

Furthermore, the effects of alcohol drinking on the driving behavior are shown in Table 1.

2.2. System requirement

In order for a driving simulator to be fully useful for virtual experience and education on drunk driving, it should meet special requirements related with drunk driving as well as general requirements for a driving simulator. These requirements are summarized in Table 2.

Tab. 1 - Performance and behavior characteristics that have been associated with increasing BAC levels [11]

BAC	Performance and behavior change
0.01%	Normal actions hardly influenced.
0.02%	Change in social behavior, mild euphoria, relaxation, increased gregariousness.
0.05%	Feeling good, less inhibited, altered judgment, lowered alertness
0.07%	Judgment impaired, likely to take risks and action not taken when sober, release of inhibitions, impulsive behavior, and slight decrease in fine motor skills.
0.10%	Slower reaction times and impaired motor function, less caution, slightly slurred speech, increased aggressiveness.
0.15%	Large, consistent increases in reaction time, balance impaired, slurring of speech.
0.20%	Major memory impairment
0.27%	Confusion, slurred speech.
0.30%	Double vision may occur; most drinkers become unconscious or fall asleep at this level and difficult to awaken.
0.40%	Barely conscious.

Tab. 2 - System requirements for DUI-DS

	System requirements	Importance
General requirement	- Easy to operate - Ease to move and install - Ease to get (low cost and maintainability) - Easy to upgrade - Minimize the Simulator Adaptation syndrome (SAS)	Required
Image generator	- Average frame rate: 60 fps (minimum 30fps) - Effects of impairment - Reduced alertness - Confusion - Reduction of peripheral vision - Visual distortion - Speed effect - Alteration of depth and distance perception	Required
Vehicle dynamics	- Delayed steering, braking, and acceleration	Required
Road environment and driving scenario	- Surround vehicle around weaving or diverging area - Dangerous passing maneuver - Straddling the centre line - Making wide turns - Tailgating - Turn on/off headlight, turning and hazard lamp - Signal control at the dilemma zone	Required

DUI-DS was developed to meet the requirements specified in the table. It enables a driver to feel the physical and physiological changes that occur in his/her body caused by alcohol consumption, and experience the consequent danger of driving under the influence of alcohol in accordance with driver's BAC level. DUI-DS provides various driving scenarios in different driving environments including urban road, rural road, and expressway for more comprehensive experience. Each driving scenario was designed to include various visual effects and vehicle dynamic simulation of drunk driving. DUI-DS can also record and replay driving behavior of each participant for feedback, and report the training results. Multiple DUI-DSs can be networked, and easily monitored and controlled by an instructor.

Fig. 1 - System configuration

2.3. System configuration

As shown in Figure 1, DUI-DS consists of three subsystems: the main system, the monitoring and control system, and the presentation system. The main system and the monitoring and control system exchange data via 1000 Mbps Ethernet (TCP/IP). The monitoring and control system records with a frame grabber the faces of the trainees from the two CCD cameras installed on the dashboard and the images on the front monitor. Any peculiar behavior or situation detected while driving are bookmarked through the cue switch and are stored with the driving video and driving behavior data synchronized so that the particular situations can be explained to the trainees after the training. Furthermore, when dangerous situations such as sudden braking (deceleration: 0.3 g or greater) and sudden steering (rotation angle velocity: 20 deg/sec or faster) are detected, or when crashes with road facilities are detected, the video and vehicle data are automatically saved, and the dangerous situation or accident can be replayed later.

The image generation engine not only realistically reproduces the road environment (e.g., day/night, fog, rain, snow, shadow) but also produces special visual effects, such as peripheral-vision reduction, visual distortion, and alteration of depth and distance perception, which occur after alcohol drinking. In particular, if the 3D mode is activated and the trainees wear 3D goggles, they can realistically experience drunk driving through the 3D videos that are generated in real time by the image generation engine.

2.4. Virtual driving environment

2.4.1. Roads

DUI-DS provides four types of roads: urban road (10 km), rural road (15 km), expressway (10 km), and exercise road (10 km). These roads were developed based on data collected by road design drawings, aerial photographs, and field surveys. The urban road is characterized by complex traffic situation consisting of buildings, crossroads, crosswalks, pedestrians, and bicycles; the rural road by simpler and darker traffic environment compared to the urban road; and the expressway by situations that may occur during converging and diverging on an outskirts beltway that connects the urban area with heavy traffic to surrounding cities. The exercise road is an expressway composed of straight and slowly curving sections. Figure 2 shows road sample screen shots. Figure 3 shows special visual effects added to the roads to simulate alcohol effects.

Expressway (A) Expressway (B)
Urban road (A) Urban road (B)
Rural road (A) Rural road (B)

Fig. 2 -Terrain sample screen shot

Crosswalk (Highway) Curve section (Highway)
On ramp (Expressway) Tunnel (Expressway)

Fig. 3 - Special visual effects

2.4.2. Traffics signals and road markings

Traffic signals were set to naturally reproduce situations such as traffic in a crossroads dilemma zone and the unexpected appearance of signal-violating vehicles and pedestrians.

2.4.3. Lighting

For the road lighting environment, not only nighttime road environments such as streetlights, building lights, shadows, and lights from the nearby vehicles can be controlled based on the fact that most drunk-driving accidents occur between 7 p.m. and 1 a.m.; the headlights (low, high, passing beam) and tail, stop, turning, and hazard lights can also be controlled in real time using the multifunction switch at the driver's seat.

2.4.4. Vehicle dynamics

Figure 4 shows a block diagram of the driver model. A steering wheel and brake model were tuned to simulate delay in the driver's decision making, muscular control, and perception reaction time (PRT). Table 3 shows default values and ranges for delayed brake reaction and delayed steering wheel reaction.

2.5. Driving scenarios and unexpected events

The driving scenarios consisted of four types of roads (exercise road, urban road→rural road, urban road→expressway, and expressway) with a total length of 40 km. Table 4 shows the events or driving tasks included in each driving road.

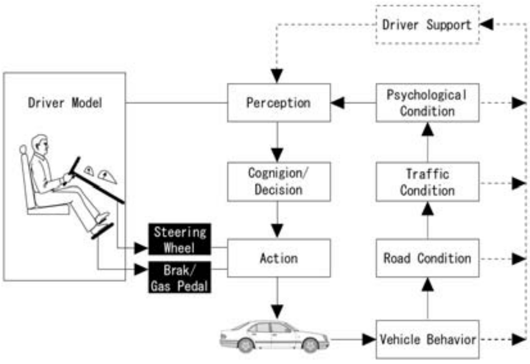


Fig. 4 - Block diagram of the driver model (DUI-DS)

Tab. 3 - Settings for special effects according to BAC

	Default	Remarks
Delayed brake reaction	Adjustable range: 0.00-1.00 sec 0.05-0.10% (0.29 sec) 0.10-0.15% (0.35 sec) 0.15-0.20% (0.45 sec)	Delay in brake reaction and increased braking distance due to such delay are reproduced.
Delayed steering wheel reaction	Adjustable range: 0.00-1.00 sec 0.05-0.10% (0.19 sec) 0.10-0.15% (0.25 sec) 0.15-0.20% (0.35 sec)	Danger avoidance ability and lane maintenance ability to horizontal dangers due to delayed steering wheel reaction are reproduced.
Downscaled peripheral-vision scope	Adjustable range: 0-100% 0.05-0.10% (20%) 0.10-0.15% (25%) 0.15-0.20% (30%)	The objects in the peripheral vision appear blurred, which decreases the sense of speed and impairs the ability to respond to sudden situations from the sides of the road.
Impairment of discrimination	Adjustable range: 0-100% 0.05-0.10% (50%) 0.10-0.15% (60%) 0.15-0.20% (100%)	Impairment of vision due to drinking is reproduced. As the discrimination of the objects at the front is impaired, it affects the judgment ability in various situations.
Wave effect	Adjustable range: 0-100% 0.05-0.10% (10%) 0.10-0.15% (15%) 0.15-0.20% (20%)	Decline of the sense of equilibrium due to drinking is reproduced. Objects are shaken, and lights appear scattered.

Tab. 4 - Driving scenarios and unexpected events

Scenario Name (Driving Distance)	Scenario Number	Description
Excerise (10 km)	000	The exercise road was designed for practicing basic operations such as acceleration, deceleration, lane change, and curved-road passage on a virtual high-grade motorway.
Urban→rural (10 km)	101	A child walks across a danger zone.
	102	A motorcycle on the left road suddenly turns left and crosses the road.
	103	A bicycle running along the shoulder of a road suddenly loses balance and enters into the road before returning to its original position.
	104	On a crossroad, a vehicle running in the opposite direction passes across the front of the simulation participant's car and turns right.
	105	On a sharply curving road, the simulation participant encounters a vehicle in the opposite lane that breaks away from the lane.
Urban→ Expressway (10 km)	201	The simulation participant meets a vehicle running on the main lane at the converging point to the outskirts expressway from the urban road.
	202	While the simulation participant is driving at a high speed, the front vehicle suddenly decelerates.
	203	The simulation participant encounters an accident site while passing through a tunnel, and he/she quickly decelerates and changes lanes.
	204	A vehicle stuck in the traffic at the shoulder suddenly transfers to the main lane.
	205	At an off ramp, a guiding voice says "Go straight" and then suddenly says "Go out to the right road."
Expressway (10 km)	301	The simulation participant accomplishes certain missions while following the front car.
	302	While following the front car, the simulation participant encounters traffic congestion, and the surrounding cars suddenly decelerate.

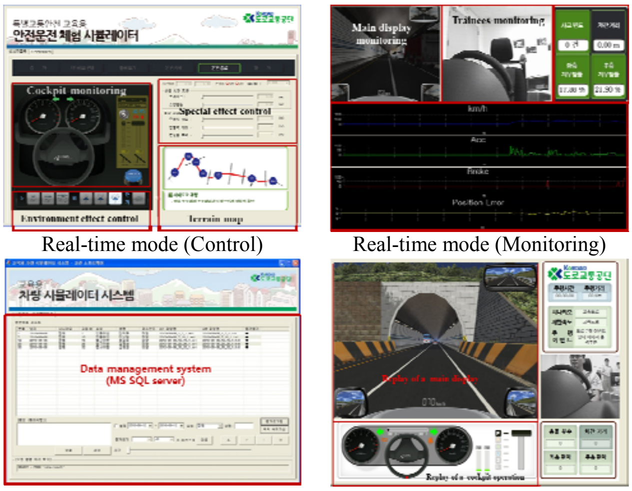
2.6. Monitoring and control

The monitoring and control system has two modes: the real-time mode, in which one can monitor all the data related to driving in real time different driving scenarios; and the presentation mode, in which one loads the data saved in the real-time mode to analyze the general driving behavior, driving actions, and information for each driving scenario, and to generally evaluate and print the driving results. Figure 5 shows the GUI configuration of the application in the real-time and presentation modes.

The simulation participant can choose the BAC level that he/she wants to experience using a selector button in the center fascia, and can experience the dangers of drunk driving in a virtual environment. For the effects of alcohol drinking on the body, the BAC range of 0-0.20% was divided into four levels. The default values for delayed brake reaction, delayed steering wheel reaction, downscaled peripheral-vision scope, impairment of discrimination in vision, and wave effect were defined based on the experimental values in accordance with each drinking indicator. The settings can be randomly adjusted in real time by the instructor. The delays in various reactions and the visual special effects according to the drinking indicator are shown in Table 3.

3. Evaluation

In the early stage of DUI-DS development, an experiment was conducted to investigate the effect of alcohol on driving impairment, especially increase in PRT.



Real-time mode (Control) Real-time mode (Monitoring)

Presentation mode (Analysis) Presentation mode (Replay)

Fig. 5 - User interface for monitoring and control system

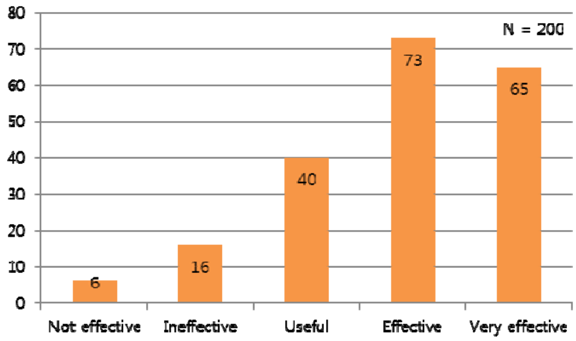


Fig. 6 - Acceptance of DUI-DS at test sites

Twenty-five subjects (average age: 34.8), 19 males and 6 females, participated in the study. The subjects first practiced driving in a driving simulator for a few minutes until they became comfortable. They then drove the urban→rural scenario in a sober condition and then under the influence of alcohol with the BAC level of 0.05 – 0.1%. Comparison of driver's reaction time to unexpected events between two conditions revealed that the mean PRT increased by 0.87 sec ($t = 1.73$, $p < .05$) under the influence of alcohol. This experiment result and literature survey became the basis for determining delays in the driver model.

Another evaluation was conducted to investigate user acceptance of DUI-DS during its test operation. Figure 6 shows the response of 200 participants to usefulness of the simulator on virtual experience and education on drunk driving. The figure shows that 89% of the participants accepted the use of DUI-DS, answering "useful", "effective", or "very effective".

The test operation also revealed that although simulator sickness is far from severe in DUI-DS, it still affects driving time in education sessions. It seems that about 10 minute driving time is appropriate for one session and the education should not be conducted for more than three times in a row. This simulator sickness issue requires further investigation and improvement.

Strictly speaking, adjusting the vehicle dynamics model of the driving simulator to add delay to steering and brake reaction up to 0.45 sec does not fully represent driver's body reaction under the influence of alcohol. However, this is the most effective method in a situation where people cannot be educated after drinking alcohol. The education scenarios of DUI-DS reproduce the PRTs in complex situations where various traffic conditions are combined instead of simply experiencing reactions, and there have been few negative opinions about it.

4. Conclusions

It can be concluded that DUI-DS is one of the most effective tools to educate general drivers as well as chronic drunk drivers on danger of drunk driving in a realistic scale. This type of education is expected to increase public awareness on drunk driving more substantially and to prevent traffic accidents caused by drunk driving more effectively. Furthermore, since DUI-DS can perform all the functions of a general driving simulator, addition of other educational contents will allow it to be used for driving practice, hazard perception training, or driving aptitude tests.

DUI-DS is being test-operated in the field until the end of 2011. In the mean time, opinions from the trainees, driving instructors, and psychologists are collected to improve the system. In 2012, it will be introduced to the nationwide education sites of Korea Road Traffic Authority. Korea National Police Agency submitted a bill to the National Assembly that requires the inclusion of experiential education using DUI-DS in educational courses for drunk drivers.

The future work should first include tests and experiments to determine more realistic reaction delays and specidal effects to represent drunk drving more faithfully. The future work also includes the implementation of more realistic visual effects and vehicle dynamics simulations of drunk driving in the training contents, and broad application in the field of driver training.

References

1. R.F. Healing, Testimony before the House Judiciary Committee. State of Maryland Regarding House Bill 763. 2004.
2. Korean National Police Agency. Road Traffic Accidents in Korea 2009 (English edition), Traffic Accident Analysis, Chapter 2. 2010.
3. Cabinet office, Government of Japan. Paper on Traffic Safety in Japan 2008 (Abridged Edition). Chapter 1. 12-13. 2009.
4. M.L. Rothschild, B. Mastin, T.W. Miller. Reducing alcohol-impaired driving crashes through the use of social marketing. Accident Analysis and Prevention 38. 1218–1230. 2006.
5. National Highway Traffic Safety Administration, Traffic Safety Facts, 2004. U.S. Department of Transportation,Washington, DC. 2005.
6. National Highway and Traffic Safety Administration. Economic Impact of Motor Vehicle Crashes 2000. Summary. Retrieved on January 28, 2003. http://www.nhtsa.dot.gov/people/economic/econimpact2000/summary.htm
7. K.P. Quinlan. Alcohol-impaired driving among U.S. adults 1993–2002. American Journal of Preventive Medicine. 28(4). 346–350. 2005.
8. R. Hingson, M. Winter. Epidemiology and consequences of drinking and driving. Alcohol Research and Health. 27. 63−78. 2003.
9. D.D. Sadler, M.W. Perrine, R.C. Peck. The long-term traffic safety impact of a pilot alcohol abuse treatment as an alternative to license suspensions. Acc. An. and Prev. 23(4). 203-224. 1991.
10. H. Moskowitz, D. Fiorentino. A review of the literature on effects of low doses of alcohol on driving-related skills, Report DOT HS 809 028, US Dep. of Transportation. Washington, DC, U.S.A. 2000.
11. L. Evans. Traffic Safety, Science Serving Society. Bloomfield Hills, Michigan, U.S.A. 2004.