

A Virtual Driving Education Simulation System - Hardware and Software with Pilot Study

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ABSTRACT

Novice drivers are often ill-equipped to safely operate a motor vehicle due to their limited repertoire of skills and experiences. However, automotive simulation tools can be applied to better educate young drivers for a number of common driving scenarios. In this paper, the Clemson Automotive Training System (CATS) will be presented to educate and train novice drivers to safely operate four wheel passenger vehicles on paved roadways. A portable automotive simulator can be programmed to emulate a variety of high-crash rate scenarios and roadway geometries. Drivers receive instructions regarding proper driving techniques and behaviors with an opportunity to practice the given vehicle maneuver. An on-line evaluation methodology has been designed to analyze the drivers' capabilities at handling these roadway events. First, a pre-simulation questionnaire evaluates their basic understanding of everyday driving situations. Second, when driving, individuals are assessed on multiple factors including vehicle speed, yaw angle, lateral acceleration, steering angle, and proper lane adherence while navigating the implemented track. Third, individuals complete a post-simulation questionnaire. Finally, a driving score is displayed on the computer screen to indicate the driver's performance. An initial human subject pilot study of novice, young, and seasoned drivers has been conducted. Overall, the driver performance improved an average of 12.75% (novice), 5.67% (young), and 4.31% (seasoned) which offers an indication of the driving simulation system's merits.

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1. INTRODUCTION

In the United States for the 2010 calendar year, 1,963 people between the ages of 15-20 were killed and another 187,000 were injured from motor vehicle crashes [1]. Studies have shown that younger drivers are more likely to be injured or killed during crash events than other driver populations [2]. Three factors contribute to the high rate of motor vehicle crashes among novice drivers. First, novice drivers generally have less ability to detect hazards quickly as they tend to overestimate their general driving proficiency [3]. Second, graduated driver licensing programs (GDL) yield tiered driving experiences [4] for novice motorists and potential opportunities for additional driver education and training may be missed. To properly prepare novice drivers for common road safety scenarios, additional resources should be offered using supplementary technology [5]. Third, telecommunications and entertainment systems can lead to distractions, so drivers need to be equipped with a proper attitudinal skill set to understand that operating a cell phone while driving often results in a delayed reaction [6]. To help

address these driver issues, an automotive simulator can be applied in the training process with targeted instructions and scenarios [7]. These computer systems can help novice drivers enhance their ability to identify potential traffic hazards [8], improve their awareness [9], and simultaneously analyze their driving performance with real time feedback [10].

Multiple studies and training programs have been piloted to decrease the crash rate among novice drivers. In the 1950s, most public high schools in the United States introduced driver education programs [11]. In 1996, the GDL program was introduced and is now used throughout the United States [12]. In recent years, universities and automotive manufacturers use driving simulators for research and product development activities. These driving simulators are applied in a variety of ways. Clemson University designed and applied automotive simulators to train and educate novice and young drivers [13] [14]. The University of Nottingham used a driving simulator to test whether a commentary driving system can remind drivers to notice potential hazards

[15]. The Korea's Automotive Technical Institute built a large scale virtual driving simulator to mimic the real world and analyze driver performance [16]. The University of Wisconsin-Madison introduced a variable message sign system and used a virtual driving simulation system to test its effectiveness [17]. FIAT applied a driving simulator to develop and test new cars [18]. The University of Stuttgart created a virtual driving simulator platform to test and measure the fuel consumption and CO₂ emissions [19]. In general, these simulators are often too large to regularly move to different locations and may not target novice drivers' needs. The Clemson Automotive Training System (CATS) has been developed using a PC-based platform, which should increase its application in high schools, driving schools and community settings. Figure 1 displays the roadway view from a third person perspective on the CATS computer screen.



Figure 1. Virtual display of the user's vehicle along a straight roadway with universal feedback symbol on the right bottom of the screen indicating satisfactory driving performance

The CATS system was developed based on VDrift [20]. VDrift is open source software and contains a good vehicle dynamic description, which allows for the development of other customized modules much easier than most commercial driving software. The tracks are fully customized and can be designed as the learning situation requires. Immense quantities of data can be collected within the virtual training environment and analyzed to evaluate a driver's performance. CATS is a PC-based virtual driving simulator, which individuals can download and engage at home instead of going to a remote location provided they have the necessary driver interface hardware (refer to Section 2). CATS, contains four specific scenarios to evaluate the driver's performance and records the data of each participant. The remainder of this paper is organized as follows. Section 2 introduces the system hardware and software for the CATS, as well as offers an overview of the four scenarios and their designed

purposes. Section 3 reviews the analysis and assessment strategies. The instruction system directs drivers how to pass each scenario correctly. The scoring system records the drivers' behaviors and then rates their driving performance. Section 4 provides a pilot study with 12 human test subjects completing the automatic simulator training program. Finally, the conclusion is offered in Section 5. A complete nomenclature list is contained in the [Appendix](#).

2. HARDWARE, SOFTWARE CONFIGURATIONS AND SYSTEM FEATURES

The virtual driving education simulator consists of three parts: computer, human-vehicle interface and real-time software. Figure 2 shows an image of the driving education simulator station. The computer hardware includes a Dell OptiPlex 980 desktop computer with Intel core i7 processor, a 19 inch monitor, and an attached speaker bar. A 1GB NVIDIA video card provides the graphics. The operating system is Ubuntu 10.10. A Logitech G27 steering wheel (900° range of rotation) with foot pedal assembly contains the throttle, brake pedal, and clutch. The steering wheel and pedals are mounted on a racing chair assembly with a seat belt. The seat can move forward or backward to adjust the distance between the driver and pedals. The driving simulator was developed based on the VDrift, which is open source driving software that uses the Vamos physics engine [21]. The track is created with Bob's Track Builder [22], which is a commercial building software, and Blender [23], a three dimensional building software. All the systems software features were written in the C++ language.



Figure 2. Portable Clemson Automotive Training System (CATS) with seat belt, standard human / vehicle interface, screen display, speaker and the host PC workstation

The driver will receive training in several manners using the created software application. An instruction system shows

interactive images and information during their driving time. A three part scoring system evaluates their driving skills; scores are displayed during and after the driving session. First, the simulator system will record the driver's data while they are driving and display a screen score on the top left. The score will update automatically after the vehicle has passed each scenario. Second, when the vehicle is approaching the next scenario, an image will be displayed to offer universal instruction about the roadway event. For example, when the vehicle is 30 meters close to the "lane selection" module, a road construction sign will be shown on the screen's right center directing the participant to the appropriate single lane which will allow them to pass the obstacle. Finally, after the vehicle has driven through a scenario, the drivers' performances will display on the right bottom of the screen.

The scoring system collects and displays information during the pre-driving period to assess general knowledge and after the road driving portion. A set of ten questions are posed to gather attitudinal and knowledge data regarding driving behavior. Each driving scenario has certain requirements; the system will score the driver's performance over four scenarios, S_i ($i=1, 2, 3, 4$), with each scenario worth a maximum of 100 points

$$S_i = \begin{cases} \sum_{j=7}^3 \alpha_{ij} \bar{K}_{ij}; & \text{for } (i=1,2,4) \\ \sum_{j=1}^7 \alpha_{ij} \bar{K}_{ij}; & \text{for } (i=3) \end{cases} \quad (1)$$

where α_{ij} provides the weighting for each of the j evaluation factors, and $\bar{K}_{ij}$ contains the given metric's score. The system also counts the number of times the vehicle has traveled off the road, N_1 , the number of times the vehicle ventured across the double yellow line, N_2 , and the number of times the vehicle was traveling faster than the posted speed limit, N_3 . Specifically, each time the vehicle travels off the road, drives across the double yellow line, or exceeds the speed limit, a penalty of β_k points will be deducted from the total score. Consequently, the driving score, $0 \leq DS \leq 100$, may be normalized as

$$DS = \frac{1}{n} \left(\sum_{i=1}^4 S_i - \sum_{k=1}^3 \beta_k N_k \right) \quad (2)$$

where k denotes the penalty index ($k=1, 2, 3$) and n corresponds to the total number of scenarios. The relationship between the driving score and the driver rating, DR , can be expressed as

$$DR = \begin{cases} \text{Excellent}; & \text{if } 90 \leq DS \leq 100 \\ \text{Good}; & \text{if } 80 \leq DS < 90 \\ \text{Average}; & \text{if } 70 \leq DS < 80 \\ \text{Fair}; & \text{if } 60 \leq DS < 70 \\ \text{Dangerous}; & \text{if } DS < 60 \end{cases} \quad (3)$$

when the participant is driving the simulator, they can check the scoring menu for their current score. After a driver finishes the first loop, the total score will also display on the screen. At the same time, the table detailed score will be recorded in tabular function and stored on the hard drive. After finishing the simulator training session, the driver can view the complete assessment of their driving behavior.

3. DRIVING SCENARIOS

Four scenarios have been designed and implemented into the simulator to evaluate the driver's overall performance. Each scenario has its own special purpose. The first module ($i=1$) is an intersection with a stop sign that evaluates the drivers' behavior when approaching a four way stop. The second module ($i=2$), where one lane is closed, tests the drivers' ability to safely change lanes before entering a road construction zone. The third module ($i=3$) offers drivers an overview on vehicle dynamics for a high speed emergency stop. Finally, the last module ($i=4$) examines the driver's ability to avoid the sudden appearance of wildlife on the road. After these four scenarios, the driver should be more familiar with the rules of the road, gain an increased understanding regarding the vehicle dynamics involved in stopping a car within certain distances and its handling, and have a better appreciation for roadway hazards.

3.1. "Traffic Control Device" Module

The first module is designed to analyze drivers' performance, to increase novice drivers' familiarity with traffic signs, and to instruct them to react properly to each roadway sign. For example, stop signs (refer to Figure 3) are often not obeyed with a complete vehicle stop before the sign. Similarly, when traveling around a curve, the driver should turn the steering wheel and accelerate smoothly while keeping the car on track. To determine whether the driver successfully passes this scenario, three factors have been recorded: Vehicle speed when accelerating through the stop sign, V ; the distance between the vehicle centerline and middle of the road, L ; and the overall steering smoothness, $\int |\delta| dt$. The speed, V , determines whether the driver has either stopped or decreased speed before the stop sign. The distance, L , indicates the position of the vehicle to make sure the vehicle is not driving off the road or across the double yellow line. A smaller steering angle, δ , while driving through this scenario is required; $\int |\delta| dt$ signifies if the driver controls the vehicle smoothly. Table 1 lists the values for α_{1j}