PROTOTYPING VIRTUAL REALITY GAME FOR EDUCATING NOVICE DRIVERS IN ROAD TRAFFIC SAFETY

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Abstract:
Emphasizing the importance of road traffic safety is a constant effort of many generations, even before the invention of motor vehicles. The paper presents a prototype of a virtual reality game that was developed to enable novice drivers the opportunity to examine, experience, and experiment with critical and/or hazardous road traffic situations and scenarios in a safe digital environment. Prototyping is about discovery, trial, and error. Virtual reality technology was chosen to get closer to the generations of novice drivers who grew up in a technologically rich environment, surrounded by various digital devices and accustomed to their use. A small-scale study was performed on a group of 18 novice drivers using the prototype. The presented approach proved to be effective and successful, so further development of the game project will be undertaken by expanding the created prototype.

Keywords:
Prototype, Virtual Reality, Game, Road Traffic, Safety.

INTRODUCTION

A prototype is a model developed to prove a concept. Virtual reality game prototypes are not intended to represent the entire game – in that case, we would be talking more about technological demonstrations or pre-alpha development versions. The main reason why a prototype exists is to mitigate the risk of creating something that doesn't work. Prototypes exist precisely because we need to make the best use of the limited time and resources we have. Having in mind the importance of road traffic safety for novice drivers, there is a clear and constant necessity for their education, presumably by using contemporary methodology and educational technologies. Traditionally, newbie drivers learn about traffic safety from handbooks, training videos, tests, or during coached driving training lessons. However, this model does not provide trainees with the opportunity to experience the consequences of risky behavior or improper driving habits. Synchronization of education needs, instructor/teacher capabilities, and digital technology availability/suitability is a constant challenge.

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The idea behind prototyping a virtual reality game for novice drivers emerged from the desire to make the digital product more appealing to this population of drivers, as most of them grew up in technologically enriched environments surrounded by smartphones, computers, digital games, virtual reality headsets, etc. There is a clear path to establish a framework based on which serious game should be conceptualized and designed, especially its game mechanics. Even though game mechanics can be reproduced in various modalities, i.e., through board games, card games, miniature games, or just a single sheet of paper with a pencil and maybe a few markers, a digital prototype is a more fiddle to the medium and the ability to create environments in real-time. Virtual reality simulations are suitable for handling complex calculations and presenting the results in an approachable manner for laypeople, thus making them an excellent choice for novice drivers. Of course, multiple technological limitations of virtual reality technology in terms of hardware and/or software applications must also be taken into account. Road traffic involves the existence of specific signaling, rules, and regulations regulated by laws that each country independently enacts, so they may sometimes differ depending on the place where people live, but all traffic participants are obliged to comply with regulations, traffic signs, markings, and traffic rules.

The rest of the paper is organized as follows. Section 2 focuses on the research overview related to educating novice drivers in road traffic safety using virtual reality simulations. In Section 3, the process of developing the virtual reality game prototype having in mind the targeted players/audience is presented. The last section gives concluding remarks on the topic.

2. LITERATURE REVIEW

The literature on educating novice drivers in road traffic safety using digital games is scarce. This could be the consequence of the general stance that virtual reality technology is still considered an "emerging" model in instructional design, even though its application is nowadays highly commercialized and affordable [1]. When observing the user perspective, virtual reality driving simulators can be divided into first-person and third-person paradigms, each with its advantages and disadvantages. Using the third-person perspective leads to faster driving speed, positioning the car more to the middle of the road, and smaller time gaps due to better situational awareness.

However, most drivers preferred the first-person, as they felt "more natural" [2]. The effects of virtual reality pedestrian crossing scenarios on children's behavior were also studied, concluding that even though the simulation proved to be useful for moving pattern data analysis, there were no significant changes in mobility habits [3]. Another group of researchers modeled a virtual one-to-one scale of the real-world high-risk pedestrian environment and compared user behavior. The results indicated that there was no significant difference in pedestrian response [4]. A group of researchers experimented on 22 participants with driving license comparing their behaviors in real-world, mixed reality, and virtual reality driving environments. They concluded that drivers could compensate for the system's visual latency to a certain limit and that the most noticeable problems were in augmented reality simulations [5]. However, they could not conclude the reasons for this imbalance. Autonomous vehicle driving algorithms were also successfully tested in virtual reality simulators. Researchers analyzed genetic algorithm performance in various driving scenarios providing a better understanding of user experience, and concluded that most drivers prefer a "conservative" autonomous driving style [6]. The emulation of vehicle and pedestrian movement in the virtual world can also be done via a microscopic traffic simulation framework. This model is used for assessing traffic operation and evaluating road network performances, thus improving traffic safety and efficiency. Combining the framework with virtual reality headsets allowed users and engineers to experience a previously unprecedented level of immersion [7].

3. RELATED RESEARCH

Correcting bad driving habits using driving simulation made in Unity software developing environment combining it with the virtual reality headset with eye-tracking capability and force-feedback driving controller (e.g., steering wheel with pedals) showed that this environment enabled practicing critical/hazardous road traffic scenarios safely. Fifty trainees were evaluated by pre- and post-simulation tests, thus determining the effects of the experiment. The response time of all examinees significantly shortened, even after a check-up that was done one week later [8]. The other group of researchers focused on analyzing driver performance by comparing the real world and simulated environment behavior. Simulated environment was modeled to imitate actual roads that participants drove on.

This enabled users to generate various virtual scenarios on urban, rural, or highway roads using automated procedures. The simulated physics engine allowed users to dynamically experience the behavior of the vehicle taking into consideration the road quality and vehicle condition [9]. Studies often focused their research questions on driver psychological predispositions (e.g., driving style) and their influence on the perception and behavior in various hazard conditions [10]. One approach was measuring the reaction time (e.g., response latency) which consists of time to first fixation and response time. The first component of the reaction time is limited/conditioned by the physical capabilities of the driver. At the same time, the second is generally psychological (e.g., decision-making) and is influenced by driver intelligence, emotion, volition, etc. The experiment was performed in two stages. First, using the HTC VIVE head-mounted display system for virtual reality simulation of traffic scenarios, and second, using eye-tracking technology for analyzing visual alert responses. The results showed that cautious drivers responded more quickly to hazardous situations compared to drivers accustomed to dangerous, angry, or anxious driving styles. Another finding was that visual alerts indeed help drivers improve road traffic hazard perception [11]. To examine the potential benefits of including driving simulations in driving tests, a comparative study was performed on 70 participants questioning if drivers who are not ready for real-world tests can be detected early in a simulated environment. Simulated road traffic critical scenarios exposed trainees to rare road traffic hazard situations. The results show that driving simulation successfully detected drivers who are confident in their abilities, but in reality, do not possess them to a sufficient extent [12]. The proposed model was combined with self-evaluation driving tests to complement them. Changes in the driving behavior of novice drivers were also investigated in a driving simulator. Researchers concluded that gaining experience was negatively correlated to mental workload and stress levels. In addition, simulating driving in a virtual environment increased trainees' driving precision and enhanced proper gaze direction [13].

4. PROTOTYPING THE VIRTUAL REALITY GAME

The software architecture is responsible for the design and implementation of high-level software structures. It is the result of putting together several architectural elements in ways that satisfy the functional and performance requirements of the system, as well as other non-functional requirements such as reliability, scalability, portability, and availability. The architecture of the virtual reality game prototype was initially defined in five layers: user interface, scenario, game objects, artwork, and application. To describe the proposed software architecture on the functional prototype that was being developed, a framework was created consisting of:

- Conceptual view - describes the system in terms of its main design elements and relationships among them by the domain. This view is independent of implementation decisions;
- Module view - captured the functional decomposition and the system layers. The system is logically divided into subsystems, modules, and abstract units. Each layer represents the different interfaces of communication that are allowed between the modules. To describe the interaction between the game functionalities a state transition, diagrams were used representing the behavior of objects that are related to game procedures in real-time;
- Code view - the source code is organized to represent the structure of the functional prototype. Furthermore, the distribution of the components in each of the layers can be observed; and
- Execution view - the structure dynamics of the game in terms of its runtime elements. Some of the aspects considered in this view are performance and execution environment.

Design patterns describe situations to which solutions have been given so that they can be used on subsequent occasions without considering the same problem again. Each pattern is a relationship between a certain context, a certain system of forces that occurs repeatedly in that context, and a certain spatial configuration that allows those forces to resolve. In short, the pattern is at the same time a thing that happens in the real or simulated world and the rule that tells us how to create that thing and when we should create it. Each pattern describes a problem that occurs over and over again in the environment and describes the core of its solution. Patterns help standardize code, making design more understandable to other programmers and solving reusability and optimization problems.

The prototype presumed multiple road traffic scenarios which were implemented in the Unity software development environment in combination with the Oculus Rift head-mounted virtual reality device. The scenarios were created so that the users could drive and study road traffic problematic situations in a safe environment. This scenario is located in an urban driving environment prototype base map that was initially created using Autodesk 3ds Max software, as shown in Figure 1.

The car was modeled and rigged using the Blender software package. The prototype was built keeping the controls as simple as possible to facilitate development and reduce its complexity. However, removing this restriction could help greatly expand the possibilities in terms of what is possible to do with the vehicle. The simplest and most economically accessible way was to use the Oculus Rift controllers as input. Even though they lack the proper control pedals for acceleration and brakes, the integrated joysticks are touch-sensitive and analog, so users quickly adapted to it.

Allowing the user to control the vehicle in greater detail also opens up the possibility of increasing the difficulty by requiring more precise control. For example, controllers can be programmed so that the most efficient way to brake is to press hard on the button first and then release it so that the wheels do not lock. When accelerating, simulated vehicle oversteers can be user-controlled by gradually applying an acceleration button to counteract it.

The simulation uses a series of Unity functions, which allow calculation when an object comes into contact with another (Colliders). Thanks to this series of functions, a prototype can detect when the user or another vehicle enters, leaves, or is simply within a defined zone. A series of scripts were developed that allow detection if a vehicle collided with another object (such as another vehicle), if the driver missed a yield (because there was another vehicle that had priority crossing the intersection) or driver jumped a red traffic light. The rendered scene from the simulation is presented in Figure 2.

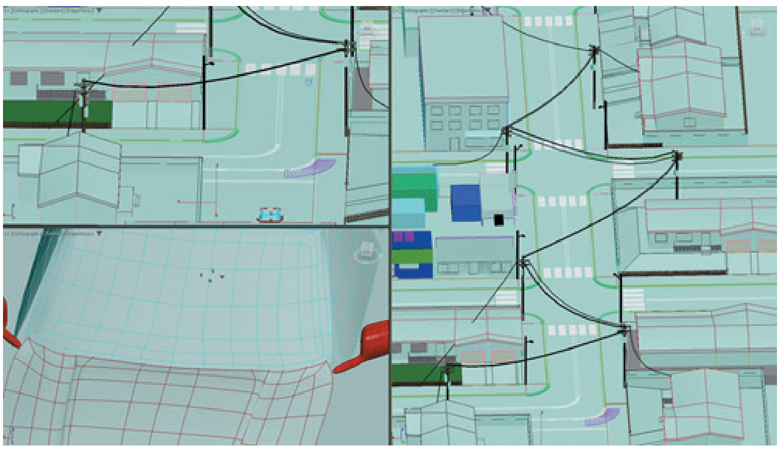

Figure 1. Urban driving environment prototype.

Figure 2. Rendered simulation scene screenshot.

At the end of the simulation, a log file is generated, containing the data from each segment of the simulation. The log file consists of three parts:

- Simulation data - scenario identifier and the time the user took to complete the scenario;
- Player position data - calculated with a configurable frequency (typically a few seconds) and accompanied by the coordinates of the user, as well as the instance of time in which the samples were made. This data may be useful to track the user throughout the journey path;
- Violations committed by the user during the simulation - a series of mandatory parameters such as the type of violation (i.e., the identifier that will determine whether the user had run a traffic light or hit another vehicle). The user's position is also saved at the moment of the violation so that the location of the violations committed can be represented and analyzed.

5. RESEARCH AND DISCUSSION

To test the prototype, a small-scale study was performed in April 2024 on a group of $N = 18$ novice driver volunteers aged 19-21. After the participants finished the virtual reality driving simulation, data from their log files was collected and analyzed. The study sample consisted of 9 male and 9 female novice drivers. Despite the possibility that the use of a virtual reality headset might induce nausea in some users, everyone reacted well and completed their simulations. Data processing and result analysis were performed using IBM SPSS Statistics v24.

Each simulation was scored depending on time of completion, precision driving and eventual violations. The mean total score was $M = 3757,9$ ($SD = 1097,6$) points. An independent samples t-test was conducted to examine whether there was a significant gender difference between drivers in relation to their scores. The test revealed a statistically significant difference between male and female novice drivers [$t = 1,53$; $df = 11,4$; $p = .001$]. Male drivers achieved higher mean scores ($M = 4139,8$; $SD = 1348,9$) than females did ($M = 3376,0$; $SD = 642,1$). However, no significant difference in score was observed between drivers that grew up in urban or rural environment.

A one-way ANOVA was conducted to explore the impact of driving experience on the achieved score. Drivers were divided into three groups according to the years they had a regular driving license (1-3 years). There was no statistically significant difference in mean scores between groups.

Tracking the number of checkpoints drivers managed to complete shows no statistically significant difference between genders. However, the test revealed a statistically significant difference between male and female novice drivers concerning the general road traffic rules and regulations (e.g., speed limit, driving within given parameters, timely turn signal, etc.) [$t = -0,89$; $df = 8,16$; $p = .043$]. Female drivers achieved significantly better scores ($M = 504122,2$; $SD = 666895,5$) than male novice drivers did ($M = 305271,1$; $SD = 67405,9$). Analog results were indicated when a type of the settlement drivers grew up was analyzed [$t = -1,19$; $df = 6,15$; $p = .024$]. Drivers who grew up in rural settlements achieved significantly better scores (M = 568971,4; SD = 747872,8) than those who grew up in urban environments ($M = 300158,2$; $SD = 103527,6$).

A Pearson correlation coefficient was computed to assess the relationship between driver score, speed, precision, and adherence to rules and regulations. As expected, there was a negative correlation between driver speed and driving regulations, $r(18) = -.580$, $p = .012$. Other correlations were not statistically significant. These findings should be interpreted as confirmation of the prototype concept.

Several implications of the presented findings should be emphasized:

- First, the research results show that novice drivers score similar simulation results in the first couple of years of driving, meaning that they are still mostly driving according to the rules and regulations they adopted during the training, which is similar to other studies [12];
- Second, even though male drivers achieved significantly better overall mean scores, female drivers made fewer errors. Male drivers were more confident in their abilities and utilized the virtual environment more effectively. This is most likely a result of traditional socio-cultural influences within Serbian society. However, it was found that this confidence among men lacked a real foundation, as ultimately women made fewer mistakes in traffic [14];
- Third, contrary to the assumption, drivers who grew up in rural areas made fewer mistakes when driving in urban environments. This is likely due to the increased attention they paid due to the unfamiliar surroundings [15].

6. CONCLUDING REMARKS

Balancing driving skills and driving style is a serious challenge in training. Overspeeding is a risky driving style often observed among novice male drivers who may not be fully matured in terms of hormonal balance, thus expressing more aggressive behavior. Paradoxically, male drivers do indeed pass the driving test more quickly and obtain driver's licenses. The role of virtual reality simulators, such as the one prototype presented in the paper, can be crucial in illustrating the potential consequences of dangerous behavior to young inexperienced overconfident drivers.

The prototype of a virtual reality game for educating novice drivers in road traffic safety contains only basic driving scenarios. One of the biggest challenges in developing the prototype has been to implement the artificial intelligence model for moving other vehicles and road users. To further develop the prototype into a real working game, it is worth highlighting that the virtual environment “map” should be expanded to cover a greater distance and other types of traffic conditions, and different scenarios in the city streets, connecting the urban section with some interurban sections, adding adverse weather conditions, etc.

This study certainly had some limitations. First, even though equally distributed, the research sample was small, so the results must be interpreted with caution. Second, considering that this is a prototype of the game, there are significant technical shortcomings in content management and virtual reality simulation itself. However, the primary goal of the research was the proof of concept, which has been achieved.

7. ACKNOWLEDGMENTS

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