Mixed Reality Driving Simulator as a Training Tool for Autonomous Vehicles

Paper ID:

Abstract

While manufacturers have invested billions of dollars in the self-driving car technology, little has been done to prepare drivers to this paradigm shift in transportation. According to a recent survey published by PAVE (Partners for Automotive Vehicle Education, 2020) of 1,200 adult drivers, 48% of American drivers say they “would never get into a taxi or ride-share vehicle that was driven autonomously”. To overcome these issues and to address this problem, we developed a highly immersive driving simulator which provides a safe platform for drivers of all ages and abilities to get a first hand experience of a self-driving vehicle. The proposed system provides a highly innovative use of mixed reality and can be easily retrofitted to any vehicle to provide mechanical immersion. Visual immersion is obtained through a mixed reality experience delivered through a Head Mounted Display. In this paper we will discuss the various mixed reality techniques that were implemented during the prototyping phase as well as the final design that was retained for the initial pilot experiment of 10 participants.

Keywords: Mixed Reality, Driving Simulation, Self-driving, ADAS, Augmented Reality, Pass-Through Technology

1 Introduction

Driving simulators have been used for years by driving manufacturers to help with human machine interface (HMI) design. They have been used in academic settings to assess the impact of alcohol, marijuana or fatigue on driving. While they started to permeate the driving school ecosystem, the prohibitive cost of an immersive realistic simulation meant that until recently driving schools could only afford a basic system. Typically this system consists of a tabletop gaming steering wheel and a set of pedals. Rendering is often limited to a single monitor. While the software provides some valuable driving scenarios and teachable moments, the inherent hardware limitations hindered the widespread adoption of this technology as a teaching tool. A single monitor means that students are limited to tunnel vision which might be counterproductive when teaching how to handle turns.The more sophisticated driving simulators which offer larger Field of View (120 to 180 degrees) or mechanical immersion through haptic feedback have been too expensive and out of reach for driving schools.

The recent advances in Virtual and Augmented Reality have meant that total immersion is now affordable at a much lower cost. Incidentally the announced revolution in transportation, with the increased use of automation in cars brings its own set of challenges. Even though vehicles of SAE level 2 of automation are commercially available, drivers consistently voice their mistrust in the technology [1]. Current research has shown the need to educate the current population about this paradigm shift in technology [2], [3].

We propose in this paper, the design of an affordable highly realistic driving simulation which offers a safe hands on experience of driving automation to users. Users can use this tool in a safe manner to drive in the typical manual mode. When they feel comfortable, they can turn on advanced automatic features such as Autopilot in a way which is similar to what they would do if they were driving on the highway.

Our proposed simulator is designed so as to emphasize immersion. The first section of the paper discusses state of the art in driving simulation. Our innovation and proposed design with use of Mixed reality technology are presented in following sections.

2 State of the art in driving simulation

Driving simulators can be traced back as far back as 1967 when the drivotrain was introduced [4] [5].. They range from basic systems that are easily deployable to costly alternatives that provide solid mechanical immersion. These different configurations, which provide different level of realism can serve research but also education

2.1 Classic simulators

Driving education has greatly benefitted in recent years from the development of driving simulators. Their modest cost has allowed driving schools to provide a hands-on experience to novice drivers. Driving situations which are hard to reproduce on-road can be easily programmed, offering valuable repeatable teaching moments to students. An example of the adoption of the technology has been the recent pilot program by the State of Ohio, through a partnership with the Children Hospital of Philadelphia [6] to create an intermediate step between the driver permit and the on-road test (figure 1). This program is a formidable step towards the adoption of driving simulation as a teaching tool.

Figure 1: PPDS used by the State of Ohio in Driving Licensing Pilot Program (Credit Children Hospital of Philadelphia)

On the other side of the spectrum, the National Advanced Driving Simulator provides a unique opportunity for a 360 visual experience within a dynamic frame (figure 2). Vehicle can be driven inside the simulator. The hydraulic platform allows for movements that can replicate the dynamic accelerations that happen in real life. This unique environment is however limited to advanced research and completely out of reach for the general public.

Figure 2: National Advanced Driving Simulator (NADS) in Iowa (Credit: University of Iowa)

2.2 Virtual Reality

The advent of Virtual Reality in recent years has opened the door to more portable and more immersive simulators [7]. The Field of View, often limited by the number of monitors, is no longer an issue. Headsets can indeed provide a 360 deg FOV so that users feel truly immersed in the scenario. They can turn their head to correctly monitor traffic before making a turn. The use of a headset can indeed eliminate the effect of tunnel vision that can be detrimental to driving education.

In addition, the wide use of development tools such as Unity3D or Unreal Engine has considerably simplified the development of driving scenarios, which can rely on a wide collection of built assets. Examples of these VR simulators include TennDrive365 developed by Toyota [8] or systems such as VRMotion [9] which also use headset rather than display monitors.

Yet, while this new class of simulators solves the aforementioned FOV problems, it brings its new set of limitations. Users often get disoriented when they wear a VR Headset. They are immersed in a scenario which is entirely virtual and are therefore somehow disconnected from reality: they cannot see their hands, they cannot see the pedals, they cannot interact with car passengers. In addition, headsets have been known to generate simulator sickness, especially for women and older users [10].

3 PROTOTYPE DESIGN

In this section, we propose the design of a new class of simulators which aims at maximizing immersion, at a low cost. The goal of this simulator is to leverage new affordable technology so driving simulators can indeed become ubiquitous, not only for novice drivers, but also for more mature elderly drivers who are eager to use the new self-driving technology.

Our design is based on two concepts. The first concept is the use of an actual car as a platform for the simulator. This allows for realistic immersion, especially for veteran drivers. The vehicle is equipped with sensors that can be retrofitted to any vehicle. This "mechanical immersion" is described below. The second concept is the use of Mixed Reality. The goal is to allow drivers to see their environment and be grounded in the real world, while they virtually navigate in a virtual driving scenario. This visual immersion is detailed below.

3.1 Mechanical Immersion

In the proposed design, an actual car is used as a simulator driving platform. This setup has proven to offer a native realistic option to users. [11]. It allows for a comfortable setting where the user can adjust seat position and inclination. Native controls such as the vehicle steering wheel and vehicle pedals are used. In our design, non-invasive sensors such as wireless Inertial Measurement Units (IMU) are placed on the steering wheel, accelerator and brake pedals to measure steering angle or pedal deflection. These sensors relay pedal and steering information to the main processor, closing the control loop. As a result of the use of this native environment, users do not need any formal introduction to the simulator. Controls do feel real as they are real.

3.2 Visual Immersion

Whether teaching a young person how to drive or introducing advanced technology to mature drivers, it is essential that driving simulators provide solid immersion. We highlighted earlier how a single monitor could lead to a small Field of View, resulting in tunnel vision.

While a number of simulators have been developed with Head Mounted Display and a resulting 360 Field of View, one limitation has been the loss of physical references. When a user wears a Head Mounted Display, he is completely immersed and can no longer see himself in this Virtual Reality World.

To mitigate this inconvenience, we propose with our design the use of Mixed reality where the vehicle and driver can be seen through the Head Mounted Display. In this concept, anything *outside the car* is a Virtual Object.

To validate this concept, a number of options were tested on our car prototype. In the first option, Chroma Key Technology was used. Our vehicle windshield and windows were covered with a green screen fabric. Drivers visualize the driving scenario through the Headset. In this Mixed Reality setup, drivers can see the steering wheel, they can see their hands, they can see themselves in the vehicle. Yet, the driving scenario they interact with is Virtual, and they truly get the sense that they are driving in this virtual scenario.

For our prototype, two Head Mounted Displays were tested. An HTC Vive Pro was used as it allows for a video passthrough. In a second experiment a ZED mini was used to supplement an Oculus Quest and provide external cameras capabilities to the headset. In both instances the desired effect was obtained. When looking at the driving simulation through the HMD, users can see the actual steering wheel, they can see their hands, the pedals as well as their foot. This provides for a very comfortable experience to users who are uncomfortable driving when they do not see their hands.

Issues to resolve to obtain the desired effect were the placement of lights inside and outside the vehicle, as well as the placement of the base station for the HTC Vive Pro. A view of the inside of the vehicle is provided in figure 3. A first person view of the simulation is provided in figure 4. Limitations of this technology appeared when a user wore a short sleeves T Shirt as some shade of green was observed on his hands, generating some undesired effect in the simulation. This effect can be mitigated through solid software calibration.

The concept of Mixed Reality simulation was tested through a second prototype. In this configuration, no green screen was needed. Mixed Reality was obtained by use of portal technology where a predefined section of the Field of View in the real scene was occluded and replaced by images from the Virtual Reality world. This effect was obtained through the use of an HTC Vive Pro. This technology seems quite attractive in the future. It effectively offers the possibility to retrofit any vehicle into a simulator without the needs of Chroma Key technology and the installation of a physical green screen. It was however not retained for the first iteration of our prototype.

Figure 3: Mixed reality Prototype with Chroma Key Technology.

Figure 4: First Person View of Unity3D Scenario with Chroma Key Technology.

4 Pilot study

Preliminary engineering tests have allowed us to validate the concept of Mixed Reality for our driving simulator. Our main concerns have been a compromise between the resolution and Field of View. While it is essential that users have the ability to look anywhere around them through the headset (360 degrees of freedom), they are naturally limited to a 180 to 200 degrees for the horizontal field of view (Human Field of View). Our pilot study is relying on the Oculus Quest which is supplemented by the ZED mini for external vision. In our setup we prioritized the FOV width over screen resolution. The second important aspect for visual immersion is the lagtime in the rendering. Our latency of 60 ms can be interpreted as about 2 frames for a video stream that would play at 30 frames per second. It is therefore negligible for our application.

Our pilot study of 10 participants is designed to validate the concept of Mixed Reality for our driving simulator application. In this study, participants are recruited based on their mistrust of the self-driving technology. A group of 10 participants are invited to our research lab to get introduced to the basics of self-driving through our in-car Mixed Reality Driving Simulator. The study is developed in collaboration with the Institutional Review Board (IRB) of The University of Pennsylvania. Through the study protocol, participants are invited to a semi-structured interview which is built to assess their knowledge and perception of the self-driving technology, For the experimental part of the study, participants are introduced to the simulator. They are invited to drive in the Virtual World the same way they would drive in reality. At some point in the drive, they encounter a deer which crosses the road. Their reaction time and steering and braking reaction are recorded. They are then invited to a second opportunity to drive, this time when the autopilot is engaged. During this second drive, the vehicle activates Automatic Emergency Braking so the vehicle safely avoids the crash. Participants experience Autopilot with its auto-steering capability. After the Driving Simulator experience, participants are invited to comment on their experience simulator and perception on self-driving after this first hands-on experience.

5 Limitation

One well known limitation of driving simulators, even when using monitors, is the simulator sickness effect. This factor might be supplemented by the reticence by some users to using a Virtual Reality Headset. One assumption in our study is that Mixed Reality can in some ways ground participants with elements of the real world, mitigating to some extent the simulator sickness effect.

Conclusion

We proposed in this paper the design of a stationary Mixed Reality driving simulator platform which provides a safe environment where drivers can learn about Advanced Driver-Assistance Systems and self-driving technology through a hands-on immersive experience. We reviewed the systems constraints and explored several Mixed Rea;ity technologies, such as chroma key or portal pass through technology. Our prototype allowed us to identify the pros and cons of the various options. We discuss the compromise between the field of view dimensions and screen resolution and the technology we adopted for our prototype. We highlight in our paper the technical challenges inherent to our application such as AR latency but also the strengths of this Mixed Reality application, which solves a real-life problem: the need to acclimate drivers of all ages and abilities to advanced automation in vehicles.

Acknowledgements

This work is supported by a grant from the Mobility21 University Transportation Center at the Carnegie Mellon University. (Project 342) which provided support for this project through the US Department of Transportation (US DOT)

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