



# Research on Key Technologies of Virtual Driving Based on Virtual Reality

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**Abstract.** The field of virtual reality technology plays a pivotal role within the automotive industry, predominantly aimed at augmenting the efficacy of driving simulations and training programs. This evolution is fueled substantially by the hefty investments poured into VR technology by leading automakers, leading to rapid advancements in this domain. This paper first delves into the concept of virtual driving and underscores the importance of novice drivers in the automotive industry. It then transitions into a detailed discussion on prevalent driving simulators in today's market, before exploring the unique contributions of VR technology within these driving simulators. Lastly, it probes the challenges and limitations that VR technology may encounter within the realm of driving simulations. The research findings reveal that virtual driving technology harbors significant benefits and potential applications within the context of driving simulation and education. Nevertheless, there remain several aspects in which the practical application of this technology can be further refined and improved.

**Keywords:** Virtual reality, Virtual driving, Driving simulator

## 1 Introduction

At the dawn of the twenty-first century, Virtual Reality technology was hailed as one of the "emerging technologies with the most potential," capturing the attention of the global scientific and technological community [1]. Today, technology permeates all facets of our society, ranging from entertainment and education to more sophisticated domains such as healthcare and military training. In particular, Virtual Reality technology is seen as a game-changer, especially in the realm of driver education. Increasingly, virtual driving is recognized as a valuable application of Virtual Reality technology [2].

The significance of virtual driving technology for novice drivers in cars is evident. Firstly, it provides a safe environment for learners to practice a wide range of driving situations they might encounter in real life. This is crucial because it allows beginners to get comfortable with driving and handling emergencies without any actual risk [3]. Virtual driving technology also offers immediate feedback and comprehensive

performance analysis, assisting beginners in pinpointing areas that need improvement. More importantly, a Virtual Reality driving simulator can endlessly replicate a specific driving scenario, a vital feature for reinforcing and sharpening driving skills. Despite the widely acknowledged benefits of virtual driving technology in driver education, how to optimally utilize this technology to cater to the needs of novices and an ever-changing driving environment remains a challenge. This article will focus on a spectrum of topics related to virtual driving, including the utilization of Virtual Reality technology in driving simulators and any potential limitations. Before delving into the specifics of Virtual Reality technology in driving simulators, a review and discussion of the current mainstream driving simulators will be undertaken. The aim is to highlight the benefits of Virtual Reality technology in driving training and simulation, while also examining its drawbacks and challenges in practical applications through comparative and data analyses [4]. The objective of this paper is to provide readers with a comprehensive understanding of virtual driving technology and its role in driving simulation and training, and to suggest directions for future research and application.

## 2 Related Principles

A virtual driving simulator is primarily designed by leveraging real driving scenarios, with 'reality' serving as the crux of the simulator. Therefore, 'reality' is simulated in three distinct ways: Image quality (software): Current leading simulators, such as City Car Driving and American Truck Simulator, offer highly detailed images and environmental rendering. For instance, the intricate modeling of a vehicle's interior allows users to view real-world elements like the dashboard, steering wheel, brakes, and accelerator, contributing to a more authentic driving experience. As shown in Figure 1.



**Fig. 1.** American truck Simulator [3]

On the other hand, the driving simulator can also simulate various environments and weather conditions, including but not limited to sunny days, cloudy days, rainy days, snowy days, and even alternation of day and night. The simulation of these

conditions not only increases the realism of driving, but also provides the driver with the experience of driving under different conditions. Even the busyness of urban traffic, so as to provide users with a more realistic visual experience [5]. As shown in Figure 2.



**Fig. 2.** City Car Driving [5]

Sound effects, constituted by both software and hardware, are a significant component in establishing an authentic driving experience. Traditional simulators often use stereo audio output to replicate vehicle engine sounds, environmental sound effects, and the like through left and right channels. However, this output method has inherent limitations regarding the sound source's spatial positioning capabilities and cannot achieve genuine omnidirectional sound positioning. Traditional simulators typically employ standard speakers or headphones, which do not offer true spatial audio effects. While enhancements in realism can be achieved through volume adjustments and sound effect processing, they cannot simulate the sensation of sound originating from a specific location. Therefore, users are unable to perceive the vehicle's position and movement in space via sound or accurately discern sounds coming from different directions. Stereo or spatial audio is integral to crafting an immersive experience within a Virtual Reality environment. For instance, a user might hear the sound of a car's engine originating from a distinct location, or a siren coming from the car's left side, indicating that another car is attempting to pass it. Moreover, spatial audio can supply environmental sound effects such as rain, wind, or other traffic sounds, rendering the driving environment more realistic [6]. Contrasting these would be interactive sound effects. Enhancing interactivity and feedback effects within the Virtual Reality world can be achieved by blending sound effects with user interactions. A more immersive experience is proffered, for instance, when a user turns the steering wheel in the driving simulator and hears the corresponding steering sound, or when they approach other virtual objects and hear the associated auditory signals.

In terms of operation feedback via hardware, the use of specialized driving hardware has become more prevalent as driving simulators have evolved. This includes force feedback steering wheels, professional pedals, and seats. This hardware

can deliver a more authentic driving experience, enabling drivers to experience sensations akin to actual driving within the simulator. For example, Logitech's force feedback steering wheel can mimic the resistance of real vehicle steering wheels, facilitating a more realistic driving experience. The professional pedals and seats can offer authentic accelerator, brake force feedback, and seat vibration sensations when driving. As shown in Fig3.



**Fig. 3.** Logitech Steering Wheel G29 [6]

**Table 1.** Comparison of Traditional Driving Simulator and VR Driving Simulator

Feature	Traditional Driving Simulator	VR Driving Simulator
Image Quality	Highly detailed images and environment rendering, including interior vehicle modeling, simulation of different weather and environmental conditions, providing a realistic driving experience.	Provides a more immersive driving experience through immersive visual experience and free observation of scenes.
Sound Effects	Utilizes stereo audio output to simulate vehicle engine sounds, environmental sound effects, etc., but cannot achieve full directional sound positioning and spatial perception.	Utilizes spatial audio technology to achieve real-time full directional sound positioning, allowing users to perceive sound direction and location, enhancing the sense of immersion.
Feedback	Simulates driving feedback and road sensations through professional driving hardware (such as force feedback steering wheels, pedals, and seats) and vibration feedback devices.	Combined with VR devices, it enhances the realism of the driving experience.

Vehicle operation feedback: During driving, various operations of the car, such as braking, acceleration and steering, will give direct feedback to the driver. Simulators

typically use vibration feedback devices to simulate these feedbacks, for example, when the vehicle bumps on the road, the user can feel the vibration of the steering wheel [7]. Road feedback: In actual driving, the vehicle will have different driving feedback under different road conditions. For example, when driving on a slippery road in rainy days and on a dry road in sunny days, there will be a significant difference in the handling of the vehicle. As shown in Table 1. Similarly, a good driving simulator will simulate these differences and give the user corresponding feedback through hardware devices such as force feedback steering wheels.

### **3 Advantage Analysis**

#### **3.1 Realize Virtual Driving**

The realization of virtual driving involves many important elements, including image quality, sound effects, and hardware devices such as steering wheel, pedals, etc. Traditional driving simulators can simulate these elements to a certain extent, but limited by technology, the experience they provide is usually not completely realistic. However, modern virtual reality technology largely compensates for these shortcomings [8].

#### **3.2 VR Glasses**

Modern VR devices mainly include head-mounted displays, which can provide a 360-degree panoramic visual experience. Compared with traditional screens, VR headsets provide higher-quality images by simulating the perspective and line of sight of the human eye, which is crucial for creating a realistic driving environment. At the same time, the wearing comfort, display delay, and motion tracking accuracy of the head-mounted display device also affect the user experience. In the market, there are many technology giants in the layout, including: Vision Pro launched by Apple in June 2023: As shown in Figure 4, this glasses are positioned as MR glasses, which can seamlessly integrate digital content with the physical world, while allowing users to keep status quo and stay in touch with others.



**Fig. 4.** Apple Vision Pro [7]

Oculus VR, As shown in Figure 5, which Facebook acquired in 2014, has since launched various Oculus series. In order to promote products to a wider user group, Facebook has relatively low prices and high quality. Among them is Oculus Quest's standalone VR headset, which does not need to be connected to a computer or game console.



**Fig. 5.** Oculus Quest 2 [6]

HTC Vive: As shown in Figure 6, jointly developed by HTC International Electronics (HTC) and Valve Corporation, released on April 5, 2016. The design leverages "room-scale" technology to transform a room into a three-dimensional space through sensors, allowing users to navigate naturally in a virtual world, to walk around, and to vividly manipulate objects using motion-tracked handheld controllers [6].



**Fig. 6.** HTC Vive Pro [6]

### 3.3 Application of VR Technology in Driving Simulation

Incorporating Virtual Reality equipment into driving simulation undoubtedly enhances the user experience significantly. Foremost, high-quality visuals and stereo sound effects furnish drivers with a lifelike and comprehensive perception of their surroundings. Whether it be heavy city traffic or a serene countryside road, every scenario can be replicated with stunning realism. Additionally, when combined with specific hardware such as a virtual steering wheel and pedals, drivers can achieve an operating experience that closely mirrors actual driving [9]. In summary, the virtues of Virtual Reality technology lie in its authenticity and immersion, offering students a simulated environment for driving instruction that closely approximates real-world conditions. Safety is another key advantage; drivers are immersed in sights, sounds, and motions so realistic that imminent crash scenarios can be convincingly presented without putting the driver in harm's way [10]. Moreover, Virtual Reality technology can record and analyze student's driving behavior and responses, providing valuable insights for instructors and students to better understand their driving habits and skills. Regarding costs, although the initial investment for Virtual Reality equipment is relatively high, it is capable of providing a durable and efficient training environment, making it cost-effective in the long run. Lastly, the flexibility and convenience of Virtual Reality technology enables driving training to be conducted at any place and at any time, thereby enhancing learning efficiency significantly.

## 4 Challenges

Traditional simulators possess distinct advantages, yet none fully replicate the driving experience. Virtual Reality technology compensates for these shortcomings in a unique manner. By combining the strengths of software and hardware simulators and leveraging its formidable image processing capabilities and immersive hardware interaction, Virtual Reality technology elevates the driving simulation experience to unprecedented heights. However, there are several challenges and limitations associated with Virtual Reality technology: Physical Discomfort: Certain users might experience symptoms such as dizziness, headaches, or nausea while operating Virtual Reality devices, a phenomenon often termed as 'Virtual Reality sickness'. When this sickness ensues, typically, the refresh rate of the image on the screen is not

sufficiently high [9]. Another interpretation is that the latency is excessively high. Since the refresh rate is slower than the brain's processing speed, it creates a disconnect between these two rates, causing users to perceive glitches on the screen. Such discomfort could potentially affect user experience and limit their duration of using the Virtual Reality device. Ultimately, these issues boil down to technical limitations.

**Technical Limitations:** As stated above, excessively high latency may induce discomfort in users, as the images they perceive are not in synchrony with their physical movements. Conversely, image resolution, the higher it is, the clearer the displayed image, and the more realistic the user's experience in the virtual environment. For driving simulation training designed for novices, a high resolution can aid in simulating more intricate road conditions and a more lifelike traffic environment. The precision of motion tracking, particularly for swift or minute movements, may not be accurately captured by current devices. In addition, the field of view of a Virtual Reality device might also constrain the range of motion tracking. To rectify these issues, new sensor technologies, superior data processing algorithms, and high-performance hardware may be necessary, leading to the following predicament.

**Hardware Cost:** Despite the decrease in prices of Virtual Reality equipment with technological advancements, high-end devices that ensure a satisfactory experience still necessitate substantial investment. For individual users or small driving schools, this might exert considerable financial pressure.

**Social Isolation:** Users are secluded in a virtual world when using a Virtual Reality device, which might result in reduced interaction with the real world. In the context of driving simulation training, this might impact the user's interaction with the instructor or other trainees.

**Lack of Content:** Current Virtual Reality content in the market is predominantly centered around gaming and entertainment, with only a handful of applications providing high-quality driving simulation experiences. Moreover, the development of top-notch Virtual Reality applications requires a significant investment of time and resources, potentially limiting the speed and breadth of their development.

## 5 Conclusion

Virtual reality technology, with its swift evolution, has forged fresh prospects in the sphere of driving education. The technology in its current form offers manifold advantages such as the simulation of driving environments, provision of real-time feedback, and support for repetitive, tailored training sessions. However, it also presents certain drawbacks, encompassing physical discomfort, hefty hardware expenses, social isolation, loss of realism, technical constraints, and a scarcity of content. These challenges necessitate attention and should not be dismissed lightly. For researchers, the task at hand is to enhance the technology's availability and user-friendliness, particularly for virtual reality driving instruction devices. Despite the present limitations of virtual reality driving simulation training, its potential and



advantages are indeed sufficient to revolutionize the landscape of driving education. This technology is poised to equip driving instructors and learners with a novel approach to understanding and practicing driving skills, thereby offering an unparalleled tool for driving education. All in all, this paper bestows valuable insights into the prospective directions for driving education by delving into the applications and constraints of virtual reality technology in driving simulators. The evolution of virtual reality driving simulation training necessitates continuous promotion and deepening of applications and research. This is to ensure that this technology can extend greater benefits to a broader range of driving students while addressing existing challenges, thereby truly realizing its potentially transformative impact.

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