Application of Virtual Reality Technology in Vehicle Ergonomics and Human-Computer Interaction

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Received: 25 May 2025
Revised: 26 May 2025
Accepted: 28 May 2025
Published: 28 May 2025

Abstract: With the development of intelligence and personalization in the automotive industry, the application of virtual reality (VR) technology in vehicle ergonomics and human-computer interaction design has become an important research field. This paper explores how virtual reality technology can play a role in vehicle seat design, cockpit layout, human-computer interaction interface and safety assessment. Through VR technology, designers can simulate and optimize different design schemes in a virtual environment, thereby improving the efficiency and accuracy of the design and reducing discomfort and potential safety hazards. In addition, virtual reality also provides a more intuitive and convenient way for drivers to interact with the on-board system, further improving the driving experience and the level of vehicle intelligence. Although virtual reality technology still faces challenges in terms of equipment cost and comfort, with the development of hardware technology and the integration of cross-domain technologies, VR has broad application prospects in automotive design. In the future, virtual reality technology will play a greater role in improving driving safety, comfort and intelligence, and promote innovation and development in the automotive industry.

Keywords: Virtual reality; Vehicle design; Ergonomics; Human-computer interaction; Safety assessment

1 INTRODUCTION

VR technology, as an innovative digital technology, has been widely used in many fields in recent years. Its development began with early experiments in the 1960s. With the continuous improvement of computer graphics and hardware performance, VR technology has gradually matured and has shown great application potential in entertainment, medical, education, engineering and other industries. In the automotive industry, VR technology provides unprecedented convenience for vehicle design, testing and optimization by creating an immersive three-dimensional virtual environment. Especially in the field of vehicle ergonomics and human-computer interaction, VR can accurately simulate the driver's operating environment and physical state, thereby helping designers solve problems that cannot be effectively solved in traditional design processes and improve the efficiency and accuracy of automotive design.

The challenges of vehicle ergonomics and human-computer interaction have always been the core issues in automotive design. How to provide drivers and passengers with a comfortable, safe and convenient riding and driving experience has become a direction that the automotive industry continues to explore [1]. Ergonomic design needs to take into account the driver's physical adaptability in different postures, ease of operation and comfort of long-term driving, while ensuring the ease of use and safety of various functions in the vehicle. In terms

of human-computer interaction, traditional button and switch operation methods are gradually becoming outdated in modern intelligent cars. How to interact with the vehicle system through more intuitive methods such as touch screens, voice recognition, gesture control, etc. has become the key to improving the intelligence of vehicles [2]. However, traditional design methods make it difficult to accurately simulate the driver's operation and reaction in the early stages of development, which in turn affects the final design effect.

Virtual reality technology provides a powerful tool to solve the above problems. Through VR technology, designers can simulate the driver's operating behavior, cockpit layout, seat design, etc. in a virtual environment, quickly evaluate their adaptability and comfort to the human body, and adjust the design scheme in real time, avoiding a lot of field testing and modification work in the traditional design process. In addition, VR can also allow designers to understand the interaction between drivers and vehicle systems from a more comprehensive perspective, optimize the design of the human-computer interaction interface, and make it more in line with the user's operating habits and psychological expectations [3]. Therefore, virtual reality technology not only helps to improve the accuracy of vehicle design, but also accelerates the design process, saves R&D costs, and promotes the automotive industry to develop in a more efficient and intelligent direction.

The purpose of this study is to explore the application of virtual reality technology in vehicle design, especially in the field of ergonomics and human-computer interaction. By analyzing the actual application cases of VR technology in these fields, it aims to reveal how VR can help improve the efficiency and accuracy of automobile design, improve the driving experience of drivers, and promote innovative development of the automotive industry in the direction of intelligence and personalization.

2 OVERVIEW OF VIRTUAL REALITY TECHNOLOGY

VR technology is a technology that uses computer-generated simulated environments to allow users to participate in them through their senses and create an immersive experience. Its basic principle is based on the high integration of computer graphics, sensor technology and interactive systems. VR systems usually include the simulation of multiple senses such as vision, hearing, and touch to create an interactive virtual world [4]. Its core components include virtual environment, user interaction interface and perception system. The virtual environment is constructed by computer graphics technology, and users interact through head-mounted displays (HMDs), handles, motion capture devices, etc., while the perception system enhances the immersion of the virtual experience through vision, hearing and even touch. In order to ensure the smooth operation of VR technology, the coordinated support of hardware and software is essential. In terms of hardware, VR systems require high-performance computers, graphics processing units (GPUs), sensors and display devices, while software is responsible for the creation of virtual environments, physical simulation and interactive design.

With the continuous advancement of hardware technology, virtual reality has been widely used in many industries. In the medical field, VR is used for surgical training, virtual treatment and rehabilitation training, and reduces training costs and improves the efficiency of skill acquisition by simulating real scenes. In the field of education, VR technology provides a more vivid and interactive learning experience, allowing students to immerse themselves in virtual classrooms for experiments, explorations and other practical activities [5]. In the entertainment industry, especially in games and movies, VR technology allows users to experience an immersive virtual world, breaking the limitations of traditional two-dimensional screens and bringing a new entertainment experience. In the industrial field, VR is used in product design, manufacturing process simulation, employee training and other aspects to help improve work efficiency and safety and reduce risks in actual operations. In addition, VR has also shown great application potential in many industries such as construction, tourism, and military.

In the automotive industry, the application potential of virtual reality technology is particularly prominent. With the continuous development of intelligence and automation, vehicle design is no longer limited to traditional two-dimensional drawings, but is fully simulated and tested in three dimensions through VR technology [6]. Designers can use virtual reality technology to create a panoramic view of the cockpit, simulate the driver's operating behavior, and quickly evaluate the impact of different design schemes on driver comfort and safety. In addition, VR technology can also help developers optimize the in-vehicle information system and human-computer interaction interface, providing drivers with a more intuitive and convenient operating experience. As people's requirements for automobile safety, comfort and intelligence continue to increase, the application of virtual reality technology in the automotive industry will surely further promote the innovation and development of vehicle design. By combining VR technology, automakers can not only reduce design costs, but also greatly improve the accuracy and efficiency of design, so as to better meet the needs of consumers.

3 THEORETICAL BASIS AND REQUIREMENTS OF VEHICLE ERGONOMICS

Vehicle ergonomics is a discipline that studies the relationship between human and vehicle systems, aiming to improve the comfort and safety of drivers and passengers in vehicles through scientific design and optimization. The ergonomic requirements in vehicle design are mainly reflected in adapting to the movement characteristics of various parts of the human body, reducing fatigue and physical discomfort caused by poor design, and improving the convenience and accuracy of operation [7]. Ergonomics not only focuses on the design of major control components such as seats, steering wheels, and pedals, but also involves the overall interactive experience between the driver and the in-vehicle environment, emphasizing the natural posture and comfort of the driver during operation. The core goal of the design is to ensure that the human body is supported and protected to the greatest extent during driving, thereby improving driving efficiency and reducing the occurrence of accidents.

In vehicle design, the comfort and safety of drivers and passengers are the most critical factors. The driver needs to maintain a certain sitting posture when operating the vehicle to ensure that the vehicle can be controlled quickly and accurately while reducing the burden on the body. The design of the seat is particularly important because it directly affects the driver's sitting posture and body posture, especially when driving for a long time, improper seat support may cause pain and discomfort in the waist, back, neck and other parts. Passenger comfort is also important. The layout of the interior space and the design of the seat should provide good support as much as possible to avoid discomfort during long rides. In addition, in terms of safety, the protective design of the seat and the reasonable layout of the in-vehicle control system can effectively reduce the harm to the human body when an accident occurs.

However, there are still many ergonomic problems in current vehicle design, which may affect the driver's operating convenience and passenger comfort. The seat design and driving posture issues are particularly prominent [8]. The height, angle and support method of the seat must be adjusted according to individual differences such as the driver's body shape and driving habits to ensure that each driver can find the most comfortable and natural driving posture. The design of the control system is also a key issue, especially in complex vehicle functions and driving environments. Overly cumbersome control systems may increase the driver's operating difficulty and lead to unnecessary operating errors. The driver's field of

vision is also very critical, especially in the design of the dashboard, rearview mirror and windows in the car. Limited field of vision may cause safety hazards and affect the driver's reaction speed and judgment ability.

In addition, the impact of long-term driving on health cannot be ignored. Being in the same driving posture for a long time, especially maintaining an inappropriate sitting posture for a long time, can easily cause health problems such as low back pain, neck discomfort, and deep vein thrombosis. When driving long distances, drivers need to take proper rest and activities to avoid the negative effects of long-term sitting. In order to reduce these health problems, vehicle design should consider how to alleviate the burden of long-term driving through seat adjustment, interior space optimization, and the design of human-computer interaction systems to provide a more ergonomic driving experience [9]. In this process, virtual reality technology can provide designers with a more intuitive and immersive simulation experience, helping them optimize the various designs of the vehicle from an ergonomic perspective, so that the comfort and health of drivers and passengers are better guaranteed.

4 APPLICATION OF VIRTUAL REALITY TECHNOLOGY IN VEHICLE ERGONOMICS

The application of virtual reality technology in seat design can provide designers with a realistic virtual environment, and identify and solve ergonomic problems in advance by simulating the impact of different seat designs on drivers. Traditional seat design relies on physical models and field testing, but this method is not only time-consuming and labor-intensive, but also costly. Through virtual reality, designers can quickly test the adaptability of different seat heights, angles and support methods to the driver's body shape in a virtual environment, and evaluate the impact of different seat configurations on driver comfort. For example, the virtual driver can show the support of the waist, back and other parts through dynamic feedback according to the set seat position and posture, so as to judge whether there are discomfort and pressure concentration problems. Through this virtual design process, the design efficiency can be greatly improved and unnecessary physical prototype production and testing can be reduced [10].

In addition, the adaptability of the seat adjustment system to the human body is a crucial part of modern vehicle design. Virtual reality can simulate the seat adjustment process, adjust the sitting posture and cushion configuration of different drivers through virtualization, and accurately judge the impact of each adjustment step on the driver's comfort and safety. Designers can simulate the driver's movements in a virtual environment, and evaluate in real time whether the seat's comfort, stability and support meet ergonomic requirements by adjusting parameters such as seat height, depth and angle. This virtual simulation enables designers to compare multiple seat design schemes in a short period of time and ultimately select the most ergonomic seat configuration.

The application of virtual reality in cockpit layout helps designers optimize the layout of various control systems in the car to make it more in line with the driver's operating needs and comfort requirements. Through VR technology, designers can simulate the driver's operating behavior in the virtual cockpit and test whether the relative positions of components such as

the instrument panel, control panel, and steering wheel meet ergonomic requirements. During the operation, the driver needs to grasp the information and respond quickly and intuitively. If the design of the instrument panel or other control systems is unreasonable, the driver may not be able to complete the operation efficiently and safely. Through virtual reality technology, designers can test the driver's line of sight and hand movement trajectory in real time, analyze the interaction efficiency with the control system, and then optimize the layout of the cockpit so that the driver can more easily access various control buttons, touch screens and display devices.

In addition, VR simulation technology can also test the driver's reaction and comfort under different driving conditions. By simulating virtual scenarios of long-term driving, designers can observe the driver's fatigue level, operational flexibility and reaction speed under different conditions, further improve the in-car environment and human-computer interaction design, and ensure the driver's comfort and safety in various driving scenarios.

In terms of safety assessment, virtual reality technology can simulate the impact of various accident scenarios and provide strong support for vehicle safety design. Through VR technology, designers can build various possible collision scenarios in a virtual environment to simulate the reactions and injuries of drivers and passengers in car accidents. This process can greatly improve the accuracy and efficiency of safety assessment. Designers can discover potential safety hazards in advance through virtual simulation, improve the design of safety devices, and reduce the possible injuries in actual collisions.

Through the optimization of seat belt and airbag positions by virtual reality, vehicle manufacturers can conduct multiple simulations and tests during the design stage. The differences in the adaptability of seat belts and airbags for drivers of different body shapes and weights in the event of a collision can be accurately simulated through VR technology to ensure that seat belts and airbags can effectively protect drivers and passengers in the best position when a real accident occurs. With this virtual simulation method, designers can comprehensively evaluate and optimize the vehicle's safety system before actual production, further improve the vehicle's safety performance, and reduce the risk of casualties in traffic accidents.

The application of virtual reality technology in vehicle ergonomics, especially in seat design, cockpit layout and safety assessment, has greatly improved design efficiency and safety, helping manufacturers better meet users' comfort and safety needs. Through this highly simulated, immersive design and testing method, the automotive industry has taken a more precise and intelligent step in ergonomic optimization.

5 APPLICATION OF VIRTUAL REALITY TECHNOLOGY IN VEHICLE HUMAN-COMPUTER INTERACTION

Human-computer interaction (HMI) refers to the communication and interaction between people and machines, which is mainly achieved through input devices, display interfaces and feedback systems. In the field of vehicles, with the development of intelligent technology, the human-computer interaction of vehicles has evolved from simple mechanical operation to modern intelligent and digital control systems. Initially, vehicle human-computer interaction

mainly relied on traditional physical buttons, switches and dashboards, and drivers controlled the car by directly operating these physical components. However, with the rapid advancement of information technology, modern technologies such as touch screens, voice recognition, and gesture control have been gradually introduced into vehicle information systems, making the interaction between drivers and vehicle systems more intelligent and intuitive. Today, intelligent control systems play an increasingly important role in modern cars. Drivers can not only operate vehicles in traditional ways, but also use advanced technologies such as intelligent voice assistants, gesture control, and even eye tracking to make the driving experience more personalized and convenient.

The application of virtual reality technology in interactive interface design has greatly broadened the boundaries of vehicle human-computer interaction. Through VR technology, designers can create an immersive virtual environment to simulate the interaction process between drivers and vehicle systems. In traditional human-computer interaction, drivers operate through buttons, knobs or touch screens, while virtual reality enables drivers to interact with the in-vehicle system through natural gestures, sight and even voice. Through VR, designers can test the efficiency and convenience of various interaction methods in real time, thereby optimizing the design of the interface so that drivers can control various in-vehicle functions more easily and intuitively during driving. In addition, as physical buttons are gradually virtualized, future vehicles may no longer rely on traditional buttons and switches, and virtual assistants will become the main bridge for communication between drivers and vehicles. Through VR technology, designers can test and improve this interface design without physical buttons to ensure that it has high operability and ease of use while meeting the intuitive needs of drivers.

In the design of in-vehicle information systems, virtual reality technology plays a vital role. The in-vehicle information system of modern cars is not limited to navigation and multimedia entertainment, but also covers many aspects such as driving assistance systems and in-vehicle environment control. Through virtual reality technology, drivers can interact with these systems directly in a virtual environment and get more intuitive feedback. For example, in the navigation system, virtual reality technology can be combined with augmented reality (AR) to provide more vivid and real-time navigation information. Through AR, virtual road guidance and traffic information can be superimposed in the driver's field of vision in real time, helping the driver to judge the route and traffic conditions more easily, thereby improving driving safety and convenience.

In addition, virtual reality can also provide innovative solutions in the visualization and operation convenience of in-vehicle information. Traditional in-vehicle information systems present driving information through LCD screens, while through VR technology, in-vehicle information can be displayed more flexibly. For example, the driver can control the information display on the screen through gestures or sight, quickly switch between various driving data and entertainment content, and even realize multi-tasking operations. Through VR, the driver can operate in a more natural way, avoid distraction problems that may occur in traditional control methods, and improve driving safety and driving experience. By simulating and optimizing the interaction between the driver and the in-vehicle system in an all-round way, virtual reality technology has brought revolutionary progress to the human-computer

interaction system of the vehicle, making the car more intelligent and the driving experience richer and safer.

6 CHALLENGES AND DEVELOPMENT TRENDS OF VIRTUAL REALITY TECHNOLOGY

VR technology has shown great potential in many fields, its challenges in wide application cannot be ignored. First of all, the cost of VR equipment has always been a major factor limiting its popularity. High-performance virtual reality devices, such as HMDs, motion capture systems, and high-end computers, are often expensive, making them unaffordable for ordinary consumers and small and medium-sized enterprises. In vehicle design and ergonomic applications, especially for automakers, although VR can bring significant design optimization and efficiency improvement, the investment cost is still high, which forms a barrier to technology application for some companies with limited budgets. With the continuous advancement of hardware technology and the gradual reduction of production costs, the popularity and acceptability of VR devices are likely to be fundamentally improved.

In addition to cost issues, the interactive experience and comfort of VR systems are also important challenges. Although virtual reality technology has made certain progress, many users still feel uncomfortable during long-term use, including visual fatigue, dizziness, and nausea. This is mainly due to the current VR system's shortcomings in visual and motion synchronization. Especially in fast motion or highly immersive experience, there may be differences between the user's perception and actual action, causing discomfort. In addition, the details of the virtual environment and the accuracy of physical simulation are still insufficient in some applications, resulting in users' immersion feeling not being fully satisfied. Although there are some solutions, such as low-latency rendering technology and high refresh rate display, the comfort and interactive experience of VR systems still need to be continuously optimized to achieve widespread application.

Looking to the future, virtual reality technology will develop to a higher level and overcome current challenges. First, the continuous progress and breakthroughs in hardware technology will drive VR devices to be lighter, cheaper and more efficient. With the improvement of computing power and the innovation of display technology, future VR headsets will no longer rely on high-end PCs, but may be combined with devices such as smartphones and integrated chips to further reduce costs and improve user experience. At the same time, the lightweight and wireless nature of the equipment will make VR more convenient, and long-term wearing will no longer cause discomfort, thereby enhancing the user's immersion and interactive experience.

On this basis, cross-domain cooperation and intelligent processes will also promote the further development of virtual reality technology. With the combination of technologies such as artificial intelligence (AI), big data, and 5G communications, VR technology will not only be limited to traditional entertainment and gaming fields, but will also be widely used in multiple industries such as automobiles, medical care, and education. Artificial intelligence can achieve personalized virtual experiences by learning user behaviors and preferences, and the low latency characteristics of 5G networks will bring VR a more real-time and smooth interactive

experience. These cross-domain technology integrations will greatly expand the boundaries of VR applications and bring more intelligent and accurate virtual experiences.

In future vehicle design, the potential of virtual reality technology will be further released. With the development of intelligence and electrification in the automotive industry, vehicle design will increasingly rely on virtual reality for optimization and simulation. Designers will use VR to test seat layout, cockpit configuration, and human-computer interaction interface to accurately evaluate the impact of each design scheme on drivers and passengers. In addition, with the development of autonomous driving technology, the interaction between vehicles and drivers will also undergo profound changes. VR will play a vital role in this process, helping to design more intelligent, intuitive and safe in-vehicle systems. With the development and breakthroughs of virtual reality technology, future vehicle design will be more accurate and personalized, and meet higher comfort, safety and intelligence requirements.

7 CONCLUSION

This study explores the application of virtual reality technology in vehicle ergonomics and human-computer interaction, and points out that VR technology has broad prospects in improving the efficiency of automobile design and improving the comfort and safety of drivers and passengers. By using VR technology, designers can simulate various design options in a virtual environment, such as seat layout, cockpit configuration, and the interaction mode of the in-vehicle information system, so as to accurately evaluate and optimize various designs and reduce the errors and discomfort that may exist in traditional designs. Virtual reality technology also provides important support for vehicle safety assessment, helping to simulate various accident scenarios and optimize the location of safety equipment such as seat belts and airbags. Through these applications, VR technology not only improves the accuracy and efficiency of design, but also provides new ideas for the intelligent and personalized development of vehicles.

However, although virtual reality technology has shown great potential in vehicle design, there are still some technical deficiencies. First, the high cost of VR equipment is still the main obstacle to its widespread application, especially among some small and medium-sized enterprises and consumers, where the popularity is low. Second, VR systems still face certain challenges in interactive experience and comfort. Wearing head-mounted display devices for a long time may cause visual fatigue or discomfort, which is especially important in vehicle ergonomic design. In addition, the immersion and reality of virtual reality still need to be improved, especially in terms of details and physical simulation. Existing technologies are difficult to achieve a completely seamless and accurate experience.

Looking to the future, virtual reality technology will play an increasingly important role in automotive design. With the advancement of hardware technology, VR devices will be lighter and cheaper, and the comfort of long-term wearing will be greatly improved. Future car design will rely more on virtual reality for seat design, cockpit layout, optimization of human-computer interaction interface, etc. Through efficient virtual simulation technology, designers can more quickly identify and solve problems in design, shorten the R&D cycle, and reduce costs. Virtual reality technology will also be combined with artificial intelligence, big data, 5G

and other technologies to further enhance the interactive experience and intelligence level, and create a more personalized and intelligent vehicle environment.

In terms of improving driving safety and comfort, virtual reality technology has great potential. Through virtual reality simulation and testing, vehicle design can more accurately consider the needs of drivers and passengers, optimize the configuration of seats, control systems and safety equipment, and ensure higher comfort and safety. With the continuous development of autonomous driving technology, virtual reality will also play a vital role in the design, testing and optimization of autonomous driving systems, helping to design more intuitive, intelligent and safe vehicle systems, and promoting the automotive industry into a new intelligent era. In short, virtual reality technology can not only improve the efficiency and quality of current vehicle design, but also show unlimited potential in the future of automotive intelligence and safety improvement.

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