# *Innovative application of virtual reality and human-computer interaction in the design of electric vehicles*

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**Abstract:** With the rapid development of electric vehicle technology, traditional design methods are facing challenges in efficiency and innovation. As cutting-edge digital tools, VR and HCI technologies are gradually being applied to the design process of electric vehicles, bringing new design concepts and practices to the industry. This paper explores the innovative application of virtual reality and human-computer interaction technologies in electric vehicle design, and analyzes how these technologies can improve design efficiency, reduce costs, and optimize user experience in aspects such as vehicle appearance and structural design, cockpit layout, and driving experience evaluation. In addition, this paper also discusses the challenges faced by these technologies, such as technology integration, user acceptance, and data security, and predicts future technological development trends. Through case analysis, this paper shows the successful application of virtual reality and human-computer interaction technologies by companies such as Tesla, Weilai, and BMW, and points out the driving role of these technologies in electric vehicle design and future development prospects.

**Keywords:** Virtual Reality; Human-Computer Interaction; Electric Vehicle; Design Innovation; User Experience

## 1 INTRODUCTION

With the in-depth promotion of the global energy structure transformation and sustainable development strategy, electric vehicles, as an important carrier of green travel, are gradually becoming the mainstream direction of the development of the automotive industry. However, compared with traditional fuel vehicles, electric vehicles have not only undergone fundamental changes in power systems and energy management, but their vehicle design concepts are also undergoing a profound reshaping [1]. Faced with consumers' ever-increasing demand for intelligent, personalized and humanized experience, how to develop products in a more efficient and accurate way has become an urgent issue for electric vehicle companies. In this context, the application of cutting-edge technologies such as virtual reality (VR) and human-computer interaction (HCI) has injected unprecedented innovative power into electric vehicle design.

The electric vehicle design process covers multiple dimensions such as vehicle structure optimization, cockpit layout, and human-computer interface interaction design. Traditional methods rely on physical prototypes and two-dimensional drawings, which have problems such as long cycles, high costs, and low iteration efficiency, making it difficult to quickly respond to market changes and user feedback [2]. The flexibility of electric vehicles in performance layout and software definition further amplifies the complexity of the design system, requiring designers to fully evaluate user experience and engineering feasibility at an

early stage, and urgently need a more intuitive, immersive, and controllable auxiliary design method.

In recent years, the rapid development of virtual reality technology has enabled designers to build and operate virtual models in a three-dimensional immersive environment, which has not only greatly improved design efficiency, but also greatly improved cross-departmental collaboration and customer engagement. At the same time, the development of human-computer interaction technology has also provided a rich channel for operation in virtual environments, expanding from traditional keyboard and mouse input to natural interaction forms such as gesture recognition, voice control, and eye tracking. The integration of these two technologies is becoming an important breakthrough for reconstructing the design process of electric vehicles and improving design quality and user satisfaction.

This study aims to systematically explore the innovative application of virtual reality and human-computer interaction technology in electric vehicle design, sort out its specific implementation paths in appearance modeling, internal structure evaluation, driving experience simulation, and other links, and explore its potential in improving design efficiency, enhancing user participation, and promoting intelligent development [3]. Starting from the technical principles, combined with typical case analysis, this article will explore key technical points and practical challenges, and then put forward strategic thinking and research prospects for future development. The structure of this article is as follows: First, the technical background and development status of virtual reality and human-computer interaction are introduced, followed by a discussion of its integrated application in electric vehicle design, and then a technical analysis is conducted with typical practical cases. Finally, the current problems are summarized and future development trends are expected.

## 2 OVERVIEW OF VIRTUAL REALITY TECHNOLOGY

VR is a three-dimensional virtual environment generated by computers, which enables users to interact with the virtual environment through special equipment such as head-mounted displays (HMDs), sensors and handles, thereby creating an immersive experience. Its core principle is to generate visual, auditory and even tactile sensory information through computer simulation, and use real-time tracking technology to enable users to interact with the virtual environment. The development of VR technology has gone through a process from early experimental applications to its widespread application in multiple fields today. In the 1960s, virtual reality technology was initially used mainly in military and flight simulation training. With the continuous advancement of computer hardware and graphics processing technology, VR gradually penetrated into industries such as medical care, education, and entertainment [4]. After entering the 21st century, with the rapid development of image rendering, motion capture and input devices, virtual reality has been widely used in design, architecture, games and other industries, especially in the field of industrial design, becoming an important tool to promote innovation and improve design efficiency.

In the field of industrial design, the application of virtual reality technology has significantly changed the traditional design method. In traditional design, designers need to evaluate design solutions through two-dimensional drawings, three-dimensional modeling and physical prototypes, which often have problems such as long design verification cycle, high cost and difficulty in adjustment [5]. The introduction of virtual reality not only allows designers to freely operate, check and optimize designs in three-dimensional space, but also can simulate and evaluate the performance of products in actual use in real time. Through virtual reality, the design team can conduct virtual testing and verification of the design at an early stage, which greatly shortens the design cycle, reduces the cost of physical prototype production, and improves the accuracy and efficiency of design decisions. On this basis, virtual reality can also provide an immersive experience for product users, allowing designers to

optimize the design from the user's perspective, thereby enhancing the user's perceived experience and satisfaction.

In the automotive field, the application path of virtual reality technology is more diverse and in-depth. With the rapid development of electric vehicles, car design is no longer limited to the optimization of appearance and performance, but pays more attention to driving experience and the personalized needs of car owners. The application of virtual reality in electric vehicle design is mainly reflected in multiple aspects such as body appearance design, interior layout, cockpit optimization, and driving experience simulation. Designers can use virtual reality technology to simulate the appearance design of different models, conduct virtual tests of different shapes and colors, and help companies make the best design decisions at an early stage [6]. In terms of interior design, VR technology can reproduce the virtual cockpit environment, helping the design team evaluate the seat layout, the display effect of the instrument panel, and the ease of operation of various in-vehicle interactive systems. In addition, virtual reality can also help R&D personnel test the power system and suspension system of electric vehicles under different road conditions by simulating driving experience, thereby achieving more refined and personalized design solutions. The deep integration of virtual reality and automotive design has greatly improved the efficiency and quality of automotive design and promoted the innovative development of the industry.

## 3 CURRENT STATUS OF HUMAN-COMPUTER INTERACTION TECHNOLOGY

HCI is a discipline that studies the interaction and communication between people and computers. Its core concept is to enable users to communicate and operate computer systems effectively in a natural and intuitive way through the design of reasonable interfaces. Human-computer interaction is not only the design of the operating interface, but also includes the analysis of user needs, the understanding of usage scenarios, and the optimization of the interactive experience with the computer system. From the initial command line interface to the emergence of the graphical user interface (GUI), to the popularization of advanced interaction methods such as voice recognition, gesture control and virtual reality today, human-computer interaction technology has undergone multiple stages of evolution. With the advancement of computing power and perception technology, modern human-computer interaction not only requires the realization of functions, but also pays more attention to the naturalness, efficiency and user immersion of interaction [7].

With the continuous development of technology, multimodal interaction technology has gradually become an important means to improve user experience. Multimodal interaction refers to information transmission and interaction through multiple input methods. Compared with traditional single input methods, multimodal interaction can achieve more natural and intuitive human-computer communication [8]. For example, voice interaction technology uses voice recognition and synthesis technology to allow users to communicate with the system through natural language, and control navigation, air conditioning, music and other functions through voice commands during driving, avoiding driver distraction during driving. Gesture recognition technology can capture the user's body movements through cameras and depth sensors. Users only need to wave gestures or make specific movements to operate the in-car multimedia system, adjust seats or lights, etc. During driving, gesture control not only provides a more intuitive way of interaction, but also improves driving safety. Eye tracking technology

analyzes the trajectory of eye movements to understand the user's focus of attention, and then optimizes the driver's interface display or provides personalized recommendations.

With the continuous advancement of intelligent technology, intelligent interactive interfaces are also showing more and more innovative trends. In traditional car design, the interface of the cockpit is usually limited to physical buttons and simple digital displays. Today, the design of intelligent interactive interfaces is no longer just at the level of information display, but tends to provide a more intelligent and personalized interactive experience through multi-dimensional methods such as holographic display, touch screen, and voice commands. By integrating multiple sensors and intelligent algorithms, the car's central control system can not only perceive the driver's intentions, but also dynamically adjust according to the driving environment, user habits and real-time data [9]. For example, an AI-based voice assistant can adjust the in-car settings according to the user's voice commands, and even provide personalized route planning and real-time traffic information. The combination of facial recognition and sentiment analysis technology enables the car to recognize the driver's emotional changes, and then adjust the in-car atmosphere lighting, music playback, etc., to provide users with a more comfortable driving experience.

In general, with the continuous innovation of human-computer interaction technology, the automotive industry is gradually entering a new era of intelligence, personalization and safety. By combining multimodal interaction methods such as voice, gestures, and eye movements with intelligent interface design, electric vehicles can not only provide a more convenient operating experience, but also bring users a more efficient, safer and smarter way of travel. In the future, with the development of technologies such as artificial intelligence and deep learning, human-computer interaction will play a more important role in automotive design, driving the entire industry towards a more intelligent direction.

## 4 INTEGRATED APPLICATION OF VIRTUAL REALITY AND HUMAN-COMPUTER INTERACTION IN ELECTRIC VEHICLE DESIGN

The integrated application of virtual reality and human-computer interaction technology in electric vehicle design has greatly promoted the innovation of the design process. In the vehicle appearance and structural design stage, VR provides an immersive design and review environment, breaking the limitations of traditional two-dimensional design drawings and physical models. Designers can intuitively see the appearance and structural layout of the vehicle in the virtual space, and quickly evaluate the visual effects and functionality of different design schemes. Through VR technology, designers can view all angles and details of the vehicle in real time, and even modify details through interactive operations, quickly feedback and optimize. Compared with traditional wireframes or renderings, VR technology makes the design scheme more intuitive and easy to perceive, providing strong support for the decision-making of the vehicle appearance and structural design [10]. In addition, combined with human-computer interaction technology, the design team can not only adjust the virtual model through gestures, voice or touch operations, but also have natural language dialogues with the system to quickly obtain modification suggestions or detect potential design problems.

In terms of cockpit design and optimization, the combination of virtual reality and human-

computer interaction also shows great potential. As an important part of electric vehicles, the cockpit not only needs to meet functional requirements, but also needs to consider comfort and user experience. Through VR technology, designers can create a highly simulated cockpit environment, simulate different driving scenarios and operational feedback, and evaluate the seat layout, dashboard design, touch screen location, and the responsiveness and convenience of various interactive systems. In this process, combined with human-computer interaction technology, users or testers can interact with the virtual cockpit through voice commands or gestures to test whether different operating methods are ergonomic. In addition, eye tracking technology can help analyze the driver's visual focus, thereby optimizing the display layout of the dashboard, allowing the driver to focus more on the road and avoid unnecessary distractions.

The construction of a virtual driving experience platform provides a new way to evaluate the driving experience of electric vehicles. Through virtual reality technology, the design team can create a virtual driving environment to simulate vehicle performance under various driving conditions, including different road conditions, climate change, and even emergencies. On this platform, drivers can experience the vehicle's handling, power system performance, and the response of the intelligent assisted driving system in an immersive way. Through the VR simulated driving platform, the team can obtain a large amount of driving data and feedback to help evaluate the various performance of vehicle design, discover potential defects, and make timely adjustments. Compared with traditional real car testing, the virtual driving experience platform not only greatly saves costs, but also enables multiple iterations and optimizations in the early design stage, shortening the time to market.

Rapid prototyping and immersive review systems bring more flexible and efficient evaluation methods to electric vehicle design. In traditional design, physical prototyping usually requires a lot of time and resources. With the help of virtual reality technology, designers can build accurate three-dimensional models in a virtual environment for interactive review and modification. Virtual review not only allows team members to fully discuss and analyze without relying on actual prototypes, but also helps designers quickly find problems in the design and make adjustments through real-time feedback and data analysis. At the same time, the immersive review system allows all parties to participate in discussions in a more intuitive and interactive way, improving the efficiency of collaborative work. Through this virtualized and digitalized design and review process, electric vehicle design can be optimized and improved in multiple rounds in a short period of time, promoting the improvement of overall design quality.

Through the integrated application of these technologies, virtual reality and human-computer interaction not only greatly improve the efficiency and quality of electric vehicle design, but also provide design teams with more flexible tools to cope with changes in market and user needs. As these technologies continue to develop, the design process of electric vehicles will become more efficient, precise, and closer to user needs.

## 5 CASE ANALYSIS AND TECHNICAL IMPLEMENTATION

Driven by virtual reality and human-computer interaction technology, many automobile

companies and research institutions have explored its practical application in electric vehicle design and achieved remarkable results. Companies such as Tesla, NIO, and BMW have adopted virtual reality and human-computer interaction technology at different stages and levels to improve design efficiency, optimize user experience, and enhance the intelligence level of vehicles. In the process of designing its models, Tesla uses virtual reality technology to review the appearance and cockpit of the whole vehicle. Designers can test the appearance and interior layout of different models in a virtual environment and simulate the user's driving experience in a panoramic virtual space. This method not only saves a lot of physical prototype production costs, but also speeds up the iteration and update of the design. NIO has widely used virtual reality and multimodal interaction technology in cockpit design. The driver interacts with the vehicle system through voice and gestures, enhancing the owner's intelligent experience. In addition, NIO has also developed a virtual driving simulation platform that allows users to test drive in a virtual environment, providing personalized driving settings to further enhance users' understanding and preferences of the vehicle. BMW has applied virtual reality and augmented reality technologies in the development of its i series models, especially in the testing of the vehicle's power system and intelligent driving assistance functions. It uses the virtual reality platform to simulate different driving scenarios, verify the responsiveness of the intelligent system, and provide data support for vehicle performance optimization.

To support these innovative applications, multiple software and hardware platforms and tools have become indispensable key components in automotive design. Unity and Unreal Engine, as industry-leading game engines, play an important role in the development of virtual reality applications. These engines can not only create highly realistic three-dimensional environments, but also support real-time rendering and interactive functions, enabling design teams to quickly optimize and test the appearance, interior and performance of vehicles in a virtual environment. Virtual reality headsets such as HTC Vive and Oculus Rift provide an immersive experience for design teams and testers. With functions such as hand tracking and eye tracking, they can accurately capture user interaction movements, making operations in virtual environments more natural and smooth. In addition, the combination of sensors and motion capture devices provides real-time feedback for driving simulation and human-computer interaction systems, enhancing the authenticity and interactivity of the driving experience.

Development process and coordination mechanism are the key to the successful application of virtual reality and human-computer interaction technologies in electric vehicle design. First of all, the application of virtual reality and human-computer interaction must be highly integrated with the traditional automotive design process to ensure that the technology can effectively support all aspects of the design. From the initial concept design to the detailed function realization, the design team needs to conduct multiple reviews and adjustments in the virtual environment, and use the VR model to interact with the user to feedback the effectiveness of the design. In terms of the collaborative mechanism, the collaboration of interdisciplinary teams is crucial. Designers, engineers, user experience experts and developers need to achieve efficient communication and interaction through the virtual reality platform. The modern virtual design platform not only supports the operation of a single designer, but also allows multiple team members to discuss and modify in the same virtual space at the same

time to ensure that the design concept can be quickly implemented. In addition, the iterative update of virtual reality and human-computer interaction technology also requires the design team to maintain flexibility and adopt new technological achievements in a timely manner to ensure the forward-looking and innovative nature of the design plan.

Through the support of these technical platforms and the optimization of the development process, the application of virtual reality and human-computer interaction in electric vehicle design not only improves efficiency and reduces costs, but also brings users a more personalized and intelligent driving experience, and promotes the rapid development of the entire industry towards intelligence and digitalization.

## 6 CHALLENGES AND DEVELOPMENT PROSPECTS

Although virtual reality and human-computer interaction technology have shown great application potential in electric vehicle design, they still face a series of challenges in their actual implementation. First, the bottleneck of technology integration and computing resources is an important factor restricting its widespread application. The high integration of virtual reality technology and human-computer interaction technology requires strong computing resource support, including high-performance graphics processing units (GPUs), large amounts of data storage, and fast data transmission capabilities. With the increasing complexity of design models and the increase in the demand for real-time interaction, traditional computing platforms often find it difficult to meet the needs of real-time rendering and efficient computing, especially during the design process, when virtual models need to be adjusted and optimized in real-time simulation, which places extremely high demands on computing resources. Although the rise of cloud computing and edge computing in recent years has provided new solutions, how to reduce computing and hardware costs while maintaining design efficiency is still an important problem facing the industry.

In addition, user acceptance and experience optimization are also major challenges in the application of virtual reality and human-computer interaction in electric vehicle design. Although virtual reality and multimodal interaction technologies can provide designers with an immersive experience, how to ensure that users can adapt to and use these technologies for a long time remains an unresolved issue. For example, virtual reality headsets may cause users to feel visual fatigue, dizziness and other discomfort, especially when used for a long time, which will affect the user experience of designers and consumers. The diversity of human-computer interaction technologies also brings about the complexity of operation. Although technologies such as voice, gestures, and eye movements can improve the naturalness of interaction, users need a certain learning and adaptation process to master them proficiently. The popularization and optimization of these technologies need to overcome the threshold of human-computer interaction, making it more intuitive and easy to use, while ensuring comfort and fluency, so as to improve the overall user acceptance and use effect.

At the same time, data security and intellectual property issues are also key hidden dangers in the widespread application of virtual reality and human-computer interaction technologies in electric vehicle design. With the collection and transmission of a large amount of sensitive data, how to ensure the security of design data, user behavior data, and virtual

model data generated during the design process has become an urgent issue to be solved. The virtual environment in the design process of electric vehicles often involves a large amount of user input, design feedback, and interaction records. This information may not only involve personal privacy, but also contain commercial secrets. How to prevent data leakage, tampering, and improper use through effective encryption and data protection technology is the key to protecting corporate interests and user privacy. In addition, with the rapid development of virtual reality and human-computer interaction technology, how to ensure that the innovative designs behind these technologies are effectively protected by intellectual property rights has also become an issue that companies and research institutions need to focus on.

Looking to the future, virtual reality and human-computer interaction technology will further develop in electric vehicle design and gradually integrate into a wider range of application scenarios. In particular, with the rise of the concept of the metaverse, virtual reality and augmented reality technologies will be more closely combined to form a more open and immersive design and experience environment. In the metaverse scenario, users can not only experience virtual driving and car design processes, but also interact with other users in a cross-platform, cross-device environment for virtual test drives, design reviews, or car owner socializing. The future virtual driving experience is no longer limited to a single device, but can be achieved through smart glasses, holographic projection, and even brain-computer interface technology. A more natural and intuitive interactive experience. In addition, with the continuous development of technologies such as artificial intelligence and 5G communications, the performance of virtual reality and human-computer interaction technology will be further improved, and data processing and real-time interaction will become smoother and more efficient. As these technologies mature, the design process of electric vehicles will become more flexible and efficient, and the user experience will be more personalized and intelligent, thereby driving the entire automotive industry towards smart manufacturing and smart travel.

In general, the application prospects of virtual reality and human-computer interaction in electric vehicle design are broad, but it is also necessary to continuously overcome challenges in technology, user experience and data security. With the continuous advancement and innovation of technology, the design of electric vehicles will become more intelligent and digital, and virtual reality and human-computer interaction technology will play an increasingly important role in it, becoming an important engine to promote the development of the industry.

## 7 CONCLUSION

Through the discussion and analysis of this article, the following core findings can be drawn: The combination of virtual reality and human-computer interaction technology has demonstrated great innovation potential and practical application value in electric vehicle design. From the optimization of vehicle exterior and interior design, to the human factors engineering evaluation of the cockpit, to the construction of a virtual driving experience platform, these technologies not only improve the efficiency of design, but also promote the overall improvement of user experience. Through virtual reality, the design team can perform multiple rapid iterations and tests in a digital environment, avoiding the high cost and long

cycle of physical prototyping and testing in traditional design. At the same time, the advancement of human-computer interaction technology has added more dimensions of interaction to the design process, making the communication between designers and users more intuitive and efficient, thereby greatly enhancing the intelligence level of automotive products and user satisfaction.

The innovative application of virtual reality and human-computer interaction technology also provides a new perspective for the improvement of electric vehicle design value. First, the integration of technology has greatly shortened the design cycle. From the initial concept design to the final review and optimization, everything can be done in a virtual environment, which greatly reduces the reliance on physical samples in traditional design and reduces development costs. Secondly, through virtual driving simulation and immersive review systems, the car's handling performance and user experience can be comprehensively evaluated and improved at an early stage, improving the market adaptability and competitiveness of the final product. Most importantly, with the continuous evolution of virtual reality and human-computer interaction technology, designers can gain in-depth insights into consumer needs and innovatively provide users with a more personalized and intelligent driving experience, driving the electric vehicle industry towards intelligence and sustainable development.

Future research and application directions can continue to deepen and expand from several aspects. First, with the improvement of computing power and the advancement of technology, how to combine virtual reality with artificial intelligence, machine learning and other technologies to create a more intelligent automotive design system will be an important research direction. Through data-driven design optimization, the system can analyze user demand changes in real time and provide personalized design solutions and driving experiences. Secondly, there is still a lot of room for development in the multimodal application of virtual reality and human-computer interaction technology, such as how to further enhance the interaction between car owners and cars through more natural voice recognition, facial expressions and emotional feedback. Furthermore, as the concept of the metaverse gradually matures, the design, production and sales of electric vehicles in the future may cross the boundaries between reality and virtuality, forming a new ecosystem that integrates virtuality and reality. At this time, how to build a car design and experience platform that highly integrates virtuality and reality will become an important topic for future research.

In summary, virtual reality and human-computer interaction technology have not only brought revolutionary changes to the design of electric vehicles, but also played a huge role in improving design efficiency, optimizing user experience and promoting the intelligent transformation of the industry. In the future, with the continuous advancement of technology and the deepening of application, virtual reality and human-computer interaction will play a more important role in the design of electric vehicles and become the core driving force for innovation and development of the entire industry.

## REFERENCES

[1] Ba, T., Li, S., Gao, Y., & Wang, S. (2022). Design of a human–computer interactio n method for intelligent electric vehicles. *World Electric Vehicle Journal*, *13*(10), 179.

[2] Cao, X., & Song, M. (2023). Research on the Application of Virtual Reality Techno logy in the Design and Evaluation of Interactive Interfaces for Renewable Energy Systems. *RE&PQJ*, *21*(5).

[3] Zenghui, T., & Albakry, N. S. (2025). Multimodal interaction design of HMI for el ectric vehicles in China: A study to enhance user experience. *KUPAS SENI: Jurnal Seni dan Pendidikan Seni*, *13*(1), 83-96.

[4] Wang, K. (2021). Human-Computer Interaction Design of Intelligent Vehicle-Mount ed Products Based on the Internet of Things. *Mobile Information Systems*, *2021*(1), 67 95440.

[5] Jin, X., Teng, J., & Shaw-mung, L. (2024). Optimizing HMI for Intelligent Electric Vehicles Using BCI and Deep Neural Networks with Genetic Algorithms. *World Ele ctric Vehicle Journal*, *15*(8), 338.

[6] Liu, W., Zhu, Y., Huang, R., Ohashi, T., Auernhammer, J., Zhang, X., ... & Wang, L. (2023). Designing interactive glazing through an engineering psychology approa ch: Six augmented reality scenarios that envision future car human-machine interfa ce. *Virtual Reality & Intelligent Hardware*, *5*(2), 157-170.

[7] Lin, J. L., & Zheng, M. C. (2024). An Empirical Investigation on the Visual Image ry of Augmented Reality User Interfaces for Smart Electric Vehicles Based on Kan sei Engineering and FAHP-GRA. *Mathematics*, *12*(17), 2712.

[8] Katona, J. (2021). A review of human–computer interaction and virtual reality rese arch fields in cognitive InfoCommunications. *Applied Sciences*, *11*(6), 2646.

[9] Duan, Z., Zhou, J., & Gu, F. (2024). Cognitive differences in product shape evalua tion between real settings and virtual reality: case study of two-wheel electric vehi cles. *Virtual Reality*, *28*(3), 136.

[10] KoÇ, H. E., Başarslan, M. S., & Canli, H. (2024, November). VR-Based Promotion and Training of Electric Vehicles. In *2024 8th International Symposium on Multidiscipl inary Studies and Innovative Technologies (ISMSIT)* (pp. 1-5). IEEE.