



# Technical Challenges Affecting the Popularization of Virtual Reality Technology

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**Abstract.** The widespread adoption of virtual reality (VR) technology is hindered by significant technical challenges that affect its functionality and accessibility. This paper explores these challenges, which include the high cost of VR devices, performance limitations of current VR headsets, issues of ergonomics and user discomfort, interoperability, and the scalability of VR systems. Each challenge is dissected to understand its impact on the deployment of VR technologies in various sectors. The paper proposes viable solutions grounded in the latest research and technology advancements that aim to mitigate these barriers. This includes the development of cost-effective VR hardware, enhancement of device ergonomics, adoption of universal standards for software interoperability, and the leveraging of advanced computing architectures to improve scalability. By addressing these fundamental issues, this study contributes to the broader discourse on enhancing VR technology for more extensive application, aiming to pave the way for its integration into mainstream digital interaction.

**Keywords:** Virtual Reality, Technical Challenges, Interoperability, Scalability, User Ergonomics, VR Adoption.

## 1 Introduction

The advent of VR has signaled a paradigm shift in digital interaction, bringing forth a technology that not only enhances user engagement through immersive experiences but also holds transformative potential across diverse sectors such as education, healthcare, and industrial training. Despite its promising capabilities, VR technology's widespread adoption remains significantly hampered by an array of technical challenges. This study delves into these barriers, aiming to articulate strategies that could propel the mainstream acceptance and effectiveness of VR technologies.

Understanding the importance of VR in contemporary digital landscapes hinges on recognizing its capacity to revolutionize traditional methodologies. For instance, VR's application in educational settings can lead to heightened retention rates and immersive learning experiences, as indicated by Howard and Gutworth [1], who highlighted the technology's effectiveness in social skills development through virtual training programs. However, the broader adoption of VR is not without its impediments, notably in realms like user experience where issues such as motion sickness and ergonomic discomfort prevail [2].

This research is anchored on a comprehensive review of the literature sourced from fifteen seminal papers, providing insights into the prevalent technical challenges and exploring innovative solutions that have emerged within the academic and industrial spheres. Among these challenges, the high cost of VR hardware and the dearth of quality content have been identified as significant barriers to VR’s mass adoption [3,4]. Moreover, issues with interoperability and data security present considerable hurdles in sensitive applications, necessitating robust solutions that bolster both user trust and technological reliability.

The methodology of this research integrates both qualitative and quantitative analyses to offer a detailed exploration of VR’s technical constraints. Through this mixed-methods approach, the study categorizes the principal challenges delineated in the literature and evaluates their impact across various sectors employing VR. This not only aids in identifying sector-specific hurdles but also in pinpointing universal barriers that affect VR’s global adoption.

The primary aim of this study is to synthesize existing research on VR’s technical challenges, propose viable solutions, and suggest future research directions that could mitigate these barriers. By providing a holistic overview of the obstacles VR faces and the potential pathways for overcoming them, this paper seeks to contribute to the broader discourse on enhancing VR technology for wider application.

In summary, while VR technology presents a frontier for innovation and has begun to impact several core industries fundamentally, its full potential is curtailed by persistent technical challenges. In this article, the author will introduce the current technical problems and make suggestions based on the Fig. 1.

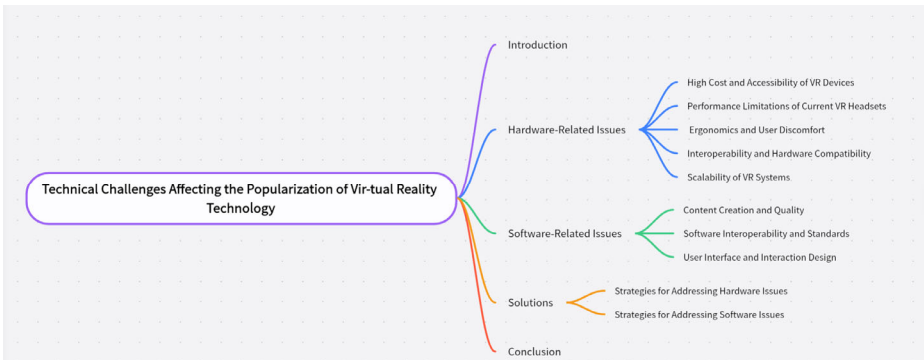


Fig. 1. Mind Map.

Through this exploration, the paper sets the stage for future studies and technological advancements that could enable VR to transcend its current limitations and become a staple in digital interaction.

## 2 Hardware-Related Issues

### 2.1 High Cost and Accessibility of VR Devices

The high cost of VR hardware significantly hampers the technology's accessibility and widespread adoption. Advanced VR setups, particularly those offering high fidelity and immersive experiences, remain financially out of reach for many individual consumers and educational institutions [4]. This economic barrier not only restricts the user base to a more affluent demographic but also limits educational and developmental opportunities that VR can offer. Consequently, the potential market growth and the evolutionary pace of VR technology are stifled, delaying its integration into mainstream applications and hindering the democratization of advanced digital learning and interaction tools.

### 2.2 Performance Limitations of Current VR Headsets

The evolution of VR headsets has been marked by significant technological advancements, yet several performance limitations continue to challenge their efficacy and broader adoption. Issues related to resolution, field of view, refresh rates, and motion latency persist, impacting the immersive experience and limiting the practical applications of VR technologies.

Resolution remains a primary concern in VR headsets, as current devices often fail to match the clarity required for a fully immersive experience. Most headsets on the market cannot deliver the ultra-high-resolution images needed to eliminate the screen-door effect, where users can see the grid of pixels, which disrupts the immersive experience [5]. This limitation not only impacts visual clarity but also can lead to visual discomfort and reduced user engagement over extended periods.

Additionally, the field of view (FOV) in current VR headsets is another critical limitation. Most commercial VR devices offer a field of view significantly narrower than the human eye's natural range, typically between 100 and 110 degrees compared to the human FOV of approximately 200 degrees [6]. This restriction can make virtual environments feel unnaturally constrained and less immersive, thereby diminishing the sense of presence that is pivotal for effective VR experiences.

Refresh rates and latency are equally crucial for a seamless VR experience. Insufficient refresh rates can result in image stuttering and motion blur, which not only detract from the realism of the VR experience but can also cause motion sickness in users [7]. High latency, the delay between user movement and visual feedback, further compounds these issues, leading to disorientation and discomfort, severely limiting VR's application in fast-paced environments such as interactive gaming or precision training simulations.

Interoperability issues also pose significant challenges, as VR headsets often require specific hardware and software configurations to function optimally. This lack of standardization hinders the integration of VR technologies across different platforms and limits their usability in diverse application fields [8]. The rapid pace of technological change in VR hardware exacerbates these issues, as frequent updates can lead to compatibility problems with existing applications and content.

Despite the rapid technological advancements in VR, these performance limitations of current VR headsets underline the need for continued research and development. Enhancing the resolution, field of view, refresh rates, and reducing latency are crucial for overcoming the existing barriers to user experience and broadening VR's applicability across various domains [9].

Addressing these technological challenges is essential for the next generation of VR headsets to realize their full potential, not only as tools for entertainment but also as transformative devices for education, training, and beyond.

### **2.3 Ergonomics and User Discomfort**

Ergonomic design is crucial for ensuring user comfort and preventing discomfort in VR systems, yet many VR headsets currently on the market fail to adequately address these issues. Ergonomic flaws can significantly degrade the user experience, leading to physical discomfort, fatigue, and even pain, particularly during extended use.

One of the primary ergonomic issues with current VR headsets is their weight and how this weight is distributed across the head and face. Many devices are front-heavy, which can cause neck strain and discomfort due to prolonged use. This imbalance requires users to constantly adjust the headset, disrupting immersion and potentially leading to longer-term musculoskeletal problems [2]. Moreover, the pressure exerted by the headset on the face can lead to skin irritation and discomfort around the eyes and forehead, which are sensitive to prolonged contact and pressure.

Another significant ergonomic concern is the heat generated by the headset during operation. As components within the VR devices work to process complex graphics and track movements, they generate heat, which, when poorly dissipated, increases discomfort and can even pose a risk of skin burns or heat exhaustion in warm environments [1]. This issue is exacerbated in enclosed or poorly ventilated spaces, where heat accumulation can make the experience unbearable over time.

Furthermore, the lack of adjustability in many VR headsets compounds these ergonomic issues. Users with different head sizes and shapes may find it difficult to achieve a comfortable and secure fit, which is essential not only for comfort but also for optimal functioning of the device. Poor fit can lead to excessive movement of the headset, which not only causes physical discomfort but also affects the visual experience, leading to blurring or double vision and diminishing the overall effectiveness of the VR experience [3].

Addressing these ergonomic challenges is critical for the future development of VR technologies. Without improvements in the physical design of VR headsets, user discomfort and health issues may continue to hinder broader acceptance and utility of VR technology. Enhanced ergonomic design focused on user comfort, better weight distribution, improved heat dissipation, and increased adjustability will be key areas for development in next-generation VR devices.

### **2.4 Interoperability and Hardware Compatibility**

Interoperability and hardware compatibility are critical aspects that significantly impact the user adoption and practical deployment of VR technologies. Despite

advances in VR, a consistent issue that persists is the ability of different VR systems and devices to work seamlessly with one another and with various software applications. This lack of standardization can lead to user frustration and limits the technology's potential for widespread integration.

Most VR hardware is designed with proprietary technology, which means that devices from different manufacturers often do not work well together without additional software or adapters. This can restrict users to specific ecosystems, limiting their choice of software and accessories and potentially increasing costs. For instance, a VR headset from one manufacturer might not be compatible with motion controllers or tracking systems from another, which limits the user's ability to upgrade their system or mix and match products to suit their needs [5].

Moreover, the rapid evolution of VR technology exacerbates these compatibility issues. With frequent updates in hardware specifications and software requirements, older models may quickly become obsolete, unable to support newer games or applications that require more advanced hardware capabilities [9]. This fast-paced obsolescence can deter individuals and organizations from investing in VR technology due to the fear of needing to continually purchase new equipment to keep up with technological advancements.

Additionally, the software that operates VR devices often requires specific drivers and updates to function properly, which can further complicate compatibility across different operating systems and platforms. When these software elements are not universally compatible, it creates a fragmented user experience and can stifle the development of a cohesive VR market where consumers can expect a reliable and consistent experience across different devices and applications [7].

To foster wider acceptance and use of VR, it is essential to address these interoperability and compatibility challenges. Ensuring that VR devices and their accompanying software can operate across various platforms and with equipment from multiple manufacturers will be crucial for the technology's future. Only then can VR hope to achieve its full potential as a versatile and universally accessible technology.

## 2.5 Scalability of VR Systems

Scalability remains a formidable challenge in the deployment of VR systems, particularly in enterprise and industrial settings. As organizations seek to implement VR for training, simulations, or remote collaboration, they often encounter limitations in scaling these technologies to accommodate larger user bases or more complex scenarios. The ability of VR systems to scale effectively is crucial for their viability in large-scale applications, from educational institutions to multinational corporations [6].

One of the primary issues with VR scalability is the requirement for high-performance hardware to run advanced VR applications. This hardware not only needs to support detailed graphics and real-time interactions but also must do so for multiple users simultaneously in large-scale deployments. The cost and logistical complexity of equipping numerous users with high-end VR systems can be

prohibitive, limiting the technology's expansion beyond small groups or specific applications [8].

Additionally, network bandwidth and latency are significant concerns when scaling VR. As the number of concurrent users increases, the data load on networks also grows, requiring robust network infrastructure to handle the increased traffic without degrading performance. Latency, critical for maintaining the immersive and interactive quality of VR experiences, can become an issue in larger networks, where delays are more pronounced and can disrupt the user experience [9].

To address these scalability challenges, future developments in VR technology must focus on optimizing system performance and network capabilities to support larger deployments without compromising on user experience or financial feasibility. This includes innovations in compression technologies, cloud-based VR solutions, and more efficient hardware designs that can deliver high-quality experiences more cost-effectively.

### **3 Software-Related Issues**

#### **3.1 Content Creation and Quality**

Content creation poses a significant challenge in the VR landscape, where the quality and depth of content are crucial for delivering immersive and engaging user experiences. Creating high-quality VR content is not only resource-intensive but also requires specialized skills in 3D modeling, animation, and interactive design. These complexities can limit the production of diverse and appealing content, which is essential for attracting and retaining users [8].

Moreover, the immersive nature of VR demands high-resolution graphics and sophisticated narrative techniques to maintain user engagement. However, many developers struggle with the technical limitations of current VR platforms, which can stifle creativity and reduce the overall quality of the VR experiences offered. For instance, achieving realistic environments and fluid character movements in VR requires advanced programming capabilities and powerful rendering engines, which are not always accessible to all developers [7].

Additionally, the need for content to be universally appealing and culturally inclusive adds another layer of complexity. VR content must cater to a global audience, encompassing various languages, cultural nuances, and accessibility needs, further complicating the content creation process [1]. The challenge is not only technical but also artistic, as creators must effectively communicate stories and experiences that resonate across different cultural contexts.

As VR continues to evolve, addressing these content creation challenges will be crucial for expanding the technology's appeal and ensuring its sustainability in the competitive digital landscape. High-quality, diverse, and inclusive content will be key drivers of VR's future growth and acceptance.

### 3.2 Software Interoperability and Standards

Software interoperability and the establishment of universal standards are pivotal for the broader adoption and seamless functionality of VR systems. Currently, the VR industry faces significant fragmentation due to the lack of standardized software frameworks and protocols, which complicates the development process and limits the potential for cross-platform applications. This fragmentation not only restricts the compatibility of VR applications across different systems but also hinders the collaborative potential within the developer community [2].

Interoperability issues stem from the variety of VR platforms, each with its proprietary systems and development tools. For instance, content developed for one type of VR headset may not function properly on another without significant modifications, if at all. This can lead to increased development costs and time, as developers may need to recreate or significantly alter their applications to cater to different platforms. Moreover, this lack of interoperability can frustrate users who expect a consistent experience across their technology devices [9].

Standards are crucial not only for ensuring compatibility across devices but also for facilitating the integration of new technologies into existing systems. Without universal standards, the introduction of advanced features like higher resolution displays or improved tracking technologies becomes a complex and often incompatible upgrade path for existing VR systems. This is evident in industries that rely heavily on VR for training and simulations, where upgrading to newer systems can be costly and logistically challenging [4].

The VR community has recognized these challenges and there are ongoing efforts to develop more robust standards. For example, the Open XR initiative by the Khronos Group aims to create an open, royalty-free standard for VR and augmented reality (AR) platforms that would enable applications to run on any system supporting the standard. Such efforts are critical for fostering an environment where innovation can thrive and where smaller developers can compete on a level playing field with larger corporations [5].

Moreover, the lack of standardized security protocols is another concern. As VR becomes more integrated into sectors like healthcare and education, the need for robust security measures to protect sensitive data becomes increasingly critical. Currently, the variation in security standards across platforms can lead to vulnerabilities that are exploitable by malicious entities, posing risks to user privacy and data integrity [6].

In conclusion, enhancing software interoperability and establishing firm standards are essential steps towards creating a unified and secure VR ecosystem. These efforts will not only reduce barriers to entry for developers but also improve the end-user experience, paving the way for VR technologies to become more integrated into everyday life and various industrial applications.

### 3.3 User Interface and Interaction Design

The design of user interfaces and interaction mechanisms in VR systems is critical for ensuring an intuitive and immersive user experience. Effective interface design in VR

is fundamentally different from traditional screen-based interfaces due to the three-dimensional and immersive nature of the environment. Users must be able to navigate and manipulate the virtual world seamlessly to maintain immersion and engagement, which presents unique design challenges [6].

The interaction design for VR requires careful consideration of user ergonomics to avoid physical strain and enhance the intuitiveness of the controls. Poorly designed VR interfaces can lead to user frustration, increased cognitive load, and even physical discomfort, detracting from the overall experience. For instance, gestures and movements that are natural in the real world may not translate effectively to VR without appropriate tactile feedback and visual cues, which are crucial for confirming user actions within the virtual environment [9].

Moreover, the complexity of VR systems necessitates interfaces that can accommodate a wide range of interactions, from simple menu navigation to complex scenario manipulation, without overwhelming the user. This balance is difficult to achieve and requires a deep understanding of human factors and behavior in immersive environments. The development of adaptive interfaces that can dynamically adjust based on user proficiency and task complexity could greatly enhance usability and accessibility in VR systems [3].

Incorporating these design principles effectively is essential for the advancement of VR technology. As VR continues to grow in popularity across various sectors, the pressure to innovate in interface and interaction design will only intensify, requiring ongoing research and development to address these complex challenges.

## 4 Solutions

### 4.1 Strategies for Addressing Hardware Issues

**High Cost and Accessibility of VR Devices.** To address the high cost and accessibility issues associated with VR devices, two viable solutions emerge from the literature. First, advancements in VR training applications demonstrate significant cost-effectiveness by eliminating the need for physical materials and trainers, thus reducing overall expenses and expanding accessibility [1]. Second, the development of more affordable VR technologies, particularly in display and interaction hardware, suggests a pathway to making these devices more accessible to a broader audience [4]. These approaches are pivotal in overcoming the financial and logistical barriers that currently hinder the widespread adoption of VR technology.

**Performance Limitations of Current VR Headsets.** To overcome the performance limitations of VR headsets, integrating advances in optical design, display technologies, and computational methods is essential. First, by utilizing advanced optics technologies, such as holographic elements and polarization-based optics, the field of view can be significantly enhanced while reducing the vergence-accommodation conflict, a common issue in VR that leads to discomfort [10]. Additionally, the employment of lightweight materials and novel fabrication techniques can decrease the weight and bulk of headsets, improving user comfort over prolonged usage periods. Furthermore, incorporating dynamic focal plane adjustments



through multi-focal systems and variable optics can address clarity and depth perception challenges, enhancing the overall immersive experience [11]. Lastly, scalable network architectures and robust processing capabilities are crucial that support increased resolution and frame rates essential [12]. By addressing these technical aspects, VR headsets can provide more realistic and comfortable user experiences, thereby pushing the boundaries of what's possible in virtual environments.

**Ergonomics and User Discomfort.** To enhance ergonomics and mitigate user discomfort in VR headsets, recent innovations emphasize tailored design adjustments and data-driven insights. Ergonomically optimizing the weight distribution and selecting skin-friendly materials can significantly reduce physical strain and irritation during extended use [9]. Additionally, applying artificial intelligence to analyze interaction data allows for real-time adjustments and insights, helping manufacturers refine designs to suit diverse user needs more effectively. By integrating these approaches, VR devices not only become more comfortable but also more adaptable to individual user preferences, thus extending session times and improving overall user satisfaction [6].

**Interoperability and Hardware Compatibility.** To address interoperability and hardware compatibility challenges in VR systems, it is essential to adopt standardized protocols and frameworks that allow for seamless integration across different hardware and software platforms. Universal design standards are crucial that ensure VR devices and content can work interchangeably without user intervention [7]. Furthermore, embracing open-source development can foster community-driven solutions that enhance compatibility and encourage innovation in VR technology [2]. These strategies not only resolve interoperability issues but also reduce barriers for developers and users, leading to a more inclusive VR ecosystem.

**Scalability of VR Systems.** To effectively scale VR systems, adopting cloud-based technologies and decentralized processing architectures is vital. It is important of using cloud infrastructures to offload heavy processing tasks from local devices, which reduces hardware limitations and costs for end-users [12]. Meanwhile, advancements in lightweight, scalable optical technologies can expand device capabilities without proportionate cost increases [13]. These strategies collectively enable broader accessibility and enhanced performance across varied user bases. By integrating robust cloud support with advanced optical solutions, VR systems can accommodate growing user numbers while maintaining high performance and reducing overhead costs.

## 4.2 Solutions for Software Issues

**Content Creation and Quality.** To enhance content creation and quality in VR, leveraging semantic communication and edge computing is vital. Semantic communication focuses on transmitting meaning rather than raw data, significantly improving efficiency and relevance for VR content delivery [4]. This approach reduces latency and ensures that users receive contextually appropriate content, enhancing the overall experience. Additionally, Steven highlights the role of edge

computing in facilitating real-time, high-quality content rendering by processing data closer to users, thereby reducing reliance on distant servers and minimizing delays [14]. Combining these technologies ensures that VR systems can deliver immersive and interactive content seamlessly, crucial for maintaining user engagement and satisfaction.

**Software Interoperability and Standards.** To foster software interoperability in virtual reality, adopting standardized interaction frameworks is essential. As demonstrated in the GGS-AR system, incorporating a combination of gaze, gesture, and speech into VR platforms can significantly enhance user interaction by allowing flexible modality configurations, thereby improving compatibility across different systems [7]. Additionally, integrating serious games into VR environments, which have been proven effective in educational settings, can standardize content delivery and interaction, facilitating a seamless experience across diverse VR hardware and software platforms [2]. These approaches not only streamline the user experience but also bolster the universal applicability and adoption of VR technologies.

**User Interface and Interaction Design.** Enhancing user interface and interaction design in VR involves integrating intuitive control schemes and robust response mechanisms. Leveraging gesture and voice control can significantly reduce the learning curve and enhance user engagement by aligning interactions more closely with natural human behaviors [9]. Additionally, Zhang discusses the importance of reducing latency and increasing the precision of user interactions through advanced algorithms and machine learning, which are essential for maintaining immersion and preventing user discomfort [6]. Together, these strategies create a more seamless and responsive VR experience, essential for broader adoption and satisfaction.

## 5 Conclusion

This paper has systematically addressed the technical challenges that hinder the widespread adoption of VR technology, pinpointing significant barriers such as cost, performance limitations, user discomfort, interoperability issues, and scalability. Through the examination of pivotal studies and current technological advancements, viable solutions have been proposed to mitigate these obstacles. Reducing the cost of VR hardware through advanced manufacturing techniques and enhancing user comfort by improving ergonomic design are identified as crucial steps towards broadening VR accessibility and user satisfaction. Furthermore, the adoption of universal software standards and the integration of scalable network architectures are essential for resolving interoperability and scalability issues, respectively. The analysis presented not only illuminates the complex nature of these challenges but also underscores innovative strategies that can support the wider integration of VR technologies. By tackling these technical constraints, VR can fulfill its potential as a transformative medium across diverse sectors, significantly improving both user engagement and operational efficiency. Ongoing research and development will be vital to advance VR technology and secure its role in the future of digital interaction.

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