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Current Status and Development Trends of Animation and Virtual Cinematography Techniques in VR Motion Sickness Prevention Design

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Abstract. Virtual Reality (VR) technology has rapidly been adopted across entertainment, education, healthcare, and industrial sectors; however, cybersickness remains a significant barrier to user engagement and comfort. This paper reviews the mechanisms underlying VR-induced dizziness, emphasizing sensory conflict, postural instability, and latency as primary contributing factors. It further examines both subjective and objective evaluation methods, including questionnaires, physiological indicators, eye-tracking, and postural sway measurements. Building on this foundation, the study systematically analyzes key technical parameters such as frame rate, Field of View (FOV), and camera motion and their influence on reducing visual–vestibular conflict. Additionally, it explores animation and virtual cinematography techniques, including camera path design, easing functions, and frame-by-frame stabilization, as essential strategies for mitigating discomfort while enhancing immersion. Existing studies demonstrate that single-parameter optimizations provide limited relief due to threshold effects and individual differences, whereas integrated multi-parameter approaches show greater potential for effectiveness. The article proposes a unified framework that combines technical and aesthetic strategies, with an emphasis on Artificial Intelligence (AI)-driven adaptation and cross-modal augmentation. This synthesis not only bridges gaps in fragmented research but also offers practical guidance for future VR content creation and hardware development. By advancing systematic design strategies, the paper contributes to establishing a more rigorous foundation for improving user comfort, immersive quality, and the long-term scalability of VR systems.

Keywords: Virtual Reality, Cybersickness, Animation, Virtual Cinematography, Immersion

1. Introduction

Virtual Reality (VR) technology is rapidly developing in fields such as gaming, film industry, education, medical rehabilitation, and industrial simulation. With its immersive interaction and highly flexible experience, it is gradually becoming a mainstream medium. However, motion sickness remains a significant barrier, limiting users' immersive engagement and reducing retention rates. Symptoms include dizziness, nausea, and eye strain; in certain cases, it even has the possibility to cause interruptions in use [1].

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Technical parameters and expressive techniques in animation and virtual cinematography play a crucial role in shaping user comfort and experience in VR. This research examines key factors such as frame rate, field of view (FOV), and virtual camera motion, alongside design strategies including path optimization, animation curve smoothing, and frame-by-frame visual stabilization. The goal is to provide systematic guidance for reducing motion sickness and enhancing immersion [2]. Animation and virtual cinematography in VR experiences not only serve narrative and aesthetic functions but also directly influence the sensory coordination between the visual and vestibular systems. Scientific and rational design of technical parameters can significantly reduce visual-vestibular conflict, enhance user comfort and immersion, thereby increasing the commercial and educational value of VR systems [3].

Existing studies have examined the role of single parameters—such as high frame rates or dynamic field-of-view restrictions—in mitigating virtual reality sickness, thereby laying the groundwork for understanding its underlying mechanisms. However, most research lacks a systematic analysis of multi-parameter combinations and their interactive effects. In addition, discussions on integrated techniques, including animation curves, virtual camera paths, and real-time stabilization, remain fragmented and lack a unified theoretical framework [4,5].

Unlike previous studies that primarily focused on hardware frame rates or a single navigation method, this article incorporates multidimensional technical parameters and expressive techniques of animation and virtual cinematography into a unified analytical framework, combining experimental results from multiple fields to evaluate their overall effectiveness in alleviating dizziness. As VR content creation evolves towards long-duration interactions and open-world scenarios, users are exposed to more complex motion visual stimuli during the experience. Traditional single-factor anti-motion sickness optimisation strategies can no longer meet demand, necessitating systematic research and practical guidance across multiple parameters and technical approaches [6]. This article reviews and synthesizes existing studies on multidimensional technical parameters and virtual photography methods in VR, examining their relationships with dizziness responses. By integrating findings from various research efforts, it proposes a conceptual framework to guide the development of quantifiable anti-dizziness strategies for future VR content creation and hardware design.

The article first introduces mechanisms and evaluation methods of VR-induced motion sickness (Section 2), then systematically reviews the key technical parameters and anti-cybersickness effects (Section 3) as well as anti-vertigo applications for animation and virtual cinematography paths (Section 4), Finally, it summarises the shortcomings of current research and proposes future development directions (Section 5).

2. Mechanisms and evaluation methods of VR-induced motion sickness

2.1. Causes of Virtual Reality sickness

Virtual reality sickness, also known as cybersickness, is generally considered the result of multiple interacting factors. The most prominent explanatory frameworks are the sensory conflict theory and the postural instability theory. Sensory conflict theory posits that when there is a discrepancy between the information received by the visual, vestibular, and proprioceptive systems, the body experiences abnormal physiological and perceptual responses that conflict with one another [7]. In practical VR scenarios, a common situation occurs when users visually perceive high-speed movement or rotation, while the vestibular system does not detect the corresponding acceleration.

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This mismatch—referred to as "visual motion without vestibular motion been shown to correlate positively with users' reported discomfort [8].

The Postural Instability Theory emphasizes that dizziness symptoms often arise after an individual has been unable to maintain a relatively stable posture for an extended period [9]. This theory is supported by experimental evidence: during visually induced sensations of movement or virtual swaying stimuli, both the amplitude and speed of postural sway increase significantly before symptom onset, suggesting that postural instability can serve as an early risk indicator [10,11]. Unlike the Sensory Conflict Theory, the Postural Instability Theory places greater emphasis on the failure of the motor control system's adaptive processes.

In addition, self-motion perception (vection) and system latency are critical factors influencing VR-induced dizziness. Vection is a type of perception triggered by visual stimuli, and its intensity is positively correlated with FOV, optic flow speed, and the extent of peripheral stimulation [12]. When the rendering and tracking latency of a VR system exceeds approximately 20 milliseconds, a perceptible time lag occurs between the user's head movements and the visual updates. This lag not only exacerbates sensory conflict but may also reduce the accuracy of motion prediction [13]. Therefore, optimizing rendering performance and improving tracking precision are essential technical prerequisites for reducing VR-induced motion sickness.

2.2. Assessment tool

Methods for assessing VR-induced dizziness can be categorized as either subjective or objective. Subjective assessments depend on the user's self-reporting, with the most commonly used tools being the Simulator Sickness Questionnaire (SSQ) and the Virtual Reality Sickness Questionnaire (VRSQ). The SSQ, developed by Kennedy et al., evaluates multiple dimensions, including motion sickness, oculomotor symptoms, and sense of direction, making it suitable for quantifying symptoms across various immersive systems [14]. In contrast, the VRSQ is simplified and specifically tailored to target symptoms associated with VR, providing immediacy [15] that facilitates repeated and rapid use in short-term, multiple-exposure experiments.

Objective assessment methods include both physiological signals and behavioral indicators. Among physiological signals, heart rate variability (HRV) is a key parameter reflecting the balance of the autonomic nervous system. Prior to the onset of dizziness, sympathetic nervous activity typically increases, evidenced by a decrease in total HRV power and a corresponding rise in the low-frequency to high-frequency (LF/HF) ratio [16]. By collecting electrocardiogram or photoplethysmographic pulse wave data in real time, fluctuations and responses of the autonomic nervous system can be dynamically monitored during exposure.

Eye-tracking is another important objective tool. Research has shown that during episodes of dizziness, the frequency of saccades, the duration of fixations, and pupil diameter all undergo systematic changes [17]. Rapid eye movements and unstable fixation may reflect compensatory scanning strategies employed by the visual system in response to conflicting stimuli. The eye-tracking modules integrated into modern head-mounted displays (HMDs) enable the real-time capture of these changes.

The postural sway indicator is widely used to assess VR-induced dizziness. Traditional methods employ a force plate to measure the displacement trajectory of the center of pressure (CoP), calculating parameters such as path length, root mean square (RMS), and the area of the 95% confidence ellipse [18]. Recent studies have demonstrated that head position data from head-mounted displays (HMDs) are highly correlated with CoP signals in low-frequency components and can serve as an alternative to force plates for sway assessment [19]. Postural sway not only reflects

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instability at a specific moment but also functions as an early indicator for predicting the risk of subsequent symptoms. Therefore, it is recommended to be used alongside subjective scales [20].

In summary, the mechanism underlying VR-induced dizziness involves a mismatch among multiple sensory signals, instability in postural control, and the interaction between motion perception and temporal delay. Evaluation methods should integrate subjective scales with objective physiological and behavioral indicators to provide a comprehensive and thorough assessment of dizziness risk, thereby offering a reliable theoretical foundation for subsequent content optimization and personalized interventions.

3. Key technical parameters and anti-cybersickness effects

3.1. Frame rate

Frame rate is a key factor influencing VR-induced dizziness. Research generally indicates that a high frame rate (90 Hz and above) can significantly reduce users' visual latency and image jitter in VR experiences, thereby decreasing the likelihood of dizziness to some extent [21,22]. Comparative experiments conducted at frame rates of 30, 60, 90, 120, and 180 fps demonstrated that user comfort improved as frame rates increased. However, beyond 120 fps, the improvement in user experience tended to plateau, indicating a clear threshold effect [22].

However, differences in rendering mechanisms, display panel latency, and synchronization strategies across various platforms (PC VR, mobile VR, console VR) lead to variations in the effectiveness of motion sickness mitigation, even when frame rate data is consistent [21]. While a high frame rate can enhance the user experience, it also imposes significant demands on hardware performance, generates heat, and increases energy consumption—issues that are particularly pronounced in mobile VR. In recent years, some studies have proposed using artificial intelligence (AI) to achieve adaptive rendering by dynamically adjusting the frame rate through real-time monitoring of users' physiological indicators (such as changes in heart rate, pupil diameter, and blink frequency) to balance user comfort and device energy consumption [23].

In addition, individual differences exist in users' optimal frame rate thresholds. For example, experienced VR users and younger individuals may have a higher tolerance for lower frame rates; male users generally tolerate lower frame rates better than female users, while users prone to motion sickness or older adults tend to rely more on higher frame rates [24].

3.2. Field of View (FOV)

The field of view (FOV) directly influences both the sense of immersion and the likelihood of dizziness in VR. A larger FOV provides more visual information, enhancing users' sense of presence and immersion. However, it also increases the amount of peripheral visual motion input, which can elevate the risk of dizziness. Conversely, a smaller FOV can reduce discomfort but significantly diminishes the sense of immersion during use [24].

FOV restriction is a common mitigation strategy that involves temporarily narrowing the field of view during high-speed movement, rotation, or acceleration phases, then restoring the original FOV once the movement has ended [24]. This method has yielded positive results for some users; however, its adaptability across different genders, age groups, and levels of VR experience requires further investigation. Another innovative approach is the asymmetric FOV restrictor, which reduces the intensity of motion perception by limiting visual input in specific directions, thereby alleviating dizziness while striving to preserve the sense of immersion [25]. Future FOV optimization could be

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combined with cross-modal interventions, such as auditory or tactile cues, to guide the user's attention when narrowing the field of view, thereby reducing psychological discomfort caused by changes in the visual field [26].

Research indicates that using either FOV restriction or snap turning alone can effectively alleviate dizziness; however, combining the two does not necessarily produce an additive effect. The study was conducted in a typical consumer-grade VR gaming scenario with a sample size of 201 participants, comparing three conditions: FOV restriction only, snap turning only, and a combination of both. The results showed that using either measure alone significantly reduced the level of motion sickness, whereas the combined use did not lower the sickness level beyond that of the single measures and, in some cases, approached the level observed when no mitigation measures were applied [26].

3.3. Camera motion

The movement of the camera within a virtual environment directly affects the user's sense of balance and spatial perception. Smooth locomotion provides a continuous visual experience and spatial coherence; however, changes in acceleration can create conflicts between the visual and vestibular systems, potentially inducing severe dizziness [27]. In contrast, teleportation effectively reduces the discomfort associated with continuous movement but disrupts spatial consistency and diminishes the sense of immersion [27].

The mode of rotation significantly influences the degree of dizziness. Generally, rotation around the vertical axis (yaw) is more easily tolerated by the user's visual-vestibular system, whereas pitch or roll rotations are more likely to induce motion sickness [28].

Introducing easing curves (ease-in, ease-out, smoothstep) in rotation and movement has been shown to reduce the impact of sudden acceleration changes on the visual-vestibular system, thereby alleviating dizziness [28].

4. Animation and virtual cinematography techniques

4.1. Virtual camera path design

In virtual photography and animation, the design of the camera path is crucial. On one hand, designers often use fixed viewpoints (such as bird's-eye view or fixed focus), trajectory following (such as character movement paths), or slow dolly in/out techniques to ensure that users have a stable visual expectation of the scene. These methods exhibit good adaptability to different narrative rhythms, but in practical applications they often rely excessively on single-path demonstrations, lacking systematic analysis of multi-path comparisons and interaction effects [29, 30]. For example, the visual differences produced by different path combinations or the collaboration of multiple cameras have not yet been systematically studied, and there is little literature exploring the impact of path switching on viewing comfort and audience attention.

Optimising the comfort of camera cuts and movement rhythm is also a challenging aspect. Currently, rhythm is largely adjusted based on the creator's experience. However, some emerging academic research suggests that in the future, AI-driven automatic camera path control based on real-time dizziness monitoring could be introduced. This would use physiological data such as eye movement tracking and head stability to instantly determine whether the user is experiencing discomfort, thereby dynamically optimising camera switching and motion rhythm [31,32]. However,

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most of these studies remain at the laboratory prototype stage, lacking large-scale cross-platform validation to ensure practicality and effectiveness.

Therefore, the researchers suggest: 1) constructing a multi-path sample library to compare the differences in visual impact and comfort among different path combinations through audience experiments; 2) exploring an interactive path selection mechanism to enable real-time path adjustments based on audience feedback; 3) integrating physiological feedback (such as dizziness index) with an artificial intelligence control module to achieve adaptive path regulation [31].

4.2. Easing functions

Easing curves are an important mechanism for achieving smooth animations and visual comfort. Common easing functions include linear, ease-in, ease-out, and ease-in-out. These functions typically reduce visual discomfort by controlling changes in speed, avoiding abrupt acceleration and deceleration that cause an imbalance between the visual and vestibular systems, which can lead to dizziness [29,33]. However, existing research mostly focuses on the optimisation of a single parameter (such as speed smoothness), lacking comprehensive multi-perspective analysis that integrates multiple factors such as field of view (FOV) and acceleration [30].

For example, in panning and rotation applications, ease-in-out is widely used to enhance the smoothness and coherence of motion, thereby reducing immediate visual impact [30]. However, if there is a sudden change in the field of view or excessive acceleration during the same operation, relying solely on curve smoothing generally cannot completely eliminate discomfort. Therefore, future research could combine easing functions with users' personalised habits, using machine learning algorithms to analyse users' historical viewing data, thereby dynamically generating customised easing schemes. For example, users who are prone to dizziness can use easing functions with longer buffer intervals, while those with stronger adaptability can use faster speed curves to enhance the immersive experience during use [32].

At the same time, easing curves can be dynamically optimised to match the contextual setting of the scene. In fast-paced or high-tension scenes, an overshoot easing with exaggerated rebound can be used to enhance the user's sense of tension within the experience, whereas in calm atmospheres, smooth and gentle curves are more suitable to enhance immersion [31].

4.3. Frame-by-frame visual stabilization

In virtual photography and animation, frame-by-frame visual stabilization technology is essential for ensuring stable and comfortable viewing experiences. Common approaches involve estimating inter-frame motion using optical flow to correct jitter, combined with motion blur and parallax correction to enhance visual quality. However, systematic research on consistency across different devices and platforms remains limited. Variations in processing capabilities among devices—ranging from mobile phones to high-performance workstations—result in significant differences in stabilization effectiveness [29,33].

Research on hardware image stabilization, specifically IMU calibration combined with visual information, remains limited. Existing studies have demonstrated that fusing IMU data with optical flow can effectively enhance video stabilization, ensuring that the corrected footage maintains high stability and image quality, even in fast-moving scenes [29, 30]. Recent work has further proposed integrating IMU data with deep learning networks to produce full-frame stabilization results, achieving improvements in stability scores of approximately 10%–15%, reductions in distortion

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values of about 20%, and decreases in cropping ratios by around 8%. Overall, these results significantly outperform those methods relying solely on visual information [30,32].

Further research introduced event cameras and combined them with traditional frame cameras and inertial measurement unit (IMU) data to decouple rotation and translation during rapid movement and rotation, significantly improving the accuracy and processing efficiency of visual perception [31]. This cross-modal approach suggests that, in the future, additional sensory modalities could be integrated into visual stabilization processes, such as haptic feedback (providing subtle vibration cues during intense screen shaking) or spatial audio correction (using sound positioning to enhance the user's spatial awareness), thereby reducing visual impact and enhancing the immersive experience [33].

5. Conclusion

This article demonstrates that animation and virtual cinematography techniques represent a critical aspect of VR anti-cybersickness design, serving not only as aesthetic and narrative tools but also as technical regulators of sensory congruence. A synthesis of current studies reveals that while isolated optimizations—such as high frame rates, field of view (FOV) restriction, or easing functions—can mitigate symptoms to some extent, their effectiveness is limited by threshold effects and individual variability. Significant progress lies in multi-parameter integration, where camera path strategies, adaptive easing curves, and frame-by-frame stabilization work synergistically to minimize visual–vestibular conflict. Furthermore, empirical evidence suggests that combining inertial sensing with deep learning frameworks substantially enhances stabilization outcomes, offering a pathway toward robust cross-platform consistency. Future research should emphasize cross-modal augmentation and AI-driven personalization, enabling dynamic real-time adjustment of cinematographic parameters. These advancements are expected to establish a more rigorous theoretical and practical foundation for VR content design, thereby improving both user comfort and system scalability.

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