Transactions on Computer Science and Intelligent Systems Research
ISSN: 2960-1800, eISSN: 2960-2238 | Volume 7
TPCEE 2024

Virtual Embodiment and Interaction Techniques in Virtual Reality Games

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Abstract. Virtual Reality (VR) technology, characterized by immersive environments entirely generated by computers, has gained significant attention during the fifth information revolution. This paper explores the core elements of VR—Immersion, Interaction, and Imagination—as described by Burdea and Coiffet (1994). It emphasizes the importance of virtual embodiment in enhancing user experience within VR gaming. The development of technologies such as the CAVE system, head-mounted displays (HMDs), handheld controllers, haptic feedback devices, and full-body motion tracking systems are discussed in detail. Furthermore, the study delves into human-computer interaction (HCI) techniques crucial for immersive VR experiences and the principles of effective user experience (UX) evaluation. The significance of personalization and user comfort in VR environments, including addressing motion sickness and latency issues, is highlighted. This paper underscores the need for continuous improvement and user-centered design to optimize VR experiences. Ultimately, the paper suggests that VR technology's future relies on balancing technical advancements with a deep understanding of user needs to create more immersive and satisfying virtual experiences.

Keywords: Virtual Reality; VR Game Design; Virtual Embodiment; Interaction Techniques.

1. Introduction

Reality refers to objective facts, real experiences, and the things this paper encounter in the physical world. In contrast, Virtual Reality (VR) is an environment entirely generated by computers. Amid the fifth information revolution, characterized by the proliferation of computers, VR technology has garnered significant attention as an emerging innovation. In Burdea and Coiffet's book "Virtual Reality Technology" (1994), they summarize the characteristics of "virtual reality" as the three I's: Immersion, Interaction, and Imagination [1]. Immersion means that users can experience a sense of presence; Interaction refers to users being able to interact with the virtual environment using their limbs; and Imagination means that these interactions can be understood and processed by the user's brain. Virtual reality is called "reality" because it unifies these three elements using information technology, collectively affecting the human nervous system and creating a sense of reality. Therefore, in virtual reality, Virtual Embodiment, Interaction and Immersion are extremely important.

It's important to note that fields related to VR gaming are receiving widespread attention. Given these factors, it is evident that VR applications in gaming will be a major area of future development. As consumer interests influence the gaming market, researchers must focus on enhancing user's virtual embodiment and interaction.

2. Virtual Embodiment

The concept of Embodiment originated in psychology, highlighting the importance of the body in perception and experience. By the late 20th century, researchers developing artificial intelligence found that agents with physical or virtual bodies could perceive and move more effectively than symbol-based systems. With the advancement of VR technology, researchers began exploring how to achieve Embodiment in virtual environments.

The CAVE system was first developed by the Electronic Visualization Laboratory (EVL) at the University of Illinois at Chicago in 1992. It was designed to provide scientists and engineers with an immersive and intuitive way to observe and manipulate 3D data. The CAVE typically surrounds the user with multiple high-resolution projection screens (usually three to six sides), which can be walls, floors, and ceilings. Each screen is projected with images to form an enclosed 3D space, enhanced by users wearing stereoscopic glasses for better visual effects. The CAVE system usually includes tracking sensors to monitor the user's head and hand positions in real-time, allowing the system to adjust the projected content accordingly, maintaining the correct perspective and interactive experience as the user moves.

Head-Mounted Displays (HMDs) are devices worn on the head to display images or videos, primarily used in virtual reality (VR) and augmented reality (AR) systems. The Sword of Damocles, developed by Ivan Sutherland, is considered the first HMD. Subsequently, HMD technology was primarily used in academic research and NASA's flight simulation training. Modern consumer-grade HMD devices surged in popularity from the late 20th to the 21st century, with Apple's newly released Vision Pro, Microsoft's Meta Quest, and ByteDance’s PICO being notable examples. Modern HMDs typically use Liquid Crystal Display (LCD) or Organic Light Emitting Diode (OLED) screens, one for each eye, providing a stereoscopic visual effect. Magnifying lenses enlarge and transmit the images from the screens to the user's eyes, making the images cover the entire field of view. Accelerometers, gyroscopes, and magnetometers track the user's head and body movements, and some high-end devices also include external tracking cameras and internal eye-tracking systems. Integrated headphones or speakers provide 3D audio, enhancing immersion. HMDs are often paired with handheld controllers, gesture recognition devices, or other input methods to allow users to interact with the virtual environment.

Handheld controllers are devices used for interacting with virtual environments. They are typically designed for easy grip and equipped with various input methods, such as buttons, touchpads, triggers, and gesture recognition. Handheld controllers are ergonomically designed for prolonged use and may resemble traditional gamepads but are usually lighter and more refined. Input methods include buttons, touchpads or joysticks, triggers, and gesture recognition. They often incorporate Inertial Measurement Units (IMUs) including accelerometers and gyroscopes to detect hand movements; optical or infrared tracking for spatial positioning using external cameras or base stations; and magnetic tracking for precise location sensing.

Haptic Feedback Devices (HFDs) are used in VR and AR systems to provide tactile sensations and force feedback. These devices allow users to feel the shape, texture, and weight of virtual objects, enhancing immersion and interaction. The earliest HFDs were used in flight simulators and game controllers. With advancements in computer graphics and VR technology, HFDs have become more precise and diverse, expanding their application range significantly. HFDs come in various forms: Glove-type devices that provide fine tactile feedback and force feedback, allowing users to feel the shape and texture of virtual objects. Exoskeleton devices that offer force feedback and motion enhancement, widely used in industrial and medical rehabilitation. Desktop devices used for fine 3D force feedback and tactile simulation, commonly applied in design and medical simulation. Handheld devices that provide 3D force feedback, widely used in gaming and training.

Full-body Motion Tracking Systems (FMTS) are technologies used to capture and record the movements of all parts of a user's body. Optical motion capture systems were the earliest FMTS, typically consisting of multiple cameras that track the positions of markers to capture motion, often used in film and animation production. With the development of microelectronics, Inertial Measurement Unit (IMU) sensors became smaller and cheaper, driving the development of portable full-body motion tracking systems. These systems use accelerometers and gyroscopes to capture motion data and are widely used in gaming, sports analysis, and rehabilitation training. Modern FMTS often combine optical, inertial, and magnetic sensors to provide high-precision, low-latency motion capture.

3. Human-Computer Interaction (HCI)

Human-Computer Interaction (HCI) is a discipline that studies the interaction processes between humans and computer systems, encompassing the theories and methods of designing, implementing, and evaluating interactive systems. The goal of HCI is to enhance the user experience with computer systems by designing intuitive and effective interaction methods. In VR gaming, the basic concepts of HCI include the following four aspects: User Interface (UI): The medium designed to allow users to interact with the operating system, including visual, auditory, and tactile interfaces. User Experience (UX): Emphasizes the overall feeling and satisfaction of users when using a product. Usability: Refers to the degree to which a system is easy to use, learn, and remember. Interaction Design (IxD): Focuses on the principles and methods of designing product behaviors to ensure users can intuitively understand and use the system.

In VR, HCI technology becomes particularly important because users are fully immersed in a virtual environment, making traditional interaction methods like keyboards and mice no longer applicable. HCI technologies in VR include:

Motion Controllers: By using handheld controllers, users can perform precise operations in the virtual environment. These controllers are typically equipped with buttons, touchpads, triggers, and gesture recognition functions.Hand Tracking: Utilizing cameras or sensors, the system can capture users' hand movements in real time without the need for additional controllers. This technology allows users to interact directly with virtual objects using their hands.Full-body Tracking: Through multiple sensors and cameras, the system can capture the movements of the user's entire body, allowing users to walk, jump, and perform other actions naturally in the virtual environment.Eye Tracking: Eye tracking technology captures the direction of the user's gaze to enable more natural interaction methods. It can be used for gaze-based selection, attention analysis, and improving rendering efficiency.Voice Recognition: By interacting with the system through voice commands, users can naturally control functions within the virtual environment.Haptic Feedback: Haptic feedback devices provide tactile sensations and force feedback, allowing users to feel the shape, texture, and weight of virtual objects.Treadmills and Locomotion Devices: These devices allow users to walk in physical space while moving within the virtual environment.Gesture Recognition: By recognizing users' gestures and body movements through cameras or sensors, the system can translate these actions into commands within the virtual environment.

As technology continues to advance, the role of HCI in VR will become even more critical. Future HCI technologies will further reduce the boundaries between users and systems, making interactions more intuitive and natural. By combining multiple sensory inputs such as vision, hearing, and touch, HCI will provide a more comprehensive and immersive interaction experience, creating more complex and diverse application scenarios. Integrating artificial intelligence and machine learning technologies, HCI can automatically adjust interaction methods based on users' behaviors and preferences, providing personalized experiences.

4. Immersive

Immersion refers to the sense of engagement and presence that users feel within a virtual environment. It is a subjective experience that includes both the physical sense of being in the virtual environment and the psychological investment, enabling users to forget their real-world surroundings and become engrossed in the virtual environment. Studies show a positive correlation between immersion and user satisfaction [2]. In traditional games, immersion allows players to escape their ordinary lives and reach new destinations [3]. In virtual reality (VR), achieving a high level of immersion is a primary goal of both technology and design.

4.1. Immersive techniques

There are many ways to achieve immersion in VR. In terms of display, high-resolution and high-refresh-rate screens provide a clear and smooth visual experience, while a wide field of view (FOV) makes users feel like they are in a vast virtual space. Stereoscopic vision allows users to perceive depth and three-dimensional space. In terms of audio, 3D sound technology provides a sense of direction and distance, enabling users to perceive the source of sounds and the acoustic environment. In terms of environmental design, realistic virtual environments are created through high-quality graphic rendering and detailed environmental design, producing believable and engaging virtual worlds. In terms of interaction, enhancing dynamic elements and interactive objects within the virtual environment allows users to experience changes and feedback from the environment, thus enhancing the sense of realism.

4.2. Avatar

The concept of avatars can be traced back to ancient Egypt, where people believed that the Pharaoh was an incarnation of the sun god Horus or Ra. Religions such as Buddhism and Hinduism also uphold the idea that deities transform into human or animal forms to descend to the mortal world for the purpose of enlightenment or salvation. In this context, avatars are manifestations of various forms aimed at teaching or saving sentient beings.

In the field of VR gaming, virtual avatars help users immerse themselves more deeply into game narratives and emotional plots. When users play specific roles through their avatars and participate in the progression of the story, they feel as if they are influencing the storyline, thereby enhancing their sense of presence and immersion. Research shows that presence mediates emotional and physiological responses, and when users experience emotional fluctuations (such as joy, sadness, and tension) in the story through their avatars, their emotional engagement in the game increases [4]. Virtual avatars in cyberspace are important representations of an individual's personality in the virtual space, and the process of selecting avatars allows individuals to reshape their real-world personalities. Notably, the customization options for virtual avatars, which allow users to personalize their appearance, clothing, and accessories according to their preferences and identity, can significantly influence users' immersion. This personalization not only enhances users' sense of belonging but also allows them to express their unique self in the virtual world [5].

4.3. User Comfort

User comfort plays a crucial role in the immersive experience of virtual reality (VR) games. If users feel uncomfortable while using VR equipment, their sense of immersion and overall experience will be severely affected. One important factor affecting user comfort is motion sickness. Motion sickness is very common in VR and is usually caused by a mismatch between visual input and the vestibular system (the inner ear structures responsible for sensing balance and motion). Sensory mismatch, which occurs when the visual input from the VR environment conflicts with the user's physical sensations of movement, is a primary cause of motion sickness. When the visual system perceives motion that the vestibular system does not, users may feel dizzy, nauseous, and uncomfortable [6]. Motion sickness can greatly disrupt immersion, making it difficult for users to use VR devices for extended periods. Developers need to design smooth movement and turning mechanisms, such as reducing rapid rotations and using "teleportation" methods, to reduce the incidence of motion sickness [7].

Another factor affecting user experience is latency. Delays between user actions and the corresponding VR responses can exacerbate motion sickness. Prolonged use of VR without breaks can increase the likelihood of motion sickness.

The comfort of the equipment also significantly influences people's willingness to wear VR devices. In mainstream commercial VR devices, the heavy or improperly designed head-mounted displays (HMDs) can cause head and neck fatigue, affecting long-term comfort. The wearing comfort of HMDs and controllers (such as soft padding and adjustable straps) also affects user comfort. Improperly worn equipment may cause pressure marks, skin irritation, or headaches. Lightweight and ergonomically designed equipment can reduce physical discomfort.

5. User Experience Evaluation and Principles

In virtual reality (VR) games and applications, user experience (UX) evaluation is crucial. Effective UX evaluation requires the comprehensive use of both subjective and objective methods, systematically collecting and analyzing user feedback. Methods for implementing UX evaluation generally fall into several categories: subjective user surveys and interviews, objective data-based behavioral analysis, physiological monitoring, and automated log analysis; and standardized tools such as the Immersive Experience Questionnaire (IEQ) and the Presence Questionnaire (PQ). It is important to note that grouping participants based on factors such as age, gender, race, occupation, and education level can significantly influence user perceptions and interactions [8]. Psychological age and individual sensitivity to stimuli can affect how users respond to VR environments [8].

The principles of UX evaluation should be user-centered, focusing on users' needs, preferences, and behavior patterns. Continuous user feedback and testing should be conducted to continually improve and optimize the VR experience. During the design and development process, regular user testing and feedback collection should be ensured, making every design decision user-oriented. Additionally, diversity and inclusion should be considered, designing to meet the needs of different user groups, ensuring that all users, regardless of age, gender, physical ability, or cultural background, can equally enjoy the VR experience. Providing personalized settings options and ensuring that interfaces and interaction methods are user-friendly and accessible to all, conducting diverse user testing and feedback collection.

6. Conclusion

This paper has examined the essential components and technologies that contribute to the immersive experience in virtual reality (VR) gaming. By exploring the historical context and advancements in virtual embodiment, this paper have highlighted the role of devices like CAVE systems, head-mounted displays (HMDs), handheld controllers, and haptic feedback devices in creating realistic and engaging virtual environments. Human-computer interaction (HCI) techniques were also discussed, emphasizing their critical role in enhancing user interaction and immersion in VR. Additionally, the importance of user comfort and personalization in VR experiences was addressed, noting the challenges posed by motion sickness and latency. Effective user experience (UX) evaluation methods, combining subjective and objective approaches, were outlined to ensure continuous improvement and inclusivity in VR design. As VR technology continues to evolve, focusing on user-centered principles and leveraging advancements in AI and machine learning will be pivotal in creating more intuitive, immersive, and personalized VR experiences.

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