

Design framework of unreal engine for VR animation space analysis

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Abstract: Unreal Engine has emerged as a leading platform for virtual reality (VR) development, offering advanced tools to enhance immersive virtual environments and user interaction. This study examines the key technological features of Unreal Engine that contribute to realism and interactivity in VR, focusing on real-time rendering, photorealistic graphics, and precise physical responsiveness. Adopting a technical analysis approach, this research evaluates the impact of key technologies, including hand tracking, real-time ray tracing, and in-camera visual effects (ICVFX), on interaction fidelity and visual realism. The findings indicate that hand tracking enables natural, gesture-based interactions without the need for external controllers, while real-time ray tracing significantly improves lighting accuracy, thereby enhancing the overall visual fidelity. Additionally, 3D spatial audio refines auditory perception by providing accurate sound directionality and depth, further augmenting user immersion. ICVFX facilitates the seamless integration of live-action footage with virtual environments, expanding the potential for realistic storytelling in VR animation and virtual production. In conclusion, despite the complexity of Unreal Engine's interface, the VR template system and OpenXR support simplify development and enhance cross-platform compatibility. The study highlights Unreal Engine's scalability for large-scale VR projects and its transformative potential across industries such as gaming, simulation, education, and virtual production. The practical implications suggest that leveraging Unreal Engine's capabilities can lead to more immersive, interactive, and efficient VR content creation, paving the way for future advancements in virtual experience design.

Keywords: Head mounted display, Immersion and interactivity, Real-time rendering, Head mounted display, Unreal engine, Virtual reality (VR).

1. Introduction

Unreal Engine, developed by Epic Games, is a leading platform in the virtual reality (VR) industry, providing a robust foundation for immersive VR development. Specifically, Unreal Engine VR is a dedicated suite of tools designed to assist developers in designing, testing, and refining VR projects within an immersive environment. By minimizing the need to frequently remove headsets or switch applications, this system streamlines the development process, allowing for a more efficient workflow [1].

A core principle of Unreal Engine's design is its emphasis on creating highly immersive and interactive virtual worlds [2]. This is achieved through the engine's advanced rendering capabilities, which enable photorealistic graphics and seamless animation transitions. Unreal Engine 5, released in 2020, further expands these capabilities and has already been employed in the development of high-end VR titles such as Phantom: Covert Ops and The Room VR: A Dark Matter [3].

The global VR market has experienced rapid growth, with a valuation of \$10.5 million in 2020 and a projected compound annual growth rate (CAGR) of 18.2% from 2020 to 2027. This expansion highlights the increasing significance and potential of VR technology, with Unreal Engine's design

principles positioned at the forefront of this innovation. By prioritizing immersive design, high-fidelity graphics, and user-friendly development tools, Unreal Engine enables the creation of compelling and realistic VR experiences [4].

Developing VR animations in Unreal Engine requires a foundational understanding of the engine's core tools and workflows. Unreal Engine 5 provides a comprehensive virtual production pipeline that allows for seamless integration of real-world footage with virtual environments in real time. For beginners, mastering the fundamental features of Unreal Engine and its VR-specific capabilities is essential [5].

The development process begins with setting up the VR environment. Unreal Engine includes built-in VR templates, developed using Blueprints, that simplify the initial configuration. Developers must ensure their VR hardware, such as the Oculus Rift or HTC Vive, is properly installed and configured. In cases of technical difficulties, troubleshooting guides are available to assist in resolving hardware setup issues.

Once the VR device is properly configured, developers can start importing or creating 3D assets to construct virtual environments. The latest update to Unreal Engine has significantly improved the VR template system, ensuring compatibility with nearly all headsets through OpenXR, thereby enhancing accessibility for a wide range of VR projects. Additionally, a variety of tutorials offer step-by-step guidance on setup and content creation, making it easier for newcomers to develop immersive experiences [6].

By leveraging these resources and adhering to structured development guidelines, aspiring VR animation creators can efficiently utilize Unreal Engine's powerful tools to bring their virtual reality projects to life.

2. Utilizing VR spaces in Unreal Engine

Integrating real-world footage into virtual environments in Unreal Engine presents several challenges in ensuring a seamless and immersive experience for users. One of the primary difficulties is achieving a natural blend between live-action footage and computer-generated elements. This requires sophisticated compositing techniques, such as green screen integration, to harmonize real-world visuals with virtual environments. Unreal Engine provides a range of tools to facilitate this process, but achieving realism remains a complex task [7].

Managing photorealistic assets also presents a significant challenge. For instance, a collaborative project by Third Move Studios and Deep3dstudio integrated a highly detailed 3D model consisting of 10 million polygons into Unreal Engine. To enhance realism, the model was further augmented with AI-generated voices and facial expressions. This example demonstrates how high-quality assets can be effectively managed and rendered to create lifelike results in virtual spaces [8].

The introduction of In-Camera Visual Effects (ICVFX) offers an innovative approach to blending real-world elements with virtual environments. ICVFX leverages LED lighting, real-time camera tracking, and real-time rendering technology to generate final pixel results directly in-camera. By significantly reducing the need for post-production green screen compositing, ICVFX enhances visual consistency and streamlines production workflows.

Building photorealistic environments is essential for achieving a seamless integration of real and virtual elements. Unreal Engine's advanced features—such as real-time ray tracing, dynamic materials, and sophisticated lighting systems—enable developers to create highly realistic virtual spaces. Additionally, integrating external data sources like Google Maps into Unreal Engine can further enhance realism, but it remains a complex process. For example, utilizing Cesium Ion to import Google Maps data may require indirect techniques, such as exporting texture maps, to achieve the desired results [9].

Learning VR animation in Unreal Engine 5 (UE5) presents several challenges for beginners. One of the most significant obstacles is the engine's complex and powerful graphics capabilities. While these

features are essential for developing high-quality and innovative VR projects, they can be overwhelming for new users, particularly when navigating Unreal Engine's extensive user interface and toolset.

Another major challenge is mastering VR-specific tools and techniques within the engine. Although UE5 introduces important updates, such as a revamped VR template system and expanded headset compatibility via OpenXR, understanding these advanced functionalities requires considerable time and effort. Additionally, setting up and optimizing a VR environment can be a steep learning curve for beginners [10].

To address these challenges, a variety of structured training materials have been developed. Beginner-focused tutorials and courses provide step-by-step guidance on essential skills such as creating realistic environments, designing custom VR avatars, and configuring lighting settings. These resources help simplify the complexities of UE5, making the learning process more accessible.

Comprehensive guides and curated tutorials further support new developers by covering Unreal Engine's VR tools and explaining how to create immersive experiences. Institutions such as the VR Division Academy also play a vital role in training the next generation of developers by offering specialized programs on real-time 3D technology. These programs help learners apply their skills in various fields, including architecture, aerospace, and virtual reality [11].

One of the primary challenges developers face when working with Unreal Engine 5 for VR development is selecting the optimal installation setup. To facilitate this process, the latest Oculus Fork of Unreal Engine 5 is recommended, as it includes built-in MetaXR and MetaXRPlatform plugins. These plugins provide essential modifications for Meta Quest development that are not available in the official Epic Games build. Additionally, this version includes a VR template project with enhanced rendering settings such as "Support Mobile Application Space Warp" and "Support XR Soft Occlusions." However, this setup requires significant storage space—approximately 250 GB after building the engine in Visual Studio, compared to 150 GB for the official UE5.4 download. Despite this, it remains an essential configuration for accurately testing the Quest 3 experience in VR Preview mode on a PC [12].

Recent updates to UE5 have revolutionized the VR template system, ensuring compatibility with nearly all headsets via OpenXR. However, despite these improvements, the complexity of UE5's tools and the introduction of new features can pose challenges for novice developers. To assist with the onboarding process, various tutorials provide an overview of the engine's VR tools and demonstrate their practical applications.

Unreal Engine 5 has the potential to redefine VR game development by pushing the boundaries of graphical fidelity and computational power. Technologies such as Lumen, which delivers unprecedented lighting realism, enhance visual depth and immersion, significantly improving the quality of VR experiences [13].

Unreal Engine 5 offers a comprehensive suite of tools for developing immersive VR experiences, and an array of training resources is available to help new users get started. Step-by-step guides designed for beginners provide clear instructions on integrating virtual environments with live-action footage in real time, making it easier to create visually compelling scenes.

Structured courses, such as those available on Skillshare, introduce beginners to Unreal Engine's user interface while focusing on critical skills like creating realistic landscapes, designing VR avatars, and mastering lighting techniques. Additionally, a complete guide to VR development with UE5 highlights the engine's support for a wide range of headsets through OpenXR and showcases its implementation in high-end VR games like *Phantom: Covert Ops* and *The Room VR: A Dark Matter* [14].

UE5's recent updates have significantly enhanced the VR template system, making it more accessible to beginners. For those seeking an intensive learning experience, a two-week immersive training program offers 40 hours of instruction per week, equipping learners with the necessary skills to effectively utilize Unreal Engine 5.

These educational resources systematically cover the fundamental aspects of UE5, simplifying the development process and accelerating the transition from concept to fully realized VR projects.

3. Character Motion and Interaction in VR Spaces

Achieving natural and immersive motion and interaction for VR-animated characters in Unreal Engine requires specialized tools and processes. Unreal Engine 5.3, in combination with Meta Quest 3, enables seamless transitions between VR and AR environments using hand gestures, eliminating the need for physical controllers. These capabilities leverage Meta Quest's hand-tracking technology and are expected to integrate further with OpenXR in future updates [15].

To implement custom hand animations, developers can utilize the default VR templates provided in Unreal Engine 4 (UE4). Within the project settings, the Motion Controller Map should be designated as the Editor Startup Map and Game Default Map to ensure proper loading. This template enables the creation of custom poses and animations, allowing for a more personalized user experience within Unreal Engine without requiring additional software.

Unreal Engine 5.4 offers substantial advancements in VR development, providing high-performance graphics processing and real-time rendering capabilities essential for creating realistic and immersive virtual environments. This versatility makes it an ideal tool for developing interactive VR applications, including virtual tours, training simulations, and promotional experiences.

Additionally, Unreal Engine's input system, influenced by OpenXR, simplifies the design of extended reality (XR) applications. By enhancing compatibility across devices and streamlining interaction and locomotion programming, this system improves the development workflow and facilitates broader accessibility for VR experiences [16].

For developers aiming to implement advanced hand-tracking mechanisms, reusable components from projects such as First Steps with Hand Tracking and Tiny Castles, provided by Oculus, can be integrated into Unreal Engine. These features can be accessed by cloning the Oculus-provided repository and launching the project within Unreal Editor. While this setup is best initiated through the Epic Games Launcher, certain functionalities, such as Hand Movement Filtering, may require the use of an Oculus-specific fork of the engine.

Character motion and interaction are fundamental to immersion and user engagement in VR environments [17]. When virtual characters move naturally and interact seamlessly with the surroundings, users perceive the digital world as more lifelike [18]. To achieve this level of realism, character behavior must accurately mirror user movements and provide intuitive interactions. Unreal Engine offers a suite of powerful tools to facilitate realistic motion and interaction design.

The responsiveness of character motion significantly impacts user experience. When users move their hands or bodies, the virtual character must immediately reflect these actions. Hand-tracking technology plays a crucial role in achieving this realism by accurately capturing user movements and rendering them naturally within the virtual space. Meta Quest's hand-tracking feature precisely detects hand gestures, enabling users to grab objects, perform gestures, and issue commands without the need for controllers.

Interactions with virtual objects must also adhere to realistic physical behaviors. For example, when a user picks up an object, the perceived weight and motion should feel natural. Actions such as pushing, pulling, or dropping objects should generate appropriate responses in the virtual environment, reinforcing the sense of presence. Unreal Engine's physics engine facilitates this level of realism by simulating accurate physical interactions between users and virtual elements.

Visual feedback further enhances the realism of character motion and interaction. Every user action should be met with an immediate and accurate response—any delay or inaccuracy can break immersion. Unreal Engine's real-time rendering capabilities ensure seamless responsiveness, delivering highly detailed graphics and smooth animations.

Auditory elements also play a vital role in reinforcing user interactions [19]. When a user moves an object or interacts with a character, corresponding sound effects enhance realism by providing spatial

cues. For instance, the sound of grasping an object or a door creaking open adds depth to the experience, complementing visual and physical interactions.

In VR environments, character motion and interaction define the way users engage with the virtual world. A combination of precise motion tracking, physical responsiveness, real-time visual feedback, and auditory integration creates an immersive and intuitive experience. By leveraging Unreal Engine's advanced tools, developers can craft highly interactive and lifelike virtual experiences, ultimately maximizing immersion and user satisfaction. These elements are essential to designing compelling and engaging VR applications, ensuring a seamless connection between users and their digital environments.

4. Key Elements of Unreal Engine for the VR Space

Unreal Engine 5 (UE5) has become a pivotal tool in VR development, extending beyond traditional video game production into a diverse range of creative applications. Its advanced features facilitate the creation of immersive virtual experiences for both entertainment and corporate projects, driving innovation in the VR industry.

One of UE5's most defining strengths is its powerful graphics capabilities, which include realistic lighting, advanced visual effects, and high-fidelity rendering. These features enable the development of deeply immersive environments, while the engine's sophisticated physics simulation enhances realism in virtual interactions. Additionally, UE5 supports a wide range of VR platforms—including Oculus, HTC, and Samsung—ensuring broad accessibility and compatibility.

Another key feature that makes UE5 particularly effective for VR development is the Blueprint visual scripting system, which allows developers to create complex VR applications without requiring extensive coding knowledge. By streamlining the development process, Blueprint makes VR content creation more accessible to a wider range of users. Furthermore, UE5 integrates seamlessly with other popular game engines such as Unity, facilitating a smooth workflow that leverages a broad set of tools and assets.

Unreal Engine offers an array of features designed to maximize immersion and interactivity in VR environments. Advanced rendering technology enables the creation of photorealistic virtual spaces with high-quality lighting and texturing. The inclusion of real-time ray tracing further enhances the accuracy of light and shadows, contributing to the realism of the environment. Additionally, dynamic materials and animation systems enable natural movement for both characters and environmental elements, ensuring fluid and lifelike interactions.

UE5's OpenXR compatibility plays a crucial role in enhancing usability by supporting a broad spectrum of VR headsets and simplifying the setup process for VR projects. The VR template system provides a standardized foundation, reducing the complexity of project initialization and allowing developers to focus on content creation. Additionally, the engine's virtual authoring pipeline enables real-time previews, significantly improving workflow efficiency by allowing developers to see their changes instantly.

The Blueprint visual scripting system further simplifies VR interaction design by enabling users without programming expertise to implement complex functionalities. Technologies such as Lumen enhance visual immersion by delivering realistic lighting and reflections, while MetaHuman Creator provides high-fidelity character modeling for more sophisticated and lifelike avatars.

To support natural input methods such as hand gestures, hand tracking features—including integration with Meta Quest—allow for intuitive interactions without the need for controllers, offering a more immersive experience. Additionally, Unreal Engine's physics simulation ensures realistic object interactions, making movements and collisions within the virtual environment feel more natural and responsive.

Unreal Engine also supports In-Camera Visual Effects (ICVFX), a cutting-edge technique that integrates live-action footage with virtual environments. This technology utilizes real-time camera

tracking and LED lighting to create virtual worlds directly in-camera, eliminating the need for traditional green-screen compositing.

Furthermore, Unreal Engine provides robust data integration capabilities, allowing developers to incorporate real-world geographical data into VR experiences. Tools such as Cesium Ion facilitate the creation of virtual environments based on Google Maps data, further enhancing realism and contextual accuracy.

Recent updates to Unreal Engine have introduced greater flexibility for developers. For example, dynamically adjustable user interfaces (UIs) make it easier to customize VR interactions, while AI-powered voice and facial expression generation tools enhance character realism. Additionally, modularized components increase the scalability and reusability of projects, streamlining asset management across different VR applications.

To support both novice and experienced developers, Unreal Engine offers an extensive range of training materials and tutorials. Courses tailored to various skill levels provide structured learning opportunities, helping users explore innovative approaches to VR development. By allowing developers to see their work in a real-time environment, Unreal Engine significantly reduces iteration time and accelerates the development cycle.

Beyond visual fidelity, Unreal Engine's audio engine plays a crucial role in creating immersive 3D soundscapes. Sound effects dynamically reflect environmental factors such as size, material composition, and spatial structure, further reinforcing auditory immersion. Additionally, Unreal Engine includes tools for designing interactive objects and physical environments, ensuring that users experience a cohesive and responsive virtual world.

By integrating state-of-the-art rendering, physics simulation, real-time interactivity, and advanced data integration, Unreal Engine 5 establishes itself as a leading platform for VR development. Its compatibility with multiple VR headsets, intuitive scripting tools, and real-time visualization capabilities make it an essential tool for both entertainment and professional applications. As VR technology continues to evolve, Unreal Engine remains at the forefront, enabling developers to push the boundaries of virtual immersion and interactivity.

5. Conclusion

In recent years, virtual reality (VR) technology has rapidly expanded across various industries, including gaming, film, and education, offering immersive content and interactive experiences. VR animation enhances the realism of virtual environments, allowing users to engage more naturally with digital spaces. Unreal Engine's technical strengths—such as high-quality graphics, physical responsiveness, and real-time rendering—play a pivotal role in enhancing the immersion of VR spaces, enabling intuitive navigation and interaction.

Building upon these advancements, this research explores the key elements and principles of VR animated space design and proposes specific strategies to improve the user experience. By analyzing the technical features of Unreal Engine from multiple perspectives, this study aims to demonstrate how these capabilities contribute to VR spatial design and interaction.

First, real-time rendering technology in Unreal Engine enhances the accuracy of light and shadow, while photorealistic graphics add depth and texture to the environment, maximizing user immersion. In particular, real-time ray tracing improves lighting effects, making virtual spaces feel more lifelike and natural.

Second, hand-tracking and gesture-based interfaces facilitate natural interactions between users, characters, and virtual objects. Through hand gestures alone, users can grab, manipulate, or interact with objects, receiving immediate physical feedback within the virtual environment. This direct responsiveness significantly enhances the feeling of presence and control.

Third, realistic object interaction plays a crucial role in defining immersion. The way objects respond to user actions—such as the perception of weight, resistance, and movement—directly affects

user satisfaction. The more accurate these physical interactions feel, the more engaging the virtual experience becomes.

Fourth, auditory elements complement visual components, further enhancing the realism of the environment. 3D audio technology provides spatial awareness by accurately simulating the direction and distance of sounds, allowing users to perceive their surroundings more effectively. The combination of visual and auditory feedback deepens immersion and creates a fully immersive multisensory experience.

Fifth, In-Camera Visual Effects (ICVFX) technology bridges live-action footage with virtual environments, significantly enhancing the realism of VR animations. By utilizing real-time camera tracking and LED lighting, this technology seamlessly integrates real-world and virtual elements, creating a more natural viewing experience for users.

Finally, intuitive user interface (UI) design enhances the usability and navigability of VR spaces. Features such as visually highlighted key paths, points of interest, and breadcrumb navigation systems help users better understand and interact with virtual environments.

To further refine these design principles, future research should incorporate UX testing across diverse user groups to evaluate the applicability and universality of VR spatial designs. Understanding user behavior and preferences will be crucial in optimizing interactive elements for a broader audience.

Additionally, AI-driven technologies can be leveraged to enhance character realism. AI-powered facial expressions and behavioral animations can create more natural, emotionally resonant interactions, fostering deeper engagement within virtual worlds.

Moreover, integrating real-world data sources can increase environmental realism in VR spaces. For example, incorporating Google Maps data to reconstruct virtual cities or natural landscapes with high accuracy could unlock new possibilities for VR design, bridging the gap between digital and physical worlds.

This study presents a design framework aimed at optimizing immersion and interactivity in VR animated spaces. Unreal Engine's advanced technical capabilities play a fundamental role in achieving this goal, enabling users to experience virtual worlds in a more intuitive and engaging manner. Moving forward, these design principles are likely to set new standards for VR content creation, paving the way for more innovative, immersive, and inclusive virtual reality experiences.

Funding:

This work was supported by the Suncheon National University's Global University Project, 2024.

Transparency:

The authors confirm that the manuscript is an honest, accurate and transparent account of the study that no vital features of the study have been omitted and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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