Construction of Urban Landscape Visualization Design System Based on Virtual Reality

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Abstract. 3D landscape models as basic data have become one of the important contents of digital city construction. At present, the demand for 3D reconstruction of reality based on computer technology is becoming increasingly urgent. Establishing a single building or a group of buildings in a certain area is no longer sufficient to meet practical needs, and the construction of a 3D landscape model for the entire city has become the primary choice for various regions. Urban 3D modeling includes all elements of a city, including various buildings, urban greening, traffic road network, rivers, lakes and other water systems, bridges, sketches, etc. It can visually reproduce the appearance of this city in 3D on a computer, achieving a combination of reality and virtuality, and is an effective way to build a digital city. This article first analyzes virtual reality technology, elaborates on the relevant theories of this technology, points out the relationship between urban landscape visualization and virtual reality technology, and focuses on the technical issues in scene modeling and roaming engine implementation. Finally, simulation experiments are used to validate different algorithms, and the experimental results prove the feasibility of the rendering method proposed in this article in terms of efficiency.

Keywords: Computer-Aided CAD; Virtual Reality; Urban Landscape; Visual Design
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1 INTRODUCTION

Virtual reality technology has become one of the important technologies that currently affect people's lives and development. It is widely used in fields such as military, medical, education, architecture, and entertainment. The current computer-aided design (CAD) software does not have sufficient means to accurately map the measurement data of a given object on site. Bartonek and Buday [1] discussed the visualization quality of 3D architectural model. It analyzed the compatibility of the CAD system during the 2D model creation process. By reducing the topology code in the promotion function of CAD systems, it continues to effectively explore 3D models of buildings. Honcharenko et al. [2] created a summary plan for engineering networks using BIM based design software. And a digital 3D model for engineering network comprehensive planning was created using AutoCAD Civil 3D. The urban 3D visualization system is an important aspect of the application of virtual reality technology. It not only realizes the digitization and virtualization of the urban 3D landscape and surrounding environment, but also provides a forward-looking basis for urban planning and development. Contemporary architecture and urban planning aim to optimize environmental development, including acoustic aspects. Therefore, it is now necessary to support computer-aided design (CAD) tools. Jablonska and Czajka [3] determined the type and location of buildings to be designed based on the collected data, and developed corresponding design plans. This includes the location and diffusion pattern of the sound source, propagation path, and attenuation mode. It uses VR technology to establish virtual reality scenes, including elements such as buildings, roads, vegetation, terrain, etc., and makes corresponding adjustments and modifications based on the collected data. Since the concept of digital city was proposed, urban 3D landscape simulation systems have emerged, to the point where many people consider digital cities as urban landscape simulation systems. In fact, the scope of urban landscape simulation is much smaller, as it is an aspect of digital city construction. The construction of a digital city must have a three-dimensional urban landscape, and the three-dimensional landscape model, as the basic data, has become one of the important contents of digital city construction. Jiang and Zhang [4] used 3D visualization technology to model landscapes in 3D, helping students better understand and master design points. Through 3D visualization technology, different scenes can be restored to help students better understand the design effects, such as landscape effects from different angles and times. Jovanović et al. [5] collected theoretical data on spatial models that can be used for the development of urban 3D technology. One of the methods for obtaining data from such 3D city models is light detection and ranging, resulting in a fully developed photo realistic virtual 3D city model. It conducts urban planning and 3D virtual simulation through modern information technology for urban planning. Ecological nonlinearity refers to the non-linear changes in the internal structure and function of an ecosystem when faced with external disturbances. In urban landscape design, Liu et al. [6] utilized the non-linear characteristics of ecology to optimize the design of urban landscapes through adaptive management.

A simulation system based on virtual reality technology is to use computers to create an information environment with immersion, human-computer interaction ability, and help participants inspire ideas, thereby achieving the ultimate goal of participants acquiring knowledge and forming concepts in the virtual environment. Landscape simulation is an important manifestation of virtual reality technology and a direction of geoscience visualization research. With the development of remote sensing and geographic information systems (GIS), the means of obtaining two-dimensional flat data are gradually diversified, and the amount of data is also increasing day by day. Traditional landscape simulation and display typically use three methods: miniature models, renderings, and 3D animations. Their shortcomings are obvious. Miniature models can only display a bird's-eye view of the simulation area, and for large-scale landscape simulation, the model accuracy is difficult to guarantee. The renderings can only provide local static views.

2 STATE OF THE ART

Virtual reality technology is a new comprehensive information technology that gradually emerged at the end of the twentieth century. It combines the latest achievements of various information technology developments, such as computer graphics, digital image processing, multimedia, sensors, artificial intelligence, network and parallel processing, and involves many research and application fields. McAlister et al. [7] used 3D visualization technology to dynamically display landscapes, helping students better understand the design effect and engaging them in landscape design. Enable students to better understand the design effects, such as the landscape effects from different perspectives and time. It has the real-time expressive force for three-dimensional space, the naturalness of human-computer interaction operating environment and the immersive feeling for people. It not only creates a new field of human-computer interaction technology research, provides a new tool for intelligent engineering applications, describes a new method for visualizing a large number of data visualization in various projects, but also is extremely helpful for people to explore and discover various laws of world development and change.

At present, there is no unified standard for the definition of virtual reality technology, which is mainly divided into narrow and broad categories. Pochodyła et al. [8] applied the software technology of computer-aided design systems (CAD software) and geographic and three-dimensional CAD programs (AutoCAD) to urban landscape visualization exploration design. What people see in a virtual environment is a three-dimensional, colorful scene that changes with different viewpoints, what they hear is the sound in the virtual environment, and what they feel is the feedback force of the virtual environment, resulting in an immersive feeling. Pereira et al. [9] developed a descriptive 3D urban information model (CIM). This model can play a passive reality construction role in parameterized tools for urban 3D information modeling. The results indicate that simply using basic modeling tools for architectural landscape design is not enough. CAD 3D models can accurately provide map information that supports decision-making. Salehi et al. [10] improve the efficiency and accuracy of architectural design and construction through digital means. It adopts a method of using three-dimensional digital technology to establish a building information model. This method integrates and expresses architectural physical and geometric information from the perspectives of architectural design and engineering. Vilventhan et al. [11] utilized three-dimensional digital technology to create an information model of buildings. This information model can not only be used during the design phase, but also be adjusted and optimized during the construction and operation phases.

2.1 Urban Landscape Visualization Design

Generally speaking, there are two implementation methods for landscape simulation both domestically and internationally, mainly based on data modeling methods. One is landscape simulation based on graphical modeling, and the other is landscape simulation based on images. Wang [12] uses layers to represent nodes and child nodes. In CAD software, layers can be used to organize and manage graphic objects, such as walls, doors and windows, and other elements in building drawings. By drawing different colors or line types on different layers, the hierarchical structure of the tree can be clearly represented.

Graphics based landscape simulation is based on computer graphics. It abstracts and simplifies the real scene, and uses triangular patches to build a three-dimensional geometric modeling of the virtual landscape, such as terrain, buildings, vehicles, etc. The model not only has three-dimensional information, but also has realistic materials and textures. This type of modeling, also known as geometric modeling, generally adopts three methods: image and DEM overlay, vector data construction, and pure 3D construction. Xian [13] uses BIM technology to help urban landscape planners and architects deepen and optimize their plans. BIM technology can visualize and collaborate different design solutions, helping planners and architects better understand and express design intentions. And optimize and adjust through digital means. landscape construction drawing design was carried out, and the specific design process and currently unsolvable problems were summarized. Analysis of keywords and spatiotemporal distribution of domestic waterfront landscape research in the past 20 years by Xinyuan et al. [14]. It has grasped the dynamic process of domestic waterfront landscape research and clarified the development context. This provides academic information with scientific basis and valuable theoretical reference for research related to waterfront in China. Yang and Yang [15] proposed and designed an urban landscape visualization simulation system based on 3D simulation technology to address the issues of inaccurate modeling and high system costs in urban landscape visualization.

Building Information Modeling (BIM) and Hybrid Reality (MR) technologies can help build real-time data transmission, enabling data sharing and real-time collaboration between different parts of building engineering. Zhao [16] analyzed the window display design model of coastal urban space. By analyzing the ecological and environmental benefits of different urban characteristics, it is believed that the design of urban waterfront spaces is becoming increasingly important in urban planning and construction. Zhao et al. [17] used simulation and virtual reality technology to preview different parts of the building before planning and construction, in order to better design and optimize it. Because panoramic images are discrete, the scene will jump when the viewpoint is transferred, so a series of technologies such as view deformation and image smooth transition are required. The urban landscape simulation system based on graphical modeling mainly consists of two parts: scene model and roaming engine. Figure 1 depicts the structure and development process of the system.

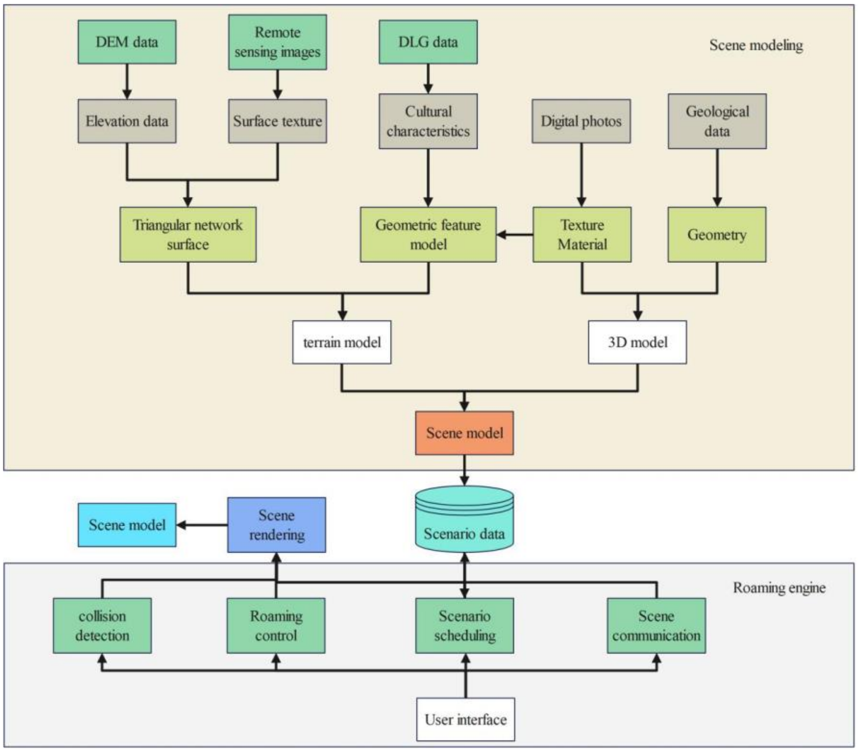

Figure 1: Structure and development process of urban landscape simulation system based on graphical modeling method.

The image method can generate high-quality landscape simulations without the need for complex geometric modeling, and the running effect is independent of the complexity of scene elements, with low hardware requirements. However, obtaining basic data requires real landscapes, and when real landscapes do not exist or are still in the planning stage, virtual scenes cannot be constructed. In addition, the scene is composed of images, and the virtual objects inside are also two-dimensional objects, making it difficult for users to interact with these objects. This type of landscape simulation system is also difficult to integrate with GIS or other systems, which limits its application.

2.2 Visualization of Urban Landscape Based on Virtual Reality

To build an urban landscape visualization design system based on virtual reality and CAD, it is first necessary to analyze the required systems to determine the required software, hardware, and functional requirements. Based on CAD technology, modeling is carried out based on elements such as urban terrain and buildings in reality. You can use 3D modeling software such as SketchUp, 3ds Max, etc., as well as CAD software for modeling. Import 3D modeled urban landscapes into virtual reality platforms such as Unity and Unreal Engine, allowing users to access virtual reality environments through devices such as VR helmets or handheld devices for operation. At the same time, the urban landscape data in the virtual reality platform is integrated with other data, such as meteorological data, traffic data, etc., to provide users with more detailed and accurate simulations. Currently, interaction between users and virtual landscapes has been achieved. Users can switch perspectives, roam, simulate natural disasters, modify buildings, and other operations to achieve visual design of urban landscapes. Output user design results to different media, such as images, videos, PDFs, etc. Through the above series of technologies and operations, we can build a visual design system for urban landscapes based on virtual reality and CAD, providing more intuitive visual references for urban planning, architectural design, and other related fields. The design of urban 3D visualization system mainly starts from aspects such as 3D model construction, program interaction, and browsing scenes. Firstly, construct the main objects in the real environment based on the actual situation and existing conditions, and establish a virtual environment that includes buildings, roads, flowers, plants, trees, etc; Next, import each virtual object into the development tool for program interaction; Then browse the scene according to various goals to ultimately achieve three-dimensional visualization of the city. The structure of the entire system is shown in Figure 2, and the specific implementation process is as follows:

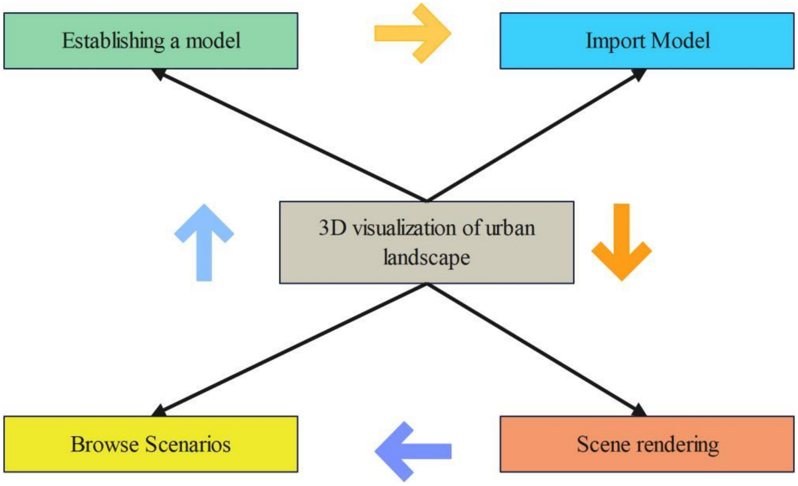

Figure 2: Urban landscape visualization design system.

3 METHODOLOGY

3.1 Rendering Model PBR Based on Physical Lighting Process Simulation

Compared to the process of using empirical formulas to fit lighting shading results in traditional rendering models, the PBR rendering model places more emphasis on simulating optical processes such as specular reflection, subsurface scattering, and Fresnel effect in scene lighting, thereby establishing a simulated physical lighting model in the rendered scene. Due to the physical correlation of material parameter values, scene designers can set parameters based on the actual data of the material when creating it, greatly reducing the instability in the art process. In addition, due to the standardization of PBR rendering in describing the rendering process, the universal ability of material rendering parameters in various rendering environments has also been greatly improved compared to traditional methods. In the entire PBR rendering process, various operations on the rendered content can be divided into three areas: physics-based materials, physics-based lighting, and physics based adaptive cameras. In subsequent PBR studies, its simplified expression is often used:

$$L_0 = L_e + \int_\Omega f_r \cdot L_i \cdot (\omega_i \cdot n) d\omega_i \tag{1}$$

In Equation 2.2, Ω represents the incident range of light on the surface of the rendering object, Li and Lo represent the incident and outgoing intensities of light within this range respectively, Le represents the self-luminous radiant intensity of the rendering object, and fr is the proportion term of incident light and outgoing light, which is generally simulated using the bidirectional reflectance distribution function model (BRDF) in academia.

3.2 Lighting Model of BRDF Based on Physical Rendering

In the process of PBR rendering, the most important thing is to calculate the surface color of the rendered object based on its angle and distance from the light source and camera, which is the physics-based shading (PBS) process. On this basis, Disney Studio began to focus on rendering efficiency and adaptability, introducing intuitive and normative principles in the shading workflow, and constructing a BRDF model based on Disney's principles. Because this model has excellent rendering expressiveness and development and design efficiency, it quickly became the theoretical framework and foundation of almost all subsequent realistic rendering models in the graphics community.

The relationship between the incident light, reflected light, incident angle, and reflection angle on the normal and tangent planes of the object surface becomes a key parameter of BRDF; Due to the special sensitivity of human eyes to light, we can see objects through the reflection and transfer of light on them; The bidirectional reflection distribution function (BRDF) can very well describe the cleverness of light on an object. The reflected light is directed towards both the observer and the light source distributed on both sides of the normal, allowing people to visually see better object simulation effects in computer and other simulation environments, as if real objects exist. The calculation method for the BRDF model is:

$$L_0(v) = L_e + \int_\Omega p(l,v) \otimes L_i(l)(n \cdot l) d\omega_i \tag{2}$$

The simplest BRDF is the Lambert model, which is represented by (n · l) in practice. But in reality, it belongs to a term of the reflection equation, while Lambert is a constant:

$$Plambert(l,v) = \frac{C_{diff}}{\pi} \tag{3}$$

In an H-dimensional scene, there are H types of light sources: Point type, Directional type, and Spot type. These local light sources are all "precise light sources" with determined sizes and directions. Since the calculation is based on the illumination at the surface point, the attenuation from the light source to the surface is not considered. Therefore, precise light sources can be represented by two parameters: color C and light source direction vector l. Introducing a micro surface light source into a general BRDF yields the limit when approaching 0, which is:

$$L_0(v) = \pi p(l_c, v) \otimes C_{light}(n \cdot l_C) \tag{4}$$

In general research, the BRDF model's representation of the model depends on the micro-surface theory used. This theory abstracts the surface of the rendered object in three-dimensional space into a rough surface composed of numerous small surfaces with different orientations that meet the optical plane standards, as shown in Figure 3.

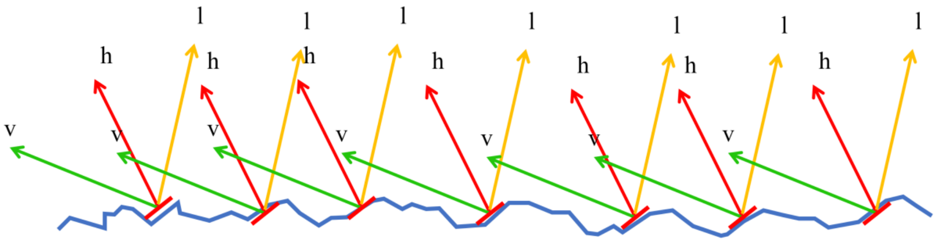

Figure 3: Distribution state of geometric terms in the micro-surface theory of the BRDF model.

The BRDF function can be expressed as:

$$p(l_c, v) = \frac{F(l \cdot h)G(l, v, h)D(h)}{4(n \cdot l)(n \cdot v)} \tag{5}$$

Where, F is the Fresnel reflection of the effective micro-plane, G is the proportion of the effective micro-plane that is not occluded, D is the normal distribution function, and is the correction factor, which is used to correct the difference in the number of discretization local spaces transferred to continuous global surfaces. Fresnel reflection acquisition:

$$F(c, l, h) = c_{spec} + (1 - c_{spec})(1 - l \cdot h)^5 \tag{6}$$

Among them, Cspec is the specular color. The commonly used reflection equation can be expressed as follows:

$$L_0(v) = (C_{diff}(n \cdot l_c) + c_{spec}(r_v \cdot l_c)^{\alpha}) \otimes c_{light} \tag{7}$$

As mentioned earlier, (n · lc) actually belongs to the reflection equation, not Diffuse, so it can be modified as:

$$L_0(v) = (C_{diff} + c_{spec}(r_v \cdot l_c)^{\alpha}) \otimes c_{light}(n \cdot l_c) \tag{8}$$

The form of the Blinn Phong model is similar to it, but it uses a more physically meaningful h quantity, which is the m quantity of the micro-face. Changing to the Blinn Phong model yields:

$$L_0(v) = (C_{diff} + \pi c_{spec}(n \cdot h)^{\alpha}) \otimes c_{light}(n \cdot l_c) \tag{9}$$

From the Lambert theorem mentioned earlier, it is found that the Diffuse term is already the same as physics based:

$$C_{diff} = \pi \frac{c_{\mathrm{diff}}}{\pi} \tag{10}$$

The rest is the Specular term. If we only look at Specular, the previous formula looks like this:

$$L_0(v) = \pi(n \cdot h)^{\alpha} c_{spec} \otimes c_{light}(n \cdot l_c) \tag{11}$$

Compare Microfacet Specular:

$$L_0(v) = \pi \frac{D(h)G(l_c, v, h)}{4(n \cdot l_c)(n \cdot v)} F(c_{spect}, l_c, h) \otimes c_{light}(n \cdot l_c) \tag{12}$$

4 RESULT ANALYSIS AND DISCUSSION

4.1 Implementation of Rendering Framework

Because the final images projected onto the screen in a 3D scene are all 2D planes, with a certain total number of pixels, theoretically, we only need to handle the visual effects of the final visible pixels (such as lighting and shadows), which greatly improves efficiency, On the contrary, normal forward rendering The process involves cutting various spatial points and processing them, with a much greater amount of processing than what we ultimately see. Because there are a large number of H-corner surfaces that obstruct each other or a complex H-corner network, due to the distance being too far, only a few pixels in size can be seen. Performing lighting and shadow calculations on these blue corner surfaces will waste a lot of resources. From this point of view, the advantage of delaying this process is self-evident. It first takes the camera The spatial point rasterization is converted into screen coordinates and then processed to calculate the number of pixels that can only be accommodated by the view resolution. Since the processing process has been placed later, the parameters required for processing must also be brought to the later process, and MRT must be used to complete this work in the delivery. The information to be transmitted using MRT generally includes: spatial position information, normal information, highlight information, AO coefficient, diffuse color, self-illumination, material number, etc. The delayed rendering pipeline can be divided into four stages; Geometry, Lighting, Composition, Post Processing, where the Post Processing stage belongs to the later stage of image processing, which is the same as traditional forward rendering.
Experimental Data and Analysis

Firstly, select different paths for algorithm validation of rendering efficiency. A total of 8 paths were selected and different algorithms were used for rendering efficiency comparison. Triangle intersection algorithm is the basis of optimization algorithm, so only three optimization algorithms are compared in line chart. The horizontal axis in Figure 4 and Figure 5 represents the three different algorithms used, the vertical axis represents the time consumption of the algorithm, and the broken line represents the four different paths under the corresponding model.

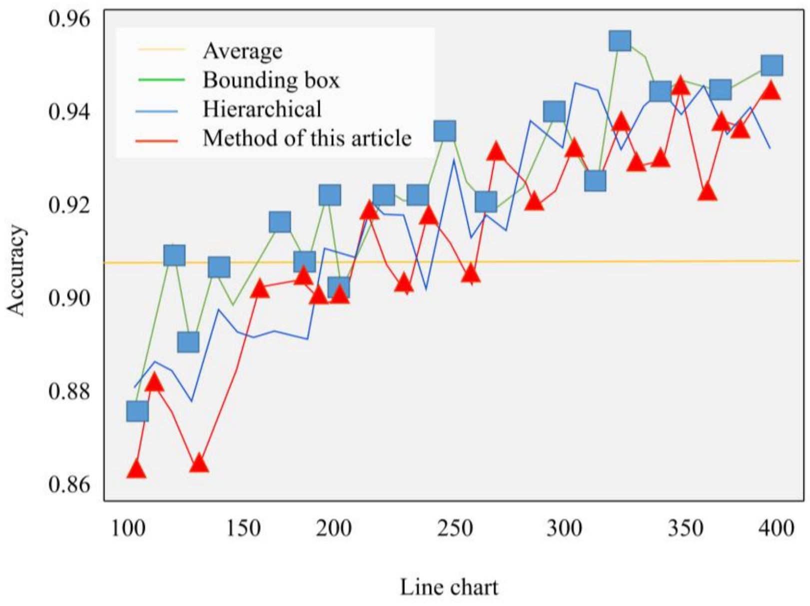

Figure 4: Comparison of experimental data with line chart.

The time cost of the three algorithms in Figure 4 shows a decreasing trend, with slight performance improvement. Due to the large number of components in Model 1 and the small number of triangular patches for a single component, the ray picking algorithm based on grid space partitioning improves performance by approximately 10%.

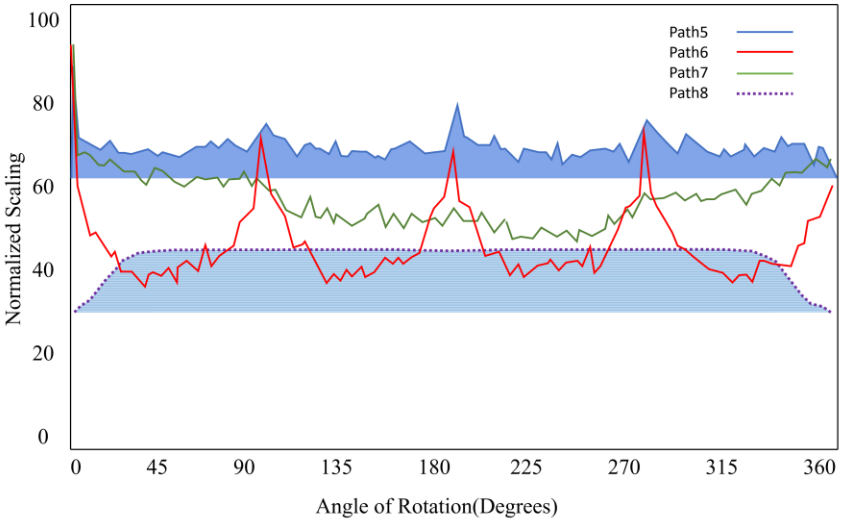

Figure 5: Comparison of experimental data with line chart.

In Model 2, the number of components is relatively small and the number of triangular patches per component is relatively large, which can better leverage the optimization algorithm. From Figure 5, it can be seen that the ray picking algorithm based on grid space partitioning can improve performance by up to 20%, with significant results.

In order to verify the efficiency of the 3D scene rendering proposed in this article, the experiment takes the average time cost of the cone removal algorithm in the same scene as the evaluation criterion, that is, the average time cost of the algorithm completing multiple cone removal detection for all bounding boxes in the scene. Where n is the number of times the algorithm has completed the detection of all bounding boxes in the scene. Ten operations including rotation and translation were used for algorithm comparison. The experiment records the completeness elimination time cost and the transitional elimination time cost. The completeness elimination time cost refers to the average time cost of the algorithm when all bounding boxes are eliminated by the same plane and the corresponding rotation and translation operations continue on this plane. The transitional elimination time cost refers to the average time cost of the algorithm from not removing all bounding boxes to using geometric operations to eliminate them all.

It can be seen from Figure 6 that in the case of completeness rejection, the performance of the translation operation is optimized in the case of right translation, up translation, down translation and back translation, of which down translation and back translation are the most optimized. Negative optimization occurs during left and front translation. The reason is that the basic algorithm uses a sequential traversal of the six planes of the viewing cone and the bounding box for elimination detection. The traversal order is right plane, left plane, lower plane, upper plane, far plane, and near plane. When the visual cone is moved to the left, right plane detection is used. In the basic algorithm, it is equivalent to changing from detecting the original six planes to only detecting the first plane. However, considering the time cost of various operations, the overall algorithm performance has still been significantly improved. Translational transitional culling simulates the camera's movement from observing all scenes to not observing the scene at all. The optimization result of translation transitional culling is the same as that of completeness culling, and the performance improvement is not as high as that of completeness culling.

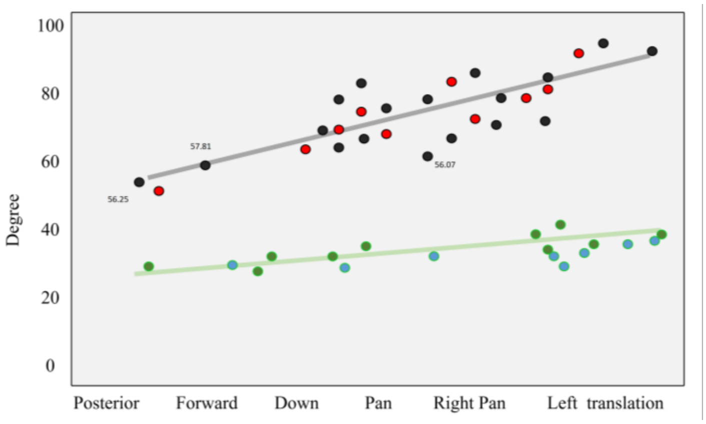

Figure 6: Comparison diagram of completeness rejection time of translation operation.

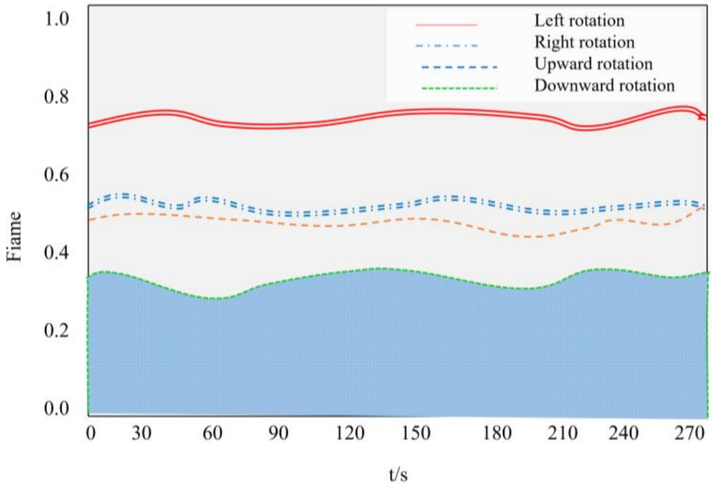

Figure 7: Comparison diagram of completeness rejection time of rotation operation.

As shown in Figure 7, the four directions of rotation operation have improved performance in the case of completeness rejection and transitional rejection. The time cost optimization of completeness elimination is higher than that of transitional elimination, in which the optimization effect of up rotation and down rotation is the best, reaching 47.7% and 57.7% respectively.

Finally, analyze the rendering effect using scenes from different viewing distances. Figure 8 shows the frame rate comparison results between viewpoint 1 and viewpoint 2 rendering methods. The results indicate that different rendering methods have different impacts on CPU load. Usually, the CPU load of viewpoint 1 is relatively high because it requires processing more geometric and material information. Viewpoint 2 can reduce CPU load by only processing the geometric and lighting information of the camera view. In summary, the frame rate comparison between viewpoint 1 and viewpoint 2 rendering methods typically depends on multiple factors such as the graphics card model used, hardware specifications, complexity of the rendered scene, and specific implementation methods. When choosing a rendering method, it is necessary to comprehensively consider these factors and choose the method that best suits your needs.

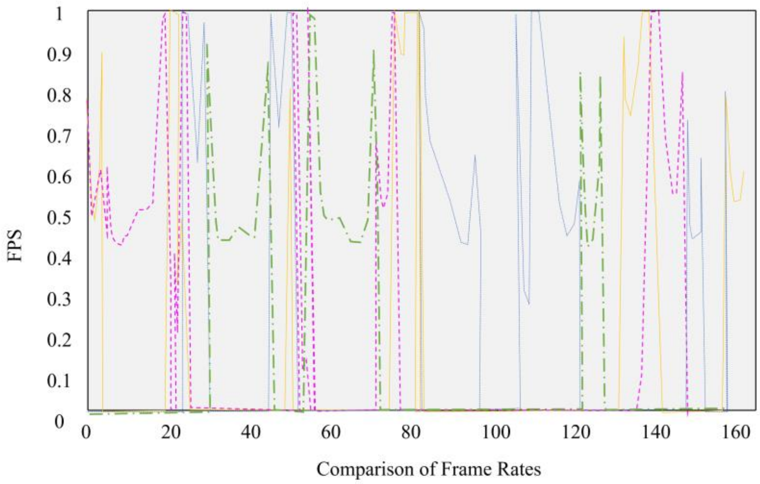

Figure 8: Comparison of frame rates between viewpoint 1 and viewpoint 2 rendering methods.

5 CONCLUSION

Urban landscape simulation based on virtual reality technology is a method of simulating urban landscapes using virtual reality technology. It can interactively experience urban landscapes in a virtual reality environment, and also analyze, evaluate, and optimize urban landscapes. By simulating real 3D scenes and objects, users can interact through appropriate devices, making them feel immersive. In urban landscape simulation, this article utilizes virtual reality technology to simulate landscape elements such as buildings in the city, and conducts dynamic interactive experience analysis on these elements. The focus is on the technical issues in scene modeling and roaming engine implementation. Finally, simulation experiments are used to verify different algorithms, and the experimental results prove that. The physics based BRDF algorithm proposed in this article has shown good performance in urban landscape visualization rendering tasks based on virtual reality.

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