Three-Dimensional Digital Modeling and Simulation of Virtual Reality Scene Using CAD Data

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Abstract. This paper proposes a method to apply CAD (Computer Aided Design) model simplification and conversion to a virtual system. We export the existing CAD model to an intermediate format and analyze it to obtain mesh data, and then use a new classification-based adaptive simplification algorithm multi-resolution simplification is performed on the mesh, that is, it is classified according to the characteristics of the CAD mesh model, and then targeted simplification is performed on the basis of the classification. The simplified 3D model is written into an industry standard format after adding materials and textures. Finally, the model generated by the above method is visually roamed in the VR visual real-time management system, and the simulation obtains more realistic and satisfactory results, indicating the above method is effective. This article focuses on the research of distributed virtual environment modeling. It systematically studies the key technologies, theories and methods of VR modeling mechanism, communication mechanism, and time synchronization mechanism for distributed virtual support environment, and realizes modeling tools. On this basis, a virtual environment analysis model is established for specific applications and a CAD application system is developed. From the perspective of virtual reality modeling, based on the needs of visual modeling, combining our existing conditions and some existing development tools, we have developed an OpenFlight system that can quickly generate virtual reality visual requirements based on existing product CAD models. The test in the virtual environment verifies that the model can better meet the real-time rendering requirements, and the visual effect is more reasonable.

Keywords: CAD; virtual reality; three-dimensional digital modeling; simulation
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1   INTRODUCTION

Virtual Reality (VR for short) is a high and new technology that has emerged in recent years. It is a comprehensive integrated technology involving computer graphics, human-computer interaction technology, sensor technology, artificial intelligence and other fields. It is realistically generated by computers with virtual three-dimensional world, through the sensory simulation of vision, hearing, touch, etc., allows users to participate in it, as if being on the scene, real-time, and unlimited observation of the world in the three-dimensional space [1]. In a nutshell, virtual reality is a new way for people to visualize and interact with complex data through computers. Compared with traditional man-machine interfaces and popular window operations, virtual reality has made a qualitative leap in technical thinking [2].

Before designing a certain model, industrial modeling software, such as CATIA, AutoCAD, etc., is generally used to draw various parts in the system. Therefore, directly simplifying these drawn CAD models according to certain methods will improve greatly. The efficiency of development can quickly get the virtual reality scene model, but the virtual reality scene simulation model and CAD model are very different [3]. The CAD model is characterized by high accuracy and contains a large amount of engineering design information. After the CAD model expressed in accurate mathematical form is converted to the VR polygonal patch model format, the number of patches is often quite large, which cannot meet the real-time rendering requirements of the VR system. In many cases, a high-resolution model is not always necessary, and there is a trade-off between the accuracy of the model and the processing time, so the model must be simplified and other processing [4].

This article starts with the construction of 3D spatial database and the system integration of CAD 3D controls, and focuses on the use of CCGIS virtual reality system to build 3D spatial database, and the use of CAD 3D controls to develop a 3D geographic information system with browsing and interactive functions. This paper performs post-processing on the building texture collected on site, and performs correction on the original geometrically distorted image, while removing the irrelevant information on the image, providing a real mapping texture for the building, and converting the surveying data (CAD file) into the CCGIS system as the basic data for VR 3D modeling. At the same time, a set of virtual scene browsing system was developed using 3D control technology. The VR system includes scene flying browsing and ground walking browsing, realizing virtual scene browsing. In this system, the user can freely observe any angle in the CAD visual scene and perform real-time query, and includes the following functions: three-dimensional roaming function, query function, measurement function, analysis function.

2   RELATED STUDIES

American scholars began the study of 3D virtual cities as early as the 1980s, and the United States put forward the call for "digital community construction". About 60 cities are developing and constructing "digital cities" for demonstration project of "digital community" [5]. Zheng et al. [6] used three-dimensional simulation technology, GIS technology, cellular automata (CA) and space syntax and other spatial analysis methods to analyze the old city in London. The protection area and some important areas carry out urban system design, and provide functions such as network interaction, online public participation and discussion interaction. The system provides spatial analysis and auxiliary decision-making analysis for urban planning and construction. Research institutions such as Rostock in Germany have established urban prototypes system, and provide related query, three-dimensional display, spatial analysis and other functions. In order to better reflect the urban characteristics and real landscape of the study area, without affecting the operation of the system. Cui et al. [7] used CAD-based three-dimensional modeling method to carry out the detailed modeling of the characteristic and landmark building models of the research area and the digital city 3D landscape modeling method based on the 2D GIS modeling method to quickly construct the 3D model of ordinary buildings. Under the existing platform, the existing

building base projection distribution data and the vectorized data of the room distribution on each floor inside are used to realize fast and batch large-scale three-dimensional outside the building through the rule file drive.

In order to simplify the mesh model, Klerk et al. [8] first proposed a mesh simplification method based on vertex removal. It first uses the local geometry and topology information of each vertex of the grid to classify the vertices of the grid, and then determines whether the vertex should be deleted according to the evaluation criteria of different vertices. If the vertex is deleted, the recursive ring segmentation method is used to triangulate the hole left after the vertex is deleted. Wang [9] gave a model simplification method based on triangle removal. The method first calculates the curvature of all vertices in the model, and then determines the weights of all triangles by the curvature of the vertices. The triangle with the smallest weight is removed, and finally re-triangulates the area left by the removed triangles, and calculates weights for all newly introduced triangles. Zhang et al. [10] used the energy function optimization method to simplify the model. By introducing distance energy, representation energy and spring energy, the simplified model became an optimized approximation of the original model. Experiments show that the effect of this method is very satisfactory, but the algorithm efficiency is low. The mesh simplification and surface fitting technology are combined to generate a simplified model of the regular quadrilateral mesh represented by the Bezier surface. Some scholars have proposed a simplified model automatic generation method of the regular quadrilateral mesh model. In addition, some scholars expressed the model as a triplet composed of the above three attributes by sampling the position, curvature, normal direction and color of the model vertices, and then simplified it according to the predetermined screen pixel error.

Some researchers have proposed a viewpoint-based triangle mesh model simplification method. This type of algorithm selects a different level of detail model for the area where the mesh model is located inside and outside the viewing cone. The level of detail model refers to the establishment of a series of simplified models and related thresholds by using grid model simplification technology for different degrees of approximation given an initial model. When in use, the same object is described with different precisions according to different requirements. The level of detail model can not only ensure a more realistic visual effect, but also improve the generation, display and operation speed of complex scenes [11].

3 3D DIGITAL MODELING AND SIMULATION OF VIRTUAL REALITY SCENE BASED ON CAD DATA

3.1 Virtual Reality Visual Space Architecture

The so-called multi-sensing refers to in addition to the visual perception of general computer technology, there are auditory perception, force perception, tactile perception, motion perception, and even taste perception, smell perception, etc. The ideal virtual reality technology should have all human perception functions. Due to the limitations of related technologies, especially sensing technologies, the current perception functions of virtual reality technology are limited to vision, hearing, force, touch, and motion. Figure 1 shows a schematic diagram of the virtual reality visual space architecture.

Generally speaking, a complete virtual reality system consists of a virtual environment, a virtual environment processor with a high-performance computer as the core, a visual system with a helmet-mounted display as the core, an auditory system with speech recognition.

$$X[t] = \{t \in R \mid x(1), x(2), ..., x(t)\} \tag{1}$$

In the application of CAD/CAM, specific engineering operations are often carried out on the basis of geometric models. In the entire product design and manufacturing process, the technologies of shape design, engineering analysis, process design, and numerical control programming are all

related to geometric models, which provide basic information for design, analysis, calculation, and manufacturing. The geometric model is a tool to describe and record the geometric shape of the design object in the CAD/CAM system.

$$y(x) = \pm\sqrt{x^2(s) + x^2(s)\sin^2\theta + x^2(t)\cos^2\theta} \qquad (2)$$
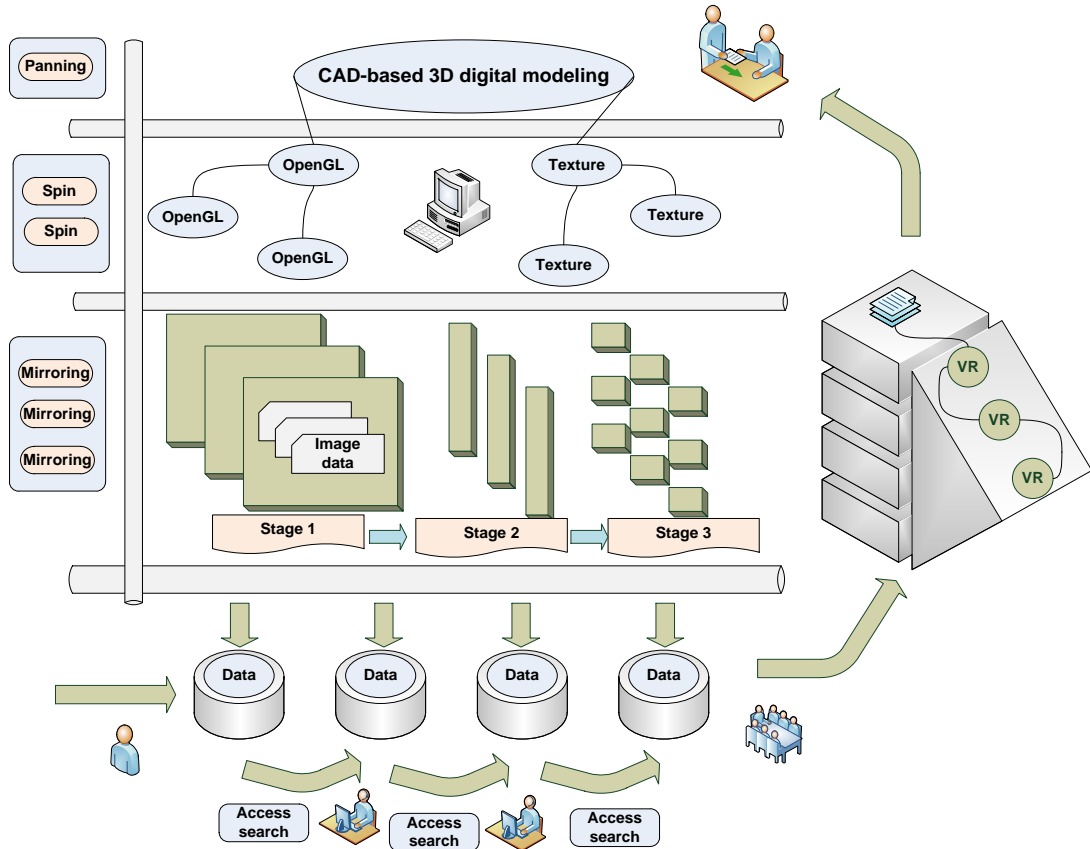
Figure 1: Schematic diagram of virtual reality visual space architecture.

There are generally three methods to build 3D models of various scenes and objects in the virtual environment. The first method is to manually draw a 3D model using 3D modeling software. On the one hand, we need to be proficient in various painting techniques, and on the other hand, we need to be proficient in the methods and techniques of using various three-dimensional modeling software. This method is most commonly used, but the modeling is cumbersome and the work intensity is high.

$$C = \{x(k) \mid x(k) = (i(k), j(k)), k = 1, 2, 3, ..., m, 0 < i(k) < j(k) < m\} \qquad (3)$$

In the mesh model, by judging the distance threshold from the vertex to a certain plane, if it is determined that the point is approximately coplanar with its neighboring triangles, and deleting the point does not affect the topological structure of the model, then this point can be deleted. At the same time, all other faces connected to the point should be deleted. Finally, the holes created by deleting vertices should be re-triangulated and repeat the above steps until all vertices have been processed.

$$Cor = \sum_{i=1}^{n}(x(i)-\bar{x})(\overline{x(i)}-x) / \sqrt{\sum_{i=1}^{n-1}(x(i)-\bar{x})^2 \sum_{i=1}^{n-1}(\overline{x(i)}-x)^2} \qquad (4)$$

For the method based on vertex removal, the advantage is that the simplification speed is faster and the memory usage is small, but due to the re-triangulation caused by the cavity, the local surface will be projected on a plane, so for the model that maintains the smoothness of the surface. The simplification algorithm for face merging refers to finding those approximately coplanar faces in the mesh model, then merging these coplanar faces together to form a new face together, and finally triangulating the new face. Therefore, the simplification of the model is obtained by reducing the number of patches. The main problem of this type of algorithm is how to judge the coplanarity of the faces. Generally, the hyperplane method is used to solve this problem, and a more reasonable method of retriangulation is provided.

$$\begin{cases} x'(i) = x(i) - k(x) \\ y'(i) = y(i) - k(y) \\ z'(i) = z(i) - k(z) \end{cases} \qquad (5)$$

The simplification algorithm of face folding refers to the introduction of a new vertex, and then for the new point, the face in the mesh model is folded. The main problem of this type of simplified algorithm is to determine the coordinate position of the newly introduced point and how to select the surface to be folded, usually by setting the weight of the triangle, sorting by the weight, and folding the triangles according to the weight. For the setting of weights, the common method is to use the product of equal angle or curvature and the product of triangle area to calculate the weight.

3.2 CAD-Based 3D Digital Modeling

OpenGL can read the image data provided by the application in various formats. By calling PixelStore, we can specify the parameters that define how to store the image data in the memory. The purpose of the OpenGL image processing pipeline is to convert the three-dimensional description of the object into the two-dimensional image that is displayed suspiciously. In order to complete the conversion from the three-dimensional to the two-dimensional image, it is necessary to perform coordinate conversion.

$$T = \begin{bmatrix} \sum_{i=0}^{n} x^2(i) & 0 & 0 \\ 0 & \sum_{i=0}^{n} x(i)y(i) & 0 \\ 0 & 0 & \sum_{i=0}^{n} y^2(i) \end{bmatrix} \qquad (6)$$

The conversion here includes basic transformation and projection transformation. The former refers to the four transformations of "translation", "rotation", "transformation ratio" and "mirror"; the latter refers to orthographic projection and perspective projection. This transformation provides great flexibility for applications.

$$(x(t), y(t), z(t)) = \sum \alpha(i)(x(i), y(i), z(i)), i = 0, 1, 2, ..., n \qquad (7)$$

In this operation, the texture coordinates associated with the fragment will be used to access a graphic called "texture memory". In the memory area, OpenGL defines many states to affect how to access the texture and how to apply the retrieved value to the current fragment. The other operations that occur in these sections are fogging and color summary.

Image index	Viewpoint elevation/m	Standard deviation	Texture deviation
1	9.92	0.42	0.65
2	9.19	0.13	0.73
3	9.61	0.72	0.52
4	8.96	0.32	0.71

Table 1: CAD-based virtual reality 3D image data parameter distribution.

Table 1 shows the parameter distribution of CAD-based virtual reality 3D image data. By calculating the distance between the geometric shape and the observer, different models are called in the virtual environment to increase the speed of virtual environment generation, and at the same time ensure the accuracy of graphic display when approaching the observer. On this basis, the progressively refined multi-level-of-detail model uses a topology-variable mesh to simplify the model, and uses vertex merging and vertex splitting to achieve smooth conversion between models of different levels of detail, so that the same model has different levels of detail. The CAD method refers to the method of converting the model into a virtual model used in a virtual environment based on an existing three-dimensional model and combined with related technologies. Existing three-dimensional geometric models are generally based on the geometric models established by the solid modeling function of. According to the position of the object model in the scene and the complexity of the object, it is a technology to determine the same object with different levels of detail, and to improve the rendering speed while maintaining the visual effect. For the geometric shapes to be virtualized in the virtual environment, the geometric model is generated by the modeling method. The model can be a surface polygon represented by a linear equation, or a curved surface represented by a flat grid. Through the identification of the model, the movement and deformation of the entire model can be realized.
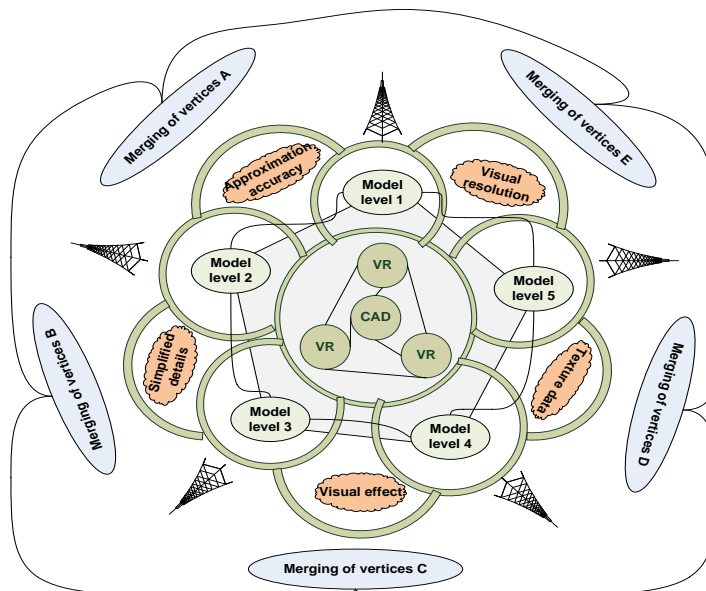

Figure 2: CAD-based virtual reality 3D digital model construction.

Because the image has the advantages of real shape and small amount of data, objects that do not need to be manipulated in the virtual environment can be generated by image-based modeling methods. Figure 2 shows the CAD-based virtual reality 3D digital model building. Compared with the original model, each model retains a certain level of detail. When the computer generates the scene, it chooses models with different degrees of precision according to the distance between the object and the viewpoint. The calculation amount of the view in the far-sighted range is quite small. The establishment of a multi-level detail model can be generated by controlling the normal angle between the two vertices of the folded edge, and different simplified conditions generate a level model of different details. The model generates 4 models with different approximation accuracy, the coarser model is used when the distance is farther, and the finer model is used when the distance is closer. After getting multiple models with different levels of detail, we can set different transfer distances for each model in real-time simulation to simplify the model instead of the original model, save drawing time and reduce the burden on the system. If the viewpoint is far away from the model object, then the number of polygons contained in the model will be reduced at this time. The accuracy of the model is not required to be very good. As the distance increases, the level of detail will gradually become more complicated. The number should be increased accordingly, so as to maintain the best visual effect, but also to meet the real-time requirements of the model in the VR system.

4   ANALYSIS OF RESULTS

### 4.1   Three-Dimensional Digital Model Simulation of Virtual Reality Scene

OpenFlight is one of the most popular standard file formats in the field of visual simulation. It is powerful, and using creator can quickly, efficiently and optimally realize polygon modeling, vector modeling, and accurate generation of large-area terrain. We use CASS software to process the original line drawing data in layers, extract preliminary modeling data and post-term texture data, give full play to the secondary development function of AutoCAD 2008. We use development tools to create CAD real-time extension functions, and apply it to AutoCAD 2008 batches to form a three-dimensional solid model. We import the three-dimensional solid model into 3DMAX, use the MAXScdpt scripting language to write the 3DMAX script, and perform batch processing on the three-dimensional solid model to form a fine model. Finally, we import the 3D fine model into ArcGIS Engine for advanced editing, establish a 3D publishing platform system, and realize the basic browsing, attribute query, measurement functions, spatial analysis and planning analysis and decision-making functions of the system, which are finally used to assist decision-making.
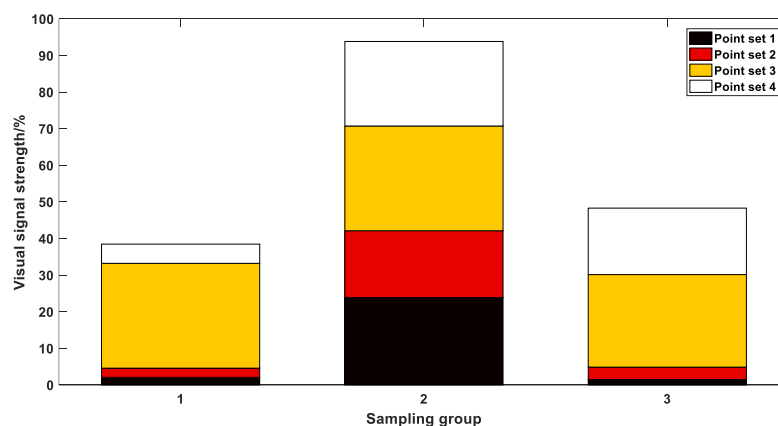
Figure 3: The histogram of the signal intensity of the virtual reality scene.

Figure 3 shows the histogram of the signal strength of the virtual reality scene. In order to improve the anti-noise ability of the scene, the algorithm embeds the same scene signal multiple times into the vertex coordinates of different parts of the point set model. To this end, the scene signal c is copied 3 times (c is the frequency, and c=3 can be used). In the detection and extraction, the same algorithm is used to obtain the points that have been embedded in the scene from the original point set, and then the point set model to be detected is resampled to obtain a point set with the same size as the original point set model. Since multiple sets of scenes are embedded in different parts of the point set model, when extracting scenes, as long as a complete set of scene signals can be obtained, the previously embedded useful information can be obtained.
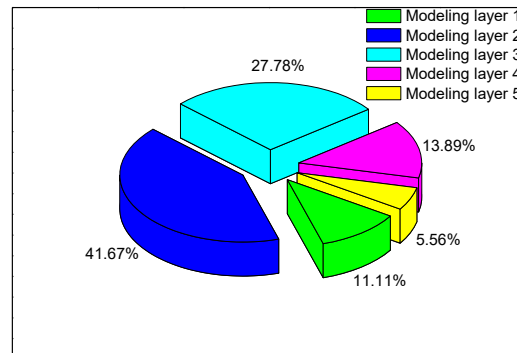
Figure 4: Hierarchical fan diagram of the virtual reality visual model based on CAD.

Figure 4 shows the hierarchical fan diagram of the CAD-based virtual reality visual model. It can be seen that the bunny point set model was tested in 5 different situations, and the vertices left by shearing were 27.78%, 41.67%, 5.56%, 13.89%, and 11.11% of the original model. The results show that when most of the vertices in the point set model are cut off, the visual information can still be extracted correctly, which shows that the algorithm has strong anti-interference ability. We first extract the initial modeling layer and auxiliary modeling layer, and generate vector data to intercept the surface part of the feature image; then perform preprocessing such as cropping, splicing, and enhancement of the remote sensing image data to intercept the top surface of the building model. We use Photoshop software corrects the digital image to get the orthophoto, then modify the size and size, rename it, and use it for post-texture mapping. The construction of the architectural model is mainly done in AutoCAD in batches, and the texture and fine model construction are mainly completed in 3DMAX. With the help of the ArcGIS Engine secondary development platform, AutoCAD 2008 and 3DMAX software are used for three-dimensional modeling, and 3ds files are generated, and the three-dimensional object model is integrated with the GIS platform in the form of point elements, and the three-dimensional scene is imported in ArcGIS Engine to achieve.

4.2 Analysis of Experimental Results

The 2D data used by the CCGIS software to construct the 3D virtual model is a DXF format file generated by AutoCAD, but the DXF 2D data that CCGIS can recognize is limited, and it can only recognize some simple plane shapes, so AutoCAD data is used. The contour of the figure is represented by a polyline, the closed contour must be completely closed, and the linear elements must be continuous. Therefore, we must organize and layer the AutoCAD plane data as continuous closed polylines, and assign the elevation field in the plane data attribute to the corresponding height. Digital elevation model (abbreviation DEM) is a digital representation of regional ground elevation. It is a data set of plane coordinates (x, y) and elevation (z) established on a regular grid

point on a map projection plane, which is geographic information of the core data system that the system relies on for analysis. Table 2 shows the vectorized attribute distribution of the virtual reality model based on CAD. The digital elevation model has two types: irregular triangulation model TIN and regular grid model GRD. Its construction of the model is usually generated by digital photogrammetry, and the passed image matching is automatically generated; we can also scan the topographic map to obtain the vectorized contour line, and interpolate it into a digital elevation model.

Attribute number	CAD layer	Elevation coordinate/m	Measurements/m	Relative error/%
1	Grid	0.49	18.52	1.72
2	Line	1.04	17.73	1.69
3	Point	0.47	17.90	1.44
4	Surface	0.78	26.31	0.99
5	Body	1.26	23.17	1.21

Table 2: The vectorization attribute distribution of the virtual reality model based on CAD.

In the experiment, a 126-bit binary pseudo-random sequence was used as the visual signal, and the experiment was performed on the three-dimensional bunny point set model. The point set model consists of 3000 points. The learning algorithm is applied to learn it, and 66 feature points that meet the threshold are obtained. We find the 42 points closest to each feature point from the original point set, remove the duplicate points, and sort 546 points according to the size of the feature value as the points to be embedded in the scene. Figure 5 shows the comparison curve of the visual recognition degree of the virtual reality based on CAD. Among them, the east-west minimum value and the north-south minimum value are obtained by two-dimensional CAD data mining, and the east-west minimum value and the north-south minimum value of the visual recognition rate are 93.5% and 98.4%, respectively.
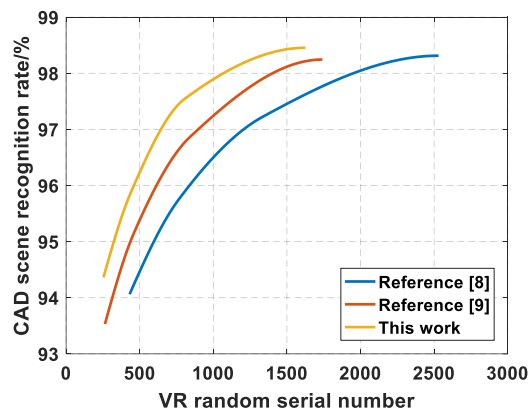
Figure 5: Comparison curve of visual recognition degree of virtual reality based on CAD.

We use the digital elevation model to scan and process the digital aerial photos or remote sensing images (monochrome or color), correct them pixel by pixel, and then perform image embedding, and cut the generated image data according to the scope of the map. CCGIS software only

supports images in BMP mode. The imported aerial orthophoto data is oriented in a single frame in the VRModel module. The parameters that need to be set are: two image points (row number and column number), and the corresponding image point coordinates of the ground point are finally generated by the software default orientation. It is calculated that the resolution of the pixel in the horizontal direction is 0.500 and the resolution in the vertical direction is 0.509.
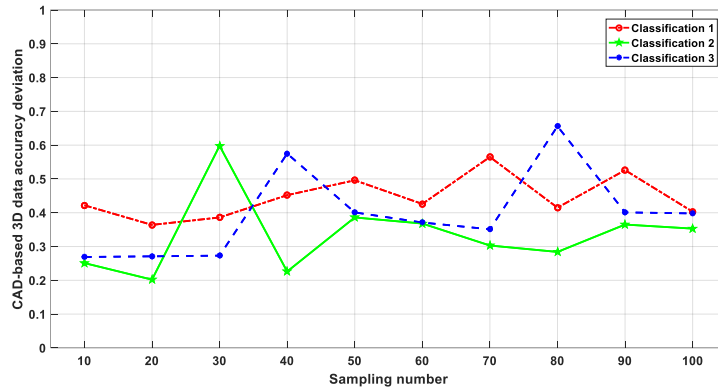
Figure 6: Comparison of the accuracy polylines of the 3D data of the virtual reality scene based on CAD.

During the running of the program, we found that it takes about 1s to process a 100-odd part model occlusion and elimination. If the model is more complex, the algorithm complexity may need to be improved. Figure 6 shows the comparison of the accuracy polylines of the 3D data of the virtual reality scene based on CAD. Under the requirement of ensuring calculation stability and calculation accuracy, we select the maximum step size. According to the above principles and experimental tests, the integration step length here is 0.01. After careful observation, it is found that the line-of-sight scanning method for each unit will repeatedly judge the nodes on the unit, because the nodes are always shared by the units.
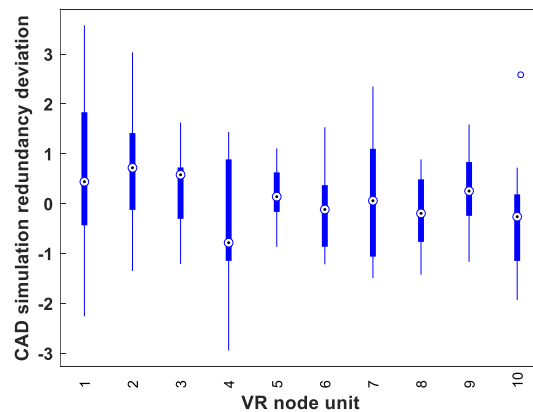
Figure 7: The redundancy of 3D data simulation of virtual reality scene based on CAD.

Figure 7 shows the CAD-based virtual reality 3D data simulation redundancy. In order to solve the calculation redundancy, a node state table can be built. While scanning the unit, whether the node

is occluding the state of the triangle projection is recorded in the table. If the same node is reused in the next unit, its state can be directly displayed in the table to query in the table to avoid repeated calculations. The state value of the point inside the projection is counted as 1, and the non-point value is counted as 0. To determine whether the surface element is occluded, we only need to examine the sum of the state values of the three nodes of the surface. If the result is low, it is completely occluded and deleted; otherwise, it is visible and retained. Therefore, the efficiency of the algorithm has been improved after this improvement.

5   CONCLUSION

In this paper, the CAD 3D mesh simplification algorithm has been deeply researched, and an edge folding simplification algorithm based on the VR normal error measurement is proposed. Experiments show that the algorithm has a better simplification effect and realizes that the original VR 3D model can be represented with as few patches as possible without affecting the visual effect. On the basis of image-based and geometry-based virtual environment modeling methods, we took interior design as the object, solved the problem of simulating real and virtual based on existing physical pictures, constructing a two-dimensional panorama of physical objects that can be viewed virtually, and building simulated virtual objects based on unknown physical objects. For the original architecture of the virtual assembly system, taking into account the hierarchical structure of the virtual environment, a hierarchical tree assembly model based on disassembly was created, and an automatic assembly sequence planning strategy was developed on the basis of this model. The virtual assembly example of linear cylindrical gear reducer illustrates the realization process of virtual assembly and virtual motion. Based on the needs of CAD-based virtual environment, this paper studies the distributed processing technology required in the virtual environment, including the network system and communication protocol of the distributed virtual environment, and focuses on the data transmission mechanism and the structure required for the intelligent virtual environment. Finally, a distributed CAD virtual decoration example is implemented based on CAD technology. Starting from the OpenFlight database construction mechanism, we studied the method of model creation and reading and writing. The simplified VR 3D model was written into the industry standard OpenFlight format after adding materials and textures, and combined with the creator's plug-in development method to realize the model's unavailability. Finally, in the visual real-time management system, the model generated by the above method is visually roamed, and the simulation obtains a more realistic and satisfactory effect, which shows that the above method is effective.

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