Three-Dimensional Modeling of Virtual Training System for Construction Machinery

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Abstract

The construction and optimization of the three dimensional model of construction machinery are presented in this work. The decomposition hierarchical structure model of excavator, a kind of typical construction machinery, is accomplished. The reconstruction method for three views of machine parts is proposed based on rapid 3D surface fitting as well as NURBS composite surface. On the other hand, the optimization of 3D model is addressed in detail. The optimizing process of 3D model of construction machinery is first presented. Then the structure optimizing method and model optimizing method are introduced respectively. The essential principle of scene blocking, structure adjustment and some key technologies of structure optimization are demonstrated. Accounting for model optimization involves deleting redundant polygons, rational use of texture, instantiation LOD and external importing techniques. The study on resuming the object's properties of shape, material and surface provides visual and realistic training objects for the virtual training system.

Keywords: construction machinery, virtual training system, three-dimensional modeling, hierarchical model, structure optimization, model optimization

1. Introduction

The precise construction of 3D model plays a crucial role in the process of development for virtual engineering machinery training system. High degree simulation of 3D model can exactly reproduce the experiment scene, machine part appearance and even inner structure. Thereby it provides users good immersion feelings and solutions of learning perceive and experience that are like or even better than real experimental environments. How to handle the simulation degree of model is very considerably crucial if the virtual reality system could be successfully completed. That is because it is restricted with the hardware and software development cost, current operating environment as well as condition and the like. The appropriate simulation 3D model is helpful for virtual training system to produce the best possible training and teaching results.

2. Analysis and Construction of the parts model for construction machinery

2.1Analysis on model architecture

According to the characteristics of complicated structure for engineering machinery, the complete geometric object of the machine is decomposed into some subsystem, and constructed to hierarchical geometric model. This type of engineering machinery consists of engine system, transmission system, riding device, brake system, electrical system, hydraulic system, working attachment, driver cab as well as steering system etc.

The composition varies greatly with different purpose and work principle. In EON studio the geometric decomposition model of the engineering machinery is demonstrated in Fig. 1 [1]

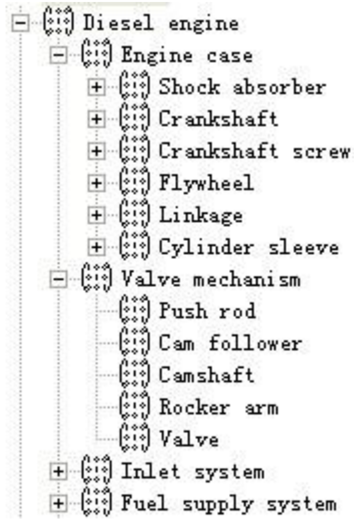

Fig. 1 Decomposition diagram of geometric model in EON

Engine case, crank and link mechanism, shock absorber, crankshaft, crankshaft screw, flywheel, link, cylinder sleeve, 配气机构（valve mechanism）,push rod, cam follower, camshaft, rocker arm, valve, inlet system, fuel supply system

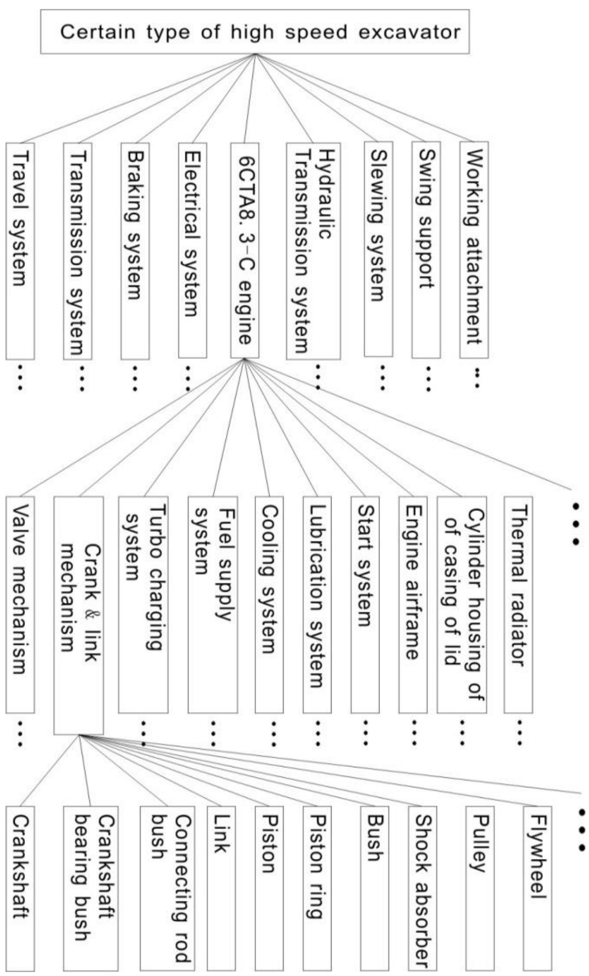

Fig. 2 Decomposition architecture of geometry model

2.2 Rapid fitting 3D reconstruction method for three views of machine part

The rapid model construction of part is implemented by means of rapid fitting of simple three projective views relation. With this method, rapid construction of 3D basic shape of machine part is performed by identifying the simple two-dimensional graphics of three positive projection direction as well as three axial fitting constraints of the machine part [2][3]. Consequently the 3D model satisfied with the corresponding requirements is obtained based on modification and processing of mathematical transform and Boolean calculation to basic part shapes. Three views rapid fitting reconstruction program are illustrated in Fig. 3.

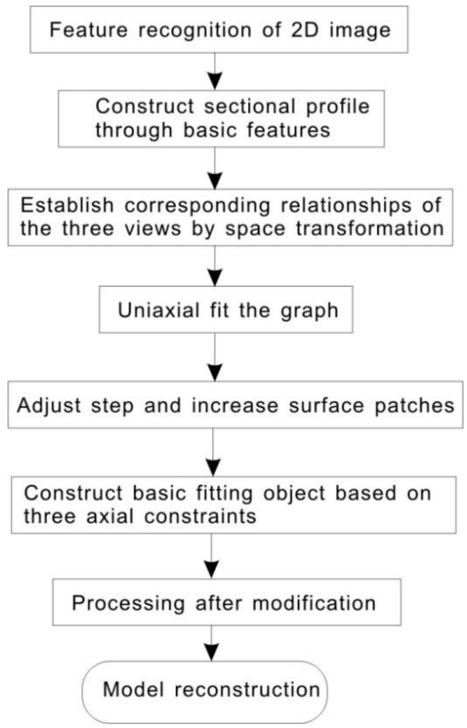

Fig. 3 Rapid fitting reconstruction steps for three views of parts

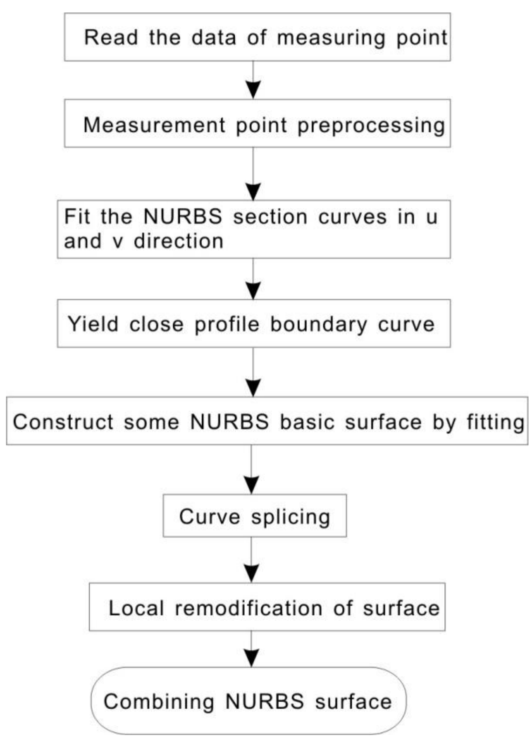

Fig. 4 NURBS surface reconstruction block diagram

2.3 NURBS composite surface reconstruction

In this work, free-form surface modeling is carried out on the basis of triangular Bezier surface construction and NURBS parametric surface fitting methods [4]. Accordingly it could construct complex and precise component model featured with precision, fine and trueness. So it provides vivid training object. The model The control vertices of NURBS surface are described on Fig. 5. The mathematical model of NURBS surface is expressed as follows:

$$P(u,v)=\frac{\sum_{i=0}^{m}\sum_{j=0}^{n}w_{i,j}d_{i,j}N_{i,k}(u)N_{j,l}(v)}{\sum_{i=0}^{m}\sum_{j=0}^{n}w_{i,j}N_{i,k}(u)N_{j,l}(v)}$$

In this paper the geometric shape of the part is classified into two categories: one is elementary analytic surfaces, such as planar, cylindrical, conical surfaces together with torus and etc. Most of the part shapes belong to it. The other is the surfaces and curves that are formed by free transform of complex ways, namely, composed of free-formed curves and surfaces, other than constructed with elementary analytic surfaces. Most of covering parts, for example combustion room of the engine, intake and exhaust manifolds, exhaust pipe and so on. are of this classification. The free-formed surface construction can accurately represent the standard analytic shape, such as conic curve and rotation surface, by utilizing NURBS curves, surfaces and its corresponding operations. When there exists free surface, analytic curves and surfaces simultaneously in the geometry object, it is most effective to construct the model with NURBS operation.

The part model construction of engineering machinery is implemented by using combination of stitching and re-modifying of NURBS surface fitting method. The basic process is: firstly, carry out the preprocessing for data filtering, sorting, reducing and segmenting of measurement point, then create several cross section NURBS curves in u and v directions, construct curve network that represents the basic shape of reconstruction surface; secondly, according to boundary point coordination on contours of parts in u and v directions, the closed reconstruction surface boundary contours are fitted so as to define the reconstructing surface region that guarantees the continuity and closeness; lastly, through technical processing of stitching, transition, extending, cutting and smoothing for the blocked surface, together with remodification by means of feature-based modeling, such as surface stretching, Boolean calculation, surface chamfering and stitching of CAD system, and achieve suitable composite surface. The surface processing flow is described in Fig. 4. The cab case of certain type vehicle is fitted with surface smoothing and stitching of NURBS algorithm, and the image is presented in fig. 6.

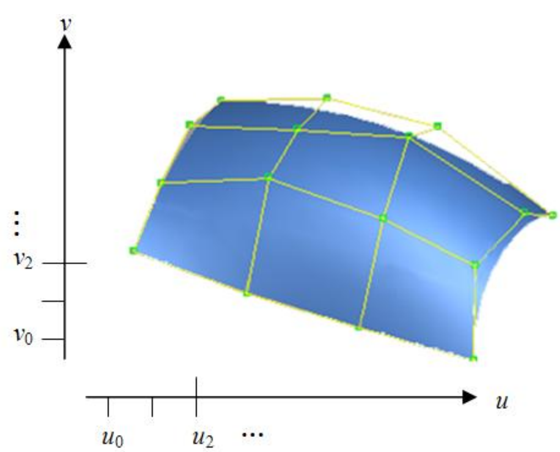

Fig. 5 Schematic description of NURBS surface control vertices

Fig. 6 Smooth connection NURBS image of the vehicle cab

3. The method for optimizing the three-dimensional objects

3.1 Optimization process of three-dimensional model

Optimization technology is an important part during three-dimensional modeling. Optimization results will directly affect the operating efficiency and display speed of relevant dynamic called maintenance scene for the main subsystems imported by system. The optimization techniques used in this system is applied throughout the entire modeling process [5]. So they are the improvement of the traditional optimization technique. The optimizing flow of three-dimensional modeling is given in Fig. 6.

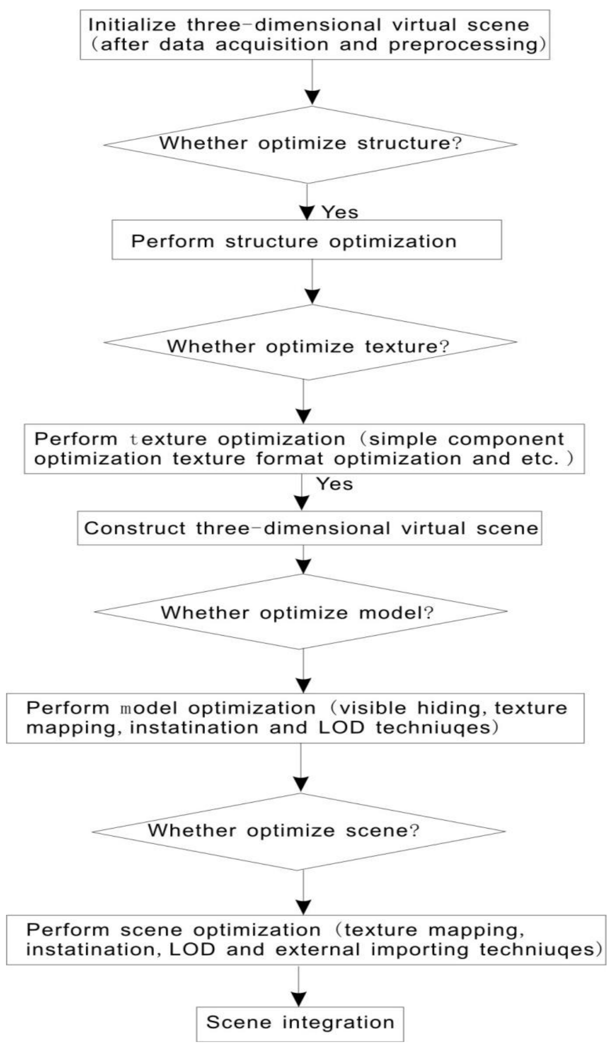

Fig. 6 Optimization flow chart of 3D modeling

The optimizing process can be described as the following steps:

(1) Structure optimization

a. With regard to the initialization of virtual scene, establish a hierarchical model in accordance with the scene block (split model) principle.
b. Impose structural adjustment based on handling with principle of adjusting level modeling.

(2) Texture optimization

According to the practical requirements of modeling, implement processing for preprocessed texture, for example transforming into simple component texture, accomplishing of texture format optimization as well as texture connection.

(3) Model optimization

Impose visible image hiding algorithm, texture mapping technique, instantiation technique as well as LOD algorithm on the processing of created model, so as to decrease the numbers of polygons and optimize the model.

(4) Scene optimization

Apply technologies of texture mapping, instantiation technology, LOD algorithm and external reference in the optimization of the overall scene for the constructed model regardless of inside or outside the system.

3.2 Structure optimization

Structure optimization for the construction of virtual scene consists of two sections: scene structure optimization and model structure optimization, namely, the microscopic and macroscopic directions of structure optimization. The basic idea is to carry out scene blocking (e. g. model splitting) , next to construct hierarchical model and then to accomplish the integration [8].

3.2.1 The essential principle of scene blocking in structure optimization

1. Generally, individual object can be blocked independently, for example warning signs, fire-proof installations and etc.
2. The same kind of objects can be grouped into a block, such as rinsing region, disassembly region and etc.
3. Visual adjacent objects can be grouped into a block, such as power distribution room and duty room as well as duty room and accessories room, and the like.
4. The associated objects (e. g. motional relationship, bound relationship and etc.) could be grouped as a block, for example, the repair shop door and ventilation window.
5. Absolutely not associated objects can classified into a block, such as sky, grass, perspective and so on.
6. The objects that have operation relationship or motional control relationship can be grouped as a block, for example the overhead traveling crane which requires the cooperation of track and controller.
7. Connected objects could be grouped as b block, such as the pipe or line that have certain connecting order and cannot go wrong.

3.2.2 Structure adjustment

Structure adjustment is part of structure optimization, especially in the adjustment of hierarchical structure. The principle and method for modeling of hierarchical structure adjustment are presented as follows:

(1) Construct hierarchical model.

A complex object can consists of many simple ones, it’s unnecessary to put each shape into its own set of nodes. The models can be established on the basis of structure characteristics of each object and assembled in one group. The assembling sequence and principle can be comprehensively achieved with various factors, for example the position, importance, degree of operation and visual range of the objects in actual scene.

(2) Try to avoid creating large span object.

Generally, the object within our visual field (the visualization part in space) is called effective object. However, all of the objects within visual range, regardless of distance, should be calculated. Even though we see only part of the object, but we had to perform calculation to large span object. If the blocking is not proper, it would be adjusted immediately.

For example, the storehouses around the construction machinery yard are of the same objects, they can be grouped into one block according to modeling principle. But it covered much wide range during image render, accordingly a huge amount of calculation is caused. Furthermore it is both time-consuming, taking up system resources, and will seriously affect the display speed of objects.

(3) Adjustment for hierarchical model of visual adjacent object.

The same grade data nodes are arranged in order from left to right. When node exists and the object is hided, the node display position should be adjusted. While part of the object is visible, some of the nodes or polygons of the hided object can removed properly.

(4) Hierarchical modeling of regular object.

Under the condition of not affecting image realism, only the model for exterior part of regular object is constructed, the internal, bottom and connection surface can be omitted.

(5) Hierarchical modeling of irregular object

The model is constructed in terms of the importance of the irregular part of the object. The important, visual and operative part can be laid emphasis on modeling, the other can be substituted with simple geometrical object, for example plane, cuboid and etc.

3.2.3 Key technology of structure optimization

(1) Cell segmentation will partition the virtual scene (model) into smaller cell, thereby only the entity in the current scene (model) will be rendered that considerably decrease the complexity of processing the scene or model. The segmentation is usable to the terrain model and large building. Because the objects in the view of the observer are only subtle part of the overall virtual scene, so processing the current visual objects would absolutely increase the system speed [9].

(2) Level of detail techniques (LOD)

LOD techniques involve optimization of model structure, namely the process for simplifying polygons of the cell-partitioned model. The purpose of simplifying polygons is not removing rough part from the original model, but creating simplified model so as to retain important visual features. The ideal result is the simplification of the original model series. Consequently, the model simplified in this way can be applied to different real-time acceleration. The visual 3D scene is given in Fig. 7. In simplifying process the following principles should be considered：

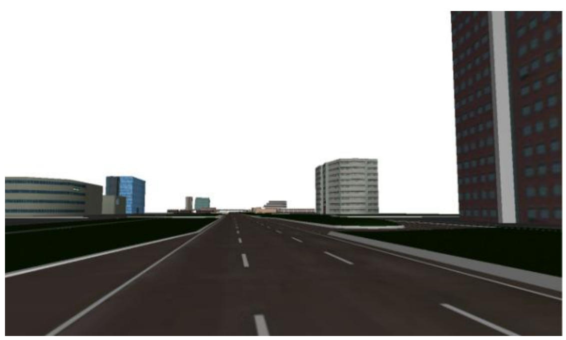

Fig. 7 3D view scene processed by LOD techniques

a. Continuity of LOD

The image jump caused by transformation of different LOD model is an urgent problem in simplifying process during real-time rendering by LOD algorithm. Therefore the proper LOD model need to be selected from simplified LOD series of model in real-time rendering. If there are merely one or two polygons difference between continuous models, the transform would maintain the view continuity of model. Data structure generated by continuous LOD model is proposed in both arbitrary mesh multi-resolution simplification algorithm and incremental grid method [10]. They make transformation of different LOD model smoothing. In this work, Morphing method is applied to carry out the smooth transformation of the adjacent level of LOD model.

b. Retention of shape

Because the simplification algorithm requires retaining the shape and surface features of the model as far as possible, the model features, for example plane curvature, cusp and characteristic edge, should be located, and then model can just be simplified through fusion of flat areas and linear variant characteristic edge. Nowadays most algorithms use characteristic edge overlapping to simplify model, or use merging small curvature adjacent surfaces to do so. Furthermore it control the simplification by threshold.

(3) Error estimation of approximation

In order to control simplification process, each step of simplification should evaluate the approximation error of model local. For instance, some methods evaluate simplification error by means of using local error estimation or Distance criterion (vertex-to-plane distance), whereas some algorithms restrict the simplification degree through geometrical body.

Presently the purpose that needs to be accomplished is as follows:

a. Automatic generation of LOD model
b. Image jump during model transformation
c. How to keep the grid continuity in different level of the same scene, and not generate crevice.
d. How to retain the surface characteristic information in simplification. These functions can all be realized in 3dsmax.

3.3 Model optimization

(1) Removing redundant polygons

There frequently exists redundancy in constructing entity model, therefore removing the hiding or invisible polygons can reduce the number of polygons in system, and this can also improve the real-time performance of the system. Because they are always in hiding position during scene browsing, removing them will not affect the view effects. But that can greatly decrease the total scene complexity. The redundant polygons here mainly refers to the invisible parts of the model observed outside the entity, for example the bottom surface of the building, internal surface of the wall as well as connecting surface between 3D model and the like.

(2) Rational use of texture

a. Using texture mapping instead of polygonal shape

Effectively using texture is not only a method for increasing scene realistic effect, but also good method of improving real-time performance. For some objects with more details, for example tree, building, railing and etc., if we place too much emphasis on details, the workload and model complexity may increase abruptly, and may cause the decrease of real-time operation speed of the overall system. In this work the method of texture mapping is often used. The detailed model is substituted with texture image covered on its corresponding position. The operating console with wooden texture effect is shown on Fig. 8.

For perspective view modeling and overall large scene system modeling, it can be substituted with a mapping, thus the rendering speed is higher than that of the model composed of several hundreds or thousands of polygons. Texture mapping will not reduce the realistic effect of the scene, reversely it can greatly decrease the numbers of polygons and complexity of the scene as well as improve the display speed of the output.

Fig. 8 Operating console with wooden texture effect

b. Using simple component texture

Under the condition of achieving anticipated effects, small area of texture should be utilized as much as possible. The smaller the geometric dimension of the texture, the smaller the data amount of the file will be. The simplistic textures of 128×128 and 16×16 pixels looks the difference is not obvious, but the document size really varies. For example, an image file with 128×128 pixels is 48.5K, and the same texture file of 16×16 pixels is only 12.5K which is a quarter of the original size. Using single component texture (grey image) is commonly more effective than that of tri-component texture (red, green and blue). That is because each pixel cell of the single component texture can be represented with a hexadecimal byte, and one pixel cell of tri-component texture will need three bytes for information storage. Accordingly combining the simple component texture and the essential material colors will yield very realistic surface.

c. Texture format optimization

3ds Max provides multiple internal texture format. Lowering the texture quality can save the amount of memory. Taking a 24-bit true color RGB texture as an example, its document size is 900KB. If you use 8-bit palette mode of the the 3dmax internal texture format, the 24-bit data are compressed into 8-bit data format and the file will be one third of the original size. The amount of memory (the amount of RAM needed on the machine to render the scene) decrease 60%. Low quality texture can be used in the moving parts of the object, long-distance scene modeling and other in real time view simulation system. Therefore it can not only yield scene representation effect, but also can greatly save memory. Also, the texture file of jpeg format is much smaller than that of RGB format file. Many rendering tools support not only RGB format file but also JPEG format. JPEG is a commonly used method of lossy compression for digital photography (image). JPEG can achieve maximum 100:1 compression. The use of JPEG format can be accomplished according to the requirements of compression ratio and image quality.

(3) Using instantiation techniques

When there are multiple objects of same geometrical shape but different positions in three-dimensional complicated model, instantiation technique can be utilized. Instantiation is the reference to pre-existed model in the database, and it is the same from appearance as the duplication. But the instance is not the geometric entity existed in database, it is just the pointer to its parent object. The instance is like the numerous shadow of the model, but only one is real object. The other objects are all yielded by translation, rotation and scaling. That is to say that the objects are load into memory only once, this is similar to the dynamic link library file. Therefore the geometric characteristics, color, texture and other properties of an object can be edited, and it will also change the properties of all the instances. If an object is repeatedly used in the scene, in other words, except the different spatial position, the other properties are the same, then only one model need to be constructed. Thus the model may be imported by means of instantiation method in the future use. In fact, it is to display the same model in different position through coordinate transformation. In this way, it can save large amount of disk storage and memory. Road environment rendering with application of instantiation method is presented in Fig. 9.

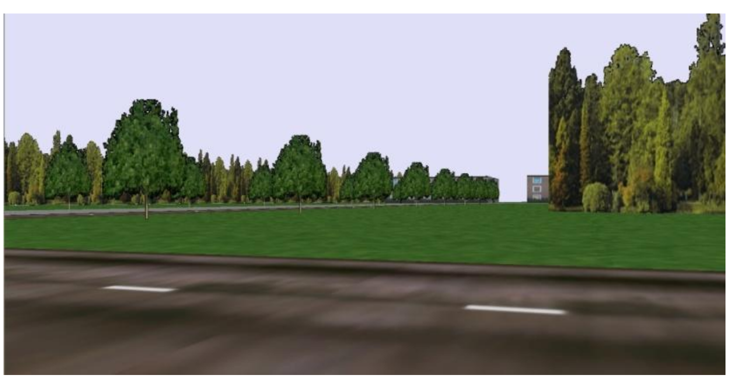

Fig. 9 Road environment rendering with application of instantiation method

(4) Using LOD techniques

The basic ideas of LOD techniques are: different object or different part of one object in the scene can use different detailed description. If an object is viewed from a great distance, or it is smaller, it may be rendered by coarse LOD model.

On the other hand, if an object is view more closely, or the object is larger, the object should be rendered with fine LOD model. Accordingly, if there are moving objects in scene, similar methods can also be put in use. The coarse LOD methods are carried out for objects when moving fast or in moving state. Whereas the fine LOD methods are applied to stationary objects.

(5) Using external importing techniques

The external importing technique facilitates users in directly introducing the required file or texture into the current scene, and re-positioning these resources. The benefits of doing so like to quicken the file download speed through segmentation of individual video file. In early stage of modeling, the proportion between every model can be calculated in advance, then create the main, fine and requiring operation models in current scene. Furthermore, the auxiliary model in scene can be imported into current scene by external importing technology. Thus the external model would be imported to the required spatial position or at the proper time. It provide great convenience for the creation of global scene, and also save memory within limits and to certain degree as well as accelerate rendering and machine operating speed. The benefits of external importing are summarized as follows:

a. Saving memory and quickening rendering speed. In 3ds Max by default the external reference points can be hidden via setting parameters. Thus it saves computer memory as well as decreases the display and refresh time of the model.
b. Organization and management of the scene. The scene construction can be accomplished by dividing into several blocks or areas according its hierarchical structure, and then carried out respectively in each area or block. Large object as a building or small one as a tree can be modeled independently, and integrated by external importing techniques.
c. Model substitution. As long as the critical parameters of position, title and material of the model doesn’t change, the model replacement can be implemented by external importing technology.

4. Conclusion

In this work, three-dimensional part models of certain type construction machinery are created on the basis of current parts prototype by modern numerical measurement techniques, computer graphics and image processing technology as well as computer-aided modeling techniques. The free surface modeling is addressed with surface construction method based on triangle Bezier surface and parametric surface fitting method based on NURBS surface. Furthermore, the complicated outer cover, for example cab outer skin, engine combustion room as well as inlet and exhaust ports, is constructed. Finally the systematic study on resuming the object’s properties of shape, material and surface provides visual and realistic training objects for the virtual training system.

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