Automatically Trimming Profile Based On Triangular Mesh Model

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Abstract. The article introduces an automatic algorithm for cutting contour based on triangular mesh model, which realizes the solid section, automatic filling and material inheritance of the 3D model in the virtual reality environment, which can be accurately visualized in the virtual reality environment. It can not only describe the solid section of the 3D model, but also inherit the material texture relatively accurately, and it has a good real-time. The algorithm is applied to the immersive virtual reality simulation platform of the hydropower plant, which can allow students to perform real-time 360-degree viewing and cutting of the equipment of the power plant, and improve the knowledge level of the employees of the power plant on the internal structure of the equipment.

1. Introduction

The triangular mesh model in the 3D model has many good geometric characteristics, it can approach the surface of complex shape with multiple triangular, and it is easy to deal with. Therefore, the triangular mesh model is widely used in computer graphics, mechanical simulation, scientific calculation visualization and so on \cite{1}.

With the development of virtual reality technology and digital precise modeling technology in industrial manufacturing, when importing triangular mesh models into the application of the virtual reality platform, there are problems of can nor cutting real-time, can not closed surface and can not inheritance of material texture, which makes the application of virtual reality simulation platform in power safety production and training evaluation has a certain impact. This paper mainly introduces the algorithm of automatic trimming of the cut contour of the triangular mesh model, and applies it to the virtual reality simulation platform of the power system hydropower plant to meet the actual production needs. This article mainly introduces the algorithm of automatic trimming of the cut contour of the triangular mesh model, and applies it to the virtual reality simulation platform of the power system hydropower plant to meet the actual production needs.

2. Project Profile

Facing with problems of design, manufacture, installation, commissioning, operation and maintenance of large-scale hydropower equipment, such as the requirement of technical skills, the planarization of data, the concealment of equipment and the contradiction between staff and study, China Southern Power Grid Peak and Frequency Modulation Power Generation Co., Ltd. focus on the difficulties of large and complex equipment and hidden equipment in hydropower plants in production management and operation and maintenance skills training and evaluation, establish a 3D accurate
model of plant and equipment based on accurate modeling technology\cite{2}, then constructed a five-sided LED-CAVE virtual simulation environment combined with virtual reality simulation technology, and built a simulation platform for hydropower plants based on virtual reality technology\cite{3}, also they developed a series virtual operation and maintenance simulation courses for hydropower plants. It provides a new platform and a new method for the fast-developing technical staff education and safety production management of power plant.

2.1. Engineering features

The virtual reality simulation platform of the hydropower plant can provide a simulation environment that is consistent with the real environment. In this environment, employees can not only conduct normal operation training, but also practice various accidents and fault handling. The virtual reality simulation platform has great significance to improve the level of staff skills, enhance the ability of emergency handling, and avoid the equipment damage, power grid disconnection and other major accidents caused by operation errors.

According to the characteristics of virtual disassembly and maintenance and maintenance simulation services, the platform needs to provide the following functions:

Virtual scene roaming: ability to move freely in a 3D virtual simulation scene of a power plant. Construct 3D models of hydropower station terrain, dams, workshops, and turbine equipment, use virtual display technology to achieve in-depth simulation and virtual scene roaming.

Equipment Structure Viewing: Ability to view the unit equipment in a predetermined scene, such as viewing the equipment at work in the plant scene. Ability to view each part of the equipment in virtual scene, even cut the equipment in order to view the internal structures.

Interactive virtual disassembly and assembly: Ability to perform virtual assembly, virtual disassembly, dynamic interference inspection, tool gripping and using. It can be used in combination with physics engine, visual script, and animation system. It can complete the functions of equipment disassembly, mechanism manipulation, dynamic interference, etc. through interactive equipment directly in the immersive environment.

Industrial-grade physics engine: Supports accurate simulation of model physical properties. By defining and editing the physical properties of the model, accurate physical simulation of model rigid body motion, scene gravity, particle motion and environmental damping is achieved.

2.2. Existing problems

Profile is an important feature of a 3D model, which represents the approximate profile and geometry of the model at a certain position\cite{4} and reflect the basic appearance of the 3D model. Cutting the 3D surface model refers to cutting the 3D model in any direction directly on the screen, and the user can easily observe the size and shape of the model section to realize the macroscopic understanding of the model section.

The 3D model in the virtual reality environment is reconstructed from a huge number of triangulars. The existing virtual reality 3D model cutting\cite{5-7} mainly uses the spatial positional relationship between the triangular mesh and the cutting plane to obtain the model cutting for the spatial information of the posterior triangular grid. The existing cutting technology mainly uses the intersecting operation of the faces in the space\cite{8}, that is, the three sides of the triangular grid are calculated with the cutting plane.

Through research and analysis of existing technologies, the following problems exist:

1. The computation cost caused by the existing method is quite large, which seriously affects the real-time performance of cutting.

2. In the current cutting method, the closed surface of the solid is not considered in the cross section of the triangular mesh and the cut surface. After cutting, the mesh model can not make up the surface automatically, and the user can not directly analyze which are solid models and which are surface or shell models. It brings some difficulties in the actual training process.

3. A profile information extraction based on triangular mesh model is disclosed in the literature [4]. The method uses 3D model data in OBJ format, and uses hierarchical slice and adjacency sorting algorithm, the profile information of Triangular Mesh model is obtained. This method is suitable for
models with topological errors, but it does not consider the problem of texture inheritance in the process of obtaining a closed profile ring.

Therefore, this problem has become a key and difficult point to be solved in the training system of 3D precise model of hydropower station based on virtual reality technology.

2.3. Solutions

In order to solve the problem of existing technology, this paper proposes a method of solid cutting for 3D model in virtual reality environment: firstly, the 3D topological data structure is established for the 3D model of objects in virtual reality environment. Next, define the cutting path and cutting direction on the projection surface of the 3D model\(^9\) to generate the cutting surface of the 3D model automatically. Concurrently, track the discrete line segment set on the cutting surface to obtain the closed contour line of the object, and finally triangulate the enclosed area of the closed contour line Points to create a solid profile.

3. Graphic Algorithm

3.1. Implementation

The principle of the cutting algorithm used in this paper is: Firstly, project a 3D model of an object on a two-dimensional plane and obtain a projected image of the object. Next, select cutting path and cutting direction on the 2D plane, the cutting surface of a 3D object will be automatically generated. Then, carried out intersecting operations with the cutting surface and the 3D object to cut the 3D object and to obtain a set of discrete line segments. Finally, track and fit the discrete line segments to form a closed contour line, thereby forming a profile. The closed contour structure is the internal structure of the 3D object on the cutting surface, so that the accurate internal composition of the 3D object can be observed.

The implementation steps of the cutting algorithm are shown in Figure 1:

![Figure 1. Chart of auto-complement algorithm for cutting contour](chart.png)
3.2. Establishment of 3D topological data

Establish a topology data structure for the 3D model of objects in the virtual reality environment, record the geometric information and topological information of the 3D model, including the quantity and texture information of the vertices, edges, faces, and volumes of the constructed 3D model. Vertex information includes vertex quantity, coordinates and color. Surface information includes the quantity of vertices, vertex label, surface color and vertex sequence. Volume information includes quantity of the surface vertex, surface label, texture label, layer label.

The advantages of this setting are:

1. By establishing a three-dimensional topology data structure, it is possible not only to efficiently query and retrieve grid geometric information, but also modify and reconstruct the grid space topology information data structure.

2. It is conducive to the physical cutting of the 3D model in the virtual reality environment, and can automatically fill the surface and inherit the material texture of the original model during the cutting process.

Grid information not only stores the spatial information of the grid, but also stores the topological information of the connection relationship between its geometric elements such as vertices, edges, triangles, etc. During the conversion of the 3D model, the geometric information and topology information of each 3D model are recorded according to the unified standard attribute and format, and
the quantity of vertices, edges, faces, bodies and texture information of the 3D model are obtained. The 3D topology data structure is established to query, modify and reconstruct these spatial topology information. Through this way of information processing, the discrete intersection lines are formed by the point operation of intersecting plane to the three-dimensional model, and the closed contour of the object is obtained by the array of intersection lines. At the same time, the relationship between the intersection line and the reconstructed topology information is traced, retrieved, detected and calculated, and the reconstructed topology information is formatted to form a new 3D object model.

3.3. Intersection of 3D object grid

Suppose that the object A in Figure 3 is an arbitrary triangular mesh object in the camera, and the object B in Figure 4 is a sectional plane. Perform the triangle operation on the cutting plane to calculate the triangle mesh intersection difference set, that is, remove the part of the model that intersects with B in A.

The overall algorithm is implemented as follows:

The final result of intersection of triangle surfaces is composed of two parts: \{ A on the triangle surface outside B \} + \{ B on the triangle surface inside A whose normal lines are opposite \}.

Firstly, describe the boundary with vertex list and triangle list. For example, a description of A square: vertex list = \{0,1,2,3,4,5,6,7,8\} , triangle list = \{ vertex triangle face 012, vertex triangle face 023, vertex triangle face 765, vertex triangle face 754, vertex triangle face 326, vertex triangle face 367, vertex triangle face 104, vertex triangle face 145, vertex triangle face 037, vertex triangle face 074, vertex triangle face 215, vertex triangle face 256\}. Use the same method to describe another B object.
\{ A \text{ on the triangle surface outside } B \} \text{ represents the original triangle surface of } A \text{ outside } B \text{ when } A \text{ and } B \text{ intersect. } \{ B \text{ on the triangle surface inside } A \text{ whose normal lines are opposite } \} \text{ represents the external set of triangles outside } B \text{ that intersects } A, \text{ but the triangle set is the part where the normal is inverse.}\text{The triangle mesh of the object obtained after } A \text{ and } B \text{ intersect is as Figure 3; red part is the triangle surface table of } A \text{ which is outside } B. \text{ Gray part is the triangle surface table set with triangle surface that with inverse normal of } B \text{ which is inside } A.\]

![Figure 5. Final result of intersection of triangles](image)

In this project, there are two functions: Plane Section and Spherical Section, so it is necessary to define section, that is, define the object \( B \) in figure 4. Plane cutting and spherical cutting are presented in the form of square entities and spherical entities in the camera. After the profile is defined, the position of the current profile in space is calculated in real time according to the user's operation. When the cutting entity in the camera intersects the 3D mesh, the cutting plane can be calculated.

3.4. Record intersecting edges of intersecting objects, add vertex indexes and connect

There will be multiple objects in the camera that intersect the cutting plane. Accordingly, each intersecting object needs to be detected separately by the intersecting loop table, each intersecting object needs to be detected separately by the intersecting loop table, and the edge-line closed detection results in a new loop table, that is, supplementing vertices at the intersecting connection edge, and supplementing triangle surface of sections with inverse normal.

![Figure 6. Plane vertices and triangles](image)

![Figure 7. Adding vertices](image)

As shown in Figure 6, a simple plane is composed of two triangular faces. If a triangular face is cut, as shown in Figure 7, we need to add two vertices, that is, add the triangle vertices through the intersecting triangle mesh intersecting edges, and then connect the vertices in the original order to fill and form a face.
Figure 8. Coordinate axis cutting triangle

As shown in Figure 8, when the triangular surface abc is divided by the X axis, the positions of d and e are determined to add the positions of the corresponding section vertices, through the dot product calculation formula \( (m \cdot n = |m| \cdot |n| \cos \angle m, n) \), \( |a| \) and \(|b|\) denote the modules of vectors, \( \angle a, b \) denote the angles between two vectors. Calculated the vector angle ratio \( S \) between \( (a-o, y-o) \) and \( (a-b, y-o) \). Then \( d = a + (a-b) \cdot S; e = c + (a-c) \cdot S \). Connectaed, bdc, cde according to the original mesh connection order, add the vertices to the section model A in sequence. Then reorder the vertices of the model, check the location of each vertex with the characteristics of surface overlap, find the location of the connected vertices and delete the duplicate vertices. Fill the sequential vertices of the cross-sectional shape to form a cut surface.

3.5. Forming discrete line segment sets

The cutting surface intersects and the triangle surface of the object to form a discrete set of line segments. First, determine the cutting surface equation, then use the binary tree structure to traverse the triangular mesh in the leaf node to determine whether the mesh intersects the cutting surface. If the mesh intersects, find the intersection point of the cutting surface and the mesh, and obtain the discrete line segments, then process the topological information of the discrete line segment, and store the processed information in the upper and lower linked lists. If the grid and the cutting surface do not intersect, determine the position of grid and the cutting surface, and store the original information in the upper and lower linked lists. The cutting algorithm is as follows:

1. Determine the cutting plane equation. A plane passes through three points \( P_1(x_1, y_1, z_1) \), \( P_2(x_2, y_2, z_2) \), \( P_3(x_3, y_3, z_3) \) of space, the plane equation is:

\[
\begin{vmatrix}
  x & y & z & 1 \\
  x_1 & y_1 & z_1 & 1 \\
  x_2 & y_2 & z_2 & 1 \\
  x_3 & y_3 & z_3 & 1 \\
\end{vmatrix} = 0
\]  

(1)

2. Find the child node which is cut in the root node.
3. Determine whether the node is a leaf node. If it is, the node search is completed and continue to the next step; if it is not, search for the next layer of child nodes in the child node, and determine whether the next layer of child nodes is a leaf node;

4. Traverse the triangular grid in the leaf node to determine whether the grid intersects the cut plane. If so, find the intersection point of the cut plane and the grid, process the grid spatial topology information, and store the processed information in the upper and lower linked lists; if not, determine the position of grid and the cutting surface, and store the original information in the upper and lower linked lists.

3.6. Determine the inclusion relationship of the outline
By tracing and fitting the discrete line segment set on the cutting surface, the closed contour of the object is obtained, and the inclusion relation of the contour is determined. It includes querying, modifying and reconstructing the topological information of the discrete line segment, calculating the format of the relationship between the discrete line segment and the reconstructed topological information, then forming a new 3D object.

3.7. Generate entity profile and inherit material properties
Triangulate the enclosed area of the closed outline to generate a solid profile.

The mesh filling of the profile is completed by the above steps and methods, next step is to calculate the normal direction of each vertex and UV to fill the material mask, and get the final entity profile.

4. Engineering Application
In the process of running the program, not only can add the section plane be added and adjusted in real time, but also complete the section plane according to the algorithm. The completed material can inherit the surface material of the model well. As shown in Figure 9, it is the final effect of the cut surface. Because the model is given a painted metal material, the cut surface material is defined as silver metal, which is more in line with the actual situation.

**Figure 9.** Schematic diagram of cut plane

Compared with the existing technology, the beneficial effects of this algorithm are:

1. Realize the solid section, automatic filling and material inheritance of the 3D model in the virtual reality environment, which can not only accurately describe the solid section of the 3D model in the virtual reality environment, but also inherit the material texture relatively accurately, and at the same time Has good real-time performance;

2. The mesh-based cutting algorithm is used to calculate the intersection between the cutting surface and the triangular surface, and the discrete line segment is tracked based on the topology
information of the mesh, which ensures the efficiency and accuracy of the 3D model cutting in the virtual reality environment.

3. By building a 3D topology data structure, we can efficiently query and retrieve the mesh geometry information, and modify and reconstruct the mesh spatial topological information data structure to ensure the accuracy of material texture inheritance in 3D model entity cutting in virtual reality environment.

5. Conclusion
The aim of this algorithm is to provide an automatic surface repair algorithm based on triangular mesh model for cutting contour. This algorithm realizes the entity profile, automatic complement and material inheritance of 3D model in virtual reality environment, which can accurately describe the entity profile of 3D model in virtual reality environment, and can inherit material texture relatively accurately, and at the same time, it has good real-time performance.

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