Research and Implementation of Mesh Model Deformation Simulation Technology

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Abstract. According to the requirement of deformation simulation of polygon mesh model which is easy to operate and control, the design idea of deformation simulation is given and realized. The deformation technique implemented in this paper is to calculate the deformation migration shape variables by acting on the local meshes to be deformed. During the deformation process, an adaptive subdivision mesh technology is proposed to solve the problems of insufficient mesh density and mesh vertices. A model cutting simulation technology is proposed, and a cover cutting simulation implementation is given for the polygon set without holes. This article uses the half-edge structure of the grid to reduce the time consumption of querying and editing the grid.

1. Introduction
The demand for 3D geometric modeling editing technology in daily life is increasing, but professional modeling software has problems such as modeling requires a reserve of expertise and a relatively high learning threshold. As a piecewise linear discrete representation method, polygon meshes have become common methods in 3D geometric models. In order to conveniently and intuitively edit the appearance of these discrete mesh models, this article through research and comparison, implements a simple and intuitive polygon model modeling deformation system. By determining the deformation area and deformation offset Deformation, which realizes more realistic model deformation simulation technology, and also realizes the cutting cover technology of the polygon surface model.

2. Drag Deformation Technology
Drag deformation is mainly to realize the user's control of a single point on the model, so as to drive the technology of local deformation of the model, so that the model can be deformed like push-pull clay.

2.1. Drag Deformation
The touch point edited by deformation is called the deformation control point P. The boundary line of the deformation mesh is determined according to the distance between the vertices of the mesh and the control point. The meshes within the deformation boundary line are called the set of deformation meshes. The movement of P and the target point P' determines the offset constraint F (P, P'). The above concept is shown in figure 1.
After the control point $P$ is determined, the mesh to be deformed and the weight of each point are calculated. The weight of grid point is inversely proportional to the distance between grid point and control point. The new position of the deformed mesh point $i$ is given by the formula:

$$V_{i(new)} = V_{i(old)} + \text{weight}_i \cdot F(P, P')$$

(1)

Among them, $V_{i(old)}$ and $V_{i(new)}$ represent the coordinates before and after the deformation of the $i$-th vertex, respectively. The drag deformation effect is shown in figure 2.

2.2. Grid Subdivision Technology

The drag deformation is more realistic when the model has a large number of meshes. When the number of meshes is small, the model does not appear smooth. This article uses the Loop subdivision algorithm\(^1\) to improve the problem that the number of model surface is not enough and the model is not smooth enough in the process of dragging. Loop subdivision algorithm is a triangle mesh algorithm based on the face splitting pattern. The coordinates of the new vertex of the subdivided grid are generated by the smooth average value of the surrounding neighboring original vertices. The grid has good smoothness and forms an approximate grid. At the same time, the Loop subdivision algorithm can guarantee the topology of each triangle.

After Loop subdivision, the drag effect of the model is smoother. Figure 3 is a grid comparison of the direct drag of the sphere and the operation after subdivision.
3. Local Mesh Deformation Technology

In the process of deformation operation of 3d model, a kind of local deformation grid technology is designed. With the user's mouse sliding over, the interactive sculptural effect is generated, that is, the area of the local mesh to be deformed is a strip of convex or concave.

3.1. Selection Of Mesh To Be Deformed

The area to be deformed is generated by the scanning method, that is, a curve is drawn on the surface of the model by user, the curve is used as the center line, and a given width line segment is used as the generatrix. Because it is difficult to generate on the model’s surface with different normals. Therefore, this article uses a local control grid to record the sampling points and boundary lines. Operating the vertices of the corresponding model by controlling the control mesh.

The center curve sampling is affected by two factors: the mouse sliding speed and the sampling frequency. The smoothness of the sampling curve affects the final result. In this paper, the Bezier curve interpolation algorithm is used to smooth the original sampling curve. The smoothness of the curve is affected by the number of interpolations between points. The formula for the k-order Bezier curve is as follows:

\[
\begin{align*}
    P_i^k &= \left\{ \begin{array}{ll}
    P_i & k = 0 \\
    (1-t)P_i^k - 1 + tP_{i+1}^k - 1 & k = 1, 2, 3, \ldots, n + k
    \end{array} \right.
\end{align*}
\]

The figure 4 shows the corresponding graphs before the Bezier algorithm interpolation with the interpolation number of 2 and the interpolation number of 50.

![Figure 3. Comparison of drag deformation before and after subdivision](image)

![Figure 4. Comparison of Bezier curves without interpolation and 2 and 50](image)

The center curve and boundary curve are determined, that is, the control grid is determined. And then establish the corresponding mapping relationship between the control grid point and the model surface. All meshes within the boundary line of the model surface are the meshes to be deformed.

3.2. Local Deformation Area Adaptive Subdivision

Most of the model mesh is relatively sparse, especially the number of vertices on the relatively flat mesh surface is difficult to achieve the above local mesh deformation, so the original mesh needs to be subdivided. In order to reduce unnecessary mesh subdivision, this article takes the area to be deformed as the criterion for subdividing the mesh triangles. The triangles in the area to be deformed use the midpoint of the three sides as the subdivision vertex, and subdivide the triangle into four triangles, the triangle outside the area to be deformed will have the following three cases, as figure shows:
3.3 Deformation Area Deformation
Calculating mesh weights on the subdivided model surface, the weight is inversely proportional to the minimum distance from the vertex to the midline. The final position of the model point is generated by the superposition of the original position of the model and the deformation amount in the normal direction of the vertex. The formula is as follows:

\[ V_{\text{new}}(x, y, z) = V_{\text{old}}(x, y, z) + \text{weight} \times N_{\text{old}}(x, y, z) \]  

(3)

Where, \( V_{\text{new}} \), \( V_{\text{old}} \) and \( N_{\text{old}} \) respectively represent the new position, original position and average normal vector of original vertex. After the new model is constructed, the local deformation of the model has been completed. The local deformation of the model is shown in the following figure:

4. Model Cutting Technology
Virtual cutting is widely used in model simulation operations. The virtual cutting of triangular surface model with realistic effects and strong real-time performance is easy to implement. In this paper, the cutter (plane) is used to cut the three-dimensional surface model. The cover algorithm after cutting is studied and implemented.
4.1. Cutting Path Generation

The cutting path is formed by the sequence of intersections of the cutting surface and model grid. In this article, the cutting path is the intersection of the plane and the triangle.

Collision detection is used to detect whether or not a collision occurs between various models in virtual environments. At present, the more mature methods are hierarchical bounding box and space decomposition[2]. This paper proposes a simpler detection method for the realized collision detection which is more suitable for this situation, The detection steps are as follows:(In the following, the axial plane means a plane perpendicular to the axial direction. For example, the axial plane of the z-axis is the xoy plane.)

Step1: The plane with the smallest angle between the plane normal and the axial plane (parallel is the best) is determined as the projected axial plane.

Step2: The rotating of projected axial plane can that the normal vector of the plane is parallel to the axis. (If parallel, omit this step).

Step3: The model is projected onto the axial plane, Use the unit vector product of the triangle vertices and the plane projection line (the cutting plane has been projected as a line at this time) to determine the relationship between the triangle and the cutting plane The judgment formula is as follows:

\[ \text{result} = \text{vec}(\text{vec}(b - a) \times \text{vec}(p_i - a)). \text{normalization} \] (4)

Among them, vec represents a vector, b and a are the end point and the start point of the projection line (both outside the model). P_i is the i-th vertex coordinate of the triangle, which represents the vector product. Normalization represents the unitization of the vector.

4.2. Cover Processing Of Cut Plane

After the model is cut, the face mesh is divided into two or more independent sub-meshes. The cover needs to be processed for a cover to become a complete model. When the boundary points are known, the problem turns into triangulation of three dimensional points. Triangulation problems in three-dimensional space can be transformed into two-dimensional space. Delaunay triangulation algorithm has mature research results in two-dimensional space. Common delaunay triangulation algorithms in two-dimensional space are: segmentation and merge method[3], point-by-point insertion method[4] and triangulation growth method[5]. These algorithms are very effective in processing the drawing of convex polygons. In this paper, the triangulated polygons include convex, concave and scattered polygon sets. For the triangulation of non-porous polygon sets in this paper, the literature[6] is reported. Figure 8 shows the cutting effect and cover image of the deformed cube model.

![Figure 8. The cutting effect and cover image of the deformed cube model](image)

In the model cutting, the situation where the model is divided into multiple sub-models (the unconnected model set after segmentation) and the processing results are shown in the figure 9.
5. Concluding Remarks
Aiming at several common deformation technologies in the simple and intuitive polygon modeling system, this paper presents the idea and implement the modeling deformation technology. The full text is implemented with a half-edge structure, which reduces the time overhead of grid editing and searching. This system is suitable for simple and intuitive modeling operation.

6. References
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