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A Three-dimension Huge Data Extraction Algorithm for Visualization Based on Computational Meshes

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Abstract

In order to accelerate the visualization processes of huge engineering data based on computational meshes, the extraction of huge data are necessary. A data extraction algorithm of engineering visualization data based on meshes is presented. Based on ordinary four-node tetrahedron elements, ten -node tetrahedron elements, eight-node hexahedron elements, the algorithms are studied to extract and simplify data for huge engineering data visualization, which includes relationships judgment between objective points and elements and interpolation algorithm in elements. Experiments of huge data transportation are given here, which show that the algorithm is reliable, and the algorithm can be used to extract visualization data from huge data of engineering computational results.

Keywords: *mesh; data visualization; interpolation; tetrahedron element; hexahedron element*

1. Introduction

The so-called scientific visualization [1] technology is to present the digital information produced by scientific computing to the researcher intuitively by image or graphic information. Among them, the engineering analysis or scientific computing data visualization, can help people understand the data intuitively, which has got the attention of more and more fields [2-5]. It can be said that the main aim of scientific visualization is to make invisible visible. But how to solve the contradiction effectively between the validity and limitations of real-time rendering hardware processing capabilities is a problem to be solved. Research on related technologies, such as meshes simplification to maintain the appearance of the model geometry, etc., has become a hot topic of computer graphics [6-8].

If huge Data is obtained from engineering calculation, such as finite element method, finite volume method and other methods, etc. It is generally based on an irregular mesh. A large number of engineering problems such as temperature field, stress field, flow field can be calculated using these methods. It has been playing an increasingly important role in engineering analysis field. Massive results data generally need to be visualized in order to view the simulation results quickly and directly, then we can use them to analysis and use on this basis. However, in the analysis, in order to obtain high accuracy relatively, the mesh is divided densely, the analysis of freedom degree which is more than ten million is very common.

If the huge data is visualized directly, a large amount of computer resources will be consumed, the display speed will become very slow, it is almost impossible to realize real-time display during the operation. Therefore, less three-dimensional

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date of grid or mesh surface should be extracted to meet the need of visualization on the basis of the large amount of data results analysis. So we need to study corresponding data of any given point P (x_P, y_P, z_P) from the grid computing. There are many mesh simplification algorithms [11-15] can be used for data visualization. The reference [11-13] proposed algorithms based on finite element method. The reference [14] proposed a mesh simplification algorithm based on edge collapse and [15] is based on half-edge collapse and visual feature. With these extracted visual data, a variety of methods can be used [9-13] to draw contour maps or color imagery. It also can easily be used to convert data under the sparse grid.

Aiming at these applications, most commonly used mesh such as four-node tetrahedron element, ten-node tetrahedron element and eight-node hexahedron element are analyzed in this paper. The scientific computing data extraction algorithm giving an arbitrary point P is proposed. There are two steps to obtain a P-point property values in this algorithm .The first step is to find the finite element mesh unit where the P point is in ,and the second is to create the interpolation function in the unit and obtain property values of P points.

2. The Extraction Algorithm of Tetrahedron Element

Because the tetrahedron element mesh is easy to achieved, and the algorithm is universal for any complex objects, It is used in many actual applications.

2.1 The Judgment of Point in Tetrahedron Element

As shown in Figure 1, if corresponding value of a point P (x_P, y_P, z_P) is calculated, first tetrahedral elements and

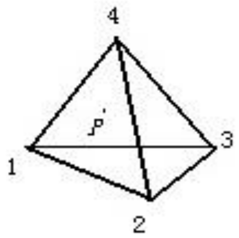


Figure 1. Tetrahedron Element

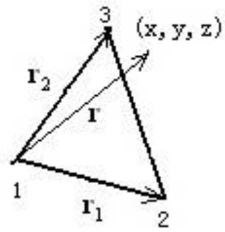


Figure 2. A Plane of Three Points

four vertices of in tetrahedron element need to be found. The following is the algorithm to determine whether the point P is in a four tetrahedron.

Let the four vertices coordinates of a tetrahedron are $(x_i, y_i, z_i), \quad i = 1,2,3,4$. Then the plane equation of the three nodes 2,3,4 is

$$ax + by + cz + d = 0 \qquad (1)$$

If point P satisfies:

$$(ax_P + by_P + cz_P + d)(ax_1 + by_1 + cz_1 + d) \geq 0 \qquad (2)$$

Then P (x, y, z) and point 1 are in the same side of the plane 234. Similar method can be used, the point P and a vertex of a tetrahedron element are located on the same side of the plane defined by the other three vertices.

If the point P satisfies the following conditions:

P and point 1 are on the same side of the plane 234

P and point 2 are on the same side of the plane 134

P and point 3 are on the same side of the plane 124

P and point 4 are on the same side of the plane 123

Then point P (x, y, z) is inside the tetrahedral element.

In the above algorithm, the equation of a plane defined by three points need to be caculated, it can be determined as follows.

As shown in Figure 2, 1,2,3 a plane is defined by three points. And wherein the vectors are respectively: $\mathbf{r}_1 = [x_2 - x_1 \quad y_2 - y_1 \quad z_2 - z_1]^T$ and $\mathbf{r}_2 = [x_3 - x_1 \quad y_3 - y_1 \quad z_3 - z_1]^T$.

Let the coordinates of any point within the plane is (x, y, z) ,let the vector is $\mathbf{r} = [x - x_1 \quad y - y_1 \quad z - z_1]^T$, then the plane defined by the point 123 may be expressed as:

$$\mathbf{r} \cdot (\mathbf{r}_1 \times \mathbf{r}_2) = 0 \qquad (3)$$

The plane equation (3) is another form of the plane equation (1), it can be applied directly to the formula (2). In addition, the plane equation (3) is laconic, and it is similar to the expressions of seeking tetrahedral volume below, they can be implemented through the same sub routine.

In order to improve computational efficiency, the distance of the point P and any node of the element can be judged firstly. If it is big enough, the point P is not within this element, then it is no need to judge and compute subsequently. Here the size of the largest element can be chosen as a basis to judge.

2.2 Interpolation Calculation in Tetrahedron Element

After the four-node tetrahedron element where the P (x, y, z) point is in has been queried, interpolation function within the element can be used, then corresponding value of the point P can be obtained.

Let a three-dimensional field quantities in each tetrahedron vertices is $f_i (i = 1,2,3,4)$ respectively, with the interpolation algorithm of finite element method, the interpolation function of that field quantity for the tetrahedron is:

$$f = \sum_{i=1}^{4} L_i f_i \qquad (4)$$

Where, L_i (i=1,2,3,4) is the volume coordinate for the point of the tetrahedron. If P (x, y, z) point is in the tetrahedron, then the volume coordinates can be defined as follows:

$$L_1 = \frac{vol(P234)}{vol(1234)} \qquad L_2 = \frac{vol(P134)}{vol(1234)}$$
$$L_3 = \frac{vol(P124)}{vol(1234)} \qquad L_4 = \frac{vol(P123)}{vol(1234)} \qquad (5)$$

Where, vol ( ) indicates the volume of the four-node tetrahedron.

Let the vectors of point P to node 1, point P to node 2, point P to node 3, point P to node 4 are $\mathbf{P}1, \mathbf{P}2$, $\mathbf{P}3, \mathbf{P}4$ respectively, let the vectors of node 1 to node 2 is $\overrightarrow{12}$, let the vectors of node 1 to node 3 is 13, let the vectors of node 1 to node 4 is 14. Then the volume of each tetrahedron are:

$$vol(\mathbf{P}123) = \frac{1}{6}\left|\mathbf{P}1 \cdot (\mathbf{P}2 \times \mathbf{P}3)\right| \quad vol(\mathbf{P}234) = \frac{1}{6}\left|\mathbf{P}2 \cdot (\mathbf{P}3 \times \mathbf{P}4)\right| \quad vole(\mathbf{P}134) = \frac{1}{6}\left|\mathbf{P}1 \cdot (\mathbf{P}3 \times \mathbf{P}4)\right|$$

$$vol(\mathbf{P}124) = \frac{1}{6}\left|\mathbf{P}1 \cdot (\mathbf{P}2 \times \mathbf{P}4)\right| \quad vol(1234) = \frac{1}{6}\left|\overrightarrow{12} \cdot (\overrightarrow{13} \times \overrightarrow{14})\right|$$

2.3 Interpolation Calculation in Ten-node Tetrahedron Element

In numerical calculation method, in the case of the same degree of freedom, with the increasing of the element nodes (or degrees of freedom) number, the calculation accuracy is increased. So the multi-node tetrahedron element is used in the vast majority of the finite element software, ten-node tetrahedron element is one of the most widely used element (Figure 3).

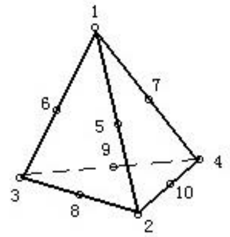


Figure 3. Ten-nodes Tetrahedron Element

The ten-node tetrahedron element can simply be regarded as tetrahedron element with the former process, ignoring the intermediate nodes of every side. For each side of ten-node tetrahedron element ,it is not a straight line necessarily, which means that each surface is not necessarily flat, processing methods where tetrahedron is applied will produce some errors . However, in most cases, this error is very small.

If ten-node tetrahedron element wants to be processed precisely, the plane through the midpoint of each side can be used. The element can be divided into six smaller tetrahedron. It will be determined whether P points is inside the six small tetrahedron respectively, in order to determine whether a point P is inside this ten -node tetrahedron element.

The same method is used to determine whether the point P is inside ten-node tetrahedron element. Once the ten-node tetrahedron element where the P point is inside is determined, the element interpolation function of finite element method can be used:

$$f = \sum_{i=1}^{10} N_i f_i \tag{6}$$

Where, $f_i(i = 1,2,\cdots,10)$ is the field quantities of each node after analysis ,the specific forms of the functions are:

$N_i = (2L_i - 1)L_i$, $(i = 1,2,3,4)$

$N_5 = 4L_1L_2$, $N_6 = 4L_1L_3$ $N_7 = 4L_1L_4$,

$N_8 = 4L_2L_3$ $N_9 4L_3L_4$, $N_{10} = 4L_2L_4$

Where, $L_i\,(i = 1,2,3,4)$ are four volume coordinates, specific form are shown as formula (5)

3. The extraction algorithm of hexahedron element

Hexahedron element meshes are shown in figure 4, because of its high computational efficiency, it is usually used in nonlinear analysis and dynamic analysis problems.

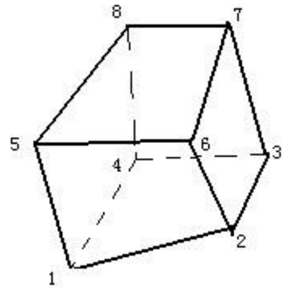


Figure 4. Hexahedron Element

The same method is used in hexahedron element like tetrahedron element, six planes of a hexahedron is determined in turns. If the point P and the vertex which is not in the plane are always located on the same side of the plane, the point P is inside the hexahedron.

In the finite element method, interpolation function within the element which is established by equal parameters element is often used. But the building process is very complex, and the calculation is very complicated, so here a simple way to create interpolation function is given.

Let interpolation function of hexahedron element be:

$$f(x,y,z) = a_1 + a_2x + a_3y + a_4z + a_5xy + a_6yz + a_7zx + a_8xyz \tag{7}$$

Where, $a_i\,(i = 1,2,\cdots,8)$ are eight undetermined coefficients.

Put the vertex coordinates $(x_i, y_i, z_i)(i = 1,2,\cdots,4)$ and the corresponding values $f_i\ (i = 1,2,\cdots,8)$ into equation (7), the following eight equations consisted of eight linear equations can be obtained:

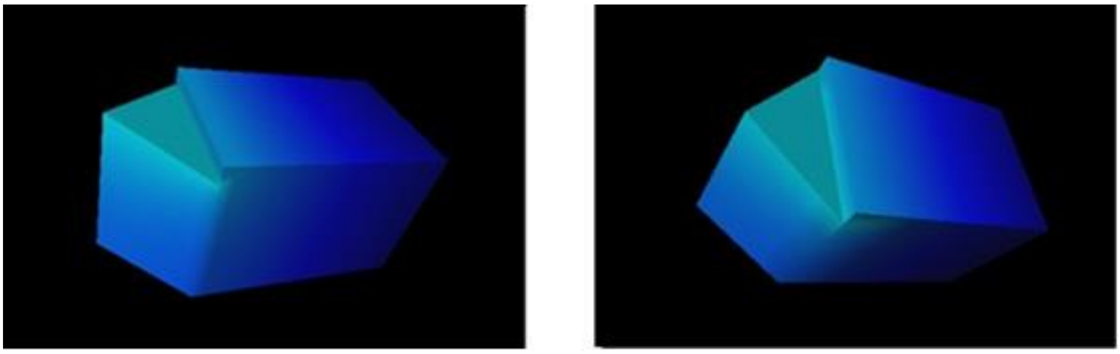
$$f_i = a_1 + a_2x_i + a_3y_i + a_4z_i + a_5x_iy_i + a_6y_iz_i + a_7z_ix_i + a_8x_iy_iz_i \quad (i = 1,2,\cdots,8) \tag{8}$$

The eight undetermined coefficients are determined by numerical calculation of linear equations, then the interpolation function in the element expressed by the equation (7) is determined, and the value of P points is calculated by using the formula (8) further.

4. Simulation Instances

The two experimental results instances of temperature field of lathe tool are given using finite element analysis. Figure 5(a) is lathe tool low-temperature field distribution figure for the ten-node tetrahedron elements using finite element analysis. Figure 5(b) is lathe tool low-temperature field distribution figure using sparse surface mesh during the visualization, where the temperature value of each node uses the simplify algorithm here. It can be seen that the temperature fields shown in figure 5 (b) and figure 5 (a) are basically the same by comparison of the two figures, the gradient is smooth and the number of nodes is greatly reduced. This will save a lot of computer resources.

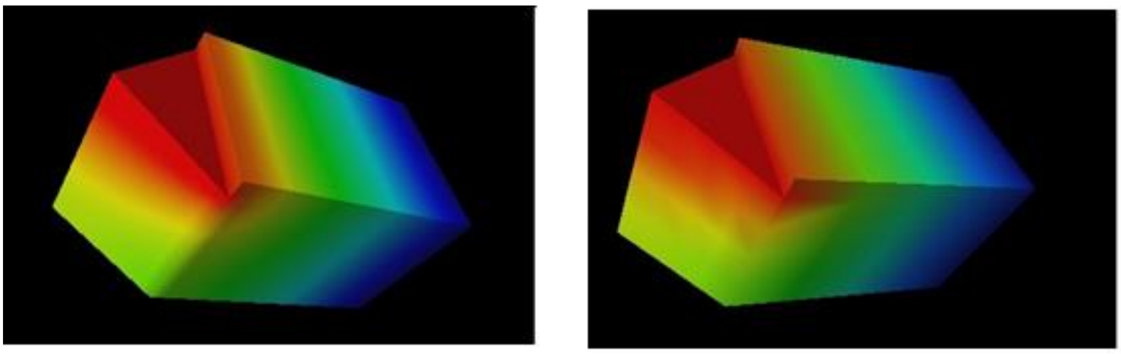
Figure 6 (a) is lathe tool high-temperature field distribution figure for the eight-node tetrahedron elements using finite element analysis. Figure 6 (b) is lathe tool high-temperature field distribution figure using sparse surface mesh during the visualization. It can be seen that the temperature fields shown in figure 6 (b) and figure6 (a) are basically the same by comparing of the two figures. Although the number of nodes is reduced rapidly, the two figures look no different, but the speed display has been improved. So we concluded that the algorithm presented in this paper can effectively simplify data and make model visualization feasible.



(a) (b)

Figure 5. Comparison of Low Temperature Field Distribution using Ten-notes Tetrahedron Elements or Not

(a)finite element analysis source data result(9872 nodes)
(b) visualization sparse mesh model data (172 nodes)



(a) (b)

Figure 6. Comparison of High Temperature Field Distribution using Eight-nodes Hexahedron Elements or Not

(a)finite element analysis source data result(3140 nodes)
(b)visualization sparse mesh model data (172 nodes)

5. Conclusion

In this paper a mesh-based data extraction algorithm of engineering calculation visualization huge data was proposed, the common four-node tetrahedron elements, ten-node tetrahedron elements and eight-node hexahedron elements mesh data are extracted and simplified. Simulation results show that the algorithm presented in this paper can be used to simplify the large amounts of data of the engineering analysis, and simplified data that visualization needs can be obtained easily.

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