Construction of Hierarchical Detail Model of Energy Environment Based on the Integration of Automatic Information Association Technology in Virtual Reality

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Abstract. In this paper, the defects of the existing models in virtual reality, such as the excessively long pretreatment time, time consuming in update operations and so on, when dealing with the large-scale automatic information association technology are analyzed. And a kind of construction method for the hierarchical detail model of energy environment (hereinafter referred to as CHDM for short) based on the integration of automatic information association technology is put forward. In this method, the information is aggregated in virtual reality to establish the hierarchical detail model of energy environment. Then the geometric parameters and form features are integrated to calculate the hierarchical details of each volume element. The topology connection relationship of the hierarchical detail model of energy environment is used to form a “Hierarchical detail model of energy environment”, which is merged and simplified in virtual reality. The experimental results show that for the automatic association of information with a patch complexity of about 10M can improve the average rate of model establishment about 3 times on the premise of guaranteeing certain construction quality on the ordinary PC. And the pretreatment time is controlled within 7min.

1. Introduction

In the process of establishing the hierarchical detail model of energy environment, model review personnel often need to browse the hierarchical detail model of energy environment through interactive construction so as to identify and report the design errors in the model in time [1-2]. Therefore, the pretreatment time and construction rate required for the model establishment directly affect the work efficiency and project progress of the model review personnel[3-4]. Since there may be some dynamic automatic association information in certain types of hierarchical detail model of energy environments, the current graphics hardware processing capacity of the design unit poses the challenge to the real-time performance of model establishment with the increase in information size and model complexity [5-6]. At present, relatively good results can only be obtained for information data with relatively small scale abroad. And most of these information design systems are operating on workstations. Due to the economic strength, most design institutes in our country use the ordinary PCs in their work [7-8]. Therefore, the research on the hierarchical detail model of energy environment technology of the large-scale complex information automatic association technology is of important significance and market value for improving the work efficiency of the model review personnel and guaranteeing the timely accomplishment of the design task [9-10].
Based on the existing CHDM method, a kind of hierarchical detail model of energy environment based on the integration of automatic information association technology in virtual reality is put forward in this paper through in-depth analysis of the constitutive features and dynamic features of the hierarchical detail model of energy environment. In this model, the automatic information association technology is used to carry out information aggregation and pipeline segmentation. The geometrical parameters and form features of automatic information technology is used to calculate the HDM of each volume element through triangulation of volume element by successively reducing precision. And the topological relationships and constitutive features of the hierarchical detail model of energy environment are used to perform merger and simplification in virtual reality. For dynamic automatic association information, the model does not require re-calculating the CHDM of the automatic association information, which has greatly reduced the computational overhead in the real-time establishment.

2. Automatic Information Association Technology in the Composition of Hierarchical detail model of energy environment

In order to carry out in-depth analysis of the constitutive features of the hierarchical detail model of energy environment, this paper takes Figure 1 as an example to perform statistics on the component information and patch information of the hierarchical detail model of energy environment. The results are shown in Table 1. In Table 1, each pipeline may be composed of multiple pipes and a number of elements, the total number of patches = Automatic association information + pipe + elements.

According to the statistics in Table 1, it can be seen that in the hierarchical detail model of energy environment, the number of patches of the hierarchical detail model of energy environment in this part generally accounts for more than 80% of the total number of patches in the entire hierarchical detail model of energy environment. Therefore, the simplification strategy for the hierarchical detail model of energy environment directly determines the construction performance of the system.

| Model | Component Information | Patch Information |
|-------|------------------------|-------------------|
|       | Equipment/unit | Pipe/unit | Element/unit | Pipeline/line | Equipment/unit | Pipe/unit | Element/unit |
| Figure 1a | 201 | 3.491 | 12.372 | 8.4 | 1129.419 | 404.456 | 4381.419 |
| Figure 1b | 108 | 8.509 | 28.959 | 11.01 | 472.484 | 987.044 | 10951.76 |
| Figure 1c | 232 | 7.787 | 31.659 | 74.3 | 577.567 | 903.292 | 18946.05 |

Firstly, according to the topological connection relations that form the automatic association information, the type and geometric parameter information of each volume element are obtained from the automatic association information database. And all the volume elements are aggregated in virtual reality as a node of the hierarchical detail model of energy environment. The main purpose of the volume element aggregation operation is as the following: 1) In the dynamic process of the automatic association information, since no changes will occur in its composition, it is easy to control the dynamic state of its volume element through the automatic association information node; 2) When calculating the CHDM of information, it is conducive to perform comprehensive control on the dissection precision of each volume element to avoid the problem of automatic association...
information or local distortion of elements caused by the excessively low dissection precision of certain volume elements, and maintain the overall form features of the information as much as possible.

In order to facilitate the overall simplification of the pipes and some of the connected elements, this model aggregates all the elements located between two connected pipes into an entity to create the "Composite element" node. Figure 2 shows the schematic diagram of the element aggregation. The flanges, gaskets and valves between the two pipes are taken as a whole to constitute the “Composite element”, as shown in the green part in Figure 2b.

In the actual hierarchical detail model of energy environment, there is certain range limit on the length of a single pipe. On the one hand, excessive length of single pipe will cause inconvenience to the pipe production and transportation; on the other hand, in actual production, if a single pipe is too long, it is prone to deformation under the influence of gravity and pressure of the fluid inside, which is not conducive to the operation and maintenance of information. However, in the modeling process, the designers generally carry out the plumbing design and the related information statistics based on the engineering rules with the pipeline as the unit.

Usually, there will be a lot of pipes in the same pipeline, and various connected pipes are linked by a number of elements. The span of the pipeline in space is usually large, which sometimes traverses the entire information model. In order to display the different pipes with different distance ranges from the observer with different resolution models, and at the same time, making it convenient to manage and perform overall merger and simplification on the “Composite elements” connected to them with the pipe as the unit, this paper first divides the pipeline into a series of pipes and “Composite elements”. Each pipe is then integrated with the "Composite element" attached to the pipe as a whole to establish the "Hierarchical detail model of energy environment" node. When a "Composite element" is connected to a number of pipes, in order to avoid the repeated construction of the "Composite element", it is only assigned to any one pipe of them in this paper. And the ID of other pipes connected to it is recorded in the "Composite element". Figure 4 shows a schematic view of the pipeline segmentation. The pipeline in the Figure 3a is composed of A ~ G7 pipes and a ~ e5 "Composite elements", a is composed of 2 flanges, 2 gaskets and 1 valve, b and c are elbows, d is tee, e is pipe cap. Figure 3b shows a schematic diagram of the pipeline separation. The pipeline is separated into 7 "Hierarchical detail model of energy environments" where the pipes and "Composite elements" of the same color form a "Hierarchical detail model of energy environment". Figure 4 shows the structure diagram of the "Hierarchical detail model of energy environment" node.
Figure 4 Schematic diagram of composite pipe hierarchical structure

After completing the aggregation and segmentation operations, a hierarchical detail model of energy environment based on the automatic association information technology is established, which uses the axis-aligned binary space partitioning (BSP) tree to perform adaptive segmentation on the automatic association information and the "Hierarchical detail model of energy environment" in the scene. Firstly, the axis-aligned bounding box (AABB) for each automatic association information and the "Hierarchical detail model of energy environment" is calculated. When performing axis-aligned BSP dissection of the scene, the direction where the longest edge of the corresponding bounding box shall be selected for equal division in each dissection. When the node contains only one automatic association information or "Hierarchical detail model of energy environment", the dissection of the node is terminated. Finally, an initial hierarchical detail model of energy environment is established according to the established BSP tree.

3. Construction of hierarchical detail model of energy environment based on the interaction of automatic association information technology

This paper uses the geometrical parameters and form features of automatic information association technology to calculate the HDM of each automatic information association technology by reducing the precision successively and retriangulating the automatic information association technology. In order to improve the construction efficiency, this paper adopts the triangle strips to represent the triangular patches of each volume element after the dissection, while using the display list technology in the construction process. The geometric parameters and form features are integrated to calculate the HDM of each volume element, which has the following two advantages: 1) It can easily control the volume element simplification error using the dissection precision while effectively reducing the complexity of model simplification and improving the efficiency of simplification; 2) The HDM calculation method based on the integration of geometric parameters and form features facilitates the use of triangle strips and display list technology, which can improve the system construction efficiency.

According to the analysis in Table 1, it can be seen that the number of patches in the “Hierarchical detail model of energy environment” generally accounts for more than 80% of the total number of the model patches. Hence the simplification strategy for the “Hierarchical detail model of energy environment” directly determines the construction performance of the system. And element is also the main component of the "Hierarchical detail model of energy environment". Therefore, before introducing the "Hierarchical detail model of energy environment" CHDM construction method, in-depth analysis of the element constitutive features is first performed.

In the hierarchical detail model of energy environment, the elements mainly include pipe fittings, valves, flanges, gaskets and so on. Among them, the pipe fittings can be divided into straight pipe fittings, curved fittings and branch fittings. The valves can be divided into straight-through valves, angled valves and so on. Figure 5 shows several common element models.
In the pipe fittings, the straight pipe fittings are mainly composed of circular truncated cones; the curved pipe fittings are mainly composed of circular sectional rings; and the branch fittings are mainly composed of cylindrical bodies. The type and the number of the volume element constituting the valve are slightly more, which mainly include cylindrical body, oblique cylindrical body, circular ring and other volume element. Flanges and gaskets are mainly used for pipe connection. Flanges are usually used in pairs. For the purpose of sealing, gaskets are added between two flanges, as shown in Figure 2b. In the hierarchical detail model of energy environment, the flanges and gaskets are the same as the pipes. They are usually represented by a cylinder, as shown in Figure 5b. In industrial pipelines, flanges and gaskets are widely used in huge quantity. The statistics of the flange and gasket information in the three hierarchical detail model of energy environments in Figure 1 is performed in this paper, and the results are shown in Table 2. In Table 2, \(N_{fg}\) stands for the number of flanges and gaskets, \(N_e\) stands for the total number of elements, \(P_{fg}\) stands for the number of flange and gasket volume elements, and \(P_c\) stands for the total number of volume elements. It can be seen from Table 2 that, compared with the other types of elements, the flange and gasket occupy the main position in the elements.

| Model  | \(N_{fg}\) | \(N_e\) | \(N_{fg}/N_e\)% | \(N_{fg}\) | \(P_{fg}\) | \(P_c/P_e\)% |
|--------|-------------|--------|----------------|--------|---------|-------------|
| Figure 2a | 1446 | 12,372 | 11.61 | 1416 | 5193 | 35.88 |
| Figure 2b | 1648 | 28,958 | 29.64 | 1648 | 31,179 | 27.19 |
| Figure 2c | 9093 | 31,009 | 29.80 | 8999 | 49,921 | 18.10 |

The first level of CHDM in the “Hierarchical detail model of energy environment” is applicable to the situation close to the point of view. At this point, the pipes and elements are the focus of the designer in the observation. And it is necessary to accurately reflect their topological relationships and constitutive features. Hence the CHDM is composed of the CHDM of the pipes and "Composite element" nodes regardless of any merger on the pipes and elements. The second level of CHDM in the “Hierarchical detail model of energy environment” is applicable to the situation relatively far from the point of view. Therefore, under the premise of ensuring the overall visual appearance characteristics, to improve the simplification rate of the model, this paper combines some of the cylinders, oblique cylinders, multi-prism and circular truncated cones in the pipes and various elements in the virtual reality. Among them, the flanges and gaskets are the focus of the merge.

4. **Experiment and Result Analysis**

The three hierarchical detail model of energy environments in Fig. 1 are taken as the example to carry out experiment on the CHDM model proposed in this paper. The land occupancy area in Fig. 1a is approximately \(213.957 \times 36.05m^2\), the occupancy area in Fig. 1b is approximately \(149.37 \times 82.964m^2\), and the occupancy area in Fig. 1c is approximately \(119.396 \times 33.658m^2\). The experimental platform is Intel Pentium Dual E2180 2.0 GHz CPU, with 4.0GB RAM, ATI Radeon X550 graphics card, 256MB graphics card memory, Windows XP operating system, VC.net2003 and OpenGL development environment.

Each volume element has different initial precision \((P_{max})\), minimum precision \((P_{min})\) and decreasing amplitude \((\Delta P)\) due to the different forms and complexities. In the experiment, the mean of \(P_{max}\) is 25, the mean of \(P_{min}\) is 4, and the mean of \(\Delta P\) is 2. For the “Hierarchical detail model of energy environment”, the average distances corresponding to the three levels of CHDM are [0,
60m), [60m, 180m) and [180m, +∞), respectively. The model is observed comprehensively according to the approach from the distant to the near in the construction, with the dynamic step length of 0.5m and the rotation angle of 2°/time.

In this paper, statistics of the aggregation, segmentation time and CHDM construction time is carried out respectively. The results are shown in Table 3. Among them, the aggregation and segmentation time depends on the number of the automatic association information in the model, the number of the pipelines, as well as the number of pipes and elements included in each pipeline, which is not related to the number of patches in the model. And the construction time of the model CHDM depends on the shape and number of the volume elements in the model and the number of HDMs of each volume element.

| Table 3 Model pretreatment time |
|----------------------------------|
| Model                  | Number of patches | Aggregation and segmentation time/s | HLOD generation time/s | Total time/s |
| Figure 1a              | 5 915 524         | 72                                  | 42                     | 114         |
| Figure 1b              | 12 416 704        | 338                                 | 68                     | 466         |
| Figure 1c              | 20 426 854        | 338                                 | 92                     | 434         |

This paper takes Figure 1b, 1c as an example and adds two sets of dynamic automatic association information along the fixed path in each model, in which the number of volume elements contained is 56 and 32, respectively. And the number of original patches is 41327 and 20842, respectively. Figure 6 shows the comparison results of the frame rate, the number of actually constructed patches, and the number of volume elements of the hierarchical detail model of energy environment under the same construction sequence.

The experimental results show that: The model proposed in this paper can obtain relatively good acceleration effect when the model is constructed from the distant to the near. When the distance is close, as the local structure of the hierarchical detail model of energy environment is often complicated, the density of the volume elements is high, and it is required to be accurately reflect the topological relationship and constitutive features of the close-up objects, the acceleration effect obtained by the model is not significant.

Figure 6 Comparison diagram of roaming performance

Figure 7 shows the comparison of the simplification effect of a “Hierarchical detail model of energy environment”. From the top down in Figure 7a, the effect diagrams of the original model of the “Hierarchical detail model of energy environment” at different distances from the viewpoint, and the number of volume elements is 18. Figure. 7b from top down corresponds to the CHDM of the “Hierarchical detail model of energy environment” at three levels. Among them, the first level of CHDM is composed of the CHDM of each volume element, and the number of volume elements is 18. The second level of CHDM is composed of the CHDM of twelve volume elements after the overall simplification of the “Hierarchical detail model of energy environment”. And the third level CHDM
represents the "Hierarchical detail model of energy environment" with its intelligent line, hence the number of volume elements is 0. Through the comparison, it can be seen that the model proposed in this paper can significantly improve the model simplification rate on the basis of ensuring certain visual appearance characteristics of the model. For the design review personnel, the second and third levels of CHDM are used far away from the viewpoint. At this point, this part of the model is no longer the focus of their review. In order to improve the construction rate and work efficiency, the visual error caused by the simplification is totally acceptable.

**Figure 7** Comparison diagram of the simplification effects of "Composite pipes"

Figure 8 shows the comparison of the effects of Figure 1a before and after the simplification at the same viewing angle. In Figure 8a, the number of volume elements is 16736, and the number of patches is 4396737; in Figure 8b, the number of volume elements is 10220, and the number of patches is 426538. From Figure 8, it can be seen that after the application of the hierarchical detail model of energy environment proposed in this paper, the number of volume elements is reduced by 6516, and the merging simplification rate of the volume elements is about 40%, which has effectively reduced the complexity of the model.

**Figure 8** Comparison diagram of hierarchical detail model of energy environment effects

5. Conclusion

Based on analyzing and summarizing the constitutive characteristics and dynamic features of PDSOFT hierarchical detail model of energy environment, a kind of hierarchical detail model of energy environment based on the integration of automatic information association technology is put forward in this paper. It has basically solved the problems of excessively long pretreatment time and low dynamic scene processing efficiency in the existing CHDM methods when dealing with large-scale complex automatic information correlation technology, and basically met the needs of the actual work of model design review personnel. The method proposed in this paper has the following advantages: The volume elements in the model are divided into two categories, that is, the automatic association information and the "Hierarchical detail model of energy environment", through the aggregation and segmentation operation. It is not only conducive to merging and simplifying the "Hierarchical detail model of energy environment" and improving the model simplification rate, but also makes it convenient to handle the situation where there is dynamic automatic association information in the model.

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