Mesh Modification System for Three Dimensional Unstructured Mesh Using VR Technology

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Abstract

This paper presents an interactive mesh modification system for three dimensional unstructured mesh using virtual reality (VR) technology. The present system is developed by the VR programming languages, OpenGL and CAVE library. Users can check the details of three dimensional mesh structures and can modify the shape of mesh idealization in VR space interactively. For the mesh modification methods, the node relocation method and the mesh refinement methods are implemented. The linear and 2-nd order tetrahedron elements are available in this system. Users can change the nodal position of the bad quality element in case of the node relocation method, and can refine the bad quality element in case of the mesh refinement method interactively. The present system is applied to the mesh modification for the simulation of 3D solid analysis and is shown to be a useful tool to assist the high quality computing.

Keywords: Virtual reality, Mesh modification, Node relocation, Mesh refinement.

Introduction

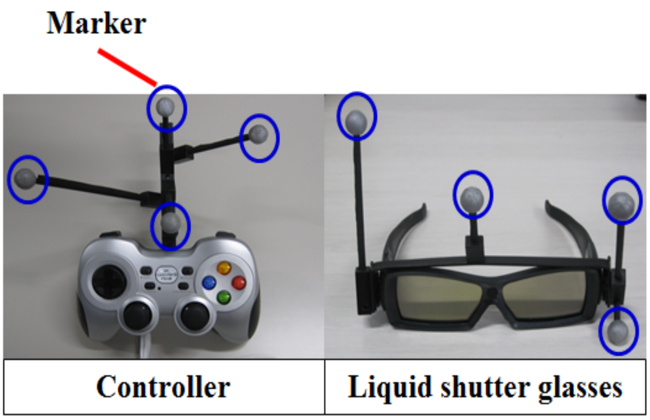
The three dimensional finite element simulations are becoming more powerful and popular tool for various CAE (Computational Aided Engineering) problems in accordance with the development of hard- and software of computers. Especially, the theory of automatic mesh generation is remarkable and a number of automatic mesh generator has been presented (Lo(2013), Cheng et al.(2013)). However, in some cases bad quality elements are created by the automatic mesh generator when the shape of computational domain is complicated. Users will try to modify the quality of mesh using the mesh idealization show on 2D display with perspective drawing. However, it is difficult to understand the position information for the depth direction cleanly.

This paper presents an interactive mesh modification system for three dimensional unstructured mesh using virtual reality technology in order to overcome the problem. Authors focused on immersive virtual reality device such as CAVE. Users can check the details of three dimensional mesh structures and can modify the shape of mesh idealization in VR space interactively by using the controller. Generally, the mesh modification method can be classified into three methods; the node relocation method, the mesh refinement method and the replacement method using higher order element. In this system, the node relocation method and the mesh refinement method are implemented. Users can change the nodal position of the element in the node relocation method, and can refine the element in the mesh refinement method. The present system is available for the unstructured tetrahedron elements based on linear and 2-nd order elements. The system is developed by the VR programming languages, Open GL and CAVE library.

The present system is applied to several mesh modification examples for the 3D finite element simulation and is shown to be a useful tool to assist the high quality computing.

CAVE Environment

The present system is designed for the use of virtual reality system based on IPT (Immersive Projection Technology) such as CAVE (Cruz-Neira et al. 1993). The stereoscopic view is realized in VR space by creating the images that corresponds to binocular retinal images. The mesh modification system is developed by using VR device “Holostage” of Chuo University. The “Holostage” consists of a PC cluster (one master-PC and four-slave-PC), three projectors, three large screens and a position tracking system. The stereoscopic image from the arbitrary viewpoint of user is displayed in VR space by the position tracking system. Users can move in VR space freely like the real space. Therefore, users can check the three-dimensional structure of the mesh clearly and it can be expected to modify the mesh accurately and easily. Users can see the stereoscopic image by using the liquid shutter glasses in Fig. 1. The silver balls which are mounted to the controller and liquid shutter glasses are marker (see Fig. 1) to track the position information by the tracking device. Fig. 2 shows the scene the user modifies the mesh idealization manually using the present system. The red color virtual beam is generated from the controller shown in the figure. User can specify the target node or mesh by moving the tip of the virtual beam.



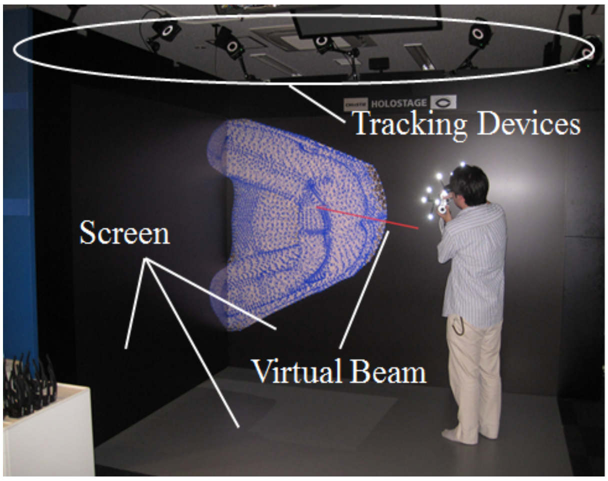


Figure 1. Device for VR system

Figure 2. CAVE environment

The three-dimensional mesh modification system

Users can check the details of three dimensional mesh structures and modify the mesh quality interactively in VR space by the present system. The present system is developed by the VR programming languages, Open GL and CAVE library. The system is available for the unstructured tetrahedron elements based on linear and 2-nd order elements as shown in Fig. 3.

Fig. 4 shows the flow chart of the present system. First, the mesh quality is computed, and then the mesh quality is improved by the mesh modification by both node relocation and mesh refinement methods. Users can select the modification method from the menu which is displayed in the VR space. Users can change the nodal position of the bad quality element in the node relocation method, and can refine the bad quality element in the mesh refinement method.

The mesh quality Q_m can be evaluated by the following equation (Freitag and Knupp ,2002).

$$Q_m = \frac{\left(\frac{1}{6} \sum_{i=1}^{6} L_i^2 \right)^{\frac{3}{2}}}{8.4796\, V} \tag{1}$$

Where L_i denotes the length of the edge of the element, V is the volume of the element. The mesh quality is to be 1 if the element is to be a regular tetrahedron and the value is to be big value if the element becomes a bent element. In this system, the elements which exceed the setting value for mesh quality are displayed by the red color in VR space.

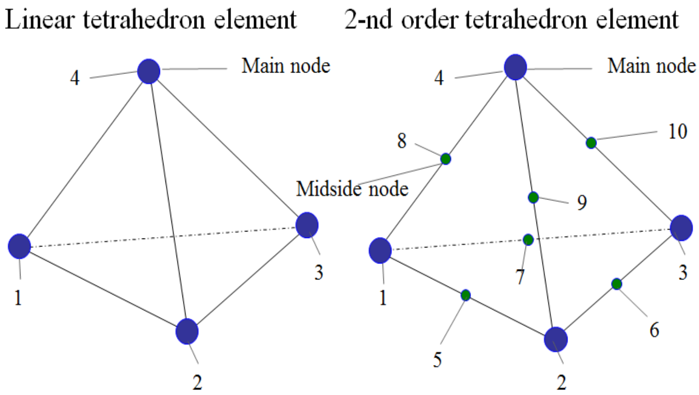


Figure 3. Tetrahedron elements

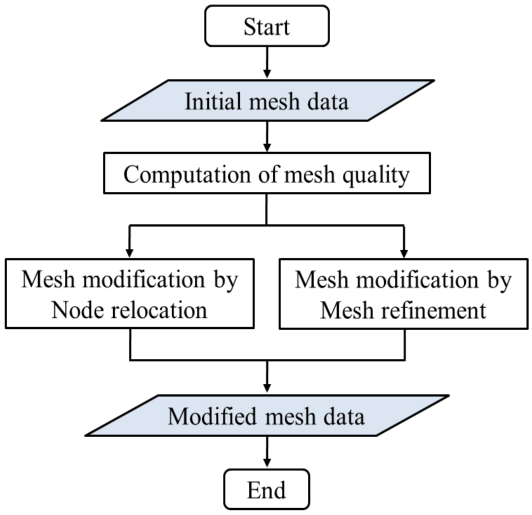


Figure 4. Flow chart of the system

Modification Method by node relocation method

Users can select functions from the menu interface as shown in Fig. 5. In the modification method by node relocation, if users move the tip of beam generated from the controller to the main node and click the button of controller, then the node can be specified and users can modify the element by the movement of tip of beam, as shown in Fig. 6.

Figure 5. Menu interface

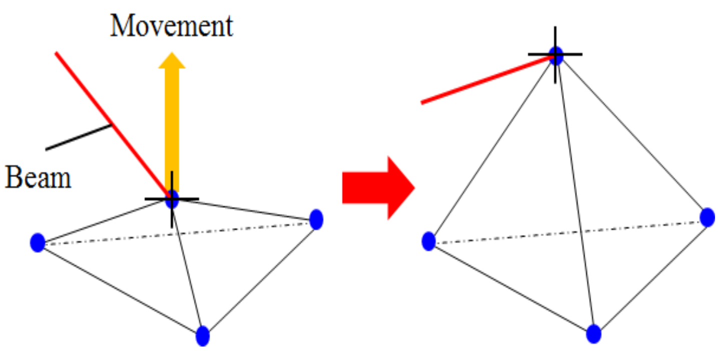


Figure 6. Modification of node relocation

In case of the 2-nd order tetrahedron elements, users move only the main nodes of the top of the element, and the position of the midside node on the edge is interpolated automatically.

In order to avoid the violation of the geometrical shape of the computational domain by the node relocation, the node movement condition must be specified for the nodes on the boundary surface. The condition is prepared by the geographical information, which is obtained by the mesh data. The nodes on the boundary surface can be classified into three types as follows; (a) Fixed node: The nodes on the uneven edge-line or surface (red nodes in Fig. 7) are assumed to be fixed point, (b) 1D movement node: The nodes on the even edge-line of the structure (green nodes) can move on the edge-line only, (c) 2D movement node: The nodes on the even surface of the structure (light blue nodes) can move on the surface only. In this system, the control of the movement of nodes is performed by the node movement condition which is generated by the information of unit normal vector as shown in Fig. 8 and Fig. 9.

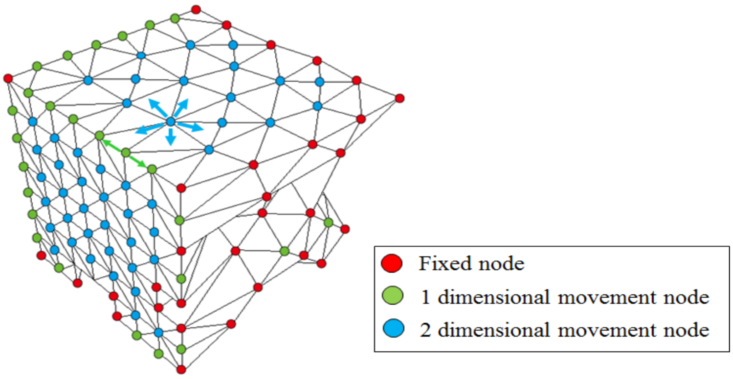
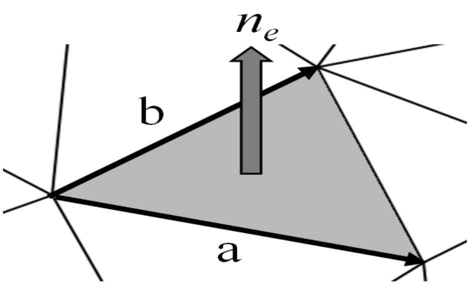


Figure 7. Node movement condition



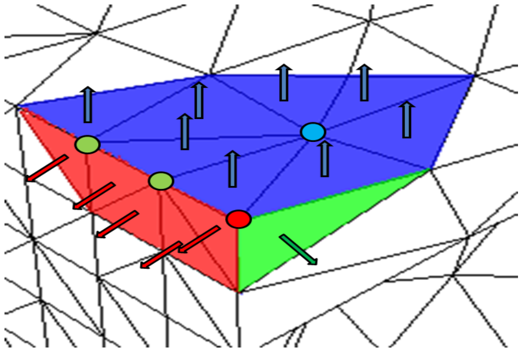


Figure 8. Normal unit vectors **Figure 9. Classification of node movement condition**

The normal unit vector of each triangles $\boldsymbol{n_e}$ can be evaluated by the following equation.

$$\boldsymbol{n}_e = \frac{\boldsymbol{a} \times \boldsymbol{b}}{\|\boldsymbol{a} \times \boldsymbol{b}\|} \tag{2}$$

Where, vector **a** and **b** is shown in Fig. 8. If the values of normal unit vectors for the triangles connected to the node have only one value, the node can be specified as the 2D movement node. If the values of normal unit vectors for the triangles connected to the node have two different values, the node can be specified as the 1D movement node. On the other hand, if the values have more than three different values, the node can be specified as the fixed node. Users can recognize the node movement condition using the nodal color information same as Fig. 7 in VR space.

Modification Method by Mesh Refinement Method

In the modification method by mesh refinement, the elements which exceed the setting value for mesh quality are refined.

Users can specify the element and decide the position by using the controller. If users move the tip of beam generated from the controller to the inside of the element and click the button, then the element can be specified. At this time, in order to investigate the judgment that the element includes the tip of beam or not for all elements of the mesh, the mapping method (Shirayama, 2002) using a generalized coordinate system is employed. The mapping method can be applied to the 2-nd order tetrahedron element.

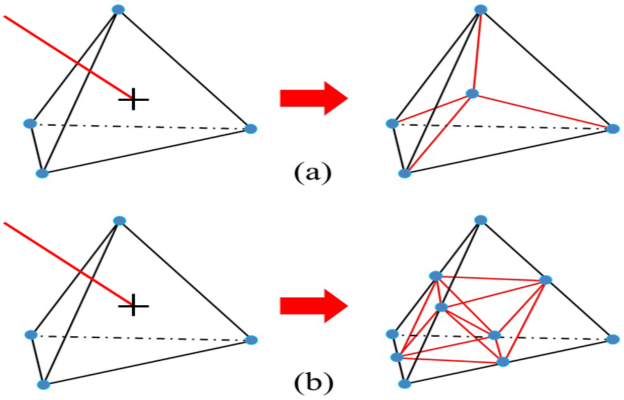


Figure 10. Mesh refinement methods

Fig. 10 shows mesh refinement patterns in this system. In the case of (a), a new node is generated at the centroid of the element. The connectivity of the element except the refined element does not change. However, the shape of the element becomes bent in this case. On the other hand, in the case of (b), a new node generated at the middle point on the each edges of the element. Therefore the shape of subdivided mesh is resemblance. However, the connectivity of the neighboring elements around the subdivide element changes and we have to manage the change of the connectivity.

The refinement patterns of neighboring elements can be classified into 64 patterns as shown in Table 1 since the tetrahedral element is constituted by 6 edges (2^6=64) where the possibility of the generation of a new node. Fig. 11 shows an example that the number of shared edge is two. Considering the rotational property of the element in (a) and (b), the left and right patterns are one and the same. The refinement patterns are reduced to 11 patterns if the rotational property of the elements is considered. Consequently, the mesh refinement is performed by using the 11 patterns. Fig. 12 shows the example for mesh refinements, where (a) shows the initial mesh and (b) shows the refined mesh, in which the blue elements show the subdivided element and the red elements show the neighboring elements for the subdivided elements. The validity of the algorithm of mesh refinements is shown in this figure.

Table 1. The refinement patterns of neighboring elements

The number of shared edges	The number of refinement pattern of neighbouring elements	The number of refinement pattern (Considering the rotation)
0	1	1
1	6	1
2	15	2
3	20	3
4	15	2
5	6	1
6	1	1
	Total:64	Total:11

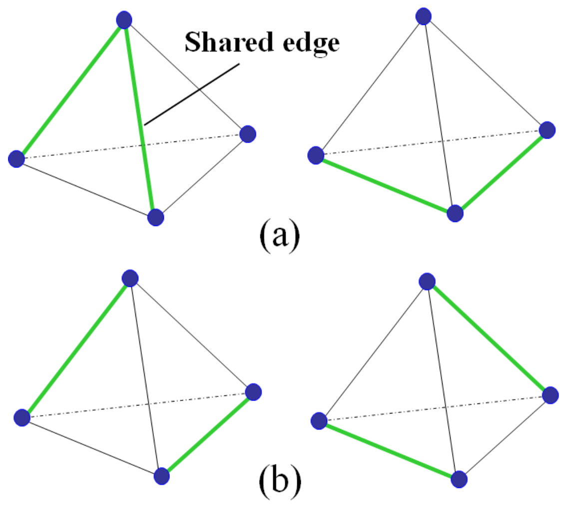


Figure 11. Example that the number of shared edge is two edges

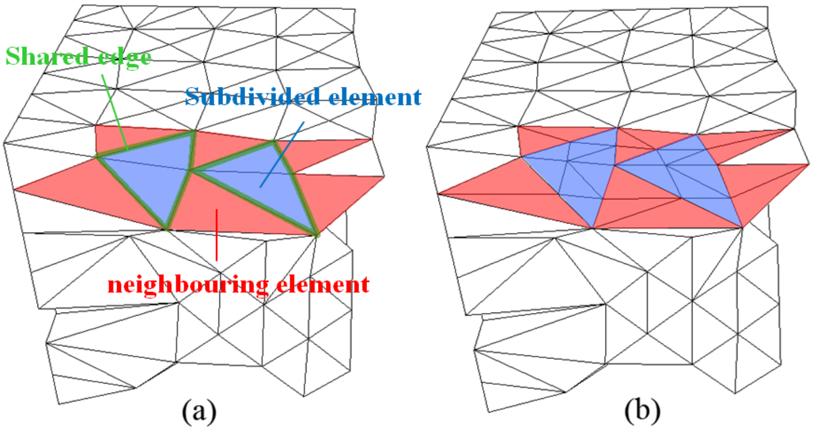


Figure 12. An example of the element refinement

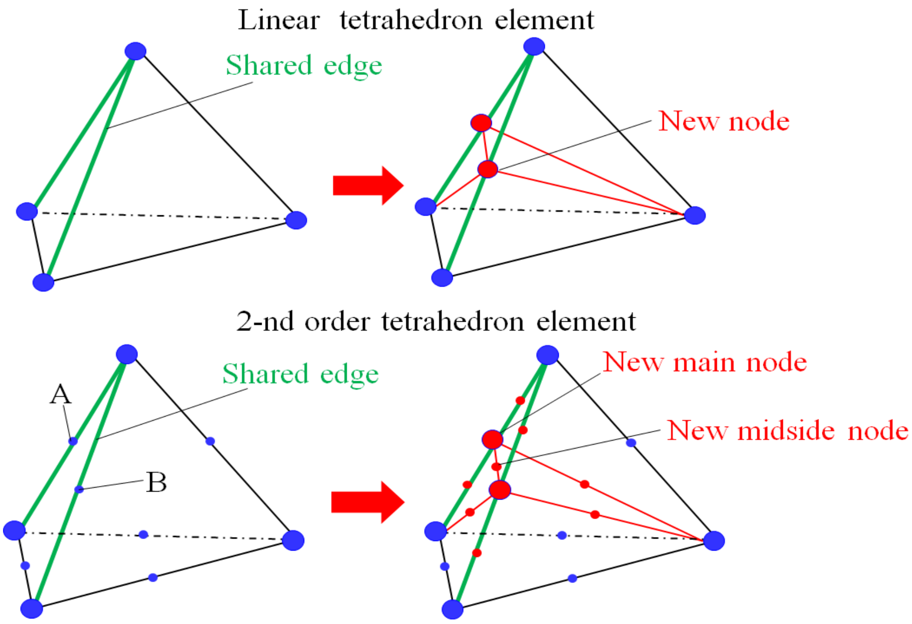


Figure 13. The generated node

Fig. 13 shows the mesh refinement for the neighboring element in case of Fig.11 (a) for linear (top) and 2-nd order (bottom) tetrahedron elements. In case of the 2-nd order (bottom) tetrahedron element, the midside nodes A and B are changed to the main nodes and a new midside node is generated at the center of each new edge (totally 8 nodes)

Application Examples

In order to investigate the validity and efficiency of the present system, the system is applied several mesh modification examples.

Dental Implants mesh

The system is applied to the mesh for stress analysis of dental implants which uses the 2-nd order tetrahedron elements. (Hirano et al. 2008). Fig. 14 shows the mesh idealization in VR space using display functions; node color ON/OFF and midside node ON/OFF. In this system, fixed node is displayed in red, 1D movement node is displayed in green, 2D movement node is displayed in light blue (as shown in Fig. 7) and the node inside the domain and midside node is displayed in blue.

The mesh modification by node relocation is employed and the modification time by using the node color ON/OFF function is compared. Fig. 15 shows the comparison of the distribution of mesh quality before and after the mesh modification by node relocation. In this case, the bad shaped elements which exceed the mesh quality values “10” (29 elements) are modified. From the Figure, it can be seen that the bad shaped elements which exceed the mesh quality values are erased perfectly.

The operation time for mesh modification are compared using the node color ON/OFF function and the results are 7m55s (ON) and 8m50s (OFF) respectively. From, this the operation time is reduced more than 10% by using the node color function.

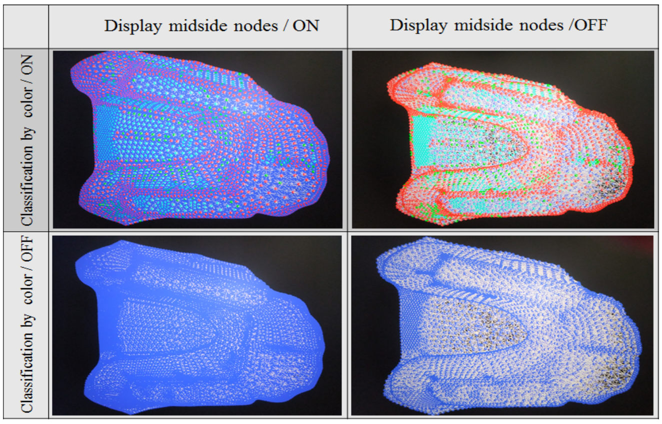


Figure 14. Dental implants mesh

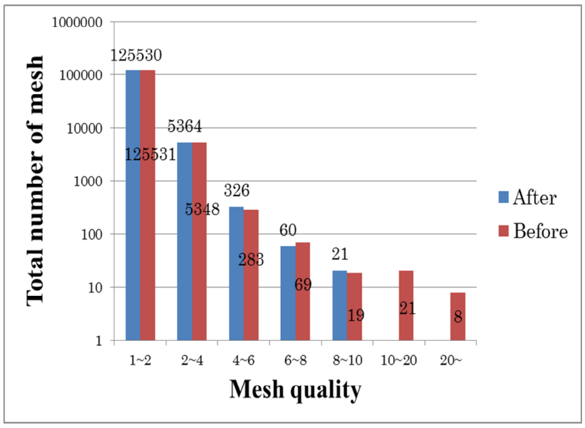


Figure 15. Distribution of mesh quality

City Model Mesh

The present system is applied to the mesh modification for wind flow simulation in urban area as shown in Fig. 16. Fig. 17 (left) shows the zoom-up surface idealization around the base of building. From this figure, it can be seen that the mesh located on the junction with the building base and the ground surface, do not reproduce the proper shape. In order to modify the nodal position on the surface boundary, the node movement condition must be released for this type of problem. So, the node movement condition is released for the node where users change the position of node. Fig. 17 (right) shows the mesh idealization after the mesh modification. From this figure, the proper shape of building and ground surface can be reproduced by the mesh modification.

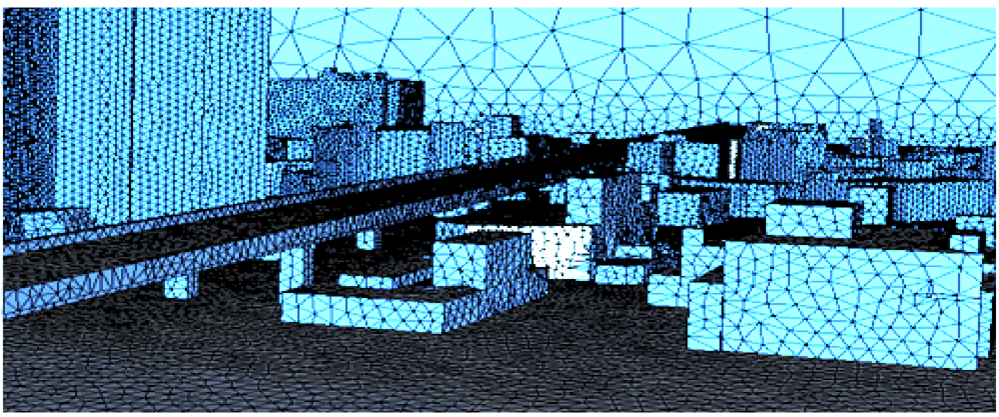


Figure 16. City model mesh

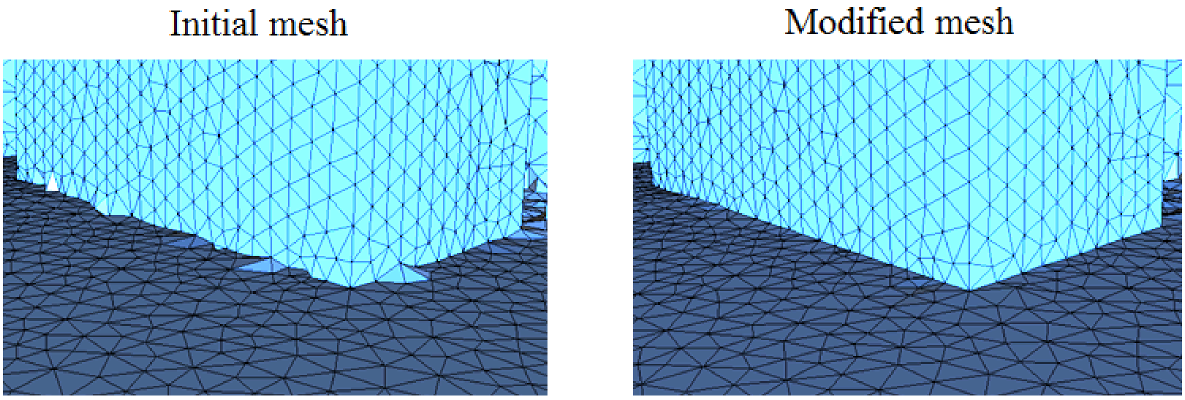


Figure 17. Comparison of before and after modification

Conclusions

An interactive mesh modification system for three dimensional unstructured mesh using VR technology has been developed in this paper. And, we got the following conclusions.

- Users can check and modify the mesh idealization interactively and easily by using the controller in VR space. From this, users can understand the three dimensional unstructured mesh structures by using the present system.

- The mesh modification system based on the node relocation method and mesh refinement method has been successfully developed. For the finite element, the four nodes linear and the ten nodes 2-nd order elements are available.

From the results obtained in this paper, it can be concluded that the present system provide useful tool to realize the high quality computing simulations. In the future, we plan to do to confirm the effectiveness of the system by application to actual problems.

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