Triangular mesh generation using knowledge base for three-dimensional boundary element method

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TRIANGULAR MESH GENERATION USING KNOWLEDGE BASE FOR THREE-DIMENSIONAL BOUNDARY ELEMENT METHOD

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Abstract: Boundary element method has been becoming a practical method for three-dimensional analysis of electromagnetic field. In the analysis, data preparation is an important process which influences the accuracy of computation results and requires much labor and time. In this paper, we propose a method of triangular mesh generation using knowledge base for three-dimensional boundary element methods. The kernel of the mesh generator coded by Lisp language is flexible and expandable because of the knowledge for the mesh generation separated from the execution module. Furthermore, a data structure of the surfaces and boundary elements suitable for Lisp system is proposed.

INTRODUCTION

In the numerical analyses of electrostatic, magnetostatic and electromagnetic problems, data preparation is an important process which influences the accuracy of the computation results and requires much labor and time. On the other hand, boundary element method has been becoming a practical method for three-dimensional analysis. Several formulations of boundary element method have been developed because of its attractive features: easy pre-processing and small computer requirement. In this paper, a triangular-mesh generator for three-dimensional boundary element method is proposed. In the three-dimensional problems, the mesh generation is performed for the boundary surfaces between two materials which are basically two-dimensional geometries. Therefore, useful techniques[1-4] in mesh generators for two-dimensional finite element method can be used. Furthermore, a paper concerning automatic triangular mesh generation on surfaces of polyhedra was presented[5]. the paper described the triangle quality and the triangulation of a polygon which includes important techniques for boundary element method.

The applications of knowledge base such as expert system are effective for the fields in which experiences and skills are required. In the triangular mesh generation, there are many rules which are decided by the approximation of unknowns, the arrangement of boundary surfaces, the geometries of boundary surfaces and the boundary conditions of computation model. Furthermore, know-how may be added in the rules. Therefore, flexibility and expandability are required to use the rules effectively. In this paper, a mesh generator using the knowledge base which consists of the rules is proposed. The knowledge base is separated from execution module and described by Lisp language in order to achieve the flexibility and expandability. Furthermore, the kernel of the mesh generator is coded by Lisp language because Lisp system is more flexible and expandable than procedural programming languages such as Fortran and C language. When the functions which are called according to the rules in the knowledge base are prepared, the kernel carries out meshing by a production system using the knowledge base. In addition, a data structure which is suitable for Lisp system is proposed in order to treat the complex data structure in the meshing processes.

This paper presents a triangular-mesh generator that consists of kernel, knowledge base, functions for mesh generator and data of computation model and is performed by a production system.

MESH GENERATOR

A mesh generator which divides the boundary surfaces into triangular elements is proposed. Figure 1 shows the configuration of the proposed mesh generator, which consists of four parts: kernel, knowledge base, functions for mesh generation and data of the computation model. The kernel carries out meshing by a production system using the knowledge base and the functions for the mesh generation. The knowledge base is including basic principles and know-how of the mesh generation as rules and is modifiable easily on the Lisp system. The basic principles are decided by the approximation accuracy of unknowns, the arrangement of boundary surfaces, the geometry of the boundary surface and the boundary conditions of the computation model. The functions perform basic operations of mesh generation according to the decisions of the production system, and some functions may be added or modified according to the addition or modification of the knowledge base. The data of the computation model consist of the coordinates of nodes, the structures of boundary surfaces and the basic data for the mesh generator: mesh generation pattern and standard length of triangular element and so on. The proposed mesh generator is flexible and expandable because the knowledge

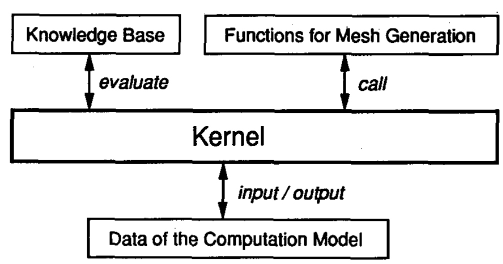

Fig. 1 Configuration of the mesh generator.

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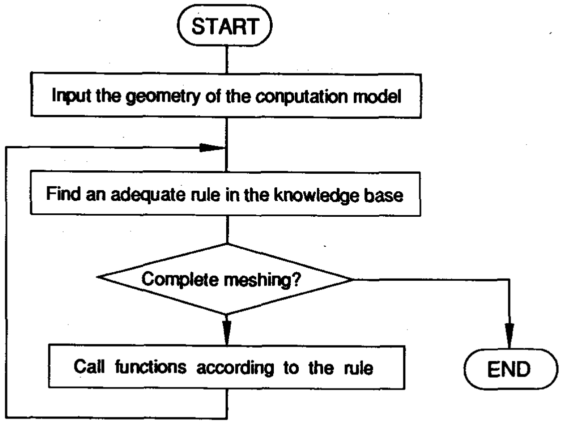


Fig. 2 Execution procedure of the kernel.

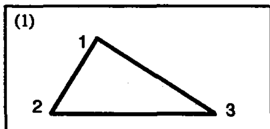
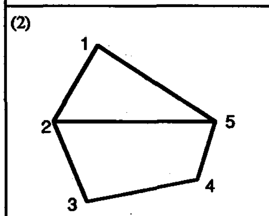
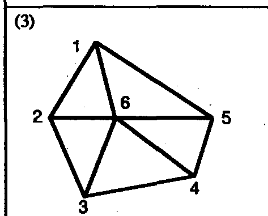
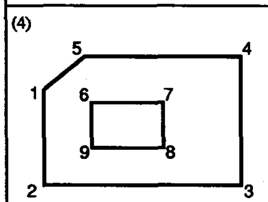
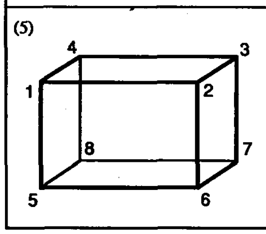
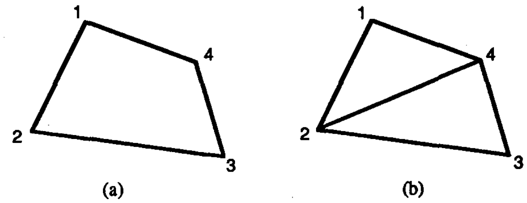
(1) 	Triangular element (1 2 3)
(2) 	Surface divided into a triangular element and a quadrangular element ((1 2 5)(2 3 4 5))
(3) 	Surface divided into five triangular elements ((1 2 6)(2 3 6)(3 4 6) (4 5 6)(5 1 6))
(4) 	Surface with a hole ((1 2 3 4 5 (6 7 8 9)))
(5) 	Shape which consists of six surfaces (((1 2 3 4))((1 5 6 2)) ((2 6 7 3))((3 7 8 4)) ((4 8 5 1))((8 7 6 5)))

Fig. 3 Examples of the data structure.



(1 2 3 4) → ((1 2 4) (2 3 4))

(c)

Fig. 4 Division of a quadrangle to two triangles, (a) a quadrangle, (b) two triangles, (c) update of the data.

base is separated from the execution module and the basic operations are performed by the functions related to knowledge base.

Figure 2 shows the execution procedure of the kernel. At the first step, the geometry of computation model is input. Next, an adequate rule in the knowledge base is found and functions are called according to the rule by the production system. The functions are executed for the basic operations to divide the boundary surface into triangles. The data which express the boundary surfaces and include the information of triangular mesh are updated by the functions. The production system is performed until all boundary surfaces are divided into triangular elements.

DATA STRUCTURE

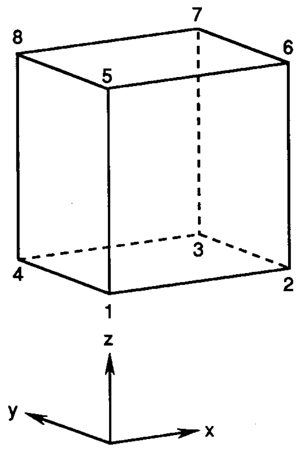
In order to describe the boundary surfaces which consist of some polygon and the triangular elements divided from a polygon, a data structure is proposed. The data structure is defined by using the expression of the list in Lisp program. Figure 2 shows some examples of the expressions for polygons, polyhedrons and triangular elements. The data structure is standardized expression for polygons which consist of any number of polygons as shown in Fig. 3 (1)-(3). Furthermore, a polygon with a hole can be express as shown in Fig. 3 (4). By the similar way, a polyhedron can be express as a group of any polygons as shown in Fig. 3 (5).

In the meshing process, the data expressing the boundary surface as a polygon is updated until a complete triangular mesh for the boundary surface is obtained. For example, the data which are updated from a quadrangle to two triangles are expressed as shown in Fig. 4.

In addition, curved surface can be treated by using planar polygons which are mapped to curved surface polygons. In this case, the mapping data from a planar polygon to a curved surface are required as additional data.

EXAMPLES OF MESHING

Figure 5 shows examples of the triangular mesh generation for a cube model. Input data consist of coordinates of nodes, shape and four parameters as shown in Fig. 5 (b). The coordinates of nodes are given by three-dimensional coordinates and the shape is given by the list of nodes. In Fig. 5 (b), the standard length of the sides of triangle, L, defines the standard length of meshing, the number of bordering steps, N, is the number of triangulating strips along the edges of boundary surface, the bordering width, W, is the width of the triangulating strips, and the decay parameter[5], R, is the ratio of the new bordering width to old bordering width. Two parameter, L and W, are given by the absolute values in the coordinate system. By changing L, N, W and R, we can obtain various



(a)

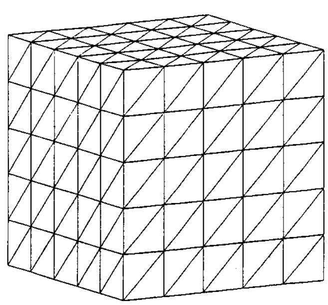
Coordinates:

node number	coordinates		
	x	y	z
1	0.0	0.0	0.0
2	50.0	0.0	0.0
3	50.0	50.0	0.0
4	0.0	50.0	0.0
5	0.0	0.0	50.0
6	50.0	0.0	50.0
7	50.0	50.0	50.0
8	0.0	50.0	50.0

Shape:
(((4 3 2 1))((2 3 7 6))((3 4 8 7))
((4 1 5 8))((1 2 6 5))((5 6 7 8)))

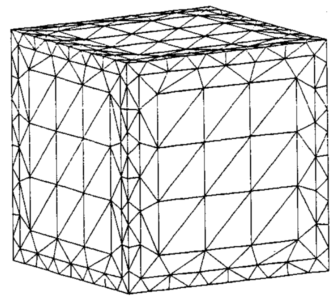
Standard length of the side of triangle (L) : 5.0
Number of bordering steps (N) : 2
Bordering width (W) : 3.0
Decay parameter (R) : 1.5

(b)



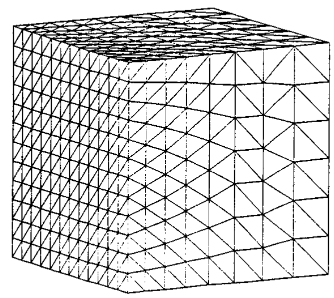
L=10, N=0, W=nil, R=nil

(c)



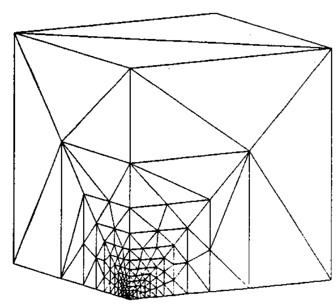
L=5, N=2, W=3, R=1.5

(d)



L=4+x/10, N=0, W=nil, R=nil

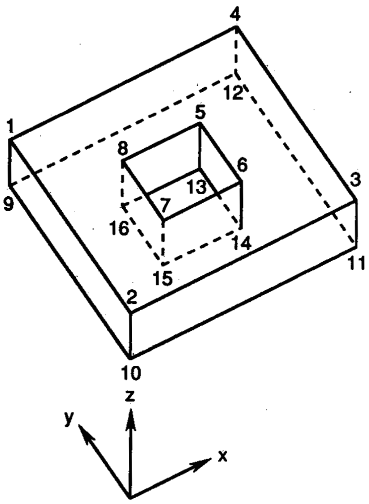
(e)



L=1+(x2+y2+z2)/50, N=0, W=nil, R=nil

(f)

Fig. 5 Examples of the mesh generation for a cube model, (a) input shape, (b) input data, (c) a homogeneous meshing, (d) a meshing concentrated near edges, (e) the standard length variable according to x-component: L=4+x/10, (f) the standard length variable according to x-, y- and z-components: $L=1+(x^2+y^2+z^2)/50$.



(a)

Coordinates:

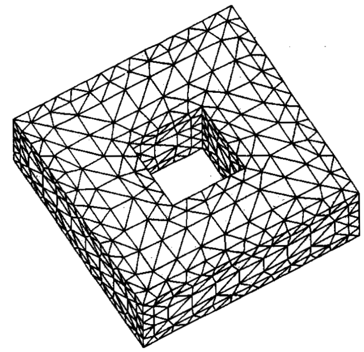
node number	coordinates		
	x	y	z
1	0.0	0.0	0.0
2	60.0	0.0	0.0
3	60.0	60.0	0.0
4	0.0	60.0	0.0
5	20.0	40.0	0.0
6	40.0	40.0	0.0
7	40.0	20.0	0.0
8	20.0	20.0	0.0
9	0.0	0.0	-20.0
10	60.0	0.0	-20.0
11	60.0	60.0	-20.0
12	0.0	60.0	-20.0
13	20.0	40.0	-20.0
14	40.0	40.0	-20.0
15	40.0	20.0	-20.0
16	20.0	20.0	-20.0

Shape:

```
((( 1 2 3 4 ( 5 6 7 8)))
 ((12 11 10 9 (16 15 14 13)))
 (( 1 9 10 2 ))
 (( 2 10 11 3 ))
 (( 3 11 12 4 ))
 (( 4 12 9 1 ))
 (( 5 13 14 6 ))
 (( 6 14 15 7 ))
 (( 7 15 16 8 ))
 (( 8 16 13 5 )))
```

L=4.0, N=2, W=3.0, R=1.3

(b)



(c)

Fig. 6 Example of the mesh generation for a thick plate model with a hole, (a) input shape, (b) input data , (c) result of mesh generation,

meshes. Figure 5 (d)-(f) show irregular meshes for respective parameters. In Fig. 5 (e), (f), the standard length, L, is defined as a variable of the coordinates. In the proposed system, special meshing can be done by changing the data which are described by the list of Lisp.

By using suitable knowledge base, special shape just as a hole can be treated. An example for a thick plate with a hole is shown in Fig. 6.

CONCLUSION

The triangular-mesh generator using knowledge base for three-dimensional boundary element method was proposed. The kernel of the mesh generator was coded by Lisp language because Lisp system is more flexible and expandable than procedural programming languages such as Fortran and C language. And then, by separating the knowledge base of the mesh generator from the execution module, we developed the flexible and expandable mesh generator. The procedure for the mesh generation is decided by rules in knowledge base and the meshing pattern of the computation model is selected by the input data. This means that a goal is given by the input data and the meshing is done by using the rules in the knowledge base in order to achieve the goal. Furthermore, the data structure of the surfaces and boundary elements suitable for Lisp system was proposed. The proposed data structure make easy to treat the complex data structure in meshing processes.

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