#7466

Journal of Wind Engineering and Industrial Aerodynamics, 46 & 47 (1993) 357–362
Elsevier

Automatic mesh generation for FEM simulation of wind flow around tall buildings

K. UEMURA and T. SAITO
Research Center, Asahi Glass Co.,LTD., 1150 Hazawa-cho, Kanagawa-ku, Yokohama-shi, Kanagawa, Japan

Abstract

In this paper, we present efficient fully automatic generation algorism of 2D triangular and 3D tetrahedral FEM mesh with arbitrary mesh size control. In the first step, relatively coarse mesh with small number of elements is generated. Then recursive local subdivision is performed until all elements satisfy the requested mesh size distribution.

We also present local element conversion algorism from triangular and tetrahedral mesh. Unstructured 2D quadrangular(3D hexahedral) mesh with arbitrary grid density distribution is generated automatically by simple conversion procedure from triangular(tetrahedral) mesh.

Using our method, 3D wind flow in actual model cases are computed using FEM solver and good results are shown.

1. INTRODUCTION

Finite Element Method(FEM) is a very excellent simulation technique because it can compute physical phenomena occurring in variety of objects with minimum distortion or modification of their original shapes. Further more, it potentially provides availability of optimized mesh size control which distributes computational errors most rationally under given precision requests. However, creation of mesh using existing mesh modelers is often very time consuming and complicated, and therefore it is quite difficult to fully make use of the advantageous features of FEM.

Automatic mesh generation is the most powerful problem shooting approach and number of such works have been reported[1-8]. While many of the reported techniques can provide excellent 2D and 3D mesh with complex geometry and optimal mesh size control, there are still considerable problems to be solved such as CPU cost, implementation difficulty, restriction of model shape, etc. Further more, no automatic generation of optimal unstructured 3D hexahedral mesh seems to have been achieved even though majority of 3D FEM simulation solvers use hexahedral mesh.

We have been studying on turbulent fluid flow analysis using FEM in 2D and 3D. Under strong requirements in pre-processing (mesh generation) and even post-processing (visualization), we have developed 2D and 3D mesh generation system. This paper describes the algorism of our method which consists of generation of coarse triangular (tetrahedral) mesh which we call base mesh, and recursive subdivision to provide optimal mesh size distribution in very efficient manner. We are also presenting mesh element conversion algorism to generate quadrangle(hexahedral) mesh. Throughout this paper, similar approach for both 2D and 3D problems are described.

2. RECURSIVE SUBDIVISION

Most of the existing automatic mesh generators create meshes which are totally usable for FEM solvers. But in some applications like 3D fluid dynamics, considerable number of elements are required, and performance of mesh generators must be high. In addition to that, strong requirement of arbitrary mesh density control to minimize the solver computation cost makes the load of mesh generators even heavier.

Recursive subdivision approach can be one of the solutions for some applications. Mesh generators only have to output coarse mesh with minimum number of elements. Subdivision procedure is performed element by element recursively. Since it requires only local processing, quite efficient execution is possible, and it is very advantageous especially in 3D simulation.

2.1 2D Subdivision

For each triangular element, its size is compared to the given size function S(x,y). Any of the three edges longer than the requested size are divided into two. When all elements have been checked, then for each element, one of three division procedures illustrated in Figure 2.1 is executed according to the number of divided edges included in the element. This two phase procedures are executed recursively until all the size of elements are small enough to guarantee the requested mesh size. Finally, smoothing process is performed to improve quality of the mesh.

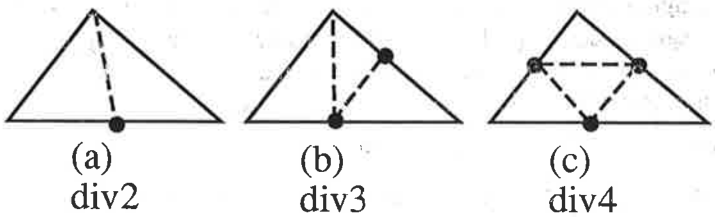


Fig.2.1 Subdivision of a Triangular Element

2.2 3D Subdivision

2D triangular subdivision can be extended to 3D tetrahedral subdivision, though some topological difficulties arise. Four procedures illustrated in Figure 2.2 are used for subdividing elements. When there are some elements which cannot be divided by any of these procedures, additional edge division is performed until every element subdivision is possible using any of the four procedures. Fig 2.3 shows haw the subdivision works.

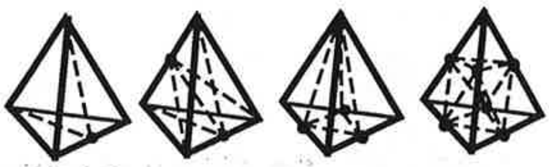


Fig.2.2 Subdivision of a Tetrahedral Element

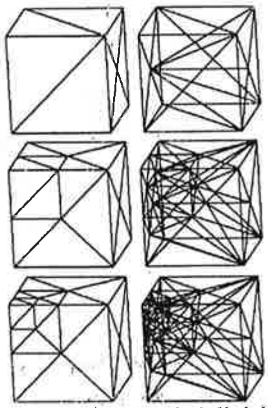


Fig.2.3 An Example of Subdivision of Tetrahedral Mesh

3. MESH CONVERSION

We have described about the triangular and tetrahedral mesh generation. Element type of FEM simulation depends completely on designing of the solver program, and cannot be changed easily in most cases. 2D quadrangular mesh generation techniques which have been reported[2,6] are completely different from triangular mesh generation, and therefore one has to develop absolutely new quadrangular mesh generator even if he already has an excellent triangular mesh generator. It is much more convenient if the triangular mesh can be converted into quadrangular mesh. The same analogy can be considered in 3D, too. In this chapter, we describe about such conversion to generate both 2D quadrangular and 3D hexahedral mesh.

3.1 Triangle Quadrangle Conversion

There are two basic procedures shown in Figure 3.1 as creating four quadrangles from two adjacent triangles(Type 1), and creating three quadrangles from one triangle(Type 2). For all original triangles, either Type 1 or Type 2 procedure is executed. Type 1 procedure is only available when both of the following conditions 1) and 2) are satisfied.

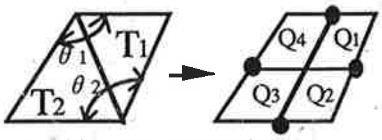
1) Two unprocessed triangles T_1 and T_2 are connected by one edge.

2) Both $\theta_1 < \theta_{max}$ and $\theta_2 < \theta_{max}$ are satisfied.

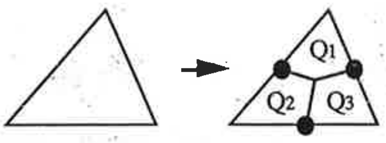
(Where θ_{max} is chosen to 170 degree.)

First, execute Type 1 procedure to as many triangle pairs as possible, and then execute Type 2 procedures to all the rest of triangles. Since Type 2 procedure creates more distorted quadrangular elements than Type 1, the important point is how to select as much Type 1 triangle pairs. Figure 3.2(a) is an example of original triangular mesh, and (b) is the result of triangle quadrangle conversion.

The basic conversion step generates quadrangular mesh which is still highly distorted. So smoothing procedure is necessary to improve the quality of the mesh. Smoothing is done by moving each node toward the centroid of all its directly linked nodes by edges, while boundary nodes should be moved only on the corresponding boundary lines. Figure 3.2(c) is a smoothed quadrangular mesh.

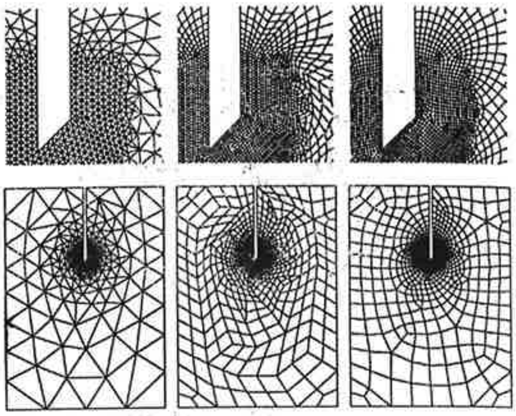


(a) Type1 conversion



(b) Type2 conversion

Fig.3.1 Triangle Quadrangle Conversion



(a) Original (b) Converted (c) Smoothed

Fig.3.2 An Example of Triangle Quadrangle Conversion (Original: 814 nodes & 1544 elements Converted:3203 nodes & 3120 elements)

3.2 Tetrahedron Hexahedron Conversion

There are only one basic procedure possible shown in Figure 3.3 as dividing one tetrahedron into 4 hexahedra though this procedure tends to create distorted hexahedral elements. However, this method seems to be the only possible way currently available to generate unstructured hexahedral mesh with arbitrary density control with fully automatic procedure. If the designing of the solver secures that it is not severely affected by element distortion, advantage of this method will be very large.

Figure 3.4 is an example of tetrahedron hexahedron conversion in a cubic domain. (a) is the original tetrahedral mesh, (b) is the subdivided result, and (c) is the smoothed result of (b). Figure 3.5 is the 3D tetrahedral mesh of a test example of air flow simulation around a unit cube. (a)and(b) shows the boundary surface. (c)and(b) shows the cross-section element surface by a vertical plane. Figure 3.6 is an example of 3D hexahedral mesh with complicated boundary for air flow simulation.

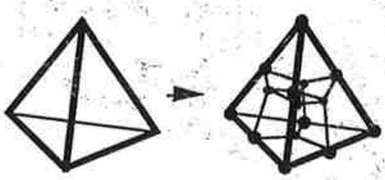
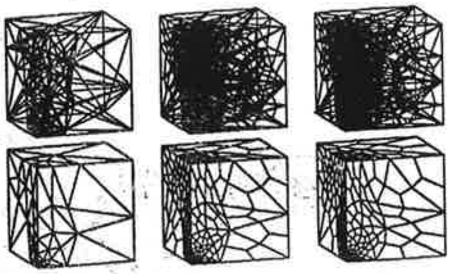
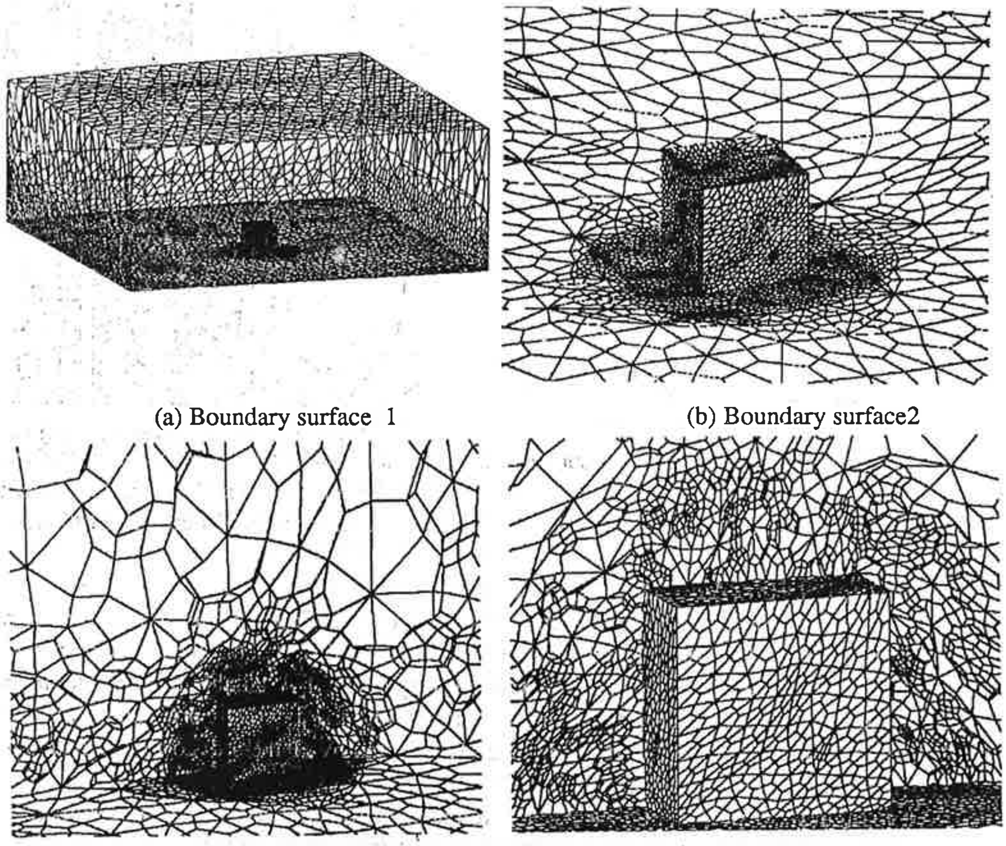


Fig.3.3 Tetrahedron Hexahedron Conversion



(a) Original (b) Converted (c) Smoothed

Fig.3.4 An Example of Tetrahedron Hexahedron Conversion (Original: 68 nodes & 198 elements Converted: 1024 nodes & 792 elements)



(a) Boundary surface 1 (b) Boundary surface2

(c) Cross-section 1 (d) Cross-section 2

Fig.3.5 3D Hexahedral Mesh for Wind Flow Simulation around a Cube.
(85,991 nodes 75,488 elements)

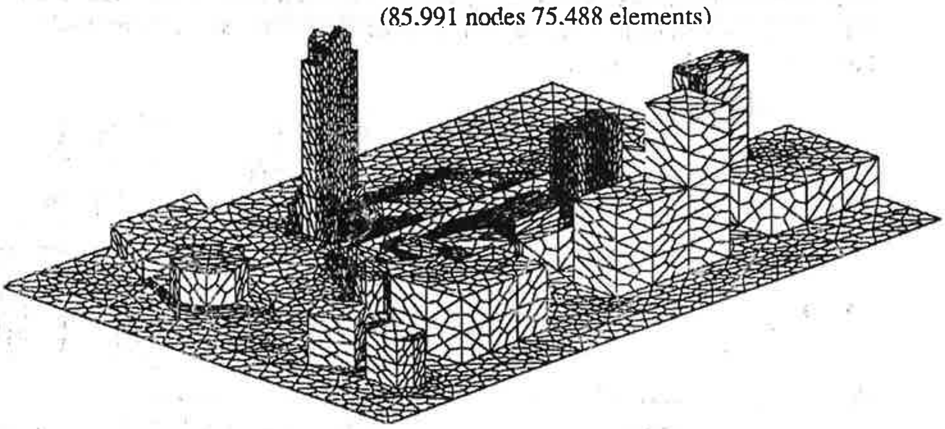


Fig 3.6 3D Hexahedral Mesh for Wind Flow Simulation around buildings
(121,563 nodes & 105,816 elements)

4. CONCLUSION

3D FEM mesh generation techniques and application have been presented. We have developed an automatic mesh generation system which can generate 2 dimensional triangular and quadrangular mesh as well as 3 dimensional tetrahedral and hexahedral mesh. And it is remarkable that a method of automatic generation of unstructured hexahedral mesh is indicated and tested on a wind flow simulation. We consider that high quality unstructured hexahedral mesh generation has a strong impact to the world of computer simulation.

5. REFERENCES

1. H.Jin, N.E.Wiberg,Two-dimensional mesh generation,adaptive remeshing and refinement,Int.J.Numer.Methods.Eng.,vol.29,1509-1526(1990).
2. Jeffrey A.Talbert and Alan R.Parkinson,Development of an automatic two-dimensional finite element mesh generator using quadrilateral elements and bezier curve boundary definition,Int.J.Numer.Methods.Eng.,vol.29,1551-1567(1990).
3. K.Deljouie,An approach to the generation of triangular grids possessing few obtuse triangles,Int.J.Numer.Methods.Eng.,vol 29,1299-1321(1990).
4. Levent Sezer and Ibrahim Zeid,Automatic quadrilateral/triangular freeform mesh generation for planar regions,Int.J.Numer.Methods.Eng.,vol.32,1441-1483(1991).
5. P.L.George,F.Hecht and E.Saltel,Automatic mesh generator with specified boundary,Comp.Methods in App.Mech.Eng.,vol.92(1991),pp269-288.
6. Y.C,Liu and H.A.Elmaraghy,Assessment of discretized errors and adaptive refinement with quadrilateral finite elements,Int.J.Numer.Methods Eng.,vol.33,781-798(1992).
7. S.W.Bova and G.F.Carey,Mesh generation/refinement using fractal concepts and iterated function systems,Int.J.Numer.Methods Eng.,vol.33,287-305(1992).
8. P.L.George,F.Hermelline,Delaunay's mesh of a convex polyhedron in dimension d, application to arbitrary polyhedra,Int.J.Numer.Methods Eng.,vol.33,975-995(1992).