Study on boundary search method for DFM mesh generation

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Abstract: The boundary mesh of the casting model was determined by direct calculation on the triangular facets extracted from the STL file of the 3D model. Then the inner and outer grids of the model were identified by the algorithm in which we named Inner Seed Grid Method. Finally, a program to automatically generate a 3D FDM mesh was compiled. In the paper, a method named Triangle Contraction Search Method (TCSM) was put forward to ensure not losing the boundary grids; while an algorithm to search inner seed grids to identify inner/outer grids of the casting model was also brought forward. Our algorithm was simple, clear and easy to construct program. Three examples for the casting mesh generation testified the validity of the program.

Key words: DFM; mesh generation; boundary search method; triangle plane contraction search
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The method for automatically generating 3D grids is a key technique in real 3D numerical simulation. Now, at home and abroad, FDM and FEM are two main methods accepted to simulate mold filling and casting solidification; and almost all the softwares in foundry numerical simulation have adopted FDM as the main algorithm at present. The sort of FDM mainly includes: Finite Difference Method (FDM), Finite Volume Method (FVM), Direct Finite Difference Method (DFDM). Generally, the grid of the mesh in FDM is a right parallelepiped grid, the shape of which is simple, and is easy to generate for a model with arbitrary shape, so its wide application has been found in the simulation area.

So far, there are several methods to construct a regular grid, for example, (1) mesh generation based on AutoCAD base elements such as cube, sphere, cylinder, cone [1]; (2) Piece slicing method based on STL file [2]; (3) Topology piece slicing method based on STL file [3, 4]; (4) Method based on increasing or decreasing small pieces in STL file [5]; (5) X-ray transmission method, which is based on STL file [6]; and (6) Boundary search method which is based on STL file [7].

Among the above methods, the first method can only be used with AutoCAD and is not general. If rendering AutoCAD to output *.DXF file and then extracting body elements, theoretically a mesh can be generated. But we have not found an example meshed by this method. The main reason is that reading and analyzing a DXF file is difficult. But it can be imagined that, compared with using an STL file, this method would have more advantages for the real geometry parameters of the extracted body elements. Using other software such as UG, PRO/E to output entity files such as *.x_t file, *.iges file, to extract body elements to generate a mesh, is also feasible. This method should have great prospects.

The 2nd to the 4th methods above are all piece slicing methods based on an STL file. This kind of method firstly needs to solve the 2D intersection loop curve on the surface of the solid model which was cut by the parting plane. In an STL file, the model surface is described by triangular facets, so cutting the model surface means cutting triangle facets. When generating mesh, each triangle facet will be cut by the parting plane and the intersection line must be solved; and then all the intersection line segments must be connected into a closed curve. When special conditions take place, such as only one point being turned out or the intersection line is one of triangular facet edges, fault-tolerance has to be produced, which is tedious and complex. Although some improved algorithms such as firstly establishing topological structure, then generating mesh [3,4]; or increasing/decreasing triangle pieces in STL file [5], have raised the mesh generating rate to some extent, the problem of fault-tolerance still exists.

Different to piece slicing methods, the Ray Piercing Method need not solve a 2D intersection loop curve on the surface of a solid model. Rather it renders a set of rays, which are distributed among the mesh region according to the mesh size and parallel to the directions of the 3 axes in the Cartesian coordination system, to shoot through the meshing solid body. Then it can solve the intersection points (pierced by the rays) in the boundary surface of the solid body. Finally based on parity matching principle, the part of the rays located among the solid body was extracted, which is the inner part of the solid body. The advantage of this method is its clear and simple algorithm. But the intersection points of each ray with all triangle pieces have to be solved, which means a large quantity of computing

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time and cost. Also fault-tolerance must be produced when the ray passes through a point, and is coincident with an edge of a triangle facet, or is on the face of a triangular facet.

The 6th method doesn't need to divide the solid body into a large quantity of layers to get the 2D contour lines. This method directly extracts each triangular facet from the STL file, calculates interval points on the triangular facet, then solves the corresponding boundary grid of each interval point. Thus all the grids the triangular facet swept are gotten, and when mesh grids swept by all the triangular facets recorded in STL file have been computed, continually using seed algorithm to mark out grids inside/outside the solid body, the mesh generation of the solid body is over. This algorithm is clear, easy and rapid, while not needing to deal with fault-tolerance, and is not sensitive to flaws occurring between the triangular pieces (but if a few of the triangular pieces are lost in the STL file, this algorithm may make mistakes).

The principle of this algorithm has been discussed in the literature [7], but there are no test examples given, and it has not been realized by computer program. In this paper, based on the principle, the method of Triangular Facet Contraction Search and Inner Seed Grid Method are put forward to carry out a 3D right parallelpiped mesh generation for casting solid body.

1 Mesh generation principle and algorithm

1.1 Identification method for judging boundary grid

Take 2D mesh generation as an example. In Fig. 1, the boundary of a curve falls within the scope of a rectangle which has two corner points PL($x1$, $y1$) and PR($x2$, $y2$), and the mesh grids are also shown in the figure. The grid size is dx in the x direction, and dy in the y direction. To find the No. of each boundary grid, named mesh ID, supposing there is a point G(x,y) on the boundary curve, so the No. of grid occupied by grid point G(x,y) can be calculated from expression (1):

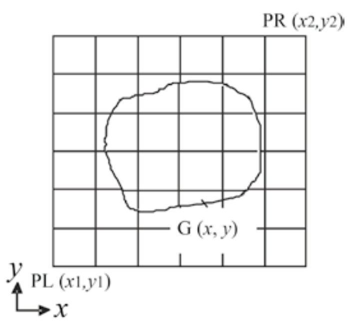


Fig.1: ID judging of boundary mesh

$$I = [(x - x1)/dx]$$
$$J = [(y - y1)/dy] \quad (1)$$

In expression (1), the sign [ ] represents rounding off (mesh ID beginning from I = 0, J = 0).

Based on the above expression, when enough points along the boundary curve are chosen, all the grids the curve swept can be searched out.

1.2 Boundary search method to triangular facets

The triangular facets stored in the STL file constitute the surface of the solid body, and 3 vertex coordinates and 1 normal vector of each triangular facet are recorded in the STL file. When generating a mesh, all the grids swept by the surface of the solid body, which is described by all the triangular facets must be computed out.

In this paper, an algorithm named Triangle Contraction Search Method (TCSM) is put forward to get all the boundary grids (shown in Fig. 2). TCSM is described as follows:

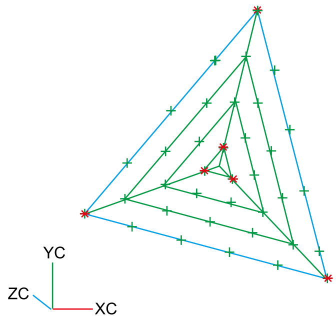


Fig. 2: Points selection by triangle contraction

(1) Calculate the coordinate of the centre of gravity of each triangular facet according to the coordinates of the 3 vertices of the facet;

(2) Choose points along the 3 edges of the triangular facets according to an interval which is the minimum of 3 cell size, that is:

$$d = \min(dx, dy, dz) \quad (2)$$

where dx,dy,dz are cell sizes in 3 axis directions in the Cartesian coordinate system.

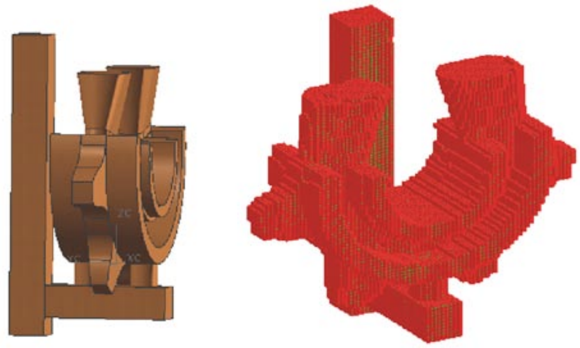
(3) Connect the 3 vertices with the centre of gravity to form 3 lines, then along these 3 lines (tending to the direction of the centre of gravity) select 3 points based on d gotten from expression (2) to form a new triangle (referring to Fig. 2). Then compute all the points' coordinates according to the method described in step 2. Then compute the grids according to expression (1). Repeat this procedure until the size of triangle edge is less than d. This algorithm in searching boundary grids is simple, rapid, and without missing any grid.

1.3 Identification of inner/outer grids of solid body

After searching all the boundary grids, the grids inside and outside the solid body must be distinguished and identified. In this paper, an algorithm named Inner Seed Grid Method is used to do the identification, that is: (1) find a grid inside the solid body as the first seed grid; (2) from the seed grid to do grid searching along the directions of the 3 axes until meeting the boundary grids; the grids between the seed grid and the boundary grid are all inner grids of the solid body. (3) Continue searching the whole meshing region. If there exists a grid which is neighboring to inner grids (which have been marked as inner grids), and this grid has not been identified before, then set this grid as a new seed grid and iterate procedure (2). (4) Iterate procedure (3) until there aren't any seed grids. Then all the inner grids of the casting are distinguished and identified. Finally, identify all the remaining grids as outer grids; now the casting's mesh generation is finished.

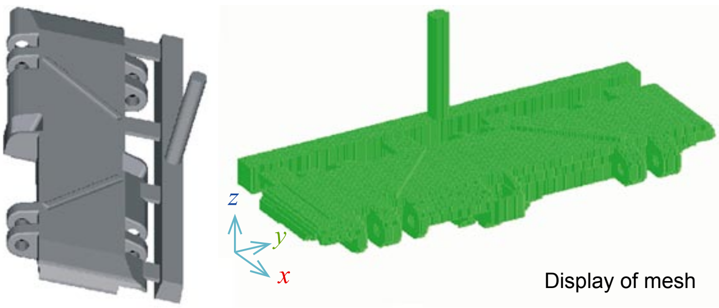
2 Meshing examples

On the basis of the above principle, a program for automatically generating 3D mesh was compiled by using C++ language and OpenGL graphic library; and was verified by several meshing examples of real castings. The following are meshes for a chain-wheel (Fig. 3), a creeper tread (Fig. 4), and a mesh of an assembly of a casting, a core and two chills (Fig. 5). Among these examples, the contour size of the creeper tread is 1,060 mm × 380 mm × 182 mm, the flask size is 1,120 mm × 544 mm × 368 mm, and the cell size is $dx = dy = dz = 4$ mm. The number of the total grids is 3503360, and the meshing time is 35 s. All the above examples are meshed on a PC with the core of AMD Athlon(tm) XP3000+ (2.16 GHz), Memory 512 M, and Hard Disk 80 G. In contrast, in the literature [1] a casting example with 12,000,000 grids meshed on P586/166 was given, which takes 440 s. Again in the literature [2] an example with 34,180 grids meshed on P II 450 (Memory 128 M, Hard Disk 40 G) takes 202.3 s. Also in the literature [4] an example with 2,841,874 grids meshed on P II 266 cost 183 s.



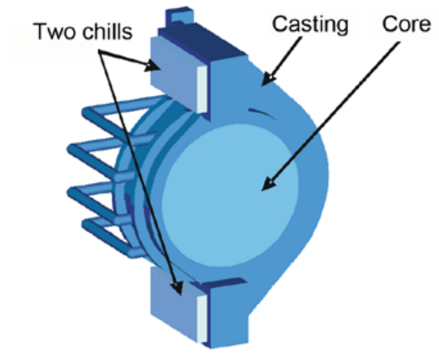
Display of STL Display of mesh

Fig. 3: Chain-wheel mesh generation

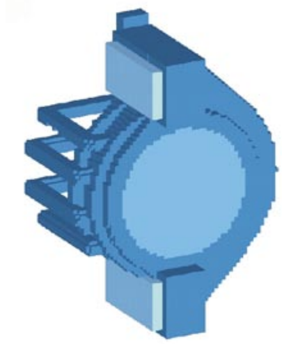


Display of STL

Fig. 4: Creeper tread mesh generation



(a) Assembly of casting, core and chills(STL)



(b) Mesh of assembly

Fig. 5: Display of mesh of assembly of casting, core and chills

3 Conclusions

(1) On the basis of Boundary Search Method, two algorithms named Triangle Contraction Search Method and Inner Seed Searching Method were put forward to generate 3D FDM regular mesh automatically. Several examples verified that our algorithm can generate 3D mesh for complex castings effectively.

(2) The algorithm of Boundary Search Method was simple and clear, and is easy to program. The result for running time shows that this method is rapid.

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