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A global approach to multi-axis swept mesh generation

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Abstract

The sweeping algorithm is a classical algorithm that can generate high quality hexahedral meshes for swept volumes. However, the traditional sweeping algorithm can only generate single axis swept meshes. In order to expand the scope of the model that sweeping algorithms are applicable to, this paper proposes a global multi-axis swept mesh generation approach, which can robustly generate hexahedral meshes for solid models composed by multi-axis swept volumes. We first globally generate all the surface meshes by applying an optimized structured quadrilateral mesh generation algorithm. After that we generate a swept mesh for each swept volume. Finally, we determine an appropriate way to optimize the topology of the generated mesh so as to improve the mesh quality. The experimental results show the effectiveness and efficiency of the proposed method.

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Keywords: Hexahedral mesh; Mesh generation; Swept mesh; Structured quadrilateral mesh

1. Introduction

1.1. Background

Finite element analysis is a numerical method used to solve problems in the domains of structure analysis, dynamics, and solid mechanics. The three dimensional volume mesh is an important input for finite element analysis (FEA). Two common categories of 3D volume meshes are the tetrahedral meshes and hexahedral meshes. Compared with tetrahedral meshes, hexahedral meshes have the advantages of lower number of elements, higher computational precision and faster convergence when applied to FEA. There are many mature methods for high quality tetrahedral mesh generation. However, there is no efficient method for the generation of high quality hexahedral mesh for every solid model. At present, the main hexahedral mesh generation methods are submapping [1], sweeping [2–6], whisker weaving [7], plastering [8,9], grid-based [10], H-morph [11], dual cycle elimination based [12,13], frame field based [14], sheet operation based [15], etc. A comprehensive review of all these methods can be found in the survey by Sarrate et al. [16]. Among all hexahedral mesh generation methods, sweeping is the most widely used, and it accounts for more than 50 percent of meshing applications [17]. While the quality of the mesh generated by sweeping is generally very high, most sweeping algorithms can only generate single axis swept meshes for swept volumes. For solid models

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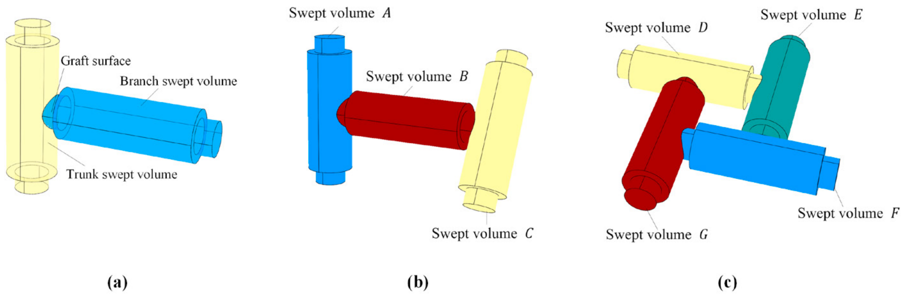

Fig. 1. (a) Grafting relationship. (b)(c) Two examples which cannot be handled by the grafting algorithm.

that are composed of swept volumes with different sweep directions, it is hard to guarantee the mesh conformity on the common surfaces. Therefore, this paper aims to propose a multi-axis swept mesh generation method, which can generate hexahedral meshes for solid models that are composed of swept volumes with different sweep directions.

1.2. Related work

Sweeping methods: Sweeping methods can generate high quality hexahedral meshes for swept volumes. The procedure used in most sweeping methods first classifies the surfaces of the input swept volume into source surfaces, target surfaces and linking surfaces, where the source and target surfaces are called cap surfaces. Then, the source surface is meshed with a quadrilateral mesh and the linking surfaces are meshed with structured quadrilateral meshes. Next, the source surface mesh is projected to the target surface to keep the mesh topology the same between the two cap surfaces. Finally, the swept mesh is generated in a layer-by-layer fashion along the sweep direction. According to the number of source surfaces and target surfaces, swept volumes can be classified into one-to-one, many-to-one, and many-to-many swept volumes, which are all suitable for generating single-axis swept meshes, and many mature methods [2–6] have been proposed by now.

Multi-axis sweeping methods: To expand the scope of the application of sweeping methods, Miyoshi et al. [18] proposed the multi-axis cooper algorithm, which can generate a hexahedral mesh through multi-axis sweeps. However, the types of applicable solid models of this approach are limited. The biggest challenge in multi-axis swept mesh generation is how to guarantee the mesh conformity at the common surfaces between the swept volumes with different sweep directions. To this end, Jankovich et al. [19] proposed the grafting algorithm, and Earp [20] further improved this algorithm. This method determines the order of the mesh generation by establishing a grafting relationship among the swept volumes with different sweep directions. A branch swept volume is grafted on the linking surface of a trunk swept volume, and the common surface between them is called the **graft surface**, as shown in Fig. 1(a). The swept mesh of trunk swept volume is generated first. Then this method locally modifies the position and connectivity of the nodes on the linking surfaces to align with the graft surfaces. Once the surface mesh is formed on the graft surface, it is swept along the branch to create a swept mesh. The grafting algorithm greatly expands the range of models that can be meshed by sweeping methods. However, it still suffers from the following drawbacks: (1) This method cannot deal with complex grafting relationships between swept volumes, such as when a branch is grafted onto two trunks at the same time, or when the grafting relationship forms a loop. (2) The quality of the mesh near the graft surface is often not satisfactory. Fig. 1(b) shows an example in which a branch swept volume is grafted onto two trunk swept volumes at the same time. The swept volume B is grafted simultaneously on the linking surfaces of the swept volumes A and C. The grafting algorithm is not able to deal with this case as it cannot guarantee the mesh conformity at both of the graft surfaces. Fig. 1(c) shows an example where the grafting relationship forms a loop. The swept volume D is grafted onto the linking surface of the swept volume E, and this in turn is grafted onto the linking surface of the swept volume F, the swept volume F is grafted onto the linking surface of the swept volume G, and this is grafted back to the linking surface of the swept volume D. For this kind of grafting relationship, this algorithm cannot find a reasonable swept mesh generation order, hence making this model unsuitable for being meshed by the grafting algorithm.