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An extension of advancing front technique on new target surface after virtual topology operations

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ABSTRACT

In this paper, an extension of advancing front technique (AFT) on new target surface (NTS) after virtual topology operations has been achieved in order to suitably represent CAD model and enhance the accuracy of numerical analyses. The extension of AFT has been accomplished through two stages. In the first stage, through analysis of the connection features of the intersecting lines with geometric continuity, a new notion of NTS is proposed. Based on the new notion, the topology of NTS is adjusted to generate meshes and meet the requirements of numerical analyses. In the second stage, AFT is extended accordingly in order to realize the topology of NTS. Specifically, based on the concise description of the front configuration of AFT, all of the subordinate aspects of AFT, including meshing order, generation of elements and nodes, and validity checking, are optimized. With the extension of AFT in this fashion, the target surfaces of AFT have been extended from the parametric surfaces to the composite surfaces. Finally, two examples are calculated with the extended AFT. The results of the calculation have verified that the topology of the composite surfaces is suitable and that the extended AFT is accurate and efficient.

1. Introduction

Surface mesh model is both a representation of CAD model and the base of numerical analyses. They make numerical analyses of CAD model possible [1]. Before the establishment of the surface mesh model, it is necessary to delete irrelevant and minute details of CAD model, which has been facilitated with the processing method of the virtual topology. Furthermore, the processing method of the virtual topology has the advantage of not changing CAD model per se but only changing the topology of CAD model [2].

The virtual topology focuses on enhancing the accuracy of numerical analyses besides representing CAD model suitably. Sheffer [3] introduces several operators to simplify CAD model. Since CAD model is not changed, the accuracy of the subsequent numerical analyses is not affected. Because of the simplification, the numerical analyses time is reduced. Pippa and Caligiana [4] consider that high density meshes should be required in the proximity of a concentrate applied load. Foucault et al. [5] consider that some faces and edges of CAD model are irrelevant. They often slow down the solver and produce poor or inappropriate simulation results. Wei et al. [6] introduce a method to modify the model's topology without changing the geometry of the model, while leaving the geometry or shape of the model, and the accuracy of the resulting mesh in representing the model, unchanged. Therefore, though the virtual topology and triangulation results may modify the properties of CAD model, these changes can enhance the accuracy of the subsequent numerical analyses. The operations of modifying the topology of CAD model seem important.

During the past periods, a number of investigators have developed several operations to modify the topology of CAD model [3–7]. Sheffer [3] clusters model surface into regions firstly; then, the virtual topology operators are generated to modify the connectivity of these regions. In so doing, a large number of irrelevant and minute details of CAD model, which are unnecessary for applications in the field of engineering, are deleted. Pippa and Caligiana [4] introduce a method named Grad-H—Correction, which guarantees the smooth continuation of the various meshes with different gradations on the multi-patch parametric surfaces. In this method, the multi-patch parametric surfaces are first divided into several sub-surfaces. Then, the analyses of and operation on the sub-surfaces are independently carried out. Here, the important variables are spread from one sub-surface to its adjacent one. Finally, all the sub-surfaces are synthesized as a unique entity. However, this method does not truly reflect the topology of the multi-patch parametric surfaces. Foucault et al. [5] introduce a mesh constraint topology (MCT) with automatic adaptation operators aimed at transforming a CAD model into a numerical analysis model. If the sub-surface is narrow or has a short edge, this sub-surface will be regarded

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as irrelevant for the automatic surface meshing. The advantage of the algorithm proposed by them is that this algorithm focuses on the processing of irrelevant sub-surfaces. What they did not take into consideration is the requirements of the subsequent numerical analyses. Wei et al. [6] introduces a notion of virtual geometry, upon which meshes are generated. This way of meshing has modified the topology of CAD model without changing the geometry of CAD model. Their notion of virtual geometry is based on 3D model and its advantage lies in the provision of an unambiguous definition through a concise representation of the bounding topology and through a clear definition of the underlying geometry of 3D model. Yet, when this way of meshing (based on the notion of virtual geometry) is applied in the parameterization of the composite surfaces, which they named harmonic mapping algorithm, the parameterization has been proved to be very cumbersome. In another paper, Foucault et al. [7] further develops their MCT, where they analyze the topological links on the composite surfaces. In this way, CAD model can be represented more precisely. However, they only focused on the specific problem of processing the details of CAD model which cause mesh inconsistencies. What they overlooked is the processing of a type of composite surfaces in a more general situation. All the papers mentioned above focus on the precise description of 3D model, and some of them touch upon the requirements of the subsequent numerical analyses. However, as is known to all in the field of CAM and FEM, numerical analyses have different purposes. In line with these different purposes, different topology is required upon the same CAD model. Therefore, besides representing precisely CAD model, different topological modifications of the composite surfaces should meet the requirements of different numerical analyses and, further, should get ready for the corresponding mesh generation algorithm.

With regards to surface meshes generation, over the past 20 years, automatic generation of surface mesh has been continuously investigated and many algorithms have been proposed. Of all these algorithms, Delaunay (DT) and AFT can be considered as the prominent ones [8–19]. DT, based on the mature mathematical principle, is a systematic algorithm aimed at generating surface mesh. However, DT has a higher requirement for the shape of the target surface and a mapping process to surface mesh generation [8–10]. On the other hand, AFT generates surface mesh in a heuristic and empirical way, which solves complex problems in a simpler and flexible way. AFT is superior to DT in that it can generate surface mesh with higher quality in a flexible way [11–19]. As a result, this paper chooses AFT as the algorithm to generate surface mesh for the composite surfaces with different topology.

AFT can generate surface mesh on both parametric surfaces and composite surfaces, and several key techniques of AFT, which affects the mesh quality considerably, have been developed. In the process of new node generation, the shape distortion is inevitable in the parametric mapping approach [13,20], so the elastic vector and metric tensor are employed to reduce the shape distortion [14–18]. The meshing order in AFT can also be controlled flexibly, and the shortest segment is often chosen to be the candidate one [13,18]. As an optimization of meshing order, the front is advanced from two opposite boundaries instead of the completed edges in order to solve the poor condition of surface corner [19]. On the composite surfaces, the sub-surfaces are meshed respectively, and then the surface meshes are integrated based on the smoothing criterion [11,12]. Although the meshes of the composite surfaces are represented as a union of sub-surfaces in this way, the mesh distribution and the generation process may not be consistent with the desired topology. To deal with this problem, Foucault et al. [7] introduces MCT to modify the topology of CAD model for meeting the desired requirements, and discusses the generation of nodes and elements, as well as validity checking across the intersecting lines of the composite surfaces. All the papers mentioned above focus on either the simplification of AFT or meeting the requirements of different mesh distribution. In fact, both of these two aspects are important. Therefore, an extension of AFT, which realizes the desired topology of the composite surfaces in a simpler way, is necessary.

This paper extends AFT to generate suitable surface mesh with regular distribution on the composite surfaces with diverse topology to suitably represent CAD model and enhance the accuracy of numerical analyses. First, it analyzes the connection of the intersecting lines of the composite surfaces by means of geometric continuity and determines NTS of AFT in this paper. Then, AFT is improved accordingly, which can be extended from parametric surfaces to NTS directly. The front configuration is described by the angles as the basis of the following improvements. Based on the angles, the new elements are formed efficiently by six operators. The meshing order is optimized based on the front configuration. An iterative process is chosen to generate new nodes accurately across the intersecting lines of NTS. The validity of new nodes is checked in 3D space instead of the parametric space. Finally, two examples with different topology and requirements are given.

2. Determination of NTS

Facing the composite surfaces of CAD geometry, the main purpose is to generate a suitable virtual topology for both the subsequent surface mesh process and numerical analyses. In this section, geometric continuity is used to determine NTS, and virtual topology operations are utilized to generate an analysis topology definition.

2.1. Analyzing connection with geometric continuity

Geometric continuity is the exact concept used to analyze the connection of the intersecting lines of the composite surfaces in this paper. The connection between adjacent sub-surfaces can traditionally be analyzed by either continuity of function or geometric continuity [21]. Geometric continuity is widely recognized as a suitable variable to discuss the surface's properties in computer-aided geometric design (CAGD). Geometric continuity is a relaxation of parameterization, but not a relaxation of smoothness.

The geometric continuity of the intersecting lines of NTS is special and important to the virtual topology operations. As shown in Table 1, the tangential directions are continuous, which means that the connection is smooth. In other words, the intersecting line with G^1 or ever higher continuity means that the connection between the adjacent sub-surfaces is smooth. This smooth connection is considerably important because different mesh distribution and analysis topology can be established [22]. Furthermore, if all of the connections of composite surfaces are smooth, the topology of this kind of composite surfaces can be adjusted based on different requirements of the subsequent numerical analyses. Therefore, a new notion of NTS is proposed for AFT in this paper, and NTS is dealt with as a whole domain instead of as individual sub-surface in the subsequent surface mesh process.

NTS exists widely in the engineering field, and it is an important component of the CAD model. For example, as an important part of the compressors, the centrifugal impeller is composed of the composite surfaces with complex connection, as shown in Fig. 1. As the important surfaces of the subsequent numerical analyses, the pressure sides and suction sides of the blades of the centrifugal impellers are repaired by the leading surfaces, and the process of repairing is done with smooth

Table 1
Geometric continuity of the intersecting lines.

G^k continuity	Coordinates	Tangential directions	Curvatures
G^0	continuous	discontinuous	discontinuous
G^1	continuous	continuous	discontinuous
G^2	continuous	continuous	continuous