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A finite element implementation of the boundary face method for potential problems in three dimensions

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Abstract

The boundary face method has been implemented with shape functions from Moving Least-square approximation. Although the method has some attractive features in common with meshless methods such as the boundary node method (BNM), it often encounters troubles when dealing with bodies with small holes and fillets. To solve problems involving domains with arbitrarily trimmed surfaces and to get better efficiency, this paper presents a new implementation with shape functions from boundary finite elements.

In the conventional BEM implementation of structural analyses, a geometric model is firstly built with a CAD package, the geometric model is then converted into a discrete model using a meshing tool. The CAD and BEM are treated as separate modulus requiring different methods and representations, which include continuous parametric models and discrete models respectively. The elements are used for boundary integration and approximation of geometry in the BEM. Once the BEM model is constructed from CAD, the information of geometry is only derived from standard elements. Therefore, geometric errors are introduced. Moreover, the link between BEM model and CAD system is often unavailable, thus makes it difficult to carry out adaptive mesh refinement.

To cope with the problems above, we have developed a boundary face method (BFM) [2]. A primary goal of our research is to make the computational model geometrically exact no matter how coarse the discretization is. Another goal is to simplify mesh refinement by eliminating the need for communication with the CAD geometry once the initial mesh is constructed. Yet another goal is to more tightly weave the mesh generation process within CAD [1]. In our implementation, both boundary integration and variable approximation are performed on boundary faces, which are represented in parametric form exactly as the boundary representation date structure in most CAD systems. The parametric surface, which encapsulates the exact geometry of corresponding face, is discretized by surface patches in parametric space. These patches are used for the boundary integration and variable approximation. For boundary integration, however, the geometric data at Gaussian quadrature points, such as the coordinates, the Jacobian and the outward normal are calculated directly from the faces rather than elements, thus no geometric error will be introduced. The direct boundary integration and approximation in parametric space of surfaces forms an intrinsic feature of the BFM when compared with the conventional BEM.

The moving least squares (MLS) approximation method has been applied to approximate variable in parametric space for the BFM successfully [2]. In this work, several additional schemes for variable approximation are developed in parametric space of a surface. In the BEM, as we know, both boundary integration and variable approximation are performed in the same region which is represented by an element.

In the BFM, however, the regions for variable approximation and for boundary integration are independent of each other. Therefore, various shape functions for variable approximation can be chosen freely in the BFM. A simple but effective approximate method through Lagrange Polynomial is fulfilled, which is based on the surface patch, similar to the standard Lagrange elements.

The mesh generation on the boundary of a solid model is a key step for successful implementation of BFM analyses. The accuracy and converge of the numerical solution with the BFM largely depend on the quality of the mesh. For the BFM, the mesh is constructed by surface patches. The patches are well-shaped in 3D space while the coordinates of their vertex nodes are given in 2D parametric space of the surface. In this work, a new mesh generation method is proposed for creating adaptive triangle or quadrilateral surface patches over parametric surface based on the advancing front method (AFM) [3]. Surface patches are generated along with a quad-tree procedure to develop local guidelines for determination of the patch size. Special care has been taken to generate patches with possibly the best shape during the advancing front. Another innovation of the algorithm presented here is the generation of internal nodes simultaneously with the surface patches. A special posteriori local mesh improvement procedure is employed to enhance the quality of the mesh so that the obtained patches are suitable for boundary integration and variable approximation in the parametric space.

In contrast with conventional BEM and FEM, the BFM is implemented directly on a solid modeling data structure, namely the boundary representation (Brep). As the Brep is used in most of CAD packages, it should be possible to exploit their Open Architecture feature, and automatically obtain required coefficients (representation). Therefore, our implementation has a real potential to seamlessly interact with a CAD software, integrating easily geometric design and engineering analysis into a completely unified framework [4,5]. To specify the advantageous feature, we have developed an interface between the BFM and UG NX. Numerical examples have demonstrated that the integration of the BFM and UG NX is successful, which may provide an important step toward automatic simulation. Some examples that involving complicated geometry have also revealed that the BFM possesses higher accuracy and is less sensitive to the coarseness of the mesh than the BEM.

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