Advances in Applied Mathematics and Mechanics
Adv. Appl. Math. Mech., Vol. **6**, No. 1, pp. 120-134

DOI: 10.4208/aamm.2013.m199
February 2014

An Efficient Dynamic Mesh Generation Method for Complex Multi-Block Structured Grid

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Received 22 April 2013; Accepted (in revised version) 18 July 2013

Available online 13 December 2013

Abstract. Aiming at a complex multi-block structured grid, an efficient dynamic mesh generation method is presented in this paper, which is based on radial basis functions (RBFs) and transfinite interpolation (TFI). When the object is moving, the multi-block structured grid would be changed. The fast mesh deformation is critical for numerical simulation. In this work, the dynamic mesh deformation is completed in two steps. At first, we select all block vertexes with known deformation as center points, and apply RBFs interpolation to get the grid deformation on block edges. Then, an arc-length-based TFI is employed to efficiently calculate the grid deformation on block faces and inside each block. The present approach can be well applied to both two-dimensional (2D) and three-dimensional (3D) problems. Numerical results show that the dynamic meshes for all test cases can be generated in an accurate and efficient manner.

AMS subject classifications: 65Z05

Key words: Multi-block structured grid, mesh deformation, radial basis functions, transfinite interpolation.

1 Introduction

Currently, the use of unstructured grid is very popular in Computational Fluid Dynamics (CFD) due to its great flexibility and easy generation. However, the unstructured grid suffers the difficulty of capturing the thin boundary layer on the solid surface, especially at high Reynolds numbers. In contrast, the structured grid is preferred to capture the boundary layer. The structured grid is usually associated with coordinate transformation. When a complex geometry such as aircraft is considered, a single-block structured grid is very difficult to be generated. Instead, the multi-block structured grid is often used, in which, the whole computational domain is divided into a number of blocks, and

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the structured grid is generated in each block. Clearly, the grid in each block is structured and the block edges are unstructured. When the complex object is moving, the dynamic change of resultant multi-block structured grid is still a challenging issue in CFD. Basically, there are two major approaches for the dynamic change of mesh. They are mesh deformation approach and mesh reconstruction approach. As compared with mesh reconstruction, mesh deformation is more efficient and accurate, and is more widely employed.

For a single structured mesh deformation, Transfinite Interpolation [1–6] (TFI) method is most frequently used, which generates the dynamic mesh with an algebraic interpolation. The computational effort of TFI is proportional to the grid number. So its efficiency is still very high when the grid number is large. However, TFI is very difficult to be applied for a complex geometry when a multi-block structured grid is used. This is because the mesh points on block edges are irregularly distributed when the mesh is deformed.

On the other hand, it is found that Radial Basis Functions [7–9] (RBFs) interpolation is a desirable approach for scattered data interpolation, which could be used to compute the mesh deformation on block edges. As a new interpolation method, RBFs method has been successfully applied to the multivariate interpolation in a fluid-structure-interaction problem [10], the numerical simulation of a flapping foil [11] and the aerodynamic shape optimization [12, 13]. Based on RBFs, Rendall and Allen [14] proposed a unified algorithm for the fluid-structure interpolation and mesh motion. In RBF interpolation, the computational effort is usually proportional to the cube of the total grid number. Thus, when RBF interpolation is applied to the whole grid, the computational effort for mesh deformation will be extremely large for a complex problem with a large grid number. Some attempts [15, 16] have been made with a reduced size of equation system to improve the efficiency of RBF interpolation. Nevertheless, the computational effort is still very large.

In this paper, a hybrid mesh deformation method, which is especially suitable for a complex multi-block structured grid, is developed. In the approach, the RBF interpolation is only utilized to generate the dynamic mesh on block edges, and TFI is adopted to generate structured mesh on block faces and within each block. The present hybrid method is firstly applied to the dynamic mesh generation for one two-dimensional (2D) and one three-dimensional (3D) problems with different complexity. Then numerical simulation of a 2D unsteady flow is conducted. Based on the given multi-block structured grids, the numerical results demonstrate that the dynamic meshes for all test cases can be generated in an accurate and efficient manner by using present method.

2 Mesh deformation on block edges by RBFs interpolation

2.1 RBFs interpolation

RBFs [17] use the interpolation function f to describe the displacement in the whole physical space, and f can be approximated by a weighted sum of the basis functions