

Development of 3D CFD solver based on gradient smoothing method

*Jianyao Yao¹ and †G. R. Liu²

¹College of Aerospace Engineering, Chongqing University, Chongqing, China

²Department of Aerospace Engineering and Engineering Mechanics, University of Cincinnati, Cincinnati, USA.

*Presenting and corresponding author: yaojianyao@cqu.edu.cn

†Corresponding author: liugr@uc.edu

Abstract

Gradient smoothing method (GSM) has been widely applied to solve partial differential equations, and we have smoothed finite element method (S-FEM) for solid mechanics^[1-3] and GSM-CFD for fluid mechanics^[4-6]. Theories and numerical examples have demonstrated that the GSM-CFD solver is accurate, efficient, robust, and insensitive to mesh distortions. However, the previous research of GSM-CFD mainly focused on 2D cases, thus the 3D version GSM-CFD solver need to be developed to extend the applicability of the new CFD solver.

During the development process, the method for the construction of smoothing domains (SDs) on 3D complex grids is firstly proposed, and the general data structure for SD is also devised. Then the algorithms for gradient approximation of flow variables in 3D domains are also developed, and the approximation accuracy is verified using manufactured solutions. The convective and viscous fluxes of Navier-Stokes equations are also discretized using GSM, and the 3D GSM-CFD solver is finally formed. The proposed GSM-CFD solver is validated and verified using several benchmark problems, and the results are also compared with the ones obtained using conventional finite volume method.

The 3D smoothing domains for gradient approximation at node (nGSD, node-associated gradient smoothing domain) and edge midpoint (mGSD, midpoint-associated gradient smoothing domain) on tetrahedral and hexahedral mesh are shown in Fig. 1 and Fig. 2, respectively. To denote these SDs in a general manner, the new edge-based data structures are also devised, as shown in Fig. 3. Here, the geometrical information for each edge is stored element-wisely, and can be used for the global operation.

The accuracy and efficiency of GSM can be compromised by choosing proper smoothing function or quadrature scheme. Here, we utilize the piecewise constant smoothing function and the one-point quadrature scheme for the gradient approximation. Currently, we are working on the verification of gradient approximation for flow field variables. We will implement the 3D algorithm to the CFD solver soon, and it very promising that we can present some meaningful results at the conference.

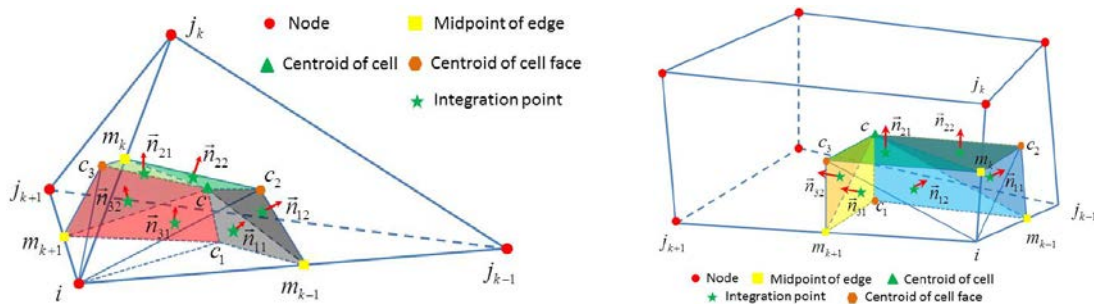


Fig. 1 nGSD on 3D meshes

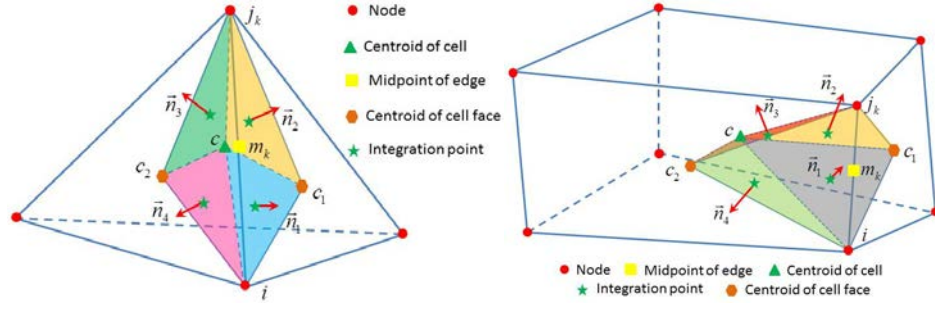


Fig. 2 mGSD on 3D meshes

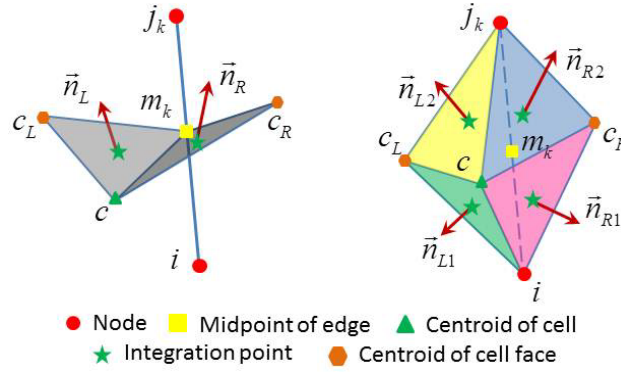


Fig. 3 General edge-based data structure for gradient smoothing method

Reference

- [1] Liu, G.-R., 2010. Smoothed finite element methods. CRC Press.
- [2] Liu, G. R. (2008). A generalized gradient smoothing technique and the smoothed bilinear form for Galerkin formulation of a wide class of computational methods, International Journal of Computational Methods, 5(2) : 199-236.
- [3] Liu, G. R.; Dai, K. Y. and Nguyen, T. T. (2007). A Smoothed Finite Element Method for Mechanics Problems, Computational Mechanics 39 : 859-877.
- [4] Liu, G. R. and Xu, G. X. (2008). A gradient smoothing method (GSM) for fluid dynamics problems, International Journal for Numerical Methods in Fluids, 58 : 1101-1133.
- [5] Yao, J.; Liu, G. R. and Chen, C.-L. (2013). A moving-mesh gradient smoothing method for compressible CFD problems, Mathematical Models and Methods in Applied Sciences, 23 : 273-305.
- [6] Wang, S.; Khoo, B.; Liu, G. and Xu, G. (2013). An arbitrary Lagrangian-Eulerian gradient smoothing method (GSM/ALE) for interaction of fluid and a moving rigid body, Computers & Fluids, 71 : 327-347.