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Exact finite volume particle method with spherical-support kernels

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Abstract

The Finite Volume Particle Method (FVPM) is a meshless method for simulating fluid flows which includes many of the desirable features of mesh-based finite volume methods. In this paper, we develop a new 3-D FVPM formulation that features spherical kernel supports. The formulation is based on exact integration of interaction vectors constructed from top-hat kernels. The exact integration is obtained by an innovative surface partitioning algorithm as well as precise area computation of the sphere subsurfaces. Spherical-support FVPM improves the recently developed cubic-support version in two main aspects: spherical kernels have no directionality and result in smooth interactions between particles, leading to an improved method. We present three test cases that illustrate the improved accuracy and robustness brought by the spherical kernel. Although computations are 1.5 times slower on spherical support than cubic support, the cost is more than compensated by lower error with a higher convergence rate.

Keywords: Finite Volume Particle Method (FVPM), Arbitrary Lagrangian-Eulerian (ALE), Spherical-support kernel, Surface partitioning

1. Introduction

The Finite Volume Particle Method (FVPM) is a meshless arbitrary Lagrangian-Eulerian (ALE) method introduced by Hietel et al. [1] in 2000 for compressible flows. This method has then been used in a wide range of applications such as incompressible flows [2], solid mechanics [3], fluid-structure interactions [4, 5], free-surface flows in Pelton turbines [6, 7] and silt erosion [8].

The FVPM includes many of the attractive features of both particle methods, such as Smoothed Particle Hydrodynamics (SPH) [9], and conventional mesh-based Finite Volume Methods (FVM) [10]. In FVPM, like in SPH, computational nodes usually move with the material velocity, which is compatible with the Lagrangian form of the equation of motion. This enables the method to handle moving interface problems like

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