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A Consistent Multi-Resolution Smoothed Particle Hydrodynamics Method

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Abstract

We seek to accelerate and increase the size of simulations for fluid-structure interactions (FSI) by using multiple resolutions in the spatial discretization of the equations governing the time evolution of systems displaying two-way fluid-solid coupling. To this end, we propose a multi-resolution smoothed particle hydrodynamics (SPH) approach in which subdomains of different resolutions are directly coupled without any overlap region. The second-order consistent discretization of spatial differential operators is employed to ensure the accuracy of the proposed method. As SPH particles advect with the flow, a dynamic SPH particle refinement/coarsening is employed via splitting/merging to maintain a predefined multi-resolution configuration. Particle regularity is enforced via a particle-shifting technique to ensure accuracy and stability of the Lagrangian particle-based method embraced. The convergence, accuracy, and efficiency attributes of the new method are assessed by simulating four different flows. In this process, the numerical results are compared to the analytical, finite element, and consistent SPH single-resolution solutions. We anticipate that the proposed multi-resolution method will enlarge the class of SPH-tractable FSI applications.

Keywords: smoothed particle hydrodynamics, multi-resolution, refinement and coarsening, fluid-structure interactions

1. Introduction

SPH is a Lagrangian method that has been used to solve partial differential equations (PDEs) associated with mass, momentum, and energy conservation laws [1]. In SPH, these PDEs are spatially discretized employing a set of particles that possess material properties and interact with each other in a fashion controlled by a smoothing, or kernel, function with compact support. These particles move according to inter-particle interactions and external forces. Due to its Lagrangian nature, SPH enables efficient modeling of multiphase flows with moving interfaces [2, 3, 4], complex fluids [5, 6, 7, 8], materials subject to large deformation [9, 10, 11], fluid-structure interactions (FSI) problems [12, 13, 14], and various transport phenomena [15, 16, 17, 18].

In most SPH simulations, the computational domain is populated with particles of uniform spacing, which leads to a single–resolution scenario. This is suitable when there are relatively small variations in the velocity/pressure gradient over the entire domain of analysis. Otherwise, it is desirable to discretize the domain with SPH particles of multiple resolutions. For instance, for a colloids-in-suspension FSI problem, the near field, i.e., next to each colloid, would call for high resolution; the far field would rely on a coarser resolution. Due to the Lagrangian nature of SPH, a locally refined region is expected to move along with the immersed body leading to an adaptive particle refinement (APR) process. In this regard, APR for SPH serves the same purpose as the adaptive mesh refinement does in the finite element and finite

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