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Point Cloud Movement For Fully Lagrangian Meshfree Methods

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Abstract

In Lagrangian meshfree methods, the underlying spatial discretization, referred to as a point cloud or a particle cloud, moves with the flow velocity. In this paper, we consider different numerical methods of performing this movement of points or particles. The movement is most commonly done by a first order method, which assumes the velocity to be constant within a time step. We show that this method is very inaccurate and that it introduces volume and mass conservation errors. We further propose new methods for the same which prescribe an additional ODE system that describes the characteristic velocity. Movement is then performed along this characteristic velocity. The first new way of moving points is an extension of mesh-based streamline tracing ideas to meshfree methods. In the second way, the movement is done based on the difference in approximated streamlines between two time levels, which approximates the pathlines in unsteady flow. Numerical comparisons show these methods to be vastly superior to the conventionally used first order method.

Keywords: Meshfree, Particle method, Lagrangian framework, Point Cloud, Movement, Fluid flow, FPM

1. Introduction

A moving Lagrangian framework is commonly used while modeling fluid flow. It often provides better approximations than the fixed Eulerian framework for flows with open free surfaces and multiphase flows with moving interfaces. The Lagrangian framework has the further advantage of avoiding the non-linear advection term, and often provides a more accurate depiction of transport phenomena. However, this comes at the cost of generally having a more restrictive time-step size control, and having the need to take special care for several aspects of conservation.

In mesh-based methods, moving the mesh causes the additional disadvantage of mesh distortion. To avoid this distortion and the need to remesh, a large class of semi-Lagrangian and Arbitrary Lagrangian-Eulerian (ALE) methods have been developed (see, for example, [5, 27]). To improve conservation properties of mesh-based Lagrangian methods, the so-called ideas of trace-back and volume adjustments for mass conservation are often used [1, 11]. The ideas include adjusting the volume of individual elements or cells based on their traced-back entities, and constructing upstream vertices and cells based on their corresponding downstream ones.

Meshfree methods provide a more natural fit to Lagrangian frameworks than mesh-based methods. They use the numerical basis of a set of arbitrarily distributed nodes without any underlying mesh to connect them. These nodes could either be mass carrying particles or numerical points. Movement of this set of nodes, referred to as a point cloud, in a Lagrangian framework could also lead to distortion. However, point cloud distortion is easier to fix, as point clouds can easily be adapted locally, especially in meshfree methods that use numerical approximation points instead of mass carrying particles.

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