A Mesh-free method for free surfaces and contact discontinuities

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In Earth and Planetary Sciences, mesh-free methods for compressive fluids are widely used for fluid simulations in which large deformations occur. As a traditional mesh-free method, Smoothed Particle Hydrodynamics (Lucy 1977 and Gingold & Monaghan 1977; hereafter SPH) is generally used. However, SPH cannot accurately handle free surfaces and contact discontinuities, where the density distribution is not differentiable.
There are two causes for this limitation. First, in many of mesh-free methods, the density of a fluid element is derived directly from the distribution of fluid elements instead of using the equation of continuity. However, the approximation formula in which the density can be derived without implicit method, does not satisfy partition of unity, causing an error. Second, the physical quantities and derivatives are estimated by the SPH approximation formula. This formula is zeroth-order accurate in space and second-order accuracy with respect to the number of neighbor fluid particles which interact with a fluid particle. Therefore there are large errors at free surfaces and contact discontinuities.
To solve this problem, we developed a high-order mesh-free method for compressive fluid. As a solution for the first problem, we integrate the equation of continuity in the new method. In addition, for the second problem, we adapt a space high-order approximation formula to mesh-free methods for compressive fluids. The formula is based on Tamai et al. (2013), in which they formulate a high-order approximation for mesh-free methods for incompressible fluids. Then we express free surface with the boundary condition which the pressure is constant. In addition, for contact discontinuities, we introduce the appropriate boundary condition depending on what it is a contact discontinuity.
We also compare the results of numerical tests of our new method to the results of SPH. These results show that our method can handle free surfaces and contact discontinuities better than SPH. However, the new method cannot accurately handle contact discontinuities with indifferentiable pressure. Therefore, we need other prescriptions for these contact discontinuities, which we will address in future work.

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