Arbitrary Order Boundary Reconstruction Algorithm for Robin Boundary Conditions in Particle-Resolved Direct Numerical Simulations

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ABSTRACT

Particle-Resolved Direct Numerical Simulation is a widely used methodology to investigate transport phenomena occurring at the particle scale in a large variety of fluid-particle systems. Such simulations are generally performed using grid-based methods where the governing equations are discretized over grid nodes or finite volumina. The representation of the particulate phase is therefore achieved by (i) creating a mesh conforming to the complex topology of the fluid domain, or by (ii) introducing new terms in the governing equations that account for the presence of the particulate phase. Unfortunately, the generation of high quality conformal grids can be difficult, and hence this approach is often not practical for fully-automated simulation workflows. The latter methodology is more promising, and often referred to as the "Immersed Boundary" (IB) method [1]. While the IB method is more effective for both static and moving particles, it is still not clear how general immersed boundary conditions should be enforced on grid nodes that are not aligned with the immersed surfaces.

In the present contribution, we extend our Hybrid Fictitious Domain Immersed Boundary Method HFDIBM [2] to be able to impose general boundary conditions with – theoretically - arbitrary order. While the HFDIBM was using second order interpolation to impose a Dirichlet boundary condition, the new method performs a Taylor expansion of Eulerian fields at the particle surface. First, a reconstruction of field properties (e.g., velocity, temperature) near the immersed boundary is performed by probing at multiple discrete positions. Subsequently, the terms in the Taylors are evaluated up to the desired order by solving a system of equations built from the probed field properties and the boundary condition to be enforced. These terms are then used to evaluate the field value at the node closest to the immersed surface.

We detail on the implementation of our method in CFDEM® [3], and show that the method is convergent and accurate for a wide range of fluid-particle systems with Dirichlet, Neumann and Robin boundary conditions. Also, we demonstrate how the method can be applied. Specifically, we will show selected results for flow, as well as heat and mass transfer in dense poly-disperse and mono-disperse suspensions in infinitely large and wall bounded systems.

REFERENCES

1. Mittal, G. and G. Iccarino, *Immersed boundary methods.* Annual Review of Fluid Mechanics, 2005. **37**: p. 239–61.
2. Municchi, F. and S. Radl, *Consistent closures for Euler-Lagrange models of bi-disperse gas-particle suspensions derived from particle-resolved direct numerical simulations*. International Journal of Heat and Mass Transfer (under revision). 2017.
3. Kloss, C., et al., *Models, algorithms and validation for opensource DEM and CFD–DEM.* Progress in Computational Fluid Dynamics, an International Journal, 2012. **12**(2-3): p. 140-152.