Numerical simulation of fluid-structure interaction problems by a coupled SPH-FEM approach

Jessica Stasch*, Bircan Avci, Peter Wriggers

Institute of Continuum Mechanics
Leibniz Universität Hannover
Appelstraße 11, 30167 Hannover
stasch@ikm.uni-hannover.de

ABSTRACT

In many technical applications, like airbag deployment and biomechanical systems, elastic structures are used to control fluid flow. Depending on the characteristics of the structure and the fluid different effects has to be taken into account. For an accurate simulation of fluid flow the used numerical method has to deal with fluid structure interactions (FSI). One method to solve this coupled problem is a combined using of Smoothed Particle Hydrodynamics (SPH) for the fluid part and Finite Elements (FE) for the solids.
SPH is a particle based method solving the Navier-Stokes equations on the basis of a disordered set of freely moving interpolation points in space. Since a constant mass is assigned to every point, the points can be considered as particles, described in a Lagrangian framework. Every field variable such as velocity and pressure is evaluated using a kernel function or its derivatives. Using this approximation method the short range forces are automatically computed with respect to the underlying kernel radius. Moreover, as SPH is a mesh-free method, it easily allows the computation of large deformations and self-intersections when compared to mesh-based methods, where very sophisticated re-meshing strategies are mandatory.
To calculate the fluid state the GPU-based open-source SPH framework 'DualSPHysics' [1] is used. The behavior of the structure is calculated using the CPU-based open source Finite Element code 'MOOSE' [2]. A FSI-coupling module for interface treatment and force exchange is implemented in the fluid solver. This module allows the communication between GPU and CPU to use the advantage of the fluid solver. The major task in FSI-simulations is the calculation of the forces on the interface and the fulfillment of the interface conditions. In general, the displacement and velocity compatibility and the traction equilibrium along the structure-fluid interfaces have to be satisfied. Therefore, a zero energy condition is implemented on the interface between the structure and the fluid. The coupled problem is solved by an iterative scheme. Both set of equations, the fluid and solid equations, are solved consecutively and individually using the latest information supplied by the counterpart of each problem. Since the time step of solid and fluid calculation differ, an adaptive time scheme is used to improve calculation efficiency. In this work, the fluid as well as the solid structure are described in a Lagrangian framework, so the interface tracking does not need any complex treatment. In contrast to the monolithic coupling method, where the fluid and the solid equations are combined and treated as one system, it requires less memory and therefore may be more applicable to solve larger problems. To calculate the reaction forces resulting from the structure onto the fluid particles, two different approaches were implemented. The first one is based on the well known Lennard-Jones-Potential, which is often used in molecular dynamics [3]. In this approach the decelerating fluid particle forces depend on the distance to the boundary and on the magnitude and direction of the velocity. The second approach generates a single layer of SPH particles on the boundary surface. These particles are fixed to the FE structure and build a barrier for the fluid particles. The pressure force induced from the fluid to the wall is calculated by means of a weighted summation of the pressure values of those fluid particles.

References

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