An OverSet Method for Fluid-Solid Interaction Analysis Based on Least-Squares Fluid Formulation

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Traditionally, FSI (fluid-solid interaction) analysis has been performed in many ways. Some methods use a directly coupled method such as ALE[1] (arbitrary Lagrangian-Eulerian) formulation, and others adopt an indirect method with a successive segregated fluid and solid analysis with interface treatments. In most cases, when the solid deformation is extremely large, a remesh or a spatial remap of the discrete variables could be necessary. These methods require complex mesh smoothing or time-space transformation of the variables, and in many cases they have difficulty handling general situations such as the descent of a bomb through air or the sinking of a stone through water.

In this paper, an OverSet method is presented for the FSI analysis with general multi-physics extension. The novelty of the method is inspired by the immersed Interface method[2] and the mortar finite element method[3]. The method utilizes two sets of finite elements for spatial representation: namely the OverSet Entity and Domain. In practice, the Domain usually represents the Eulerian fluid flow region while the Entity consists of Lagrangian finite elements moving over the Domain. The interface compatibility constraint requires the common variables shared by the two sub sets to be compatible on the interface, while the governing equations from the two different sub sets must satisfy the dynamic equilibrium on this interface. In most cases, the interface is chosen as the boundary of the moving Entity, and the Lagrange multiplier method is applied to enforce the compatibility constraint on this interface. A detailed analysis of the method reveals that the weighting of the multiplier is tied to the simple local node-to-element spatial interpolation parameters. Other multi-physics fields such as the thermal, electric, or magnetic field variables, if they exist, can be treated easily using the same constraint. Furthermore, the numerical implementation takes advantage of a simple LSFEA fluid formulation and a velocity strain based solid finite elements method that make the interface constraint easy to implement.

Since the interface is not known *a priori,* it adds to the nonlinearity of the implicit method, and the solution is subjected to a critical time/step size constraint. The geometry interface checking of the Domain and Entity elements can be time consuming, and a quick Delaunay convex point set algorithm is adopted to speed up such interface searching. Example applications and verifications are presented with further refinement discussions. Several numerical sensitivity studies are also performed and discussed.

References

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