Simulation of particle filled viscoelastic flows using grid deformation methods

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Simulation of Particle Filled Viscoelastic Flows using Grid Deformation Methods

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Introduction

The presence and the motion of particles in fluids is ubiquitous in our everyday life, both in nature and in technology. In fluid-particle systems, the apparent properties of suspensions depend on the spatial distribution of particles. In viscoelastic fluids, the distribution of particles is not uniform even if particles are uniformly distributed initially. Hence, we want to know the evolution of multi-particle structures and the mechanisms that induce particle migration especially in polymeric fluids.

Numerical Methods

For the direct numerical simulation of fluid-particle systems we developed a finite element program using fictitious domain methods [1]. The basic idea of the fictitious domain method is that the rigid body is filled with the surrounding fluid and it is assumed that the fluid inside each particle moves like a rigid body. By using this method, we can eliminate the need for remeshing at each time step (Fig. 1(b)). However, to obtain accurate solutions of fluid-particle motions, very fine meshes are needed along the fluid-particle interface which requires huge computational cost. To overcome this problem, we adopted grid deformation methods to obtain mesh refinements only local to the interface, reducing the number of elements needed (Fig. 1(c)) [2].

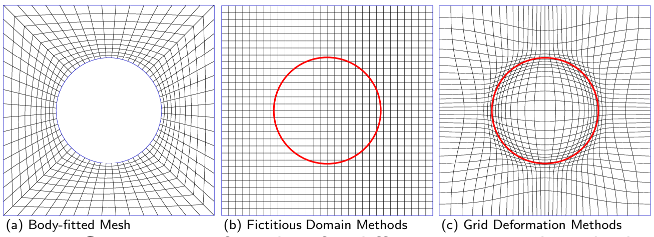

Figure. 1: Comparison of meshes for different numerical methods.

Example : Cavity Flow

A unit square domain is filled with a viscoelastic fluid and a unit driven velocity is applied of the top plate. An Oldroyd-B constitutive model with two viscoelastic modes is used ($\eta_s = 1.0$, $\eta_p = \{0.8, 0.5\}$, $\lambda = \{1.0, 0.4\}$). Initially, a particle of radius $r = 0.1$ is positioned in the middle of the square domain (Fig. 2).

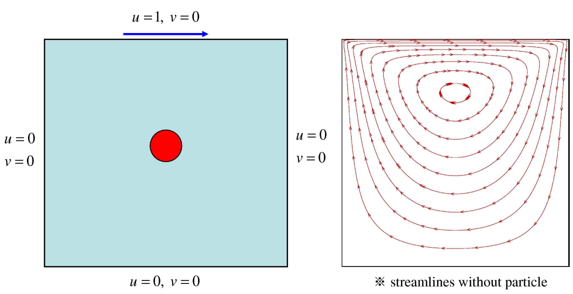

Figure. 2: Geometry for the driven cavity flow.

Results

For the simulation of this problem, we used three different meshes - ① a coarse 50×50 regular mesh, ② a fine 100×100 regular mesh and ③ a deformed mesh based on the coarse 50×50 mesh. The results with grid deformation methods are almost the same as the results of a twice finer regular mesh (Fig. 3). However, the computation time and the memory needed are much less than for the finer regular mesh (Tab. 1).

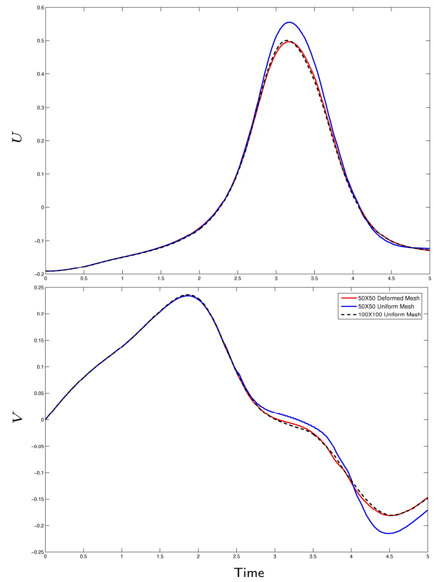

Figure. 3: Comparison of the translational velocity of particle.

Table. 1: Comparison of error and CPU time.

	Error Norm*		CPU time
	U	V	
50×50 deformed mesh	1.26×10^{-1}	7.17×10^{-2}	20.53
50×50 uniform mesh	6.79×10^{-1}	4.61×10^{-1}	12.51
100×100 uniform mesh	reference	reference	76.80

*Error Norm $= \|u_{\text{ref}} - u\|_{L^2} = \sqrt{(u_{\text{ref},1} - u_1)^2 + \cdots + (u_{\text{ref},n} - u_n)^2}$

Conclusions

- A viscoelastic particulate flow analysis program has been implemented using fictitious domain methods and grid deformation methods.
- Comparably accurate particle motions are obtained with less computation time and memory compared with the results using a finer regular mesh.

References:

[1] R. Glowinski et al., *International Journal of Multiphase Physics* **25**, 755-794 (1999)

[2] D. Wan and S. Turek, *Journal of Computational Physics* **222**, 28-56 (2007)