Multiscale and multiphysics coupling methods with application in vascular blood flow simulations

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1 Abstract

In this work, we consider the partitioned approach for fluid-structure interactions, and we develop new stabilized algorithms. There are two approaches in formulating the discrete systems in simulating fluid-structure interaction (FSI) problems: the monolithic approach, and the partitioned approach. The former is efficient for small problems but does not scale up to realistic sizes, whereas the latter suffers from numerical stability issues. In particular, in vascular blood flow simulations where the mass ratio between the structure and the fluid is relatively small, the partitioned approach gives rise to the so-called added-mass effect which renders the simulation unstable. I will present a new numerical method to handle this added-mass effect, by relaxing the exact no-slip boundary condition and introducing proper penalty terms on the fluid-structure interface, which enables the possibility of stable *explicit* coupling procedure. The optimal parameters are obtained via theoretical analysis, and we numerically verify that stability can be achieved irrespective of the fluid-structure mass ratio. To demonstrate the effectiveness of the proposed techniques in practical computations, I will also discuss two vascular blood flow applications in three-dimensional large scale simulations. The first application is obtained for patient-specific cerebral aneurysms. The 3D fractional-order PDEs (FPDEs) are investigated which better describe the viscoelastic behavior of cerebral arterial walls. In the second application, we apply the stabilized FSI method to heart valves, and simulate the coupling of the bioprosthetic heart valve and the surrounding blood flow under physiological conditions. Lastly, I will present the progress of our ongoing project on the multiscale coupling of the peridynamic and the classical elastic theories, with an application on simulating the material damage in arterial simulations, say, the aneurysm rupture or the heart valve failure problems.

2 Biography

Dr. Yue Yu is an Assistant Professor of Applied Mathematics at Lehigh University, where her work focuses on computational multiphysics/multiscale problems. She received her B.S. (2008) degree in Mathematics from Peking University. She earned her M.S. (2013) degree in Mechanical Engineering and her Ph.D. (2014) degree in Applied Mathematics from Brown University. She was a postdoctoral fellow at the School of Engineering and Applied Sciences, Harvard University before she joined Lehigh University in Fall 2014. She is the Committee member of the FSI Technical Trust Area of the United States Association for Computational Mechanics (USACM). She is the recipient of the 2014 Dunmu Ji Thesis Award from Brown University for her dissertation entitled "Numerical Methods for Fluid-Structure Interaction: Analysis and Simulations."