Development of particle-based simulation method for structural damage prediction during water-induced disasters including floating objects

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論 文 名　：Development of particle-based simulation method for structural damage prediction during water-induced disasters including floating objects
（水害時における漂流物の影響を考慮した構造物被害予測に向けた粒子型シミュレーション技術の開発）

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論　文　内　容　の　要　旨

This work is motivated by the 2011 Tohoku Earthquake (Mw9.0) which didn't directly make serious damages to the structures but induced a great tsunami to destroy the buildings near the coast. Besides, with the increasing of the natural disaster like the flood or debris flow caused by heavy rains, it is necessary to predict the area of the immersed places and to analyze the impact force from the water wave together with the floating objects. It is clear that the bridges are weak for the tangential impact from the water wave. After that, the floating objects may crash into other structures and cause secondary damage, obstruct the flow or even directly threaten people's lives. However, doing experiment or calculating by hand to make the prediction is too time-consuming and expensive. Instead, with the development of computer techniques and hardware, to deal with this kind of large-scale analysis, numerical simulation becomes a better choice because it's cheap and fast. Though it is hard to say that the numerical simulation can predict the disasters as same as the real world, a reasonable result can be provided for the engineers to improve their purposes. In this thesis, a fluid-rigid body interaction simulation solver is developed mainly based on impulse dynamics coupled with Incompressible Smoothed Particle Hydrodynamics method (ISPH) as a tool aiming to analyze the disaster with fluid and floating structures. For the fluid simulation, a conventional mesh-free method ISPH is chosen to solve the large deformation of the water. Despite penalty method is the most common choice to deal with the contact force between the rigid bodies or deformable ones in the area of engineering, since it's easy to implement and understand, a new energy tracking impulse-based method (ETI) is developed in this thesis as an attempt to improve the stability and performance in multi-body dynamics simulations. Combining ETI and ISPH method, a couple of validations for fluid structure interaction problem are implemented in this work.

This Thesis consists of six chapters. Chapter 1 gives an overall introduction, detailing the background, motivation, and objective for developing a new simulation tool.

In Chapter 2, I first discuss the related work about the rigid body solvers including the traditional penalty method, the most popular idea in game engines as impulse-based method

and the constraint based method which is usually used in the robotic mechanics. Then we briefly cover the history of the particle based methods for the fluid solvers and the fluid-structure interaction coupling techniques.

In chapter 3, the detail of the rigid body solver including the particle based representation, collision detection used in the particle based method is introduced. Then the schemes of Energy Tracking Impulse-based method (ETI), which is originally developed point-to-point contact problem with polygon based rigid body solver, are enhanced to manage not only the single point collision, but also for surface-to-surface collisions as multiple points contacts. To apply the idea of the original ETI into the particle based model and concurrent multiple contact points, some improvements are made in this thesis. At the end of this chapter, the validations and verifications are also listed to show the accuracy and robustness of proposed ETI.

Chapter 4 starts from the introduction of the fundamental knowledge of developed fluid solver, SPH method, from its traditional version weakly compressive SPH (WCSPH) and its extension version ISPH. After that, the detail of combining the proposed ETI as the rigid body dynamics solver and the fluid solver is developed, especially about how to map the hydrodynamic force to the surfaces of the objects. Then a verification and validation tests of the developed fluid structure interaction problem are performed. For the validation process, a bridge washout experimental test and multi-body contact example are designed, and numerical simulation solutions are compared with these experimental data including rigid body motion recorded with a 3D motion capturing system.

Chapter 5 is an extension work, where some improvements are proposed according to the existing flaws of proposed ETI in the chapter 3, like the problems of the impulse distribution and the accuracy of the accumulated energy that influences the bouncing behavior. Then some simple numerical test results are listed to show the necessity of the improvements.

Thesis concludes in Chapter 6, summarizing the research findings and the recommendations for future topics on the related numerical techniques for fluid-rigid body interactions using the particle-based method.