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Overlapping MPS Method for 2D Free Surface Flows

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ABSTRACT

An overlapping MPS (Moving Particle Semi-implicit) method is applied into 2D free surface flows. The basic idea of the overlapping MPS method is to distribute the low-resolution particles in the whole domain and the high-resolution particles in the concerned local region, such that the computational cost can be reduced while high-resolution on the concerned local domain can be reached. The low-resolution particles are first solved in the whole domain, which provide the truncation boundary information in solving the refined local region flow. An algorithm to generate dynamically the fine particles in the concerned local region is introduced in the present paper. Validation is carried out against two cases. First, a 2D dam breaking flow is simulated. The water height obtained by the overlapping MPS is compared with traditional MPS and the computational cost is analyzed. To further verify the efficiency of the overlapping technique, solitary wave breaking and post-breaking on a plane slope is also performed. Comparison of the plunging wave and splash-up by using the overlapping MPS and traditional MPS shows that the overlapping MPS can obtain better results than the traditional MPS using entire low-resolution particles, while the CPU time cost is much less than that by using high-resolution particles in the whole domain.

KEY WORDS: MPS (Moving Particle Semi-Implicit); Overlapping particle; dam break; solitary wave; free surface flow.

INTRODUCTION

In recent years, meshfree particle methods have been developed widely and applied successfully into practical engineering. The fluid is presented as a set of Lagranian particles, and there is no constant topology relationship between particles. Thus it is suitable to deal with flows with largely deformed free surface and moving boundaries, as proved by some researchers (Liu, 2008; Khayyer, 2008; Tanaka, 2010). MPS (Moving Particle Semi-implicit) (Koshizuka and Oka, 1996; Koshizuka, 1998) is one of such meshless methods. It is first proposed by Koshizuka (1996) to simulate truly incompressible free surface flows, and then improved by many MPS practitioners to suppress the pressure fluctuations such as mixing source term (Tanaka, 2010), a higher order Laplacian model (Khayyer, 2012), error-compensating in the source term (Kondo, 2011). These original or modified MPS schemes have been applied into a wide variety of violent free surface flow problems, such as liquid sloshing (Zhang and Wan, 2012a; Zhang and Wan, 2012b), dam breaking (Khayyer and Gotoh, 2012; Shakibaeinia and Jin, 2011), wave breaking (Gotoh and Sakai, 2006; Khayyer and Gotoh, 2008) and ship-wave interaction (Shibata et al., 2012a). Despite being an excellent method for solving the largely deformed free surface problems, it still has some disadvantages. Unlike the classical SPH method, the MPS method suffers from high computational cost due to its semi-implicit algorithm. Especially when it is applied into 3D flows, the computational cost increases sharply as a large number of particles is necessary. To solve this problem, parallel computation (Zhang et al., 2013) and GPU computation (Hori et al., 2011; Zhu et al., 2011) are introduced by many researchers to accelerate the MPS computation. However, their work has mainly focus on the feasibility of parallel computation and GPU computation in MPS, and the efficiency of these computation should be studied further. At the same time, these methods have to increase additional computational resources. An alternative way is to use multi-resolution simulation. In the framework of SPH, Vacondio et al. (2012, 2013) presented a dynamic particle refine algorithm based on particle merging and coalescing during the simulation. However, this refine algorithm is very difficult to apply to the MPS due to the semi-implicit scheme in MPS. On the other hand, overlapping particle technique (OPT) was firstly proposed by Shibata and Koshizuka (2012b) to implement multi-resolution simulation in the MPS and applied into a 2D green water. Unfortunately, validation is not given in the article.

In the present work, the overlapping particle technique (Shibata and Koshizuka, 2012b) is applied into 2D free surface flows. In particular, we adopt the different pressure gradient term near the truncation boundary to consistent with the conversation gradient model. Furthermore, an algorithm to generate dynamically the high-resolution particles in the concerned local region is discussed. In addition, the validation of the overlapping MPS is carried out through two simulations, one is about solitary wave breaking and post-breaking on a plane slope, the other is a 2D dam break flow. Results are compared with other numerical results or experimental results. Meanwhile, the efficiency and the computational costs are analyzed.