博士論文（要約）

Improvement of polygon wall boundary condition in moving particle semi-implicit method

（MPS 法におけるポリゴン境界の改良）

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The polygon wall boundary condition based on the moving particle semi-implicit (MPS) [1] method was proposed by Harada et al. [2] to simulate complex geometry in three dimensions with high efficiency. However, the inaccuracy of wall contribution namely the wall weight function near non-planar wall boundaries and drastic pressure oscillation cause the unphysical motion of the fluids, which dramatically influences the accuracy of simulations.

To address these issues, in this research an improved wall weight function method is proposed to improve the wall weight function near non-planar wall boundaries in the polygon wall boundary condition. The proposed method can improve the wall weight function near non-planar wall boundaries and suppress the pressure oscillation to some extent. However, the wall weight function near slopes and curved wall boundaries is still not accurate.

We verify our method of comparing the wall weight functions against the method by Harada et al. [2] through hydrostatic simulation. The classic dam break problem is tested using our proposed method and the method by Harada et al. [2] to compare the obtained distributions of the particle number density. Finally, a dam break with a wedge is simulated to verify the applicability of our method to complex geometries.

To accurately calculate the wall weight function near non-planar wall boundary, an initial boundary particle arrangement (BPA) technique is proposed coupling with the improved wall weight function method to improve the particle number density near slopes and curved surfaces. Two uniform grids are utilized in the proposed technique. The grid points in the first uniform grid are used to construct boundary particles, and the second uniform grid stores the same information as the first method. The wall weight functions of the grid points in the second uniform grid are calculated by newly constructed boundary particles. The wall weight functions of the fluid particles are interpolated from the values stored at the grid points in the second uniform grid. Because boundary particles are located on the polygons, complex geometries can be accurately represented. The particle number density near slopes and curved wall boundaries is dramatically improved.

The performance of the first method with the boundary particle arrangement technique is verified in comparison with the first method without boundary particle arrangement by investigating two example geometries. The simulations of a water tank with a wedge and a complex geometry show the general applicability of the boundary particle arrangement technique to complex geometries and demonstrate its improvement of the wall weight function near the slopes and curved surfaces.

In MPS [1] method, the accuracy of the particle number density is crucial because the Poisson equation is calculated by the variation of the particle number density. After improving the particle number density, improvement of pressure distribution becomes possible. In the third research, the initial boundary particle arrangement (BPA) technique is used to accurately supplement the wall weight function. The problems in the Poisson's equation is analyzed, and then the source term proposed by Tanaka & Masunaga [3] is introduced to suppress the pressure oscillation of fluid particles far from the wall boundary. To the fluid particles close to the wall boundary, a proportion factor is introduced to the source term to accurately represent the contribution of the fluid and wall parts of Poisson's equation. The asymmetric gradient model [4] is adopted to further improve the pressure calculation and suppress the numerical oscillation. The proposed method can dramatically improve the pressure distribution with high efficiency to arbitrary geometry in three dimensions.

Four 3-D examples are tested to illustrate the performance of the proposed method. The hydrostatic simulation is tested to illustrate the improvement of the pressure calculations. The dam break simulation is compared between the proposed method and other models to verify the effectiveness of the proposed method to suppress the pressure oscillation near polygons. Finally, two complex geometries are simulated to demonstrate the general applicability of the proposed method to improve the pressure distribution in complex geometries.

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[2] T. Harada, S. Koshizuka, K. Shimazaki, Improvement of wall boundary calculation model for MPS method, Trans Jpn Soc Comput Eng Sci (20080006).(in Japanese), (2008).

[3] 田中正幸, 益永孝幸, 疑似圧縮性効果による MPS 法の安定化と圧力の平滑化, Transactions of JSCES, 20080025 (2008).

[4] A. Khayyer, H. Gotoh, Development of CMPS method for accurate water-surface tracking in breaking waves, Coastal Engineering Journal, 50 (2008) 179-207.