GPU Based Computational Dynamics

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Abstract

Computational studies conducted by using graphics processing unit (GPU) based implementations will be presented and discussed for a range of applications, including granular dynamics, vortex dynamics, and wave motions. The discrete element method and smoothed particle hydrodynamics (SPH) are used in studies of granular dynamics and the SPH method is used for wave motions. The vortex dynamics studies are based on the unsteady vortex lattice method. Benchmark problems such as hopper discharge, material segregation through vibration, and force chains in a rotating drum will be presented in the context of granular dynamics, and the classic dam break case will be discussed in the context of wave dynamics. The accelerations obtained in the computations will be discussed along with the role of nonlinearity in these studies.

Keywords: granular dynamics, vortex dynamics, wave motions, smoothed particle hydrodynamics, discrete element method

Extended Summary

Several classes of physical systems characterized by short-range interactions of discrete particles are well suited for acceleration on graphics processing units (GPUs). As two examples, it is mentioned that in both granular dynamics and hydrodynamics simulations, one can describe the dynamics in terms of local interactions of discrete elements. The computational algorithms applied to study these systems are similar to those utilized in Molecular Dynamics (MD) simulations. While MD simulations represent a large and significant area of GPU computing efforts, other areas, which model macroscopic systems, are important to further our knowledge of the natural world. For efficiently utilize computing resources, special attention must be paid to domain decomposition. Since the interactions are exclusively local in nature, spatial binning, or tree codes need to be implemented to ensure that particles are only tested against other spatially close particles. Proximity in the physical domain does not reflect proximity in RAM. Particles must therefore be deliberately reordered to reflect proximity in the spatial domain. Furthermore, additional computational elements are required to determine spatial proximity. While these spatially oriented algorithms add complexity and overhead to the code, asymptotic complexity can be reduced from quadratic to linear in the number of particles in the simulation domain.

Grid based numerical hydrodynamic simulations are resource intensive and can have difficulty in resolving free surface waves. Lagrangian methods, such as SPH, in which one moves with the material being simulated offer several advantages in this type of simulation. First, Lagrangian methods naturally handle the water's free surface in a hydrodynamic simulation. Second, the simulation domain matches the domain of interest. By contrast, grid based schemes often require the inclusion of cells that only briefly contain useful information; that is, the domain above the free surface which may briefly contain a wave. For these reasons, here, SPH will be used to simulate the free surface under several conditions. This method is well suited to simulate gravity waves, breaking waves, and the focusing (interference) of wave trains, as indicated by preliminary results. Simulation results will be presented to demonstrate the efficacy of SPH in simulating these effects. An emphasis will be placed on wave trains composed of sinusoidal waves, cnoidal waves, and breaking waves. Focusing of several wave trains and isolated waves will be simulated. The height of the initial wave trains will be compared to the height of the focused wave. The accuracy of the wave focusing in light of the dissipation typically associated with the SPH method will be presented.

This work presented here is based on the material presented in references [1]-[3].

References

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