A proposition of analysis method for the system with contact between largely deformable body and rigid body

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Abstract

In general, wheel drive systems are adopted for locomotion of planetary exploration probes due to their mature technologies. On the other hand, jumping system is also gathering a lot of attractions because driving efficiency of the wheel drive system become worse in microgravity astronomical object. In such an environment of low-microgravity, it is possible to achieve high jump with low energy, however, there is a problem that any optimal jumping method is not established. Therefore, interaction between the probe and ground is quite important for achievement of optimal jump, that is to say, contact between the probe and the ground has to be analyzed. In this study, we propose a method for analyzing interactive behavior of the system with largely deformable body assumed to be the ground with regolith and rigid body assumed to be the probe.

There are some contact models for rigid bodies and idea of unilateral contact proposed by Pfeiffer (here in after called "Pfeiffer model") [1] and "Voigt Model" are generally well known. In our study we employ the Pfeiffer model as the contact model between probe and ground by reason of its calculation accuracy, computational speed and the advantages of multi-point simultaneous contact analysis. Un Pfeiffer model deals with the relationships between the contact force and relative acceleration of bodies, and between impulse and relative velocity as sets of linear complementary problem (LCP), which leads to effective computation. Features of this approach are accurate representation of the state transitions for the contact states i.e. continuous contact, stick, slip, detachment, collision.

There are also several types of model for largely deformable ground, and “Material Point Method : MPM [2]”, “Distinct element method : DEM”, “Smoothed Particle Hydrodynamics : SPH” are generally well known. We employ MPM as ground model by reason of its calculation accuracy and computational speed. MPM represents the analyzed object as several sets of particles and deformation of the object is calculated in a manner similar to existing FEM and makes it possible to perform large deformation analysis [2]. Furthermore, it is advantageous that the method can assume particles to be the representative points for contact because MPM regard a continuum as a set of particles.

In this study, we propose an analysis method that combines the above-mentioned MPM and Pfeiffer model. In the proposed method, material points defined in MPM are assumed to be representative point of the continuum bodies which have contacts with rigid bodies, and contact problems are solved using LCP if the contact between the representative points and rigid bodies are detected. As a result, we can calculate the contact forces and impulses acting between rigid and flexible bodies in an effective manner. Then, the behaviors of the rigid body, i.e. the probe, and the deformable body, i.e. the ground, are analyzed by the use of the derived forces and impulses. In this study, we focus on the landing of the probe as an example to verify the validity of the proposed method. As Figure1 shows, the probe and ground are assumed to be rigid sphere and flexible beam, respectively. In the numerical example, the flexible beam is assumed to be elastic, and the internal friction is not considered. Furthermore both ends of the beam are fixed rigidly. In addition, the Young's modulus of the flexible beam and the Poisson's ratio are 10 [MPa] and 0.5, respectively. Moreover, it is assumed that collision of the rigid sphere and the flexible beam is a perfect inelastic collision. Results of numerical analyses are shown in Figure 2. Left figure in Figure 2 shows a time history of vertical displacements for the bottom of the rigid sphere and representative point of the beam, respectively. After the first collision, we can observe consecutive state transitions between contact state and non-contact state. Right figures in Figure 2 show the time histories of energy of the system. Upper, middle and lower figures shows the energy of the rigid sphere, flexible beam and the whole system, respectively. After first collision, the rigid sphere loses energy and flexible beam receive energy from rigid sphere. In addition the total energy of the rigid sphere and beam decreases after first collision and become steady state after three

seconds. Eventually repeat of the state transitions leads to continuous contact and, that is steady state. These results show the qualitative validity of the proposed analysis method. Moreover, it is observed that the accuracy of the proposed method depends on the size and number of the grid used for MPM, which is also reported in other studies of original MPM. Therefore, careful choice of the grid is required.

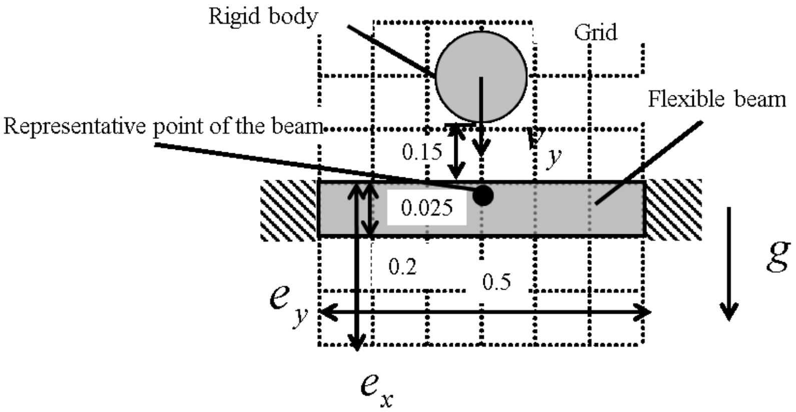

Figure 1: Collision between flexible beam and rigid sphere

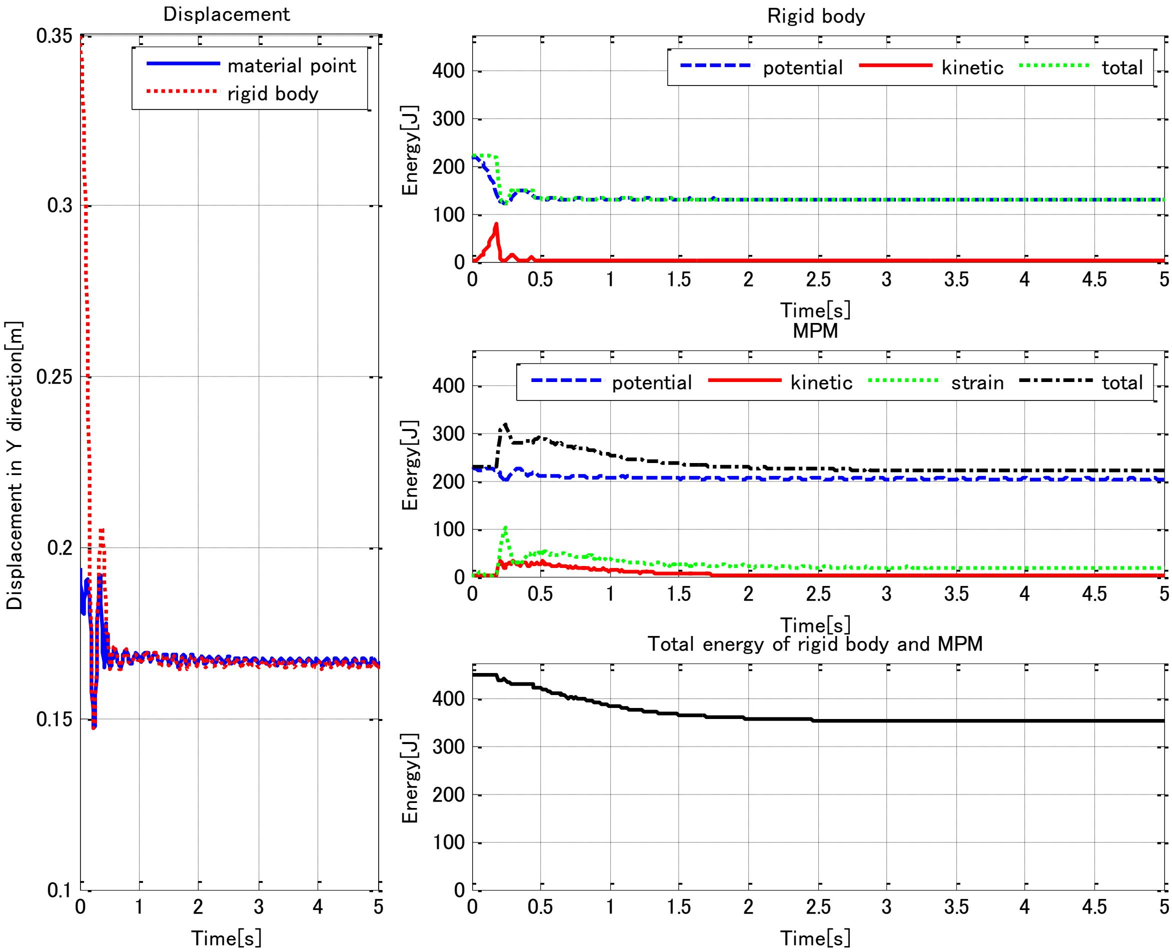

Figure 2: Time history of vertical displacement of the representative point of the beam and the bottom of rigid sphere and system's energy

References

[1] Pfeiffer, F. and Glocker, C., "Multibody Dynamics with Unilateral Contacts", Wiley-VCH, 1996.

[2] Sulsky, D., Zhou, S., Schreyer, H. L., "Application of a particle-in-cell method to solid mechanics" , Computer Physics Communications, Vol.87, pp.236-252, 1995