CONTACT DYNAMICS METHODS TO STUDY REGOLITH PROCESSES.

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Introduction: Granular mechanics methods are used in the planetary science community to study asteroid evolution due to angular velocity changes [1,2]. The models developed for large scale morphological changes can also be used to study the spacecraft-regolith interactions [3]. Both within the granular mechanics community and the planetary science community, Discrete Element Method (DEM) models are most common. However, the granular mechanics community has developed a second, less common simulation method that may be better suited to studies of regolith process and/or spacecraft-surface interactions. The Contact Dynamics (CD) simulation method has characteristics of both Hard Sphere DEM (HSDEM) and Soft Sphere DEM (SSDEM) methods. Additionally, it is easier to implement aspherical grains in CD methods [4], which is beneficial when studying highly angular regolith grains. We present our CD model of monodisperse, spherical grains in a dense system with an external gravity field in order to expose the planetary science community to this new simulation method.

Model Description: In SSDEMs, a small, constant timestep size is specified. At each timestep, the positions and velocities of the grains are propagated based on the forces acting on the grains. When two grains collide, the grains are allowed to overlap slightly and the force between the grains is calculated based on previously specified hypothetical spring and damper coefficients of the grains. HSDEMs differ from SSDEMs in that grains are not allowed to overlap and the timestep varies. Given the state of the system at the initial timestep, a list of upcoming collisions is populated and then the system is moved forward to the time of the next collision (i.e., the time at which the colliding grains have just come into contact). A force is then applied to the grains to give them the proper post-collision velocities and, given the new states, the upcoming collisions are detected. HSDEM codes do not work well for dense granular systems since the timestep size becomes infinitely small.

The CD method is a hybrid of HSDEM and SSDEM models. Like SSDEM, CD uses a constant timestep size. Like HSDEM, CD grains are not allowed to overlap, so there are no hypothetical spring and damper constants. The CD method, upon detection of an impact in the next timestep, applies a force to the grains to give them the appropriate post-impact velocity based on the coefficients of friction and restitution of the material [5].

In our model, we numerically integrate the position, velocity and angular velocity of spherical, uniform grains in a confining cube. The interactions between the grains and between the grains and walls are controlled by coefficients of friction and restitution. External gravity is included in our model and can be changed to simulate other planetary bodies. Additionally, although torque is calculated when grains are in contact with the confining walls, rolling friction is not included. The basic outline of our CD model is:

1. Initialize Grains: Specify initial position, velocity and angular velocity of the grains.
2. Place Grains in Cells: We use a cell method similar to that described by Sánchez [6] to speed our contact detection time. Thus, the simulation space is divided into a grid of cells.
3. Detect Contacts: Detect grain-grain and grain-wall persistent contacts and collisions that will occur in the next timestep.
4. Calculate Initial Forces: When a contact is detected between two grains or a grain and a wall, a force is calculated such that the grain(s) have the appropriate post-collision velocity given their coefficient of friction and restitution (for derivation of forces, see [5]). Note that these forces are calculated assuming a binary collision.
5. Iterate for Final Forces: The initial contact forces are calculated assuming binary collisions. However, for dense systems, many grains may be in contact. Thus, it is necessary to iterate through the contacts to update the contact forces. This iteration process is unique to the CD method.
6. Calculate New State: Once the contact forces are calculated, update the position, velocity and angular velocity of the grains.
7. Continue to Next Timestep: Repeat the process (beginning at Step 2) for the new timestep until the simulation is complete.

After the simulation is complete, we can use the output file to either numerical study the motion of the grains or produce a visualization, using our Open-GL-based visualization code.

Results: Currently, we are able to model 100 grains using our CD model. Figure 1 shows the the evolution of a system of 100 grains with random intial states, coefficient of restitution equal to zero, coefficient of fricition of 0.5, and terrestrial gravity.

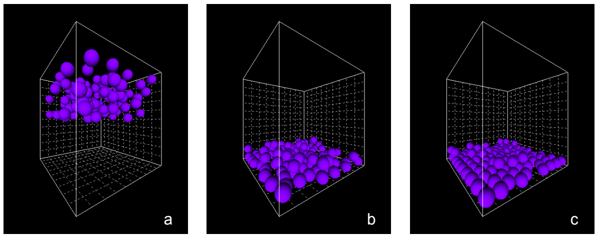

Figure 1 Simulation results for 100 grains with coefficient of restitution equal to zero over 4000 timesteps. (a) initial timestep, (b) t=2 sec, (c) t=4 sec. In this simulation, terrestrial gravity is present, so the grains fall to the bottom of the container. Over the 2000 timesteps between (b) and (c), the system dissipates energy by grains settling.

Figure 2 shows the evolution of the energy of the system shown in Figure 1. Note that for this system, we simulate 1 m radius grains in a 20 m cube. Despite the resulting unrealistic densities, masses of 1 kg were assigned to each grain for the purpose of debugging.

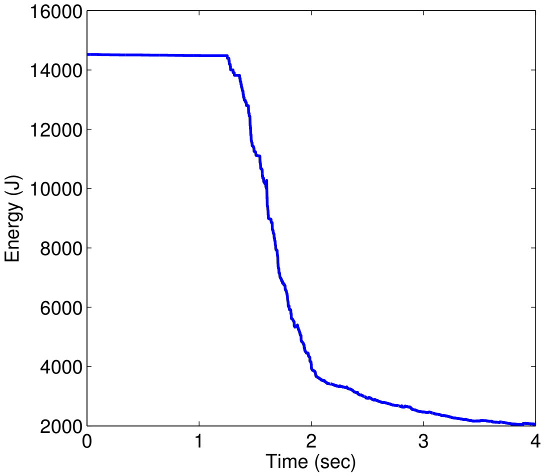

Figure 2 Energy variation for the system shown in Figure 1.

Figure 2 shows that the energy of the system remains constant as the grains fall towards the surface and then rapidly decreases as the grains accumulate on the bottom of the container. The grains settle in a relatively ordered structure because there is no rolling friction, so grains tend to roll to the edges of the container.

Conclusions: Contact Dynamics presents a new method of modeling regolith systems and is well-suited to model dense regolith systems. We demonstrate an implementation of a 100 grain 'sticky' system with external terrestrial gravity. We have also tested the system for coefficient of restitution equal to one (energy conserving) system (results not shown here). In the future, we will continue to increase the number of simulated grains, test asteroidal gravity conditions and include cohesion between grains. This work was supported by the Keck Institute for Space Studies.

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