Contact Dynamics Investigation Using Microgravity Experiment for Asteroid-Related Scenarios

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Abstract

We present an experimental approach for estimating parameters of a multibody code, with application to asteroid-related scenarios. The context is the ERC-funded project TRACES, whose goal is to characterize granular mechanics in the asteroid environment. This has implications for the dynamical evolution of asteroids, and for characterizing physical processes occurring on their surfaces. Indeed, most asteroids are now thought to be rubble-piles, that is, gravitational aggregates held together by gravity rather than the strength of their bulk material [1]. This nature suggests that their dynamics can be effectively simulated using N-body codes, such as GRAINS, whose contact dynamics is based on Project::Chrono [2]. The main goal of TRACES is to create a framework for asteroids dynamical simulations in which the accurate modelling of the interactions at particle scale is key. To this aim, the validation of GRAINS against experimental results represents the first milestone of the project. The possibility to rely on a code validated at particle-scale is expected to lead to a great improvement in full-scale simulations. We plan to observe the low-speed collision between two 10-15 cm sized cobbles in a micro-gravity, vacuum environment. The experiment will be conducted at the ZARM Drop Tower, in Bremen, where micro-gravity conditions are created by dropping a capsule in a 110 m high quasi-free fall. To validate GRAINS to particle-level, we will reproduce the results of the experiment with numerical simulations. To this goal, we need to acquire and reconstruct with a high accuracy the 6-dof motion of each cobble, before, during and after the collision.

A spring-based release mechanism will provide the initial velocity to the cobbles. Each spring will slide around a stiff guiding rod, mounted on intersecting paths to make the collision possible. One end will be attached to the bottom and the other one to a bin that will contain each cobble. An electromagnet will be used to lock the mechanism in the compressed condition until the release time. It will be screwed around the rod at the bottom, whereas a simple magnet will be attached to the bin containing the cobble. In this way, when the current in the electromagnet will be cut off, the magnet-bin system will be pushed by the elastic force of the spring. This is necessary to avoid the gravitational release of the spring due to the $1g - 0g$ transition. The whole experiment will be mounted inside a vacuum chamber, to simulate the low-pressure environment encountered in asteroid environment. A visual representation of the release mechanism is reported in Fig. 1.

The selection of the sensors is driven by the need to reduce as much as possible the interaction with the

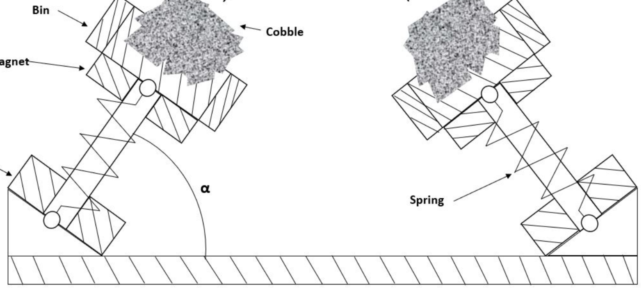

Figure 1: Release Mechanism

motion of the cobbles. For this reason, we will track their motion with a set of high-resolution, high-speed cameras, made available by ZARM facility. We will place markers on the cobbles to facilitate the tracking procedure. The shape of the cobbles will be acquired precisely using a 3D scanner, and fed to the multibody model as a realistic mesh. A body reference triad is set for each cobble, with origin in a point O.

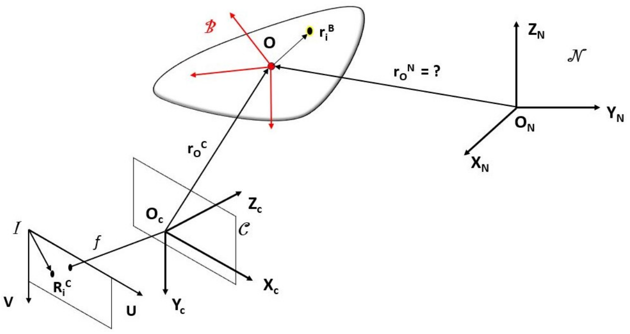

Figure 2: Reference Frames

We are interested in estimating the position and velocity of point O in inertial frame, $\mathbf{r}_O^N$ and $\mathbf{v}_O^N$, the attitude of the cobble's body frame with respect to the inertial frame, $\mathbf{A}_{B/N}$, and its angular velocity in inertial frame, ω_N. This will be used to estimate contact parameters of the multibody model, by comparing real-world and simulated trajectories after the collision. Indeed, the contact models found in literature and implemented in N-body codes involve a wide series of parameters, whose value has a significant influence on the outcome of the simulation. Moreover, we will investigate which model is better for the simulation of the problem, for instance between smooth and non-smooth contact models [3]. The augmented state vector reads:

$$\mathbf{x}_{aug} = [\mathbf{r}_O^N, \mathbf{v}_O^N, \mathbf{A}_{B/N}, \omega_N, \mathbf{p}]^T \tag{1}$$

where $\mathbf{p}$ is the vector of the parameters, which depends on the contact model implemented. For instance, in non-smooth contact, it typically includes the friction coefficient μ or the coefficient of restitution CoR. The sensors will provide information about the 2D coordinates of each marker in the image plane, ${}^I\mathbf{R}_{ij}^* \; \forall \; i = 1...n, \; \forall \; j = 1...N_t$, where n is the number of tracked points and N_t is the number of samples in time. A series of rigid transformations is needed to project the tracked points from a conveniently selected inertial reference frame, N, to the image plane I (see Fig. 2): they are combined to obtain the measurement equation of the problem, ${}^I\mathbf{R}_{ij} = \mathbf{h}_i(\mathbf{x}_j)$, that relates the states $\mathbf{x}_j$ to their image coordinates. The states are estimated in a batch least squares problem, where the difference $\delta\mathbf{y}_{ij} = {}^I\mathbf{R}_{ij}^* - {}^I\mathbf{R}_{ij}$ is used to build the cost function.

The outcomes of the state and parameter estimation will be compared to the results obtained with GRAINS simulations: the goal is to reach a position accuracy within 10% of cobbles' characteristic size and a spin rate accuracy within 10% of cobbles' typical spin rate. The validation and fine tuning performed through the experimental micro-g campaign will consolidate the reliability of the numerical tool to reproduce particle-scale physics for granular material on asteroids, and will enable larger macro-scale investigations on more realistic asteroid scenarios.

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