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Modelling a wheel in the regolith of a small body – a Project Chrono study

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Abstract

The objective of this study is to examine Project Chrono as a modelling tool for wheel-regolith interaction in the milligravity regime of a small body. The composition and behavior of regolith on small bodies is unknown and may vary widely from one body to the next. Nevertheless, it is generally accepted that cohesion plays an important role and how this material settles and flows. In this poster, we present how Project Chrono, an open source physical engine allowing for fast parallelized simulation, can be adapted and utilized to model the plowing of a wheel, or any other object, in regolith with cohesive properties. This cohesive model and its implementation are discussed as well as other parameters and options of Project Chrono.

1. Introduction

Many missions have made it their goal to explore the multitude of smaller bodies in the solar system and, if possible, in situ. Landers have been envisioned in many proposals (e.g. Discovery 2014 proposal BASiX) and realized with Philae aboard Rosetta. Mobile explorers, like hoppers and rovers, offer the possibility to explore multipe sites. The hopper solution, using an external or internal mechanical momentum device to jump from places to places, has been examined for locomotion on a small body (e.g. Mascot aboard Hayabusa 2).

Because of the low gravity, a rover can have difficulty finding traction. On the other hand, the preponderance of cohesion in the regolith behavior [6] could provide the traction that weight would in higher gravity contexts. Moreover, a rover could allow for easier operations and mobility.

To decide on the means of transportation of such a lander, it is thus essential to understand how a wheeled vehicle would interact with the regolith in a low-gravity environment. Discrete element method (DEM) simulations are a staple instrument for soil-object interactions on earth and come in two varieties, hard-sphere DEMs and soft-sphere DEMs. For a bed of regolith, we have chosen to use soft-spheres.

To carry out these simulations, we have chosen Project Chrono. Project Chrono is an open-source physics engine that allows a wild range of simulations, notably DEMs [4]. However, the specific properties of regolith requires a careful examination of the forces modeled in Project Chrono, and in particular cohesion.

2. Project Chrono

To build an accurate model, it is required to grasp the intricacies of how Project Chrono models the grain-grain and grain-vehicle interactions.

Project Chrono employs a SSDEM adaptation by the name of smooth contact method (SMC) alongside a HSDEM adaptation named non-smooth contact method (NSC). The SMC model allows the user to specify a set of material parameters that influence how an object interacts with others. These are Young's modulus E, Poisson's ratio ν, the coefficients for static and sliding friction μ_{s} and μ_{k} as well as the coefficient of restitution (COR) e. Adhesion can be set as a constant force or according to the Derjaguin-Muller-Toporov (DMT) model [5]. All these parameters are then used to calculate the stiffness and damping coefficients, which are necessary to model collisions. Project Chrono features implementations of a Hookean and a Hertzian contact force model to simulate the repulsive forces experienced by colliding objects [1]. They do however exhibit some behaviour one would not intuitively expect.

For instance, as displayed in Figure 1 and 2, testing the coefficient of restitution delivers the expected results for high CORs, but shows a significant difference for near-zero CORs. This is a property inherent to many Hertz/Hooke-based force models [2], but might require modification as very low CORs may occur for fluffy regolith particles. Implementing a dif-

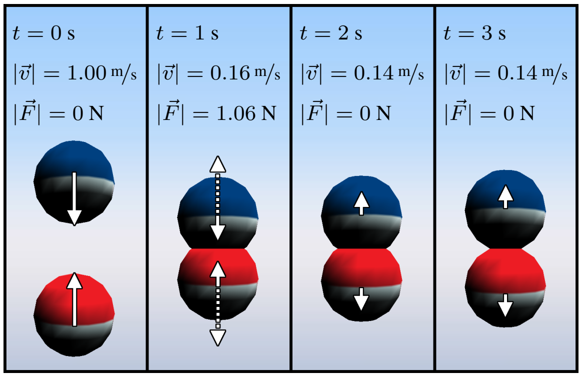

Figure 1: Two spheres with a set coefficient of restitution $e = 0$ and Young's Modulus $E = 2$ Pa colliding. Their velocity is shown as straight arrows, the contact force as dashed arrows. They do not experience the force for the whole duration of overlap and retain an outgoing velocity.

ferent contact force model such as the one described in [3], which exhibits a closer agreement between pre- and post-restitution coefficients is possible in Project Chrono and should be considered an option if so desired. Similar investigation will be done for the implementations of static and kinetic friction as well as cohesive forces. Rolling friction seems to be available only for the HSDEM NSC model and will need some attention to use it in the SSDEM simulation.

The poster will expand on Project Chrono implementations of the different material properties (including COR, friction coefficients, cohesion, etc.).

3. Application to a wheel

To simulate the conditions on a regolith bed on a small solar system body, a large number of individual soft spheres will be subject to gravity on the scale of $10^{-4} - 10^{-2}$ m/s². The material properties of regolith are not well understood and the simulation should be run for different sets of estimations (particle distribution, physical properties, etc.). Then a single wheel is placed on top and we observe its traction and plowing performance.

The poster will show how Project Chrono can be used to carry out these simulations with the presentation of some preliminary results. Although this setup can be used to simulate a wheel in regolith, it could also be used to model any mechanical device penetrating regolith, such as mechanical sampler. Upon completion the code will be made available as open-source.

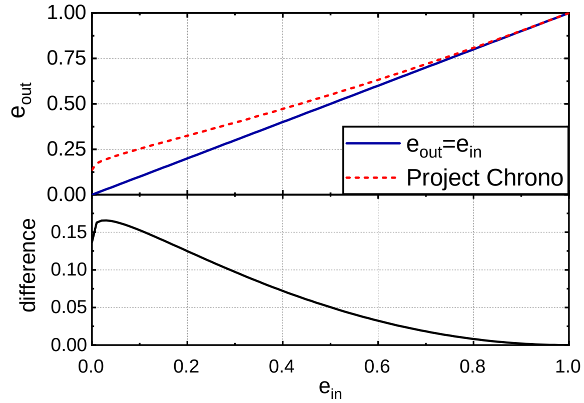

Figure 2: Comparison of the measured coefficient of restitution e_{out} and the pre-set e_{in}. The straight blue line represents a perfect model where both are the same, the dashed red line Project Chronos implementation. Their difference is shown in the black line, which outlines a good match for high coefficients of restitution, but a higher divergence for smaller ones.

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