Coupled simulation of granular media and poly-articulated systems

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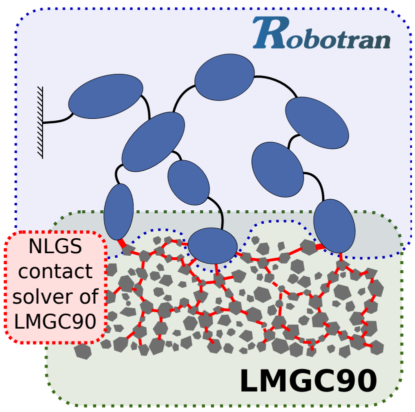
Granular material are widespread in nature and human environment, like sand, ore, aggregates, agri-food products... Modeling such media, also called divided media, is particularly challenging since their behavior depends on the dynamic conditions they are subject to. In particular, discrete element methods (DEM) were develop to simulate granular material, accounting for each grains of the media and the interactions between those. Furthermore, in many industrial processes such as railway track maintenance, granular media are handled by complex machines. The latter can efficiently be modeled as multibody systems (MBS). Coupling MBS and DEM is thus very promising in order to understand the dynamic interactions between granular media and mechanical devices.

The suitable coupling strategy strongly depends on the approach adopted to model each subsystem. Regarding DEM, modeling the contact between grains is a key point that allows to distinguish two main strategies. On one hand, ”Molecular Dynamics” considers regular contact laws, allowing interpenetration between particles. On the other hand, ”Contact Dynamics” assumes rigid contacts and requires to solve geometric and dynamics contact conditions for the whole media at each time step. Several paper proposes to couple MBS-DEM using co-simulation techniques [1, 2], generally modelling the divided media using Molecular Dynamics approaches.

In the present paper, we resort to the second family, in particular to the Non-Smooth Contact Dynamics (NSCD) method proposed by Moreau and Jean [3, 4]. Indeed, it is well adapted to study very hard stones such as the railway ballast. Attempts to couple this technique to a multibody model using simple co-simulation strategies highlight stability problems because the MBS dynamics was not accounted in the contact problem resolution. Consequently, we propose a strong MBS-DEM coupling strategy. The multibody system is modeled using the relative coordinate approach. By doing so, in the case ot tree-like systems, the MBS equations are formulated as a set of ordinary differential equations (ODE). In presence of kinematic loops, the coordinate partitioning technique [5] is used to solve the loop constraint equations and to recover an ODE system.

The coupling consists in extending the NSCD approach to the MBS equations. The two sets of equations are thus formulated in term of differential measures and the coupling comes from the contribution of contact forces. The system must be completed by contact conditions. In the present paper, Signorini-Coulomb conditions are considered (Fig. 1). The system of equations is then discretized using a θ-schema as proposed by Moreau and Jean.



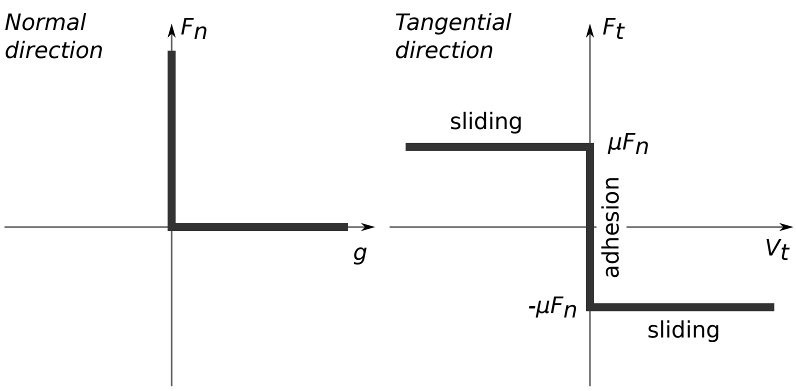
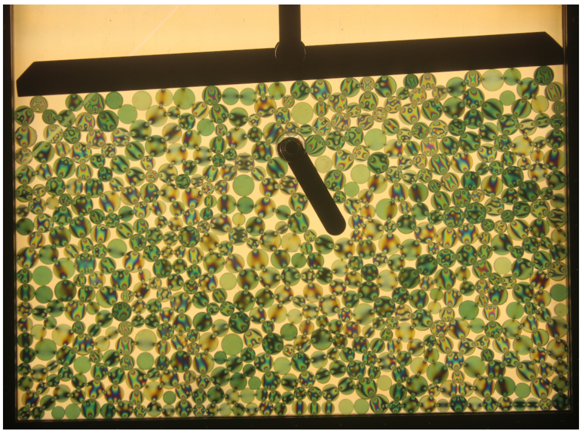


Figure 1: Left: Illustration of the MBS-DEM coupling. Right: Signorini-Coulomb non-regular contact laws: in the normal direction a non-penetration condition is imposed, in the tangential direction the Coulomb friction is considered (F_n: normal force, g: gap between particles, F_t: tangential force, V_t: tangential relative velocity, μ: friction coefficient).

The contact problem is solved using an iterative Non-Linear Gauss-Seidel (NLGS) procedure which accounts for the dynamic response of both the granular media and the multibody system. In practice, this methodology is implemented by coupling two software applications: LMGC90[1] which is dedicated to granular media and ROBOTRAN[2] which generates symbolic equations of motion for multibody systems. The NLGS solver of LMGC90 is used to solve the contact problem. This strong coupling strategy is described in detail in [6].

The presented technique is used to simulate various systems involving MBS and DEM without any stability problem. Depending on the time step size, small inter-penetrations between grains may appear at contact point due to the drift-off effect of the contact conditions formulated at velocity level. This is acceptable as far as the collective behavior of the grain is correctly captured. On the contrary, such a problem does not occur for the MBS joints thanks to the use of relative coordinates combined with the coordinate partitioning method. Several applications are treated (Fig. 2). First a planar mechanism that blends a granular media is considered. This device was designed as a benchmark to test and validate the coupling method. Then the tamping process of railway tracks is analyzed. This maintenance operation consists in restoring the geometry of the track and stabilizing it by vibrating the ballast underneath the sleeper. It is shown that neglecting the dynamics of the tamping machine and the reaction coming from the ballast may lead to overestimate the process performances. This example demonstrates the interest of such a coupling technique for industrial applications.



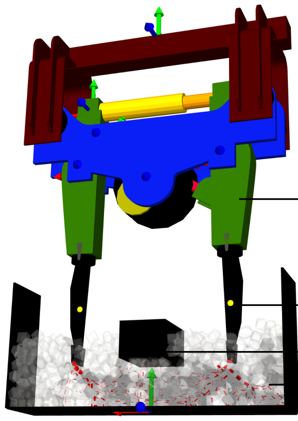


Figure 2: Illustrative applications. Left: Experimental setup for testing the planar benchmark: photoelasticity is used to highlight thr force chain in the granular media. Right: MBS-DEM 3D model of the ballast tamping process.

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