Simulation of a Hall Flowmeter Funnel with a novel non-smooth numerical procedure for granular media

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Summary. Previous work proposed a new NSCD procedure fixing convergence issues for small dynamical systems. We demonstrate here the resulting improved implicit solver efficiency compared to the existing Jean-Moreau scheme, when applied to large systems such as granular media.

Introduction

The Discrete Element Method [Cunedall and Strack, 1979] has emerged from rock mechanics problems and is now applied to many other engineering problems. Besides DEM, the lesser known NonSmooth Contact Dynamics procedure [Jean, 1999] offers an alternative procedure for this type of problems. This latter scheme, essentially a stable backward Euler scheme in time, is mathematically more sounded [Moreau, 1999]. However, Alart and Renouf [Alart and Renouf, 2018] point out that the procedure is still hampered by non- or slow-convergence pathologies linked with its incremental solver. In a previous work [Charles et al., 2018], a new NSCD procedure was set up to fix convergence issues in small (dof) dynamical systems simulations. Since one cannot expect this convergence to be granted for larger systems, the procedure is applied to granular media simulation and shows a great improvement in solver efficiency for these problems compared to Jean-Moreau.

Numerical procedure

Differences and common points with respect to the original Jean-Moreau NSCD scheme are shown in Table 1. Both are Backward Euler schemes with a midpoint update rule. However, at step 5, Jean and Moreau solve at the same time impact and dry friction whereas we solve first the frictionless impact and only then friction in a staggered way. Jean and Moreau's way conveys a very direct implementation but challenges the convergence of the Nonlinear Gauss Seidel. This leads to drift-off in the simulation due to the necessary cut-off in convergence search after a given (high) number of iterations is reached. Jean notes that "The method has proven in applications to behave nicely as soon as the time step is small enough and the friction coefficient is lying in the range allowed" [Moreau, 1999, Jean, 1999]. One can object the subsequent error being only controlled by refining the time step, this somehow cancels the advantage of using an NSCD method versus a DEM. The presented procedure instead conveys a more intricated implementation and the necessity at step 3 to infer, from Coulomb law, a dry friction constitutive law in terms of Lagrange's generalized forces. We show next that the current method does however scale well and the gain is worth the pain in the case of a Hall Flowmeter Funnel simulation.

Step	Jean Moreau	current procedure
1	Evaluation of midpoint approximants	
2	Contact detection	
3	a. Normals and tangents **in euclidian space**	a. Normals and tangents **in Lagrange's generalized forces space** b. Inference of a dry friction law on the Lagrange's generalized forces [Charles and Ballard, 2014]
4	Contactless equation of dynamics and contactfree predictor	
5	a. Coulomb and standard inelastic shock laws resolution with a Nonlinear Gauss Seidel (max 3000 iterations)	a. Standard inelastic shock law resolution (NLGS, max 1500 iterations) b. Inferred friction law resolution (NLGS, max 1500 iterations)
6	Actualization of final velocities and positions	

Table 1: Comparison of the Jean Moreau and the current NSCD procedure

2D Simulation of a Hall Flowmeter Funnel

The increase in efficiency for solving the contact conditions using the novel procedure is illustrated with the simulation of the flow of a granular medium under gravity through a funnel, inspired by the Hall Flowmeter Funnel. In Figure 1 the initial state of the simulation is shown, along with the state of the granular medium at two subsequent moments during the flow. This case was chosen due to the compacting phase the granular medium has to go through and the resulting multiple self-equilibrated contact force networks usually causing convergence issues.

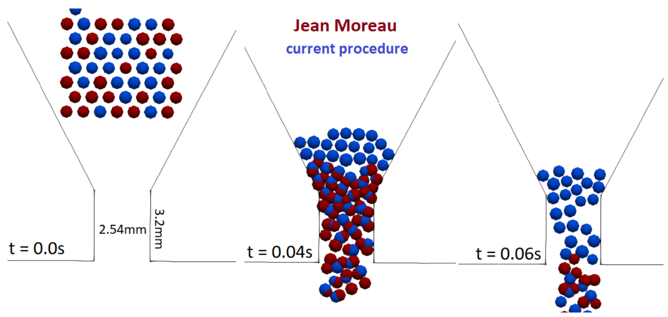

Figure 1: Illustration of the 2D Hall Flowmeter funnel with evolution of the granular medium configuration with time for the same 50 particles (the radii following a normal distribution of average $0.3mm$ and a deviation of 5%) for both procedures and here with a time step of $1e^{-4}s$. The difference in behaviour due to higher interpenetrations for Jean Moreau is clearly visible.

The simulation is run using both procedures for a total simulated time of $0.1s$. The results in terms of CPU time and cumulative penetration error when varying the time step are given in Figure 2. The penetration error is the sum of particle interpenetrations as well as residual penetration of particles in obstacles.

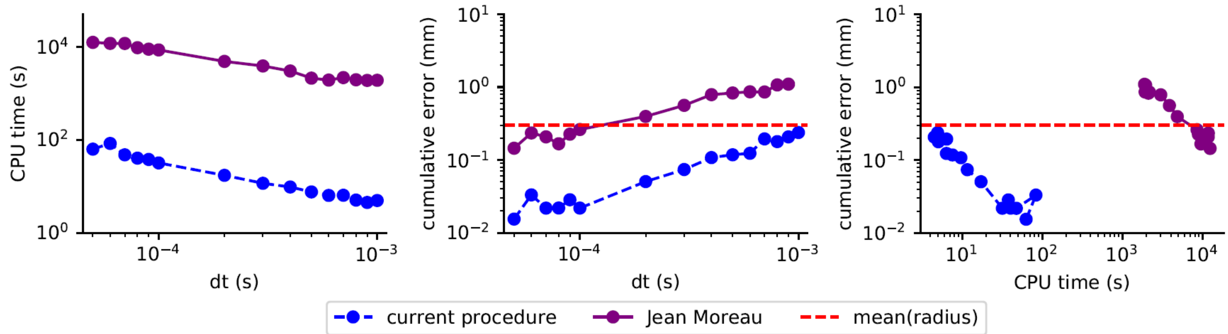

Figure 2: Influence of time step on CPU time and cumulative error for both procedures in the case depicted in Figure 1.

The source for this difference in computational efficiency can be traced to the time spent iterating during the solving of the contact conditions as depicted in Figure 3. One clearly sees the NLGS of the Jean-Moreau procedure maxing out its (unusually high) number of allowed iterations while the novel approach, thanks to its preconditioning and reformulation of the problem, converges very quickly (in less than 100 iterations) even though it has to go through two NLGS.

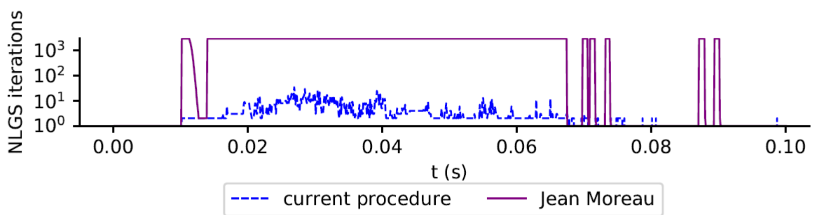

Figure 3: Total NLGS iterations for contact resolution at each time step in the case depicted in Figure 1.

Take aways

In the presentation, a novel nonsmooth procedure, until then limited to small archetypal problems, is upscaled to the case of granular media. The final outcome is a swift integration in time (3 orders of magnitude faster than the typical JM NSCD for an equivalent penetration error). The procedure is also illustrated on a selective laser melting powder bed spreading.

References

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