University of Stuttgart
Institute for Nonlinear Mechanics

Bachelor's thesis
Term paper
Master's thesis

High precision experiments for frictional contact and impacts

Topic Areas:	nonsmooth dynamics, experimental mechanics, frictional contact
Advisors:	Dr. Jonas Breuling, breuling@inm.uni-stuttgart.de
Responsible Professor:	Prof. Remco Leine
Prerequisites/Prior Knowledge:	interest in experimental work, Python/Matlab

Numerical methods for mechanical systems with frictional contact and impacts, such as Moreau–Jean time stepping, are well developed. How accurately they predict reality, however, is rarely quantified. Experiments on rocking blocks [1] or tossed cubes [2] show that small imperfections of corners and surfaces make single tests irreproducible, and that simulators deviate considerably from measured trajectories. Even classical examples such as wooden toys are compared with simulations only qualitatively [3].

This thesis turns the problem around. Instead of modelling a complex system as well as possible, very simple experiments are designed such that an ideal rigid-body model with perfect contacts and joints describes them. Candidates are a rocking block on a steel base or a short row of dominoes [4].

Key requirements are accurately manufactured contact geometries, hard and flat contact surfaces and a repeatable release mechanism. Friction and restitution coefficients are identified in separate tests, so that the subsequent simulation is a true prediction rather than a fit. The motion is recorded with a high-speed camera. Since impacts amplify small deviations, each experiment is repeated many times and the simulation is compared with the measured distribution instead of a single trajectory.

Specifically, the goals of this thesis are

- to review existing contact experiments and design one or two simple benchmarks with well-defined contact geometry,
- to manufacture and instrument them, including high-speed video tracking and the independent identification of friction and restitution, and
- to compare repeated measurements with simulations by the institute's nonsmooth time-stepping schemes and quantify the remaining sim-to-real gap.

References

[1] G. Cocuzza Avellino *et al.*, "Shaking table seismic experimental investigation of lightweight rigid bodies," *Buildings*, 2022.

[2] B. Acosta *et al.*, "Validating robotics simulators on real-world impacts," *IEEE Robotics and Automation Letters*, 2022.

[3] R. I. Leine *et al.*, "Nonlinear dynamics and modeling of various wooden toys with impact and friction," *Journal of Vibration and Control*, 2003.

[4] G. Lu *et al.*, "Effect of particle shape on domino wave propagation: a perspective from 3D, anisotropic discrete element simulations," *Granular Matter*, 2014.