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Master Thesis Proposal – ESE/MST/SEE/Math

# The Time-Freezing for Contact-Rich Optimal Control

Controllers and planners for robotic systems which interact with their environment must deal with the complex, nonsmooth, behaviors of contact and friction. The primary difficulty in these cases is the discontinuous behavior of the state of the system when contacts are made or broken which occurs both in traversal and manipulation scenarios.

One approach that has been proposed for efficiently dealing with the discontinuities caused by inelastic collisions with friction is the so-called "time-freezing" method [1,2]. This method augments the system with a physical time variable which is "frozen" while the state jump caused by an impact is calculated. This transforms the system with state jumps into a piecewise-smooth system which can be handled accurately by the "Finite Elements with Switch Detection" (FESD) method [3]. A basic implementation of this pipeline exists in the MATLAB package *nosnoc,* but some open questions on the accurate discretization remain.

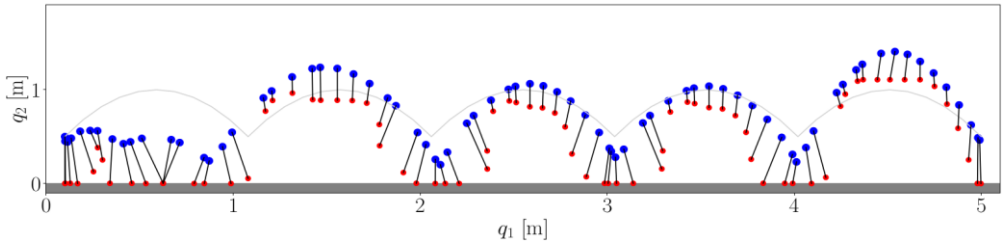


*Figure 1: Optimal control of a hopping robot with a telescoping leg.*

**Master topic:** The goal of this thesis would be the implementation of the automatic time-freezing reformulation for systems with inelastic collisions in the python package *nosnoc_py,* as well as exploring extensions of the FESD method tailored to the piecewise-smooth systems it generates. Moreover, the developed pipeline should be applied to solving relevant robotic manipulation tasks.

**Your skills**: A strong background in systems, control and optimization as well as programming skills (Python/CasADi) are necessary.

**Supervisors and contacts:** Prof. Dr. Moritz Diehl, Dr. Armin Nurkanović, Anton Pozharskiy

If you are interested, please feel free to contact: Dr. Armin Nurkanović <armin.nurkanovic@imtek.uni-freiburg.de> and/or Anton Pozharskiy <anton.pozharskiy@imtek.uni-freiburg.de>

[1] Nurkanović, A., Albrecht, S., Brogliato, B., & Diehl, M. (2023). The time-freezing reformulation for numerical optimal control of complementarity lagrangian systems with state jumps. *Automatica*, *158*, 111295.
[2] Nurkanović, A., Sartor, T., Albrecht, S., & Diehl, M. (2020). A time-freezing approach for numerical optimal control of nonsmooth differential equations with state jumps. *IEEE Control Systems Letters*, *5*(2), 439-444.
[3] Nurkanović, A., Pozharskiy, A., Frey, J., & Diehl, M. (2024). Finite Elements with Switch Detection for numerical optimal control of nonsmooth dynamical systems with set-valued heaviside step functions. *Nonlinear Analysis: Hybrid Systems*, *54*, 101518.