University of Stuttgart
Institute for Nonlinear Mechanics
Institute for Systems Theory and Automatic Control

Master's thesis

Solving frictional contact problems using interior point methods and numerical continuation

Topic Areas: optimization algorithms, numerical continuation
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Prerequisites/Prior Knowledge: numerical optimization, nonlinear dynamics

Dry Coulomb friction is ubiquitous in mechanical engineering — from robotic grasping and granular packings to multibody vehicle dynamics and deformable solid mechanics. Accurately resolving contact forces in these systems is both practically essential and mathematically challenging, because the underlying problem is nonsmooth, nonconvex, and generically rank-deficient when constraints are redundant.

Following recent work on interior point methods for frictional contact problems [1], this thesis aims at the development of a *novel numerical method* that combines primal-dual interior point techniques with numerical continuation. In contrast to existing solvers, this approach requires the implementation of a *custom, nonstandard interior point method (IPM) from scratch*, tailored to the structure of second-order cone complementarity problems (SOCCPs).

In practice, frictional contact problems are predominantly solved using first-order methods based on proximal mappings. While these approaches are robust and easy to implement, they exhibit only linear convergence, making high-accuracy solutions computationally expensive or infeasible. Primal-dual IPMs offer a fundamentally different approach. By perturbing the complementarity conditions using a barrier parameter μ, they follow the so-called *central path* and achieve superlinear or even quadratic local convergence. However, standard IPM implementations for conic problems (e.g., [2], [3]) cannot be directly applied here.

A key observation from [1] is that the central path of the frictional SOCCP may exhibit *turning points*, where the barrier parameter μ is no longer a valid global parameter. As a consequence, classical IPMs that enforce a strictly decreasing μ fail to converge in such situations. This thesis addresses this limitation by interpreting the central path as a solution manifold of a parameterized nonlinear system

$$\boldsymbol{F}(\boldsymbol{w}, \mu) = \boldsymbol{0}$$

and applying methods from *numerical continuation* to track this manifold robustly through singular and non-monotone regions.

The project is a joint effort between INM & IST and lies at the intersection of numerical optimization, nonlinear mechanics, and scientific computing. You will gain considerable experience with numerical methods for optimization by developing new algorithmic solutions to this challenging problem while working on a *research-level numerical method* with direct relevance to modern simulation tools.

References

[1] V. Acary *et al.*, "Solving contact problems with Coulomb friction using an interior point algorithm and path following techniques," 2026.

[2] P. J. Goulart *et al.*, "Clarabel: An interior-point solver for conic programs with quadratic objectives," 2024.

[3] G. M. Chari *et al.*, "QOCO: a quadratic objective conic optimizer with custom solver generation," 2026.