University of Stuttgart

Institute for Nonlinear Mechanics

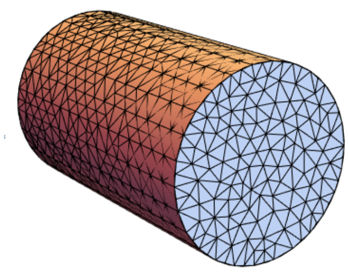
Bachelor's thesis
Term paper
Master's thesis

Real-time collision detection with non-standard primitive shapes

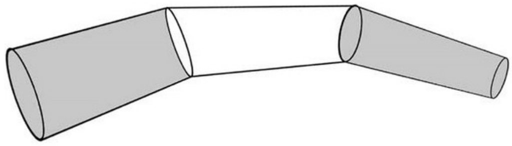
Topic Areas:	numerics, optimization, geometry
Advisors:	Dr. Jonas Breuling, breuling@inm.uni-stuttgart.de
Responsible Professor:	Prof. Remco Leine
Prerequisites/Prior Knowledge:	Convex optimization

Collision detection for convex bodies lies at the heart of modern physics engines, robotics, and simulation software. Modern software libraries such as coal [1] rely on elegant geometric and optimization-based algorithms—most notably the Gilbert–Johnson–Keerthi (GJK) algorithm and its companion, the Expanding Polytope Algorithm (EPA).

For the spatial discretization of long, slender bodies, rod finite elements are known to provide an efficient and sufficiently accurate modeling approach. To faithfully capture their spatial interaction, however, robust contact distance and contact manifold computations are indispensable. In a naive approach, the surface of a rod is discretized using a large number of triangular elements. This allows existing collision detection algorithms to be applied directly, but at the cost of significantly increased computational effort and slow collision queries.



To enhance the collision detection, it is possible to define a non-standard convex primitive, tailored for the collision detection of rod finite elements with circular cross-sections. Therefore, a new primitive shape has to be implemented that consists of the convex hull of two arbitrarily oriented disks, a shape that can be interpreted as a conic section. This geometry provides a much more faithful representation of rod finite elements than a triangulated surface, while remaining compatible with modern convex collision detection algorithms.



Implementing such a new convex primitive requires a detailed understanding of modern collision detection methods and their close connection to convex optimization problems [2]. In particular, support functions and Minkowski difference formulations play a central role in algorithms such as GJK and EPA and form the mathematical foundation for extending collision detection libraries to new convex shapes.

Specifically, the goals of this thesis are

- to study the theory of modern collision detection methods and their relationship to convex optimization,
- to implement the new convex primitive within the coal library [1], and
- to conduct numerical experiments to validate the implementation and assess its numerical performance.

References

[1] J. Pan *et al.*, "Coal: An extension of the flexible collision library," 2024.

[2] L. Montaut *et al.*, "Collision Detection Accelerated: An Optimization Perspective," 2022.