DiSECt: A Differentiable Simulation Engine for Autonomous Robotic Cutting

diff-cutting-sim.github.io

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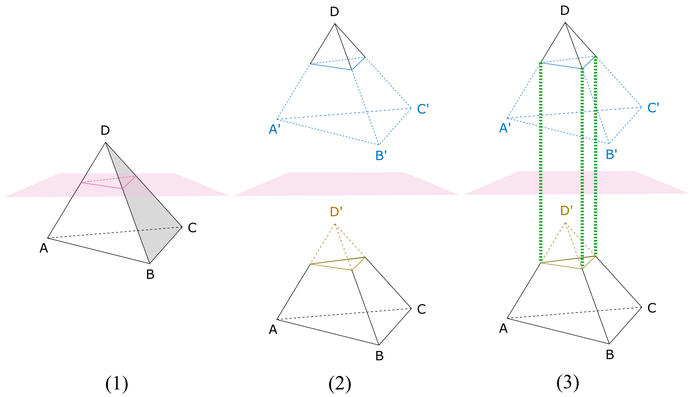
Overview

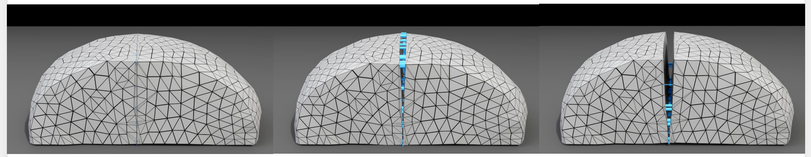
- first differentiable simulator for robotic cutting
- novel continuous model for crack propagation, damage
- close the reality gap by optimizing simulation parameters
- find human-like sawing motions through trajectory optimization

Approach

- represent objects as tetrahedral meshes
- simulate deformation through Finite Element Method (FEM)
- simulate contact forces by modeling knife geometry through signed distance field



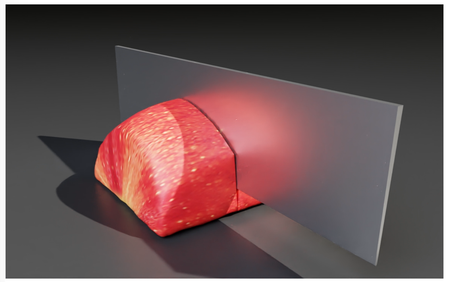
(1) duplicate mesh elements intersecting the cutting surface
(2) add extra vertices (virtual nodes) at intersection points
(3) connect virtual nodes by springs

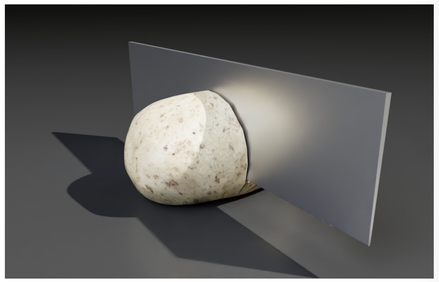


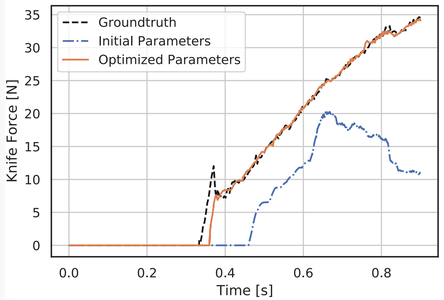
- springs are weakened in proportion to knife contact force
- continuous (differentiable) model of crack propagation

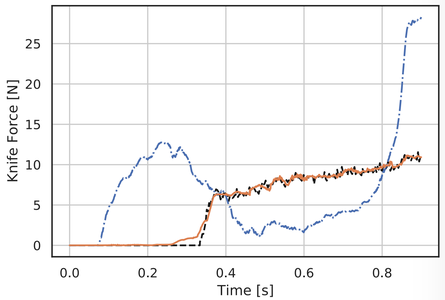
Simulator Calibration

- match forces and deformations from real robot cutting foodstuffs
- optimize hundreds of sim parameters simultaneously
- parameters generalize to different knife velocities, trajectory lengths



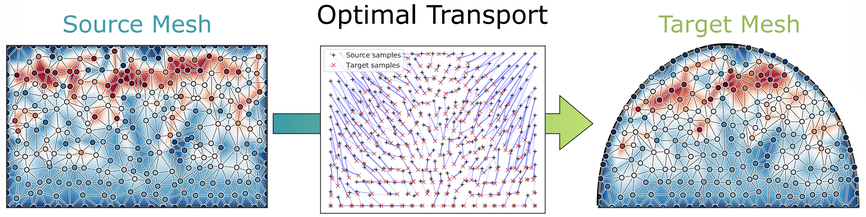






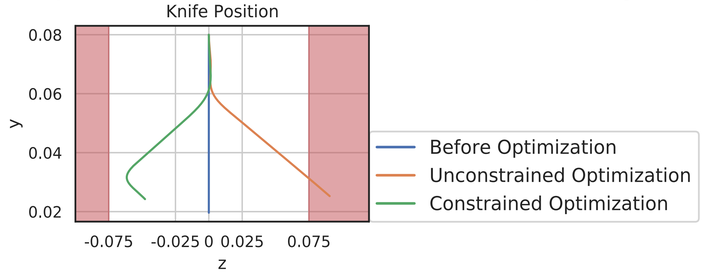
Mesh Transfer

- transfer simulation parameters to topologically different meshes via Optimal Transport
- achieve accurate force predictions for unseen objects with known material properties



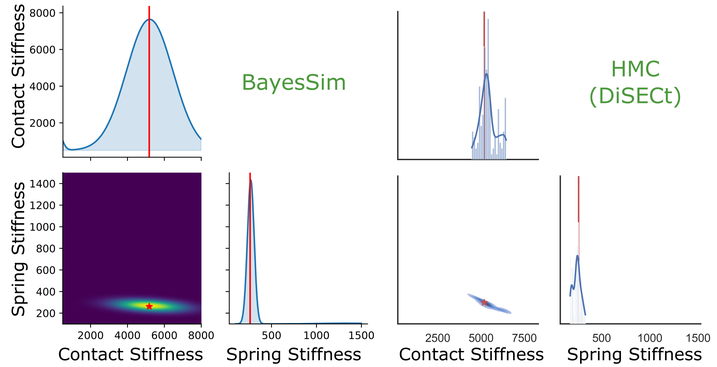
Trajectory Optimization

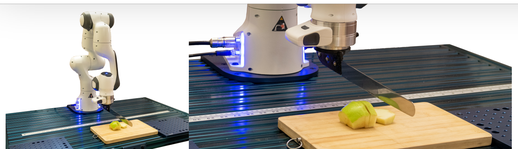
- minimize applied force and maximize cutting velocity
- human-like sawing motion emerges through constrained optimization
- requires 15% less force than a downward pressing motion



Bayesian Inference

- infer distribution over simulation parameters
- gradient-based inference (SGLD, HMC) much more efficient, accurate than likelihood-free methods (BayesSim)





Ongoing Work

Closed-loop control on the real robot with DiSECt coming soon!