Discrete Elastic Rod Simulation of Shoelace Knots and Strength
Final presentation

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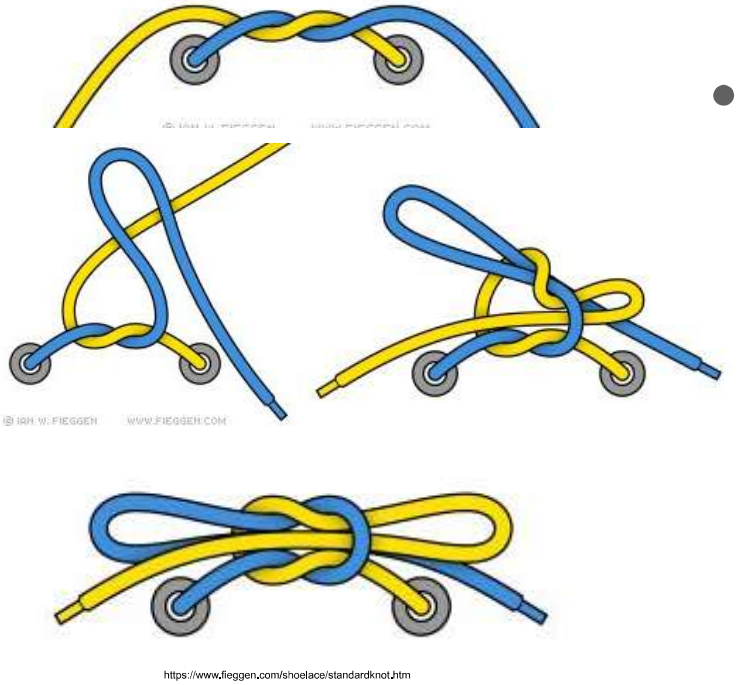
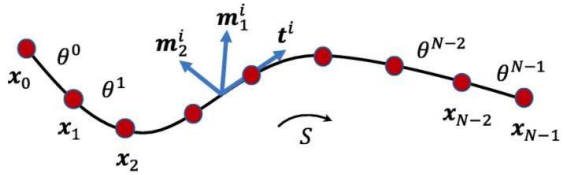
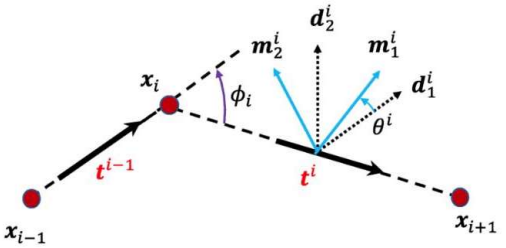
Review of Problem



https://www.fieggen.com/shoelace/standardknot.htm

- Discrete Elastic Rods (DER) algorithm with Implicit model
- Tying & Untying the knot
  - Measuring force required to untie reef knot
  - Effects of shoelace stiffness and friction on knot strength



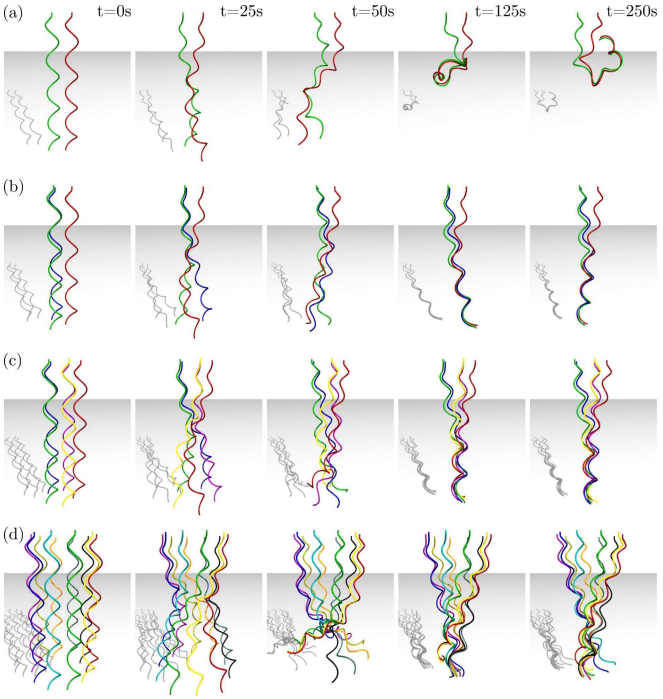


https://images.app.goo.gl/grqPd8ZQ2AxtSE9i9

Existing work

SCI lab - Contact between rods

https://github.com/StructuresComp/rod-contact-sim

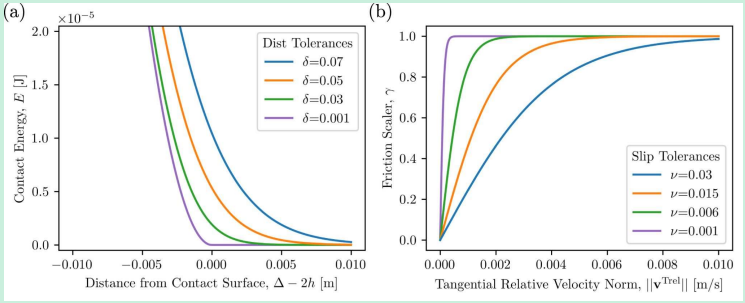


Algorithm characteristics:

1-D Kirchhoff based model

Implicit Newton's method

Implicit Contact Model: differentiable contact energy to stick to implicit model



Achievements

Implementation structural changes

1) **Free and fixed DOF:**
At each time step, we defined the free DOF based on the given boundary conditions
2) **Dumb viscosity:**
Implementation of a fluid viscosity force, which is useful to avoid divergence when releasing previously fixed DOF

Reef knot tying

1) **Boundary conditions:**
Definition a sequence of hard written BC to reach a tied reef knot shape
2) **Parameter study**:
Study of the simulation and physical param to ensure the convergence (friction coef, time step, Young's modulus ...)

Reef knot untying

1) **Boundary conditions:**
Untying boundary conditions definition
2) **Force VS displacement**:
Study of the force/displacement slope to quantify the strength of the studied knot
3) **Parameters influence:**
Quantification of the influence of several parameters on the force/displacement slope

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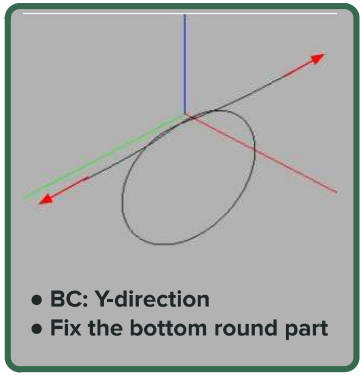
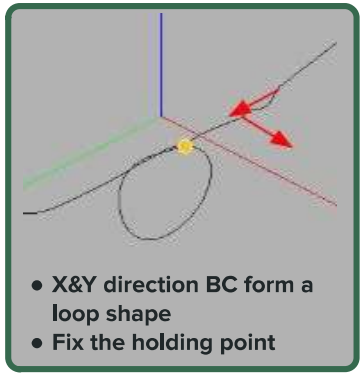
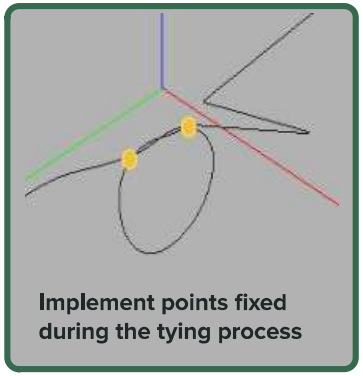
Implementation Details



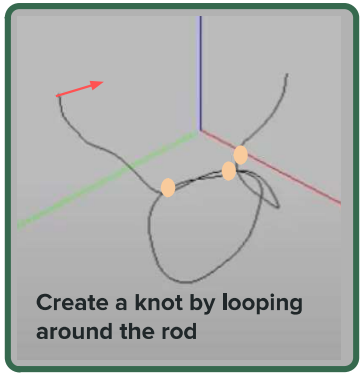
- BC: Y-direction
- Fix the bottom round part



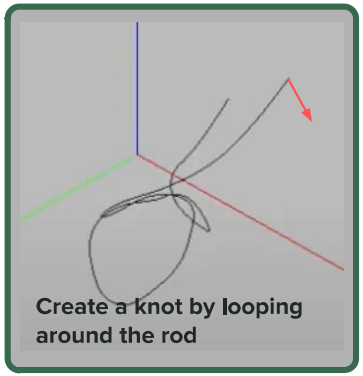
- X&Y direction BC form a loop shape
- Fix the holding point



Implement points fixed during the tying process



Create a knot by looping around the rod



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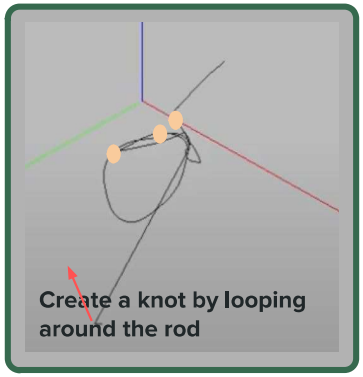

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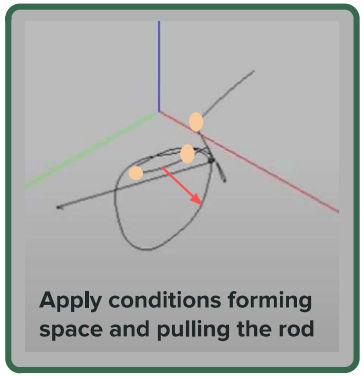
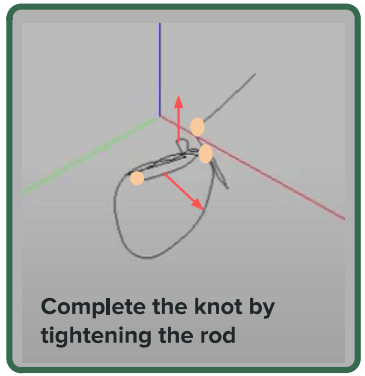
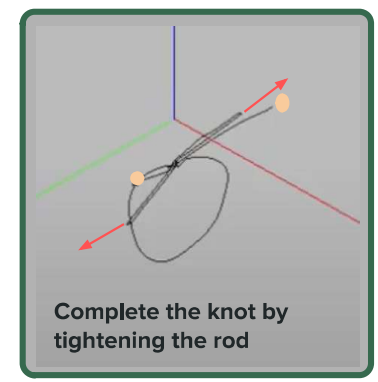


Apply conditions forming space and pulling the rod



Complete the knot by tightening the rod



Complete the knot by tightening the rod

Reef knot tying

Video

Selected parameters:

Rod radius: 1.6mm

Poisson coef: 0.5

Young: 0.18MPa if t < 27.5s
1MPa otherwise

Contact energy parameter nu: 1e-4

Nb of vertices: 340

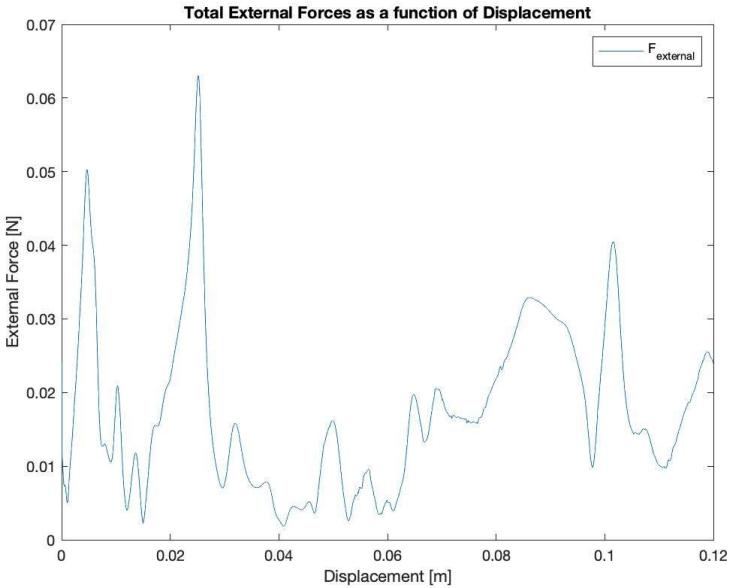
Contact energy parameter delta: 1e-5

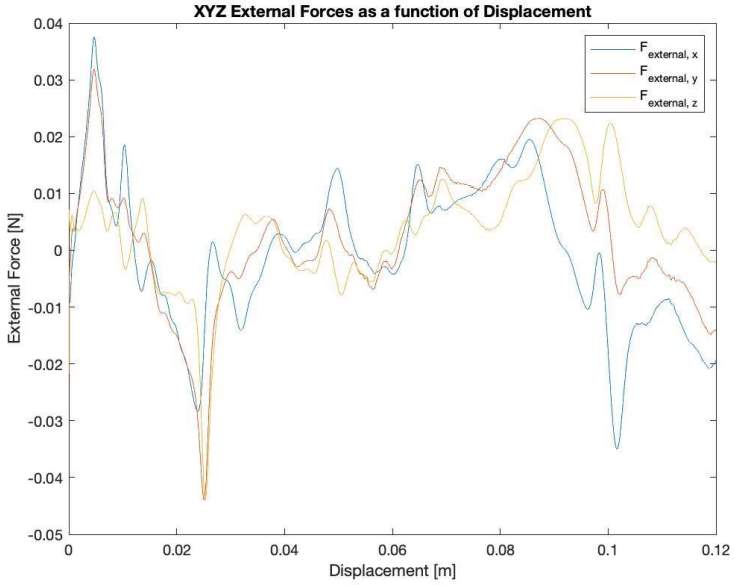
Time step: 0.001s

Solid friction coef: 0 if t < 27.5s
0.5 if t > 27.5s

Fluid friction coef: 0 if no released DOF at the considered t
1 otherwise

Reef knot untying





Challenges

- Identifying successive boundary conditions in displacement to correctly form the knot
- Releasing the previously fixed nodes correctly to obtain a tied reef knot (final step)
- Avoid storing too much internal energy
- Choose the good parameters to avoid divergence
- Obtain a strongly tied knot

Conclusions, limits and further ideas

We obtained a tied reef knot and observed the untying phenomena. Our method is adaptable to other types of knot.

Major limit: the tying process depends a lot on the chosen parameters. For now, we chose them to achieve the tying and avoid any divergence.

We did not had the time to simulate the granny knot, but the comparison between the two knots can be interesting to pursue.

Reef

Granny

Pictures from https://www.fieggen.com/shoelace/grannyknot.htm

Thank you! Questions?