Robotic Manipulation for Automated Stability Testing of Elastic Rods

Award Title: "NRI: FND: Physics-based training of robots for manipulation of ropes and clothes"

Dezhong Tong, Andrew Choi, Jungseock Joo (Co-PI), M. Khalid Jawed (PI), University of California, Los Angeles
https://structures.computer/roboticmanipulation

ABSTRACT Experimental analysis of the mechanics of a deformable object, and particularly its stability, requires repetitive testing and, depending on the complexity of the object's shape, a testing setup that can manipulate many degrees of freedom at the object's boundary. Motivated by recent advancements in robotic manipulation of deformable objects, we address these challenges by constructing a method for automated stability testing of a slender elastic rod — a canonical example of a deformable object — using a robotic system. **Reference:** Tong, D., Borum, A. and Jawed, M.K., 2021. Automated stability testing of elastic rods with helical centerlines using a robotic system. *IEEE Robotics and Automation Letters*, 7(2), pp.1126-1133. doi.org/10.1109/LRA.2021.3138532 **Graphical Abstract:** youtu.be/O48iDElWy-8

CHALLENGE

(1) Mechanical analysis, e.g., stability testing, of slender structures requires repetitive testing

(2) Precise control of multiple degrees of freedom may be necessary at the boundaries of a structure undergoing testing

(3) Systematic exploration of parameter space requires innumerable experimental trials and, therefore, robots are the only option

SCIENTIFIC IMPACT

(1) Introduction of robotics to the field of experimental mechanics

(2) Systematic experimentation on the stability of highly deformable structures that sheds light on the fundamental mechanics of such structures

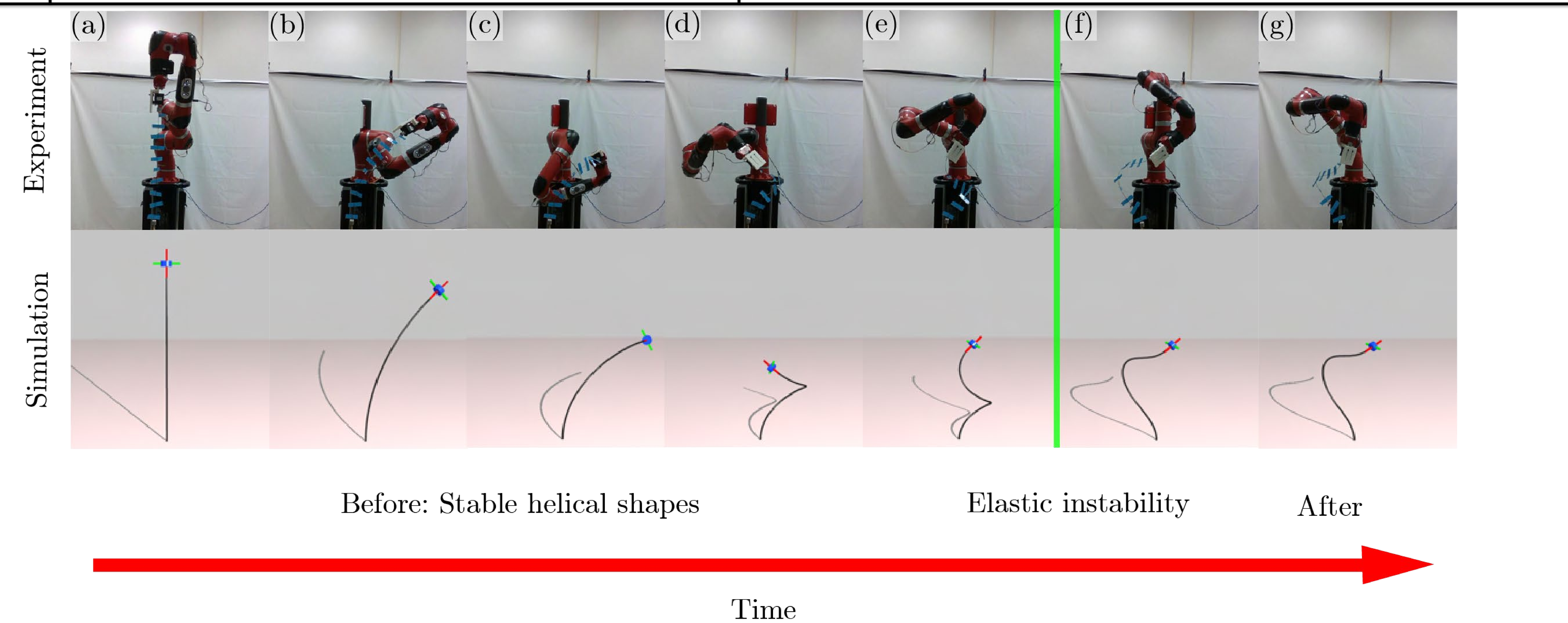
(3) Fundamental understanding of the stability of elastic rods that can should be incorporated in robotic motion planning during manipulation of such structures

TECHNICAL APPROACH

We focus on rod configurations with helical centerlines since the stability of a helical rod can be described using only three parameters, but experimentally determining the stability requires manipulation of both the position and orientation at one end of the rod, which is not possible using traditional experimental methods that only actuate a limited number of degrees of freedom. We construct and implement a manipulation scheme to explore the space of stable helices, and we use a vision system to detect the onset of instabilities within this space. The experimental results obtained by our automated testing system show good agreement with numerical simulations of elastic rods. The methods described in this project lay the groundwork for automation to grow within the field of experimental mechanics.

Key innovations:

- Robotic manipulation to test the structural stability of elastic rods in an automated manner without human in the loop
- Numerical modeling tools based on discrete differential geometry for efficient simulation of (geometrically nonlinear) deformation in elastic rods



Snapshots of an elastic rod manipulated by a robot from stable helical configurations to non-helical configurations after an instability. (a-e) Stable helical configurations; (f-g) non-helical configurations after an instability; elastic instability happens at the vertical green line.

BROADER IMPACT ON SOCIETY

(1) Physics-based training for robot manipulation enables robots to handle complex tasks, such as tying knots, folding towels and clothes, etc.

(2) Robotics manufacturing, assistance, and service can greatly benefit from robust physics-based manipulation policies

BROADER IMPACT ON EDUCATION

(1)Training of 2 postdoctoral scholars and 2 graduate students

(2) New graduate level course on physics-based simulations (Course materials: structures.computer/slenderstructures)

(3) Open-source tools (github.com/QuantuMope/imc-der)

QUANTIFIABLE IMPACT

(1) Experimental equivalent of a triple nested for-loop

(2) Fast simulation tools for elastic rods that can run faster than real-time on contemporary desktop computers

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