An Under-actuated Curved Surface Display

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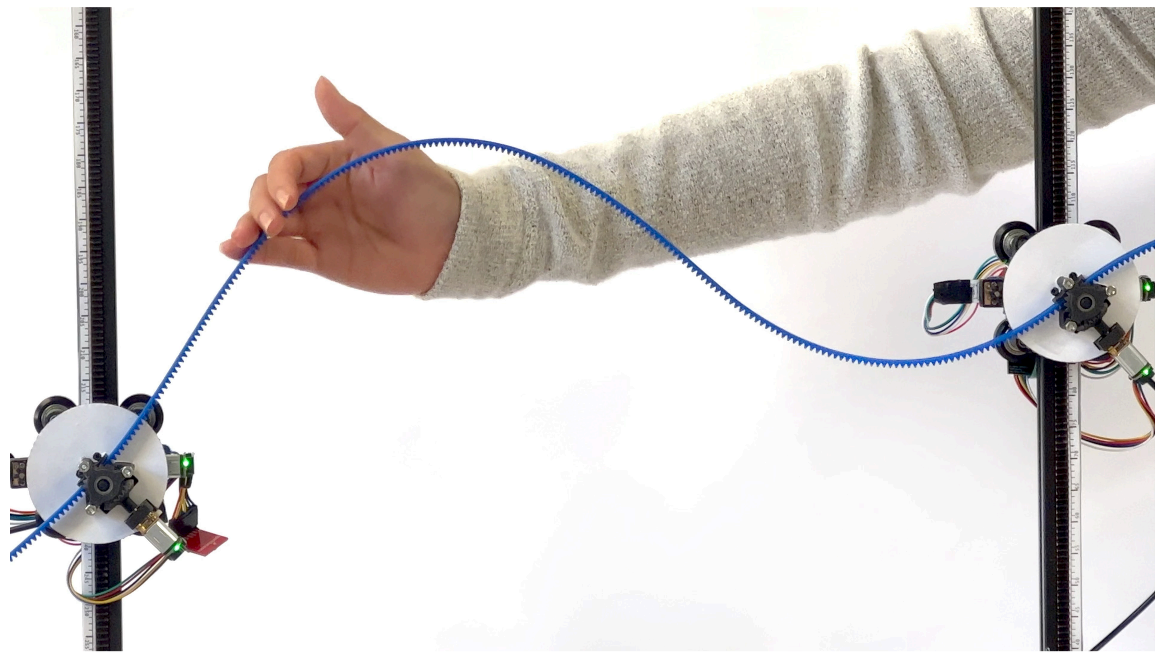
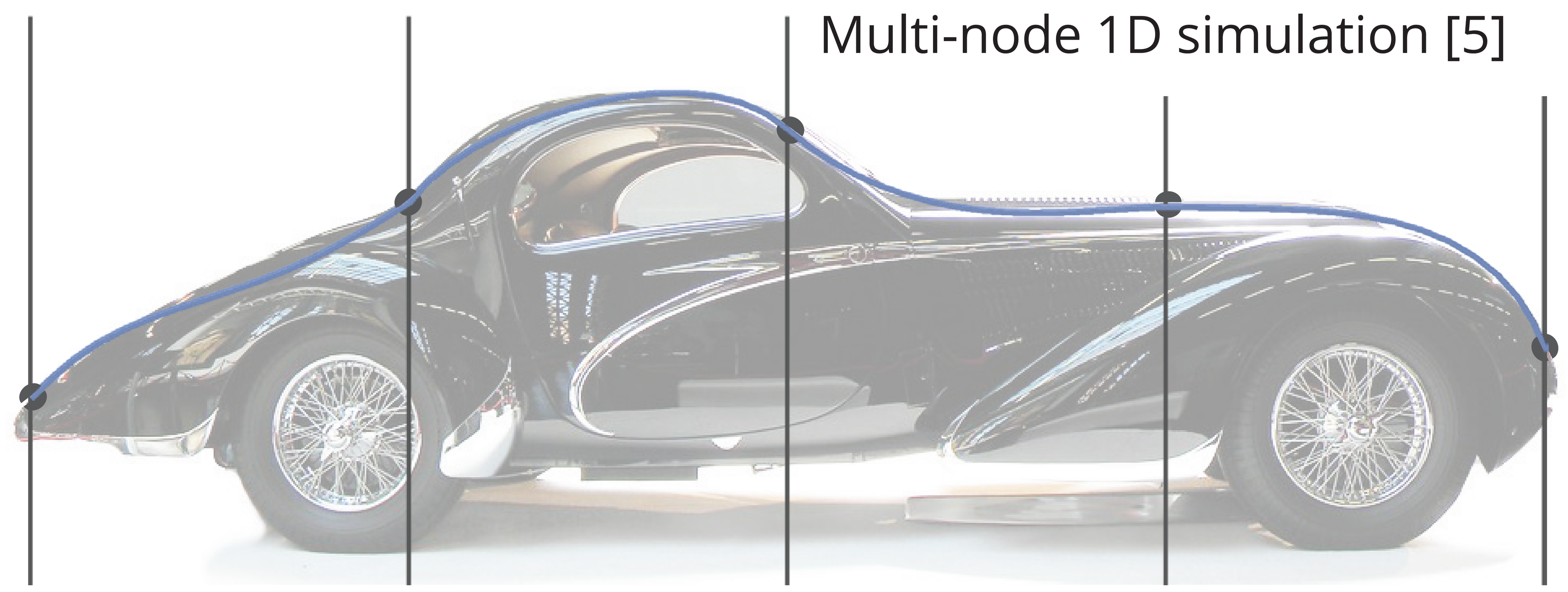
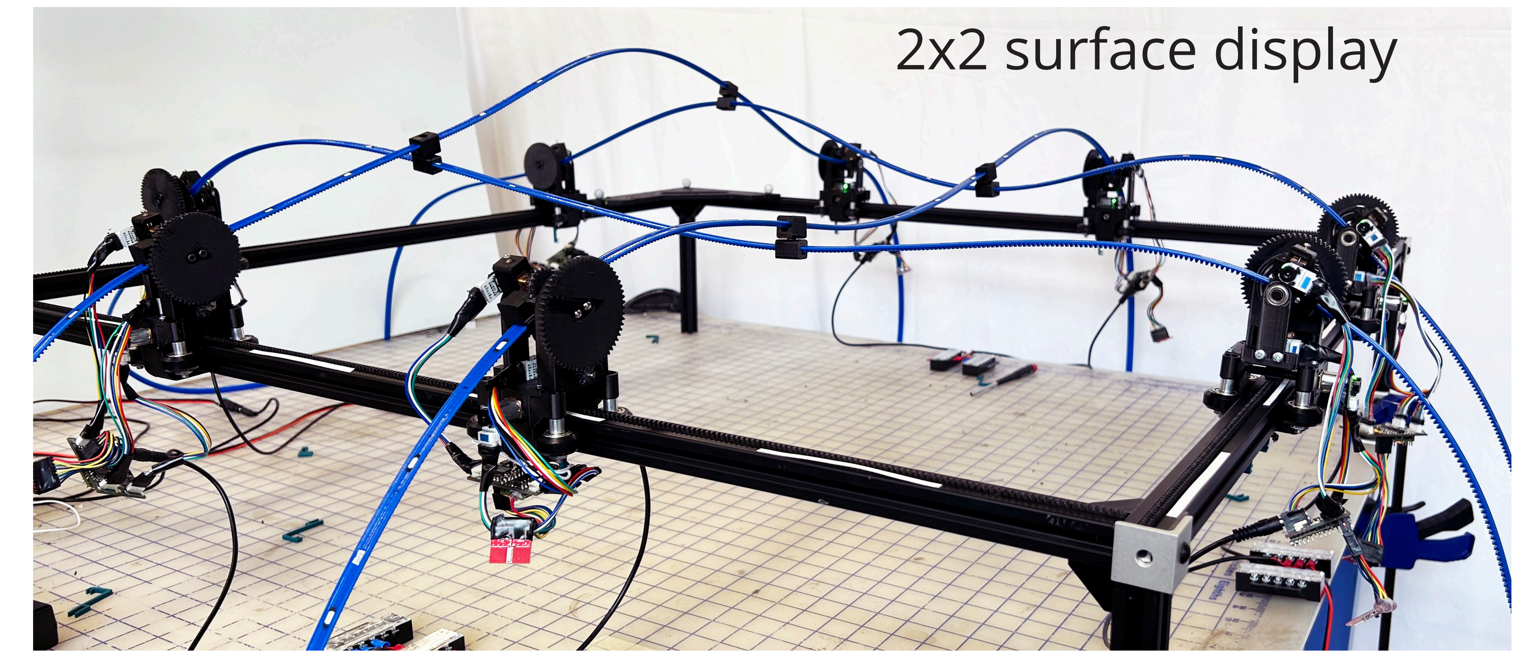




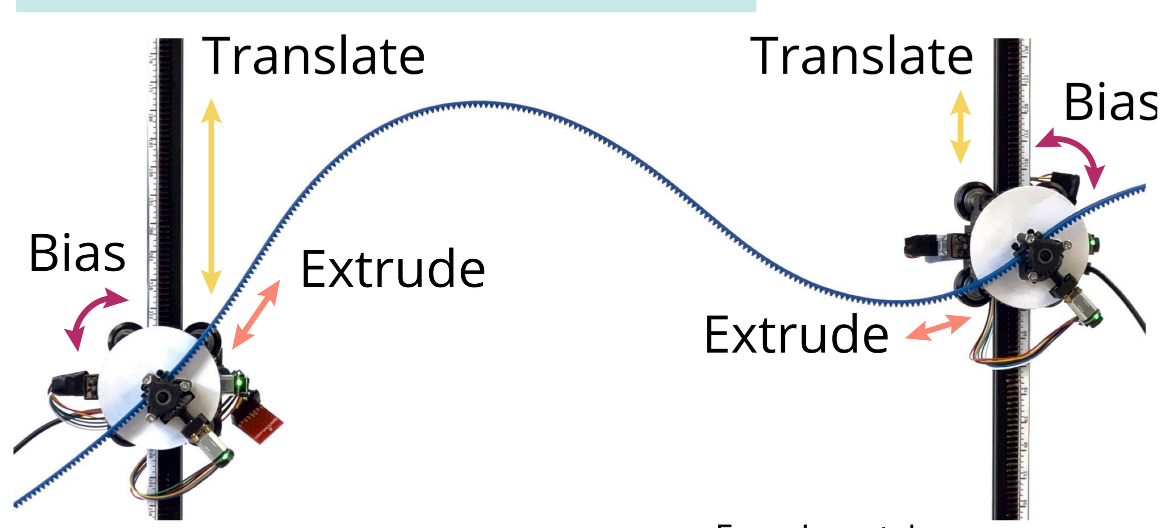


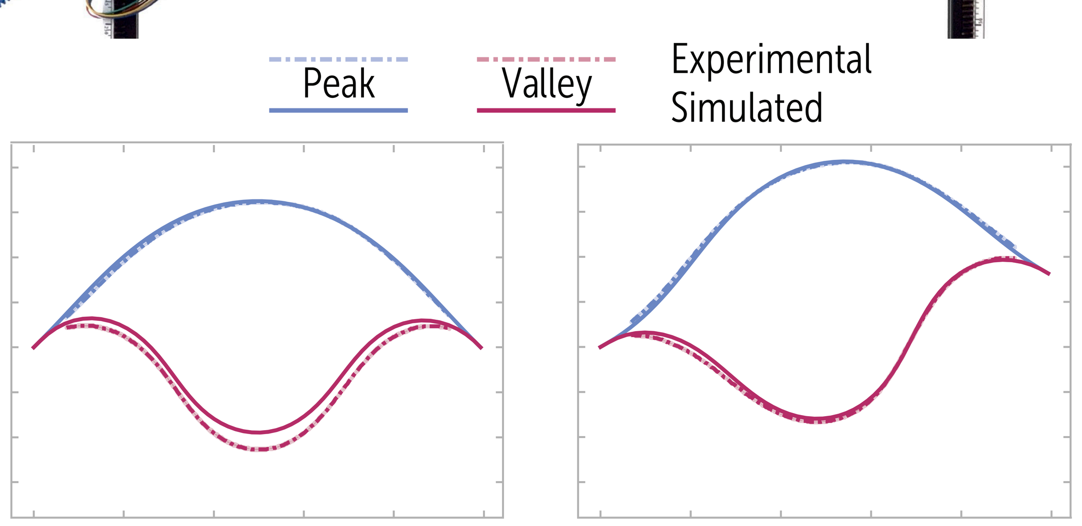
Manipulating flexible rods with sparsely placed actuators allows shape displays to make smooth geometries. The multistability of these rods makes modeling and control more compex, but provides a greater shape space

Motivation

Shape-changing displays utilize robotics to offer visual and tactile interaction as well as design feedback for 3D modeling. Traditionally they are made of rigid components, which struggle to make smooth shapes [1]. We can overcome this by deforming flexible materials at their boundaries to create continuous curves. We present two systems using under-actuated elastic rods: a **1D line display** [2] and a **2D surface display** created by coupling a grid of flexible rods at their intersections.

Line Display

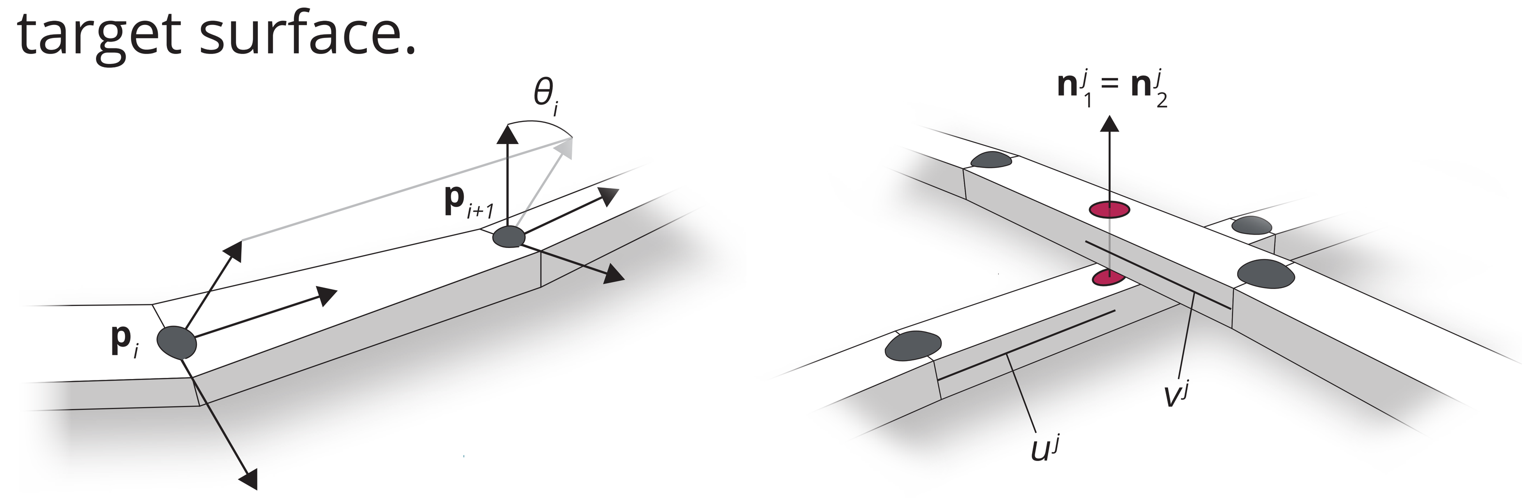




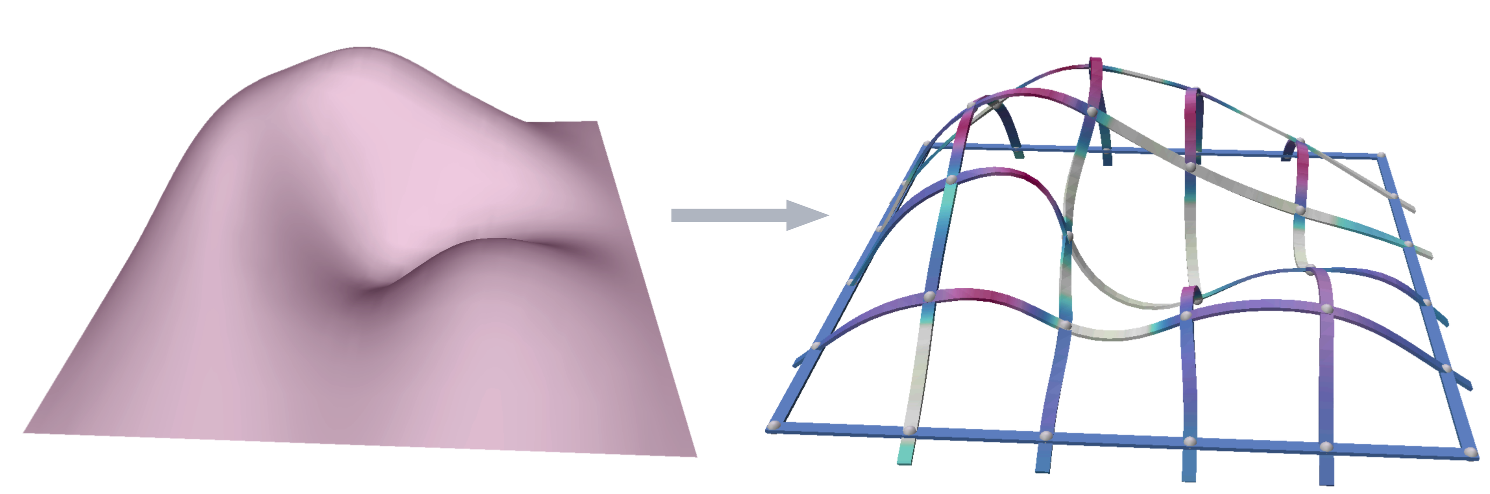
Our 1D line display exploits the bistability of elastic rods to create a variety of curves by changing actuation order.

Surface Display Model

Elastic rods exhibit nonlinearity and multi-stability, which makes them difficult to model analytically. We use the numerical discrete elastic rods method [3] to model the bending, twisting, and stretching of the flexible racks used in our systems. For the 2D system, we extend this technique with Eulerian-on-Lagrangian degrees of freedom [4] at the rod intersections, in order to model the passive sliding. We optimize over the model to a target surface.

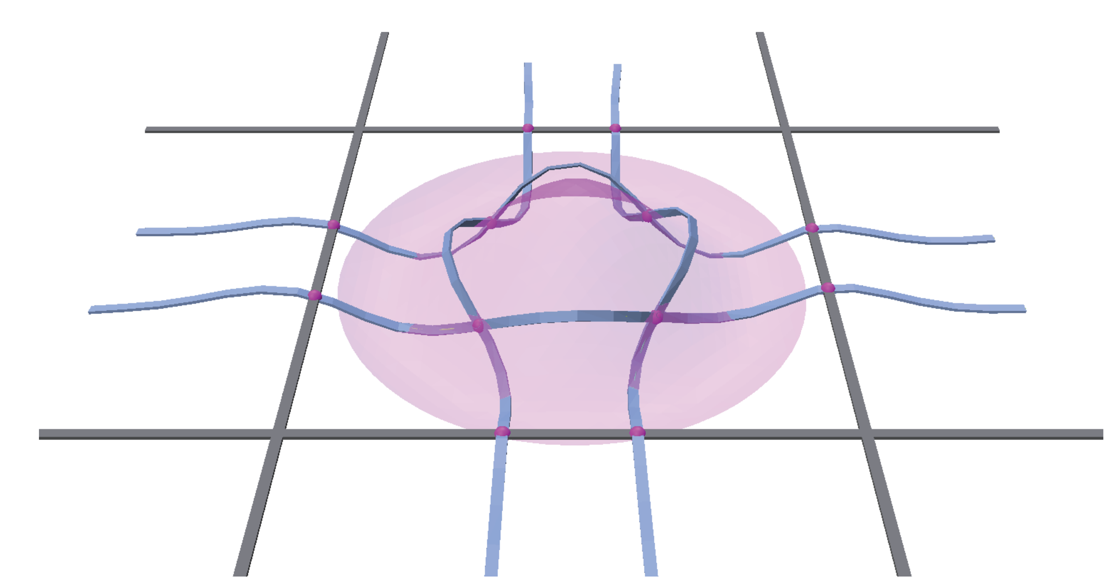


The rod centerlines are discretized and adapted frames keep track of bending and twisting. Material coordinates and interpolated normals represent passive intersections.



Future Work

We hypothesize that multi-robot systems can exploit the elasticity of materials to create large shape match with sparse actuation. However, a large challenge for this system is controls because of the high-dimensionality of the system and the non-convexity of the energy landscape. We plan to use a Model Predictive Control solution to deploy shapes on the system, and optimize control in the same step as the model solve to avoid bilevel optimization. We also plan to add more nodes to increase the resolution of the 2D device.



This shows a control simulation trying to approximate a target shape (in purple), but overshooting.

References

[1] S. Follmer et al., “inFORM: dynamic physical affordances and constraints through shape and object actuation,” UIST 2013. pp. 417–426.
[2] W. Law et al. “A Multi-Stable Curved Line Shape Display.” ICRA 2024.
[3] M. Bergou et al., “Discrete viscous threads,” ACM Trans. Graph., vol. 29, no. 4, pp. 1–10, Jul. 2010.
[4] S. Sueda et al. “Large-Scale Dynamic Simulation of Highly Constrained Strands.” ACM SIGGRAPH 2011 Papers, 1–10.
[5] “1938 Talbot-Lago T150-C Speciale Teardrop Coupe 5” by Jack Snell is licensed under CC BY 2.0. Background removed and image overlaid.

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