University of Stuttgart

Institute for Nonlinear Mechanics

Bachelor's thesis
Term paper
Master's thesis

PINNs for Cosserat Rod in Simulation and Control

Topic Areas:	Multibody Dynamics Deep Learning and Control
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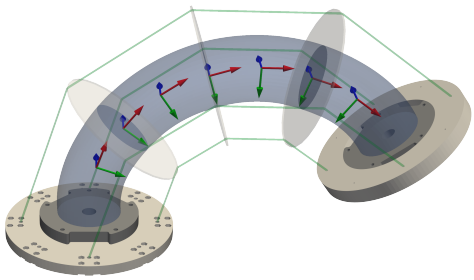
Prerequisites/Prior Knowledge:	Basic courses in dynamics and programming skill

Tendon-Driven Continuum Robots (TDCRs) are a prominent research area in soft robotics. Due to their slender and flexible structure, TDCRs are typically modeled using the Cosserat rod theory. Within this framework, various strain-based modeling approaches have been proposed, such as piecewise constant curvature and piecewise linear strain models.

At our institute, we take a different approach: rod models with spatial discretization, equivalent to the one-dimensional finite element method (1D FEM), which offers increased flexibility and accuracy over traditional models. However, 1D FEM is often not computationally efficient enough for real-time model-based tasks such as state estimation and tracking control. To address this limitation, we explore the use of physics-informed neural networks (PINNs) to improve computational efficiency while maintaining physical accuracy.



Tendon driven continuum robot model

In this project, you will begin by thoroughly familiarizing yourself with our current 1D FEM Cosserat rod implementation. The project will then proceed through the following stages:

1. Validate a polynomial ansatz to characterize the static input-output behavior, specifically the mapping from tendon forces to the rod's tip position.
2. Develop a PINN to approximate this input-output relationship, and explore their use for inverse mapping.
3. Use the trained PINNs to provide tip position control.
4. Extend the PINN to dynamic systems, such as rods with attached payloads.

As an additional exploration, you can also consider robot design variations, such as rods with non-constant cross-sectional areas, to achieve specific functional behaviors.

Literatur

[1] Grube, Drücker & Seifried. Open Loop Dynamic Trajectory Tracking Control of a Soft Robot using Learned Inverse Kinematics combined with a Dynamic Model. *2024 European Control Conference (ECC)*, 2024.

[2] Liu, Borja & Della Santina. Physics-Informed Neural Networks to Model and Control Robots: A Theoretical and Experimental Investigation. *Advanced Intelligent Systems*, 2024.