ECE228 Project Proposal: Physics-Informed Neural Networks for Soft Robot Kinematics

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1 Problem Background & Motivation

Soft robots offer advantages in adaptability and safety due to their compliant structures. However, accurately modeling their kinematics is challenging because of their nonlinear deformations and complex material properties. Traditional modeling approaches often struggle to capture these dynamics, especially when dealing with diverse actuation mechanisms like pneumatic and tendon-driven systems. Developing models that can generalize across different actuation types is crucial for advancing control strategies and real-world applications of soft robotics.

2 Related Works

The dataset titled *Positional Data of Soft Robots with Diverse Actuation Types* provides positional data for three types of soft robots: simulated pneumatic, simulated tendon-driven, and real-world tendon-driven robots [Barakat, 2025]. This dataset is designed to aid in developing machine learning models for learning the kinematics of soft robots with various actuation types.

Recent studies have explored the use of physics-informed neural networks (PINNs) to model the complex deformations of soft robotic systems. For instance, the PINN-Ray model integrates the principles of elastic mechanics into the neural network's loss function to accurately predict the behavior of Fin Ray soft robotic grippers [Wang et al., 2024]. Additionally, research has demonstrated the application of PINNs in modeling and controlling complex robotic systems, highlighting their potential in handling non-conservative effects and improving control performance [Liu et al., 2023].

3 High-Level Methodology

Our project aims to develop physics-informed neural network models that can accurately predict the kinematics of soft robots with diverse actuation mechanisms. The approach involves:

- Utilizing the provided dataset to train PINNs that incorporate physical laws governing soft robot behavior.
- Designing neural network architectures that embed the minimum potential energy principle from elastic mechanics into their loss functions.
- Evaluating the models' performance in predicting positional data for both interpolation and extrapolation scenarios.
- Comparing the effectiveness of PINNs against traditional data-driven models in terms of accuracy and generalization capabilities.

Through this methodology, we aim to demonstrate the advantages of integrating physical principles into neural network models for soft robot kinematics.

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References

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