



Ph.D. DISSERTATION DEFENSE

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Degree: Doctor of Philosophy
School: Charles V. Schafer School of Engineering and Science (SES)
Department: Mechanical Engineering
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Title: Stochastic Estimation of Shape and External Wrench for Continuum Robots

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ABSTRACT

Continuum robots are slender, flexible robotic systems that can safely navigate confined and delicate environments, making them promising for applications such as minimally invasive surgery, inspection, and manipulation in constrained spaces. However, their compliance and continuously deformable structure make it difficult to accurately estimate robot shape and interaction forces in real time, which remains a major challenge for sensing, modeling, and control.

This dissertation develops stochastic estimation frameworks for shape and external wrench inference in continuum robots. A compact reduced-order representation is employed to describe robot deformation in a tractable state space, enabling estimation using limited sensing information while maintaining computational efficiency. Building on this framework, the dissertation first presents a stochastic shape estimation approach that accounts for modeling uncertainty and measurement noise. It then introduces an integrated shape-force estimation framework that combines polynomial curvature kinematics with a virtual-work-based formulation to infer external loads from estimated deformation states. Finally, the dissertation investigates stochastic estimation strategies for coupled shape and wrench inference in spatial continuum robots using sparse sensing modalities. Through simulation and experimental studies on cable-driven continuum robotic systems, this work demonstrates that the proposed methods can provide accurate, computationally efficient, and practically deployable estimates of robot shape and interaction loads without requiring dense external measurement systems. The results contribute estimation methodologies for continuum robotics and support the development of more reliable sensing and control strategies for flexible robotic devices operating in uncertain environments.