Mechanical Engineering Doctoral Defense

Dynamic Modeling, Robust Control and Contact Estimation of Soft Robotics

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Abstract

"Soft robotics has garnered attention for its substantial prospective in various domains, such as manipulation and interactions with humans, by offering competitive advantages against rigid robotic systems, including inherent compliance and variable stiffness.

Despite these benefits, their theoretically infinite degrees of freedom and prominent nonlinearities pose significant challenges in developing dynamic models and directing the robots along desired paths. Additionally, soft robots may exhibit rigid robot-like behavior and potentially collide with their surroundings during path tracking task, particularly when possible contact points are unknown. In this research, reduced-order models are used to describe the behaviors of three varied soft robot designs, introducing both linear parameter varying (LPV) and augmented rigid robot (ARR) models.

While the reduced-order model comprehensively captures the majority of the soft robot's dynamics, modeling uncertainties remain notably non-negligible. Non-repeated modeling uncertainties are addressed by categorizing them as a lumped disturbance, employing two methodologies, H-infinity method and nonlinear disturbance observer (NDOB) based sliding mode control, for its rejection. The H-infinity method is designed for a second order LPV model using a linear matrix inequality (LMI) while the NDOB method is applied to both a 4-link ARR model.

For repeated disturbances, we implement an iterative learning control (ILC) with a P-type learning function to enhance trajectory tracking efficacy.

Furthermore, the NDOB facilitates the contact estimation, and its results are jointly used with a switching algorithm to modify the robot trajectories. The stability proof of all controllers and corresponding simulation and experimental results are provided. In essence, this study tackles modeling uncertainties in soft robots, enhancing tracking performance in tasks with rich contacts."

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