# Mechanical Engineering Doctoral Defense

## Sensing, Modeling, Control and Evaluation of Soft Robots for Wearable Applications

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## Abstract

While wearable soft robots have successfully addressed inherent design limitations faced by wearable rigid robots, they possess a unique set of challenges due to their soft and compliant nature. Some of these challenges are present in the sensing, modeling, control and evaluation of wearable soft robots. Machine learning algorithms have shown promising results for sensor fusion with wearable robots, however, they require extensive data for training and retraining models for different users and experimental conditions. Modeling soft sensors and actuators require characterizing non-linearity and hysteresis, which complicates deriving an analytical model. Experimental characterization can capture the characteristics of non-linearity and hysteresis but requires developing a synthesized model for real-time control. Controllers for wearable soft robots must be robust to compensate for unknown disturbances that arise from the soft robot and its interaction with the user. Since developing dynamic models for soft robots is complex, inaccuracies that arise from the unmodeled dynamics lead to significant disturbances that the controller needs to compensate for. In addition, obtaining a physical model of the human-robot interaction is complex due to unknown human dynamics during walking. Finally, the performance of soft robots for wearable applications requires extensive experimental evaluation to analyze the benefits for the user.

To address these challenges, this dissertation focuses on the sensing, modeling, control and evaluation of soft robots for wearable applications. This work introduces a model-based sensor fusion algorithm that improves the estimation of human joint kinematics, with a soft flexible robot that requires compact and light-weight sensors. To overcome limitations with rigid sensors, an inflatable soft haptic sensor is developed to facilitate mutual gait sensing and haptic feedback. Through experimental characterization, a mathematical model is derived to quantify the user's ground reaction forces and the delivered haptic force. Furthermore, this research optimizes user interaction with wearable soft robots by employing a reinforcement learning controller for real-time optimization of walking performance with an inflatable soft exosuit. The performance of a wearable soft exosuit in assisting human users during lifting tasks is evaluated, and the benefits obtained from the soft robot assistance are analyzed.

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Zoom Link: https://asu.zoom.us/j/82563472886