CAREER: Morphological Computation for Resilient Dynamic Locomotion of Compliant Legged Robots with Application to Precision Agriculture

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Motivation

- Unprecedented challenges to meet the growing global demand for food (e.g., climate change, global population growth, aging and shrinking agricultural workforce, etc.)
- Agrobotics technology can improve input (e.g., water) utilization through proximal sensing and physical sampling
- Legged robots' mobility and adaptability may create new avenues to interact physically with crops

Goal

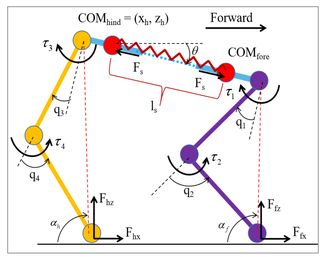
- Investigate how compliance embedded in legged robots can be harnessed to facilitate control and computation for efficient and resilient field navigation

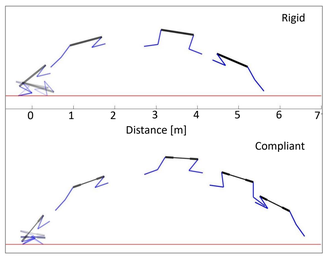
Objectives

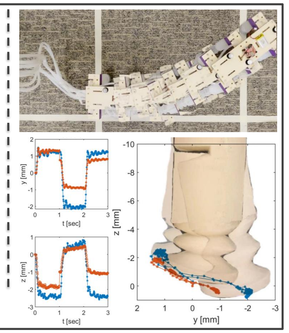
- Investigation of effect of various forms of compliance on center of mass motion and gait stabilization for certain classes of legged robots
- Introduction of new hardware designs that can harness compliance and enable principles of morphological computation
- Development of compliance-aware legged locomotion controllers according to principles of whole-body and central pattern generator-based
- Development of non-holonomic motion planners based on robot body morphology and embedded compliance for efficiency and resilience

Significant Results

- Modeling and trajectory optimization for quadrupeds with spinal compliance to improve standing jump performance
  - Elastic model for a prismatic robotic spine that is actively preloaded and mechanically lock-enabled at initial and maximum length
  - Constrained trajectory optimization to co-optimize the elastic parameters and motion trajectories toward enhanced jumping distance
  - Less stiff springs can improve jumping performance by unleashing more motor power while trading-off overall energy efficiency
- A closed-loop trajectory tracking control scheme based on pneumatic feedback for soft legged robots
- Additional results: Pneumatic circuits with memory to reduce number of valves; and Learning-based models via Koopman operator theory for soft robotics







Educational Activities

- School-wide robotics makerspace (ongoing)
- Robotics summer camp for middle school students
  - First offered in July 2021
  - Repeats July 2022

Broader Impacts

- Theory and practice of harnessing compliance to improve efficiency of locomotion and resilience to perturbations
- Contributions to hardware design and dynamic modeling, locomotion control, and non-holonomic motion planning and autonomous navigation
- Supporting legged robots' use in precision agriculture

Products

- K. Ye and K. Karydis, "Modeling and Trajectory Optimization for Standing Long Jumping of a Quadruped with A Preloaded Elastic Prismatic Spine," IEEE/RSJ IROS 2021.
- Z. Liu and K. Karydis, "Position Control and Variable-Height Trajectory Tracking of a Soft Pneumatic Legged Robot," IEEE/RSJ IROS 2021.
- S. Hoang, K. Karydis, P. Brisk, and W. H Grover, "A Pneumatic Random-access Memory for Controlling Soft Robots," PloS one 2021.
- L. Shi and K. Karydis, "ACD-EDMD: Analytical Construction for Dictionaries of Lifting Functions in Koopman Operator-based Nonlinear Robotic Systems," IEEE RAL + ICRA 2021.

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