NRI: INT: Soft Multi-Arm Robot (SMART) for Synergistic Collaborations with Humans

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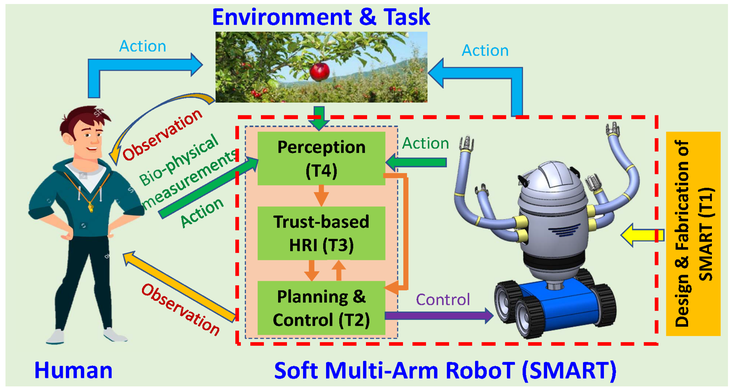
Project Objectives



- Design and fabrication of soft multi-arm robots capable of dexterous manipulation
- Motion planning and control of soft multi-arm robots
- Trust-based human-robot interaction for efficient cooperative manipulations
- Environment and human motion perception
- System demonstration and evaluation in the apple harvesting application

Scientific Impact

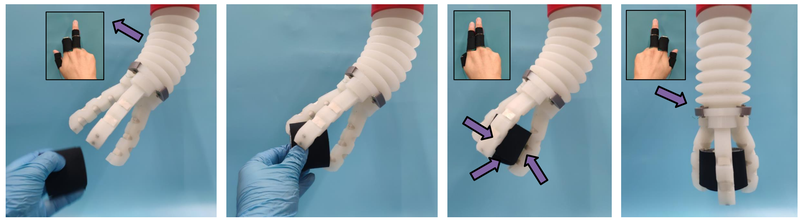
- Advance key design principles for soft robots that address joint optimization and control of actuation and stiffness-tuning
- Provide solutions to the daunting problem of motion planning and control for multiple soft robotic arms operating in dynamic environments
- Develop a trust-aware human-robot collaboration scheme that explicitly exploits the evolving human-robot trust to design the robot control policy
- Develop a multi-sensor fusion framework for efficient and robust perception of complex environment and human motion

Education and Outreach

- Undergraduate research on soft robot development, motion planning and control, HRI, and computer vision
- Demos of soft multi-arm robots at various outreach events
- Disseminate research to the agriculture and robotics industry

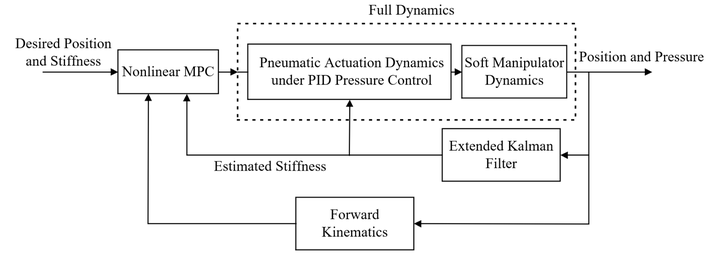
Development of Soft Robotic Manipulators

Soft gripper and soft robotic arm with tunable stiffness

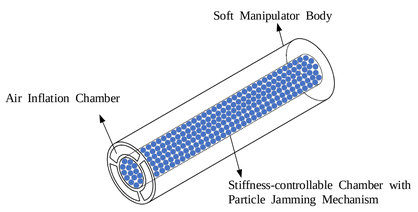


- Designed and prototyped a soft robotic gripper for dexterous grasping of objects with different shapes and weights
- Designed and prototyped a soft robotic arm capable of stiffness varying and omnidirectional bending in 3D space
- Developed a modular design and method for a multi-segment soft robotic arm
- Developed a new actuation method by combining the cable actuation and the pneumatic actuation for rapid actuation and self-weight reduction.

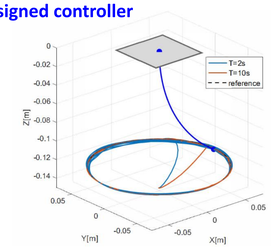
Soft Robot Control Algorithm



Block scheme of the designed controller



The soft manipulator with stiffness-tunable core

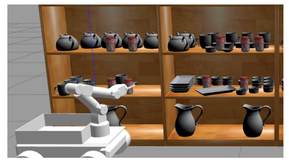


Tracking result in the task space

- Extended a Lagrangian-based dynamic model with the stiffness-tuning mechanism for the soft manipulator
- Developed a nonlinear model predictive control (NMPC) framework to control the motion and stiffness simultaneously in the configuration space and the task space
- Validated the efficacy of the proposed model and controller with simulation, showing the average error of 0.001m when tracking one circular trajectory.

Trust-based Human Robot Interaction

3D Virtual environment



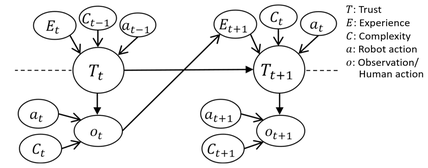
Optimal Trust-aware policy

$$\begin{cases} \text{seek assistance}, & \text{if } C_t = \text{high, and} \\ & \mathbb{P}(T_t = \text{high}) < 0.75, \\ \text{collect autonomously}, & \text{otherwise.} \end{cases}$$

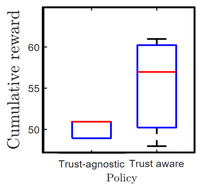
Optimal Trust-agnostic policy

$$\begin{cases} \text{seek assistance}, & \text{if } C_t = \text{high}, \\ \text{collect autonomously}, & \text{otherwise.} \end{cases}$$

Trust-based Human Behavioral Model

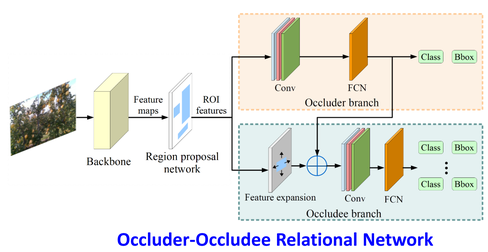


Team Performance

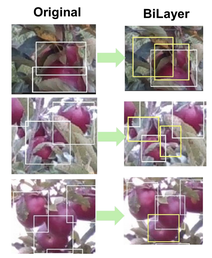


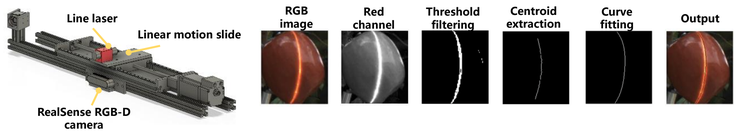
- Human supervises a robot tasked with picking objects
- Current work focused on how the complexity of the scene and assistance-seeking by the robot affect human trust
- Input-Output Hidden Markov Model for human behavior
- Estimated model suggests that trust may increase when the robot asks for assistance in high complexity scenes
- Optimal policy is a threshold-based in high complexity scenes
- Trust-Aware policy outperformed Trust-Agnostic policy

Perception for Apple Picking Application



Occluder-Occludee Relational Network





- Collected a comprehensive orchard dataset with multiple apple varieties and varying lighting conditions
- Developed an Occluder-Occludee Relational Network to improve detection of cases with occlusion scenes, achieving 0.96 accuracy and 0.88 F-1 score
- Developed a novel active laser scanning localization scheme with <6mm error, working indoors and outdoors
- Successful field demonstration with >80% fruit picking rate

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