Graduate Research Plan Statement

1 Introduction/Motivation

Robots revolutionized the manufacturing industry 30 years ago, but they have yet to truly transform our personal lives. Imagine a robot that could gently help a disabled person into their wheelchair, lift a survivor to safety in a disaster scenario, or even work alongside an astronaut in space. Industrial robots, though highly precise and capable, have a relatively high inertia which severely limits how quickly and safely they can move when operating in close proximity to humans to avoid unexpected collisions and high impact forces.[1] Development of soft, lightweight robots that are inherently safe around humans will enable robots to play a much more personal role in our lives without breaking themselves or harming humans. They will play a major beneficial role in assisted living, rehabilitation, search and rescue, space exploration, and many other applications limited only by the imagination. In short, these robots have the potential to revolutionize our personal lives.

Figure 1: Soft robot developed by Pneubotics

I recently began my graduate studies at Brigham Young University in the Robotics and Dynamics (RaD) Lab. My research is focused on coordinated, multi-arm manipulation using inflatable, pneumatically actuated (soft) robots like the one in *Figure 1.*

2 Background

Many everyday tasks such as opening a bottle to give medicine to someone with a disability, lifting heavy and bulky objects, or completing household chores are difficult with only one arm. This problem has sparked research into dual arm manipulation. One difficulty in this field with traditional robots is that small deviations in end effector position or orientation from either arm while holding a rigid object can result in large stresses on both the object and internally on the arm. To compensate, many researchers have proposed hybrid force/position control schemes.[2] Coordinated control of multiple traditional arms becomes even more challenging because of the need to coordinate high bandwidth centralized controllers.

An alternative and novel approach is to mitigate buildup of high internal forces by using a robot with flexible links and joints. Soft robots are inherently compliant, so they lend themselves nicely to tasks involving several arms. Even tasks with one rigid arm and multiple soft arms become simpler. Therefore, one of the major concerns with successful implementation of coordinated, dual arm manipulation is eliminated. On the other hand, compliant links and joints introduce new challenges (addressed below) into the control paradigm.

3 Hypothesis

I propose that multi-arm manipulation can realistically (and usefully) be implemented with an inflatable, pneumatically actuated robot. My goal is to implement control for (1) impact tasks with rigid objects and (2) soft object manipulation tasks. Here are the underlying questions to address:

- A key challenge with soft robots is repeatability. The fabric does not fold on itself the same way with each movement and the bladders often reseat themselves, so the dynamics of the arm change regularly. What type of control scheme will result in the highest task space repeatability?
- Some tasks require more stiffness than a single soft arm has. I propose that such tasks could become more feasible by grasping one arm with the other (increasing the rigidity by forming a closed kinematic chain). This type of task would not be feasible with a rigid robot. How will the control scheme need to be altered to accurately control this system?

4 Research Plan

Manipulability Improvement: After spending the last year in the RaD Lab, I am familiar with the challenges of accurately controlling soft robots. Recent design changes have left the robot in *Figure 1* with only four degrees of freedom per arm. To perform multi-arm manipulation tasks, each end effector needs to accurately be controllable in six degrees of freedom. I have already enlisted the help of two interested undergraduate students to help add at least two additional degrees of freedom to improve manipulability. Another researcher in the RaD lab recently submitted a paper to ICRA 2017 on rigorous design optimization of soft robots. I will build on this work in selecting which degrees of freedom to add and how they should be mounted.

Hybrid Controller Development: Task space accuracy and repeatability are affected by dynamic and kinematic model error (it is difficult to get accurate Denavit-Hartenberg parameters for the robot in *Figure 1*). Previous researchers in the RaD Lab have designed a model predictive controller that can accurately command a single arm in joint space.[3] I will use inverse kinematics to compute desired joint angles for this controller; however, this control method alone will not result in accurate task space positions and orientations. My first approach to this problem will be to create a hybrid controller using the RaD Lab's high-precision motion capture system for servoing to close the task space position error and improve repeatability. A more mobile solution will incorporate an HTC Vive virtual reality system with sub millimeter tracking accuracy. This system tracks targets which, when attached to the end effectors, should provide task space position/orientation feedback. I will approach multi-arm manipulation by designing and implementing an object level controller with each arm acting as force/torque inputs.

Closed Kinematic Chain Modeling: To address my second research question, I will begin by modelling the gripping of one arm by the other as a closed kinematic chain. This then becomes a control problem for a single kinematic chain with two additional tuning parameters (the stiffness of the gripping arm and the gripping location) which can be optimized for a given task.

5 Broader Impacts of Proposed Research

Soft robots with multi-arm manipulation capabilities will play a major role in assisted living, stroke rehabilitation, search and rescue, and even space applications (the robot in *Figure 1* is an order of magnitude lighter than Robonaut 2). I will make my work publicly available as open source code, enabling other researchers to build on what I learn. In order to ensure dissemination of our results, I will submit my research to multiple robotics conferences and journals.

Additionally, I will focus on helping young students get excited about engineering. I have already reached hundreds of students through participation in multiple lab outreach opportunities (such as the Utah STEM fest and several open lab demonstrations) as a part of the RaD Lab. I will be continuing this outreach pattern by giving monthly hands-on robotic demonstrations in RaD Lab open houses and at local elementary, middle and high schools. For many students – especially those from a disadvantaged background – these interactions with my research will motivate a desire to pursue a STEM education. In keeping with the RaD Lab's culture, I will involve multiple undergraduate students in my research. Participating in research and writing a conference paper during my undergraduate studies inspired me to pursue a graduate degree. I hope to similarly inspire other students.

[1] Haddadin, S., Albu-Schäffer, A., & Hirzinger, G. (2010). Safe physical human-robot interaction: measurements, analysis and new insights. In Robotics research (pp. 395-407). Springer Berlin Heidelberg.

[2] Sakaino, S., Sato, T., & Ohnishi, K. (2011). Precise position/force hybrid control with modal mass decoupling and bilateral communication between different structures. IEEE Trans. on Industrial Informatics, 7(2), 266-276.

[3] Best, C. M., et al. (2016). A New Soft Robot Control Method: Using Model Predictive Control for a Pneumatically Actuated Humanoid. IEEE Robotics & Automation Magazine, 23(3), 75-84.