AA 228 Final Project Proposal

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1 Introduction

Standard serial robotic manipulators (Fig. 1) have been the subject of considerable study over the past three decades, and the control of such systems in known environments is effectively a solved problem. Recently, soft, flexible manipulators and robotic arms have seen a resurgence in popularity. These systems, for which trajectory planning and control are difficult, offer safer operation near humans and are generally more robust to variable and hazardous environments [1].

For a given manipulator, the workspace is defined as the space $W \subseteq \mathbb{R}^3 \times SO(3)$ in which a robotic system can maintain static equilibrium [2]. A reachable state s_f is a state which, for a finite period of time $[0, T]$, $s(T) = s_f$, given $s(0) = s_0$. All poses in a fully-connected workspace W are reachable for an initial pose within that workspace. We will define the space S as consisting of all reachable poses, such that $W \subseteq S \subseteq \mathbb{R}^3 \times SO(3)$.

Figure 1: A rigid serial manipulator.

Figure 2: Soft actuator moving along the workspace [3].

2 Objective

For a perfectly rigid manipulator, the reachable space $S = W$. However, for a flexible manipulator, the dynamics of the system allow for a larger reachable space $S \supset W$. Typically, the flexibility of manipulators is minimized to simplify planning and control. In this work, we aim to use the flexibility of a pneumatically actuated, soft robotic manipulator to reach predefined poses that would normally inaccessible. Given some initial pose $x_0 \in W$, we aim to reach a pose outside the static workspace $x_f \in S - W$.

The manipulator system is a 1 DoF soft manipulator whose end position is governed by varying the pressure gradient of a pneumatic fluid (air) on both sides of the arm (Fig. 2). For example if the arm is actuated to have higher pressure on the left than the right, the arm will curve to the right. As the pressure differential is changed the end effector will trace out an arc [4]. This arc is the workspace W. We propose a method to achieve an arbitrary pose via a precise series of pressure differentials that leverage the compressibility of the pneumatic fluid. Fundamentally, this relies on using the momentum of the manipulator to swing out of the static workspace.

3 Approach

For a non-redundant serial manipulator, the state space has $2n$ degrees of freedom, where n is the number of joints. For a continuum manipulator, the state space describing the manipulator is infinite. Equivalently, the flexible manipulator has infinite degrees of freedom. As such, any representation of the system that captures the full dynamics requires discretization of the manipulator. We can approximately model the system as consisting of k linkages, each of which have simple curvatures. Each simple linkage has the same pressure differential acting on it, however, the bending moment on each link varies due to inertial effects. This discretized representation of the state of the continuum manipulator leads to a non-deterministic transition function between states.

In order to apply the POMDP framework we first express the parameters of our model as a *belief* with some probability distribution [5]. Additionally, we can describe the state space as grid world with positive rewards along the path or at the end state and negative rewards for obstacles and boundaries. We also will penalize large control inputs, to minimize large spikes in the pressures applied. Upon generating a model and a simulator which policies can be tested upon, we will unitize existing POMDP solving frameworks such as *POMDP.jl*.

A simulated model of a continuum manipulator suffers from the same problem as the control model, in that the exact mechanics are difficult to describe. If the system described in this project is implemented, the training could be done on a real experimental platform. In this work, the simulation will be a far less coarse approximation of the continuum manipulator. Various models in the literature will be examined to determine the best representation. Time permitting we will examine the following extensions to our framework:

- Multiple actuated degrees of freedom
- Uncertainty in state observations
- Sudden rapid changes in plant dynamics (modeling damage)
- Complex environments

References

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