Merging Segments in Configuration Space for Soft Manipulator Planning

Scott Chow[1] and Geoffrey A. Hollinger[2]

The advantage of soft robotic manipulators comes from their flexibility and deformability, which allow them to maneuver through tight spaces inaccessible to rigid manipulators. However, these properties also cause planning algorithms to struggle because of the increased dimensionality of the search space. This work features a comparison of search-based and sampling-based planning for soft manipulators and examines reducing the complexity of the problem to make planning feasible for more complex soft manipulators.

I. Search-Based Planning

Previous work has used search-based planning algorithms for manipulation by discretizing the space using a set of motion primitives, which are small atomic actions that move one or more joints by a small amount. A graph was constructed using the motion primitives and Anytime Repairing A* was used to find the lowest cost path [1]. To adapt this algorithm for soft manipulators, we use motion primitives that change the curvature of the segments. We use the tip travel distance as a cost function to minimize. For a heuristic, the shortest distance from each voxel to the goal is precomputed, which provides a lower bound on the cost.

II. Segment Merging Approach

We model the segments of the arm using the piecewise constant curvature model [2]. To reduce the dimensionality of the planning problem, we merge the segments in configuration space. This is accomplished by actuating the segments together such that they always have the same curvature. Thus, we treat the two segments as a single longer segment.

The key to this approach is determining which segments to merge. We merge segments by examining the environment and merging segments that are far any obstacles. This leads to an idea of dynamically merging and unmerging segments during execution rather than fully evaluating a merged configuration before switching configurations. Additionally, we can leverage the precomputed shortest distances used in the heuristic to determine feasibility and the number of segments to begin the algorithm with. If the shortest path from the base of the link to the goal position is longer than the arm, then there is no feasible path for the arm. By examining the number of places on the shortest path that deviate from the direct path, we can estimate the number of segments that may be necessary.

[1]chows@oregonstate.edu, [2]geoff.hollinger@oregonstate.edu
Both authors are part of the Collaborative Robotics and Intelligent Systems (CoRIS) Institute, Oregon State University

By planning for a merged arm, we consider a smaller space and thus decrease the planning time. We use an anytime approach that iteratively runs the search-based planning algorithm with increasing numbers of segments. While the initial solution found by the algorithm is valid, it is not guaranteed to be optimal because the optimal solution may require the independent actuation of every segment. Thus, the algorithm reports an initial solution quickly, then continues searching the space while unmerging segments. Since the algorithm converges to running the search-based planning algorithm on the full arm, it retains the properties of resolution completeness and optimality.

III. Results and Discussion

Initial results demonstrate the limitations of scaling both search-based planning with motion primitives and sampling-based planners to soft arms of six or more segments, even in relatively uncluttered environments. We will perform additional experiments using segment merging with search-based planning and measure planning time and solution cost. We anticipate segment merging will reduce the time to first solution for search-based planning in less confined spaces where all segments do not need to actuate independently. This work will make planning algorithms feasible for soft manipulators with large numbers of segments.

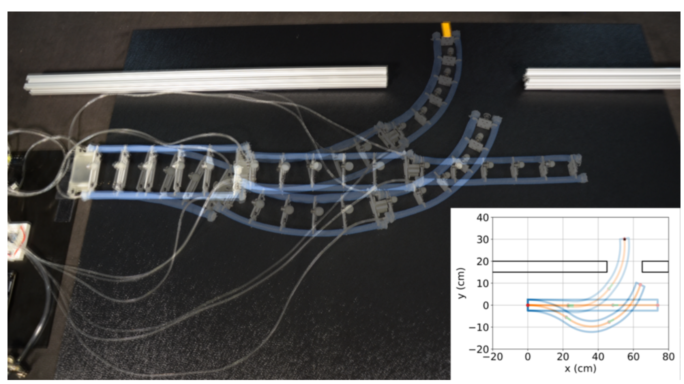

Fig. 1. A three-segment soft manipulator executing a plan. Bottom right shows the plan in a simulation environment.

References

[1] Benjamin J Cohen, Gokul Subramania, Sachin Chitta, and Maxim Likhachev. Planning for manipulation with adaptive motion primitives. In *ICRA*, pages 5478–5485. IEEE, 2011.

[2] Bryan A Jones and Ian D Walker. Practical kinematics for real-time implementation of continuum robots. *IEEE Transactions on Robotics*, 22(6):1087–1099, 2006.