Manipulation Algorithms Project Proposal
Trajectory Retiming for Manipulation Planning

ARJUN MENON
Carnegie Mellon University

1 Problem

This project is to design a motion planner that accounts for kinodynamic constraints and moving obstacles. The project aims to circumvent the curse of dimensionality in the kinodynamic configuration-space, $\mathbb{C}_d$, for search-based planners through adaptation of Bobrow's trajectory retiming algorithm [1].

2 Approach

2.1 Kinodynamic Constraints

Since planning in the kinematic configuration-space, $\mathbb{C}$, and consequently retiming the trajectory for dynamics is not a complete approach, the project will leverage previous work that allows us to efficiently assess whether a given path in $\mathbb{C}$ can be traversed with respect to the kinodynamic constraints [2]. By propogating the velocity intervals (the set of valid velocities) for a given waypoint in $\mathbb{C}$, the proposed planner is able to ensure that a valid retiming exists for a plan, that respects the kinodynamic constraints.

2.2 Moving Obstacles

Dealing with moving obstacles may create inadmissible islands to retimings below the maximum-velocity curve of Bobrow's algorithm [3]. Literature survey currently does not turn up any method to path around these regions in the phase-plane, so the possible approaches the project will explore are:

- Graph-based search in the phase-plane using the velocity field over the phase plane as defining the motion primitives.
- Integrating the SIPP framework [4] with Bobrow's algorithm providing a way to compute the *safe* time-intervals of the states in traversals.
- Designing the switching point strategy for object collisions.

3 Motivation

A common theme among all of the common motion planning tasks for a robot arm is that the arm is manipulating objects in static environments. The manipulation of static objects is well researched and multiple approaches have been presented in the last decade that are fast and proven to be reliable. However, autonomous manipulation amidst dynamic environments poses new challenges to motion planning. Sampling-based planners do well in kinodynamic spaces [5], but search-based planners are intrinsically hamstringed by the high dimensional search-spaces. This project seeks to use Bobrow's algorithm as a means of dimensionality reduction, to enable tractable search-based kinodynamic motion planning.

4 Deliverables

Progress	**Deliverables**	**When**
50%	• Implement and test numerically robust Bobrow's Algorithm. • Visualize collision regions in the Phase-plane with moving obstacles. • Develop augmented $\mathbb{C}$-space planner with velocity interval propogation.	Oct-30
75%	Develop and implement a scheme mentioned in Section 2.2.	Nov-14
100%	• Develop naive approach using *VIP* and simple collision checking. • Create test scenarios. • Compare naive approach with approach from Section 2.2. • Analysis of planner variants.	Nov-28
125%	Try other approaches itemized in Section 2.2.	Stretch

References

1. James E Bobrow, Steven Dubowsky, and JS Gibson. Time-optimal control of robotic manipulators along specified paths. *The International Journal of Robotics Research*, 4(3):3–17, 1985.

2. Quang-Cuong Pham, Stéphane Caron, and Yoshihiko Nakamura. Kinodynamic planning in the configuration space via velocity interval propagation. In *Proceedings of Robotics: Science and Systems*, Berlin, Germany, June 2013.

3. Kang Shin and N McKay. Minimum-time control of robotic manipulators with geometric path constraints. *Automatic Control, IEEE Transactions on*, 30(6):531–541, 1985.

4. Mike Phillips and Maxim Likhachev. Sipp: Safe interval path planning for dynamic environments. In *Robotics and Automation (ICRA), 2011 IEEE International Conference on*, pages 5628–5635. IEEE, 2011.

5. Steven M LaValle and James J Kuffner. Randomized kinodynamic planning. *The International Journal of Robotics Research*, 20(5):378–400, 2001.