A Differential Dynamic Programming approach for Planning In-Hand Manipulation Tasks with Contact

AA203 Project Proposal

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1 Introduction

A key step towards executing complex multi-robot manipulation tasks is the ability to intelligently make and break contacts with an object, defined as contact switching. Humans rely on contact switching when performing any sort of manipulation task, particularly when working as a team. Our ability to effortlessly reposition fingers and hands allows us to obtain stable grasps on objects of different geometries and to adapt to constraints imposed by the environment or task. Similarly, teams of robots must also reason about when and how to make contact switches to efficiently carry large objects through cluttered environments.

Planning multi-robot manipulation tasks that involve contact switching presents many challenges. The large state space of robot manipulators and the long duration over which such tasks typically take place results in a high-dimensional planning problem. Finding the optimal solution, or even a feasible solution, to such a large problem requires long computation times. Collaborative manipulation systems must be able to plan in real-time to succeed in changing environments, which demands more efficient planning methods.

2 Relation to Current Research

Recently, Claire has been focusing her research on the manipulation with contact problem by looking at open loop planning methods outlined in [1] and [2]. In this class, our group hopes to support her research by looking at a similar problem setup using closed loop planning methods like Differential Dynamic Programming (DDP) to plan trajectories though a set of fixed contact points.

3 Project Summary

For this project, we will apply Differential Dynamic Programming (DDP) to the problem of multi-limbed manipulation, or in-hand manipulation. DDP has many advantages over other direct methods such as IPOPT or DIRCOL, especially due to their relative speed and low memory footprint. Although iterative methods like DDP have faced challenges in applicability to severely constrained problems, their performance on hardware has shown them to be much more applicable to real-time motion planning algorithms [3]. The critical drawback of DDP compared to direct methods is the difficulty of successfully modeling hard constraints such as contact forces within the algorithm. In order to apply DDP to traditional contact-implicit problems such as gait-handling or team lifting, many authors have turned to implicit hard constraints that are modeled within the cost function [4] or a hybrid approach that can handle potential contact switching [5]. For the purposes of this exploration, we will focus on the contact-implicit approach that uses pre-determined contact locations.

We will consider an in-hand manipulation scenario with the following dynamics:

- Object dynamics: $M_o\ddot{x} - G\lambda = g_{app}$, where G is the grasp matrix, that relates end-effect forces/velocities to contact point velocities relative to the object.
- Hand dynamics: $M_h(q)\ddot{q} + J^T\lambda = u(t)$, where J is the hand Jacobian, that relates joint torques/velocities to end-effector force and velocity.
- Contact point velocity constraint (we do not allow sliding): $J\dot{q} - G^T\dot{x} = 0$

For this scenario, we will model our contacts as point contacts with friction, which means we will need to deal with friction cone constraints. In the planar case, this constraint is: $\mu f_{normal} - |f_{tangent}| \geq 0$, where μ is the coefficient of friction, and $fnormal$ and $f_{tangent}$ are the normal and tangent components of the contact forces.

References

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