PhD Project: Planning of Accurate and Robust Trajectories for In-Hand Manipulation

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Abstract

Human-like in-hand manipulation of objects is one of the key challenges in robotics as it would reduce system complexity and programming time of robotics applications involving pick and place of objects. In this project, the focus is on planning in-hand manipulation of objects with known geometry. The planning will take place on a constrained subset of a high dimensional space. There are several challenges with this, including finding an efficient mathematical representation of this subset; establishing roadmaps using kinodynamic local planners; connecting the initial configuration to the roadmap. It is an important part of the project to ensure robustness of the derived trajectories to pose uncertainties.

Image of the shadow hand [3].

Introduction

Humans possess an extraordinary ability to manipulate various objects with their hands. They can fold cloth, tie shoelaces, and reposition a wide range of items in their hands, such as beads, pens, and screws. The list of tasks they can accomplish with their hands seems endless, due to their ability to adapt to all
sorts of objects. Such tasks remain challenging for robots. Thus, it is relevant to expand the research in this field. In this project, we will address this challenge of in-hand manipulation of objects with known geometry. To plan the motions, we cannot search for trajectories in the entire configuration space of a multi-fingered dexterous hand and an object since the dimensions of this space are too large. Therefore, we need to address:

1. How to reduce the number of dimensions in the search space and how to map the search space to the entire configuration space.
2. How to include the dynamical constraints in the search space.

As a dexterous hand has multiple fingers, we may gain information that is not attainable with only one finger (or one robot arm). We aim to use this information to ensure robustness towards pose uncertainties and include it in the search space.

Dimensionality Reduction

The initial idea is to describe the movements of the object relative to the hand in a space S with few dimensions, rather than considering the entire configuration space, C, for both the hand and the object. A mapping from C to S is necessary. Since C has higher dimensions than S, some information will be lost in this mapping. Some of this lost information may be represented as kinematic constraints that must be satisfied. We aim to identify one or more possibilities for space S and describe the necessary constraints for mapping from C to S. For simpler systems, where micro-manipulation is considered, some ideas on how to do this already exist [1], and they can serve as a starting point for our investigation into more complex systems.

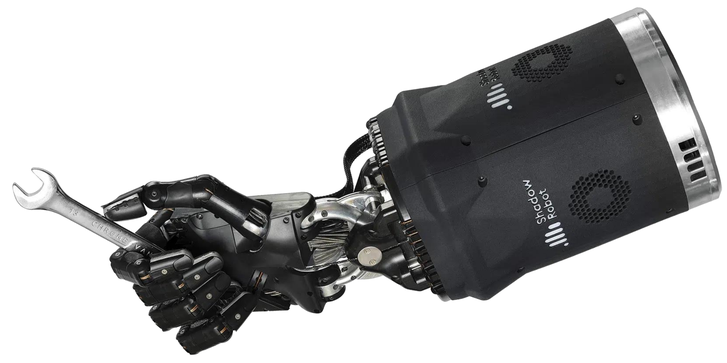

Image of the shadow hand [3].

Roadmaps and Kinodynamic Planners

In classical robotics, one of the ways to find a trajectory or path in a configuration space is to create roadmaps. Then, when given an initial and goal configuration, these are connected to the roadmap. We plan to replicate this idea to develop roadmaps for the search space S. There is a consensus that in-hand manipulation is changing the position and orientation of a grasped object in the hand [2]. Thus, the initial and goal conditions must describe how the object is held in the hand. Additionally, in practice, a system has physical characteristics that must be considered. If these are not taken into account, there will be no hope of achieving in-hand manipulation. Therefore, we must thoroughly understand which dynamic constraints need to be considered when manipulating an item and include them in the search. It means we need to consider both the kinematic and dynamic constraints and incorporate them into the roadmaps. In traditional robotics, when such constraints are part of the system, kinodynamic local planners can be used to establish the roadmap. We hope to resample this idea.

Methodology

We want to test the ideas that cannot be mathematically proven. To do this, we use a simulation tool called MuJoCo, where the Shadow hand [3] has already been modeled and is ready to be used. Using this simulation as a starting point, we will test if the ideas can be applied to the Shadow hand.

Conclusion

This project focuses on in-hand manipulation of objects with known geometries. Our goals include reducing the configuration space dimensions, which may introduce kinematic constraints. We will address dynamic constraints, and we plan to adapt classical robotics methods like roadmaps and kinodynamic local planners to plan motions. A multi-fingered hand may provide information that we can utilize to enhance robustness against pose uncertainties in in-hand manipulation tasks.

References

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