Planning In-Hand Manipulation: Dexterous Manipulation Graphs

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***Abstract*— This work focuses on dexterous manipulation of rigid objects by analyzing their shape to provide feasible in-hand motions. The object's shape analysis produces a graph that is used for planning the robot manipulator's movements for achieving a successful object repositioning.**

I. Introduction

In-hand manipulation consists in moving an object within the robot's end-effector without the need for releasing it.

When equipped with multi-fingered hands, a robot can exploit its several Degrees of Freedom (DOF) to move the object inside it [1]. Conversely, with simpler grippers solutions that exploits external supports to compensate for the lack of DOF allow the robot to successfully reposition an object without regrasp [2]. Both cases often rely on non trivial contact modeling between objects and fingers.

In our work, we focus on vision-based manipulation. We plan the motion of the object within the gripper as a sequence of rotations and translations. These two motion types are generated from a representation of the manipulation interaction as a Dexterous Manipulation Graph (DMG). This graph describes the possible motions of the gripper's fingertips on the object's surface.

II. In-Hand Manipulation Planning with a Graph

We use the DMG to plan in-hand manipulation with a parallel gripper.

A. Graph Generation

The DMG is generated by subdividing the object's surface into small areas. These areas represent parts of the object that can be in contact with the gripper's fingertip. The fingertip can move from one area to another, by rotating and translating, only if there is no gap or sharp edge in between. We refine the connectivity between adjacent areas by taking into account discrepancies in the surface normals and discontinuities in the orientation transitions (Fig. 1).

Once the connectivity is refined, we obtain the DMG. The DMG is a disconnected undirected graph $<N, E>$, in which a node $n \in N$ represents a point on the object surface and a continuous set of fingertip orientations; an edge $e \in E$ connects two nodes if it is possible for the fingertip to move from one to the other by rotating and translating.

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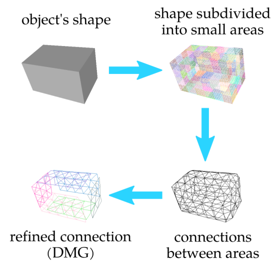

Fig. 1: The generation process of the Dexterous Manipulation Graph.

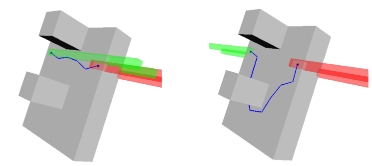

Fig. 2: Examples of paths (from red to green fingers positions); different orientations can produce different solutions.

B. In-Hand Motion Planning

Since the DMG contains several connected components, it can be used to determine if a solution exists to move the object withing the hand without releasing the grasp by verifying if the initial and the desired nodes are in the same connected component. If they are not, the DMG is used to suggest areas that are good for regrasping, and provides solutions in case the desired grasp is difficult to achieve and requires additional in-hand manipulation after the regrasp.

When it is possible to move the object inside the gripper without releasing the grasp, we find a solution that links the different nodes in the graph using Dijkstra's algorithm. This solution is a sequence of rotations and translations along the surface of the object (Fig. 2). During planning, particular attention must be taken to ensure that the plan is feasible for both of the gripper's fingers, because the DMG takes into account the motion of only one.

III. Conclusion

The DMG provides a solution for in-hand manipulation based on vision, without the need for modeling complex dynamic properties. In fact, the DMG depends only on the shape of the object and the fingers. However, the subsequent planning and execution will be specific to the used robot and gripper.

If the robot is dual arm, the execution of the in-hand rotations and translations can be achieved by exploiting the several DOF available. Otherwise, the robot has a single arm, it is possible to execute rotations and translations by exploiting external supports, such as pushing against a table.

References

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