Regrasping by Fixtureless Fixturing

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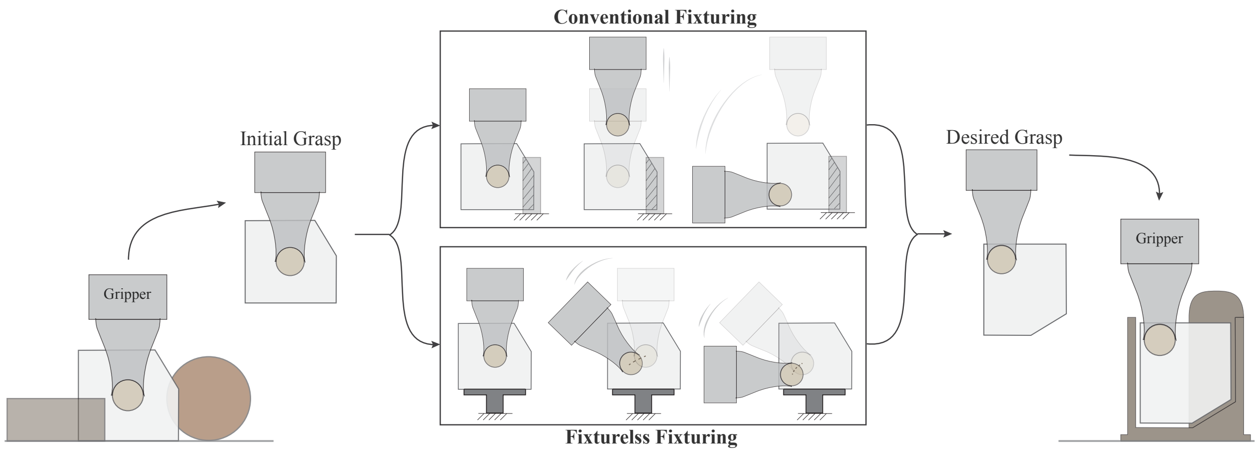

I. Introduction

The need for regrasp is ubiquitous in assembly operations. In-hand manipulation skills allow one to pick up a part, reorient it in the hand, and then use/insert/assemble it. Robots, especially those with parallel-jaw grippers, lack the dexterity to autonomously adjust the grasp on an object.

This paper presents an in-hand manipulation technique that allows a robot with a simple parallel-jaw gripper to regrasp an object in the gripper. The robot pushes the object against external contact/s in the environment such that the object sticks to the external contact while the fingers slide over the object. Since the object is held stationary in the environment without any fixtures, we call this approach *fixtureless fixturing*.

Fixtureless fixturing is a variant of prehensile pushing that is robust against uncertainties in the system parameters. Based on the mechanics of pushing, we define a subspace of robust prehensile pushes and refer to it as a *robust motion cone*. The robust motion cone can be computed as a linear image of the generalized friction cone [1] of the pusher contact. It is is invariant to all the system parameters listed above except friction at the external contact/s.

We present a sampling-based planning framework that uses robust motion cones to build long pushing strategies for regrasping. Exploiting the knowledge of the motion cones for dynamics propagation, the planner rapidly builds a tree of reachable grasps. A path is this tree is a pushing strategy, possibly involving pushes from different sides, to manipulate the object in the grasp as shown in Fig. 1.

II. Related Work

The work presented in this paper is motivated by our recent work on stable prehensile pushing [2]. In that work, we present a planner to regrasp an object in a gripper using the external pushes for which the object sticks to the pusher. To find feasible stable prehensile pushes, the planner evaluates a dynamics check for multiple random push directions. This dynamics check depends on the knowledge of the object inertia, grasping force, and coefficient of friction at the fingers and at the features in the environment. Consequently, the stable prehnsile pushing is sensitive to these parameters. In contrast, the fixtureless fixturing presented in this paper uses only the stable prehensile pushes whose dynamics is invariant to these parameters except for the friction at the features in the environment. Moreover, the knowledge of the motion cones avoids the need of dynamics check and speeds up the regrasp planning.

The idea of robust motion cones is inspired by the original concept of the motion cone presented by Mason [3]. Mason studies the mechanics of pushing a planar object on a horizontal plane with a point pusher. He proposes the *motion cone* as a set of pushes that lead to sticking contact between the pusher and the object. Our recent work [4] extends the idea of motion cones to prehensile tasks in a more general setting and demonstrates their application for fast in-hand manipulation planning. The application of robust motion cones for regrasp planning brings robustness to in-hand manipulation planning.

III. Regrasping via Robust Motion Cones

We propose a manipulation planning framework that is compatible with several of the practical implementations for the prehensile pushes. We consider that an object is grasped in a gripper that is fixed in the world. A moving pusher pushes the object to a new pose in the grasp. In our implementation, the pusher motion is a reflection of the

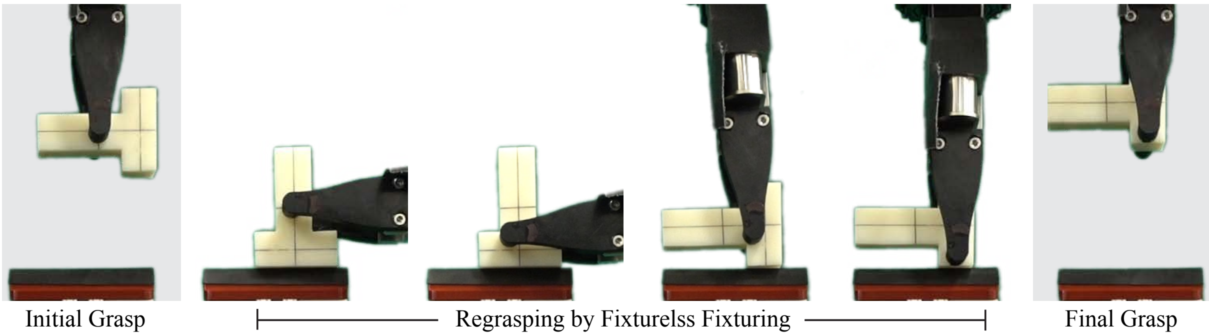

Fig. 1. An example of regrasping using fixtureless fixturing. A T-shaped object is regrasped in a gripper by pushing it against an edge contact in the environment. Note that during the regrasp process, the object sticks to the environment while the fingers slide on it.

Algorithm 1 : Regrasp Planner

input : q_{init}, q_{goal}
output : tree $\mathcal{T}$

$\mathcal{T} \leftarrow$ initialize tree(q_{init})
generate_robustCones($\mathcal{T}, q_{init}$)
while $q_{goal} \notin \mathcal{T}$ **or** cost(q_{goal}) > cost threshold **do**
  $q_{rand} \leftarrow$ sample random configuration($\mathcal{C}$)
  $q_{parent} \leftarrow$ find nearest neighbor($\mathcal{T}, q_{rand}$)
  $q_{sample} \leftarrow$ take unit step(q_{parent}, q_{rand})
  if $q_{sample} \notin \mathcal{T}$ **then**
    if transition test($q_{parent}, q_{sample}, \mathcal{T}$) **then**
      $q_{new} \leftarrow$ robust_push(q_{parent}, q_{sample})
      if transition test($q_{parent}, q_{new}, \mathcal{T}$) **and**
       grasp maintained(q_{new}) **then**
        $q*_{parent} \leftarrow$ optimEdge($\mathcal{T}, q_{new}, q_{parent}$)
        add new node($\mathcal{T}, q_{new}$)
        add new edge($q*_{parent}, q_{new}$)
        generate_robustCones($\mathcal{T}, q_{new}$)
        rewire tree($\mathcal{T}, q_{new}, q*_{parent}$)

robot motion against the fixed environment. Now, planning the robot motion to regrasp an object is equivalent to finding a pushing strategy that forces the object to the desired pose.

Algorithm 1 shows our regrasp planner. The proposed planning framework works at two levels. At the high-level, a T-RRT* based planning architecture samples the configuration space of different grasps, similar to our work in [2]. At the low level, the planning tree is grown in the direction of the sampled poses using the knowledge of local reachable poses in the form of robust motion cones. Exploiting the efficient dynamics propagation via motions cones, the planner rapidly explores the configuration space and generates feasible pushing strategies to move the object in the grasp.

TABLE I
PLANNING TIMES (IN SECONDS) WITH DIFFERENT METHODS FOR UNIT-STEP PROPAGATION

Manipulation	**Goal** $[X, Z, \theta_Y]$	**Plan Time**	**Plan Time** [2]	**Plan Time** [5]
Horz. offset (low μ)	20, 0, 0	0.39	2.83	592.8
$[X, Z, \theta_Y]$ Regrasp	15, -13, 45	0.65	2.54	17684
T-shaped	25, 17.5, 0	0.60	0.82	32657

IV. Regrasp Examples and Experiments

We validate our regrasp planner in simulation and with experiments. As shown in Table I, the proposed planning method performs much faster than our prior work on planning in-hand manipulations. Moreover, the experimental results show that the outcomes of the regrasp strategies is affected minimally when the friction parameter and the gripping force at the fingers are varied. This validates the efficiency and robustness of our planning approach based on the motion cones.

V. Discussion

We present a manipulation method that acts as a fixturing technique for regrasping without using a conventional fixturing hardware. Based the mechanics of prehensile pushing, we construct convex polyhedral sets of object motions that can be produced with fixtureless fixturing. We demonstrate their application for planning in-hand manipulations with a parallel-jaw gripper.

Our planner generates pushing strategies in a fraction of a second to force the object to the goal pose. Moreover, the generated pushing plans are robust against the uncertainty in the object inertia, friction at the fingers, and gripping force.

Using the fixtureless fixturing technique, robots can exploit simple features in the environment as versatile fixtures. The flexibility gained by using fixtureless fixturing facilitates dexterous manipulation even with simple grippers.

References

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