It takes two hands to ~~clap~~ grasp: Towards Handovers in Bimanual Manipulation Planning

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I. Introduction

Research in robotic grasping and manipulation has a long, rich history [2]. Most of the pioneering work in this area has focused on the *grasp planning problem*, that is, to select an end-effector configuration to grasp an object robustly. Traditional approaches regard this as an optimization problem, for which accurate knowledge of the object's geometry is required in order to guarantee that the grasp exhibits force-closure [3].

Progress in grasp planning has reached a mature point which has recently allowed research efforts to focus on *manipulation planning*, which addresses the question of *What does the robot do with the object once it is grasped?* In this paper we are particularly interested in exploiting the task goal to guide the planning process. Rather than treating it as a constraint to be satisfied, we seek to exploit the knowledge of the manipulation goal to prioritize the selection of grasping poses that increase a dexterity metric, such as manipulability.

In this paper we present an approach to solve the pick-and-place problem for dual-arm fixed manipulators. While there is a vast amount of research regarding robot manipulation, most of it addresses the scenario in which a single arm (either fixed or movable) is sufficient to achieve a given task. We are interested in problems in which both arms are required, hence interaction between them is needed (Figure 1)

Regarding bimanual manipulation [6], there exists work addressing grasping objects with two hands [7, 9, 10]. Our approach is closely related to the strategies used by Vahrenkamp et al. [8], who address planning *handover poses* between manipulators. Rather than considering the handover as the goal of the manipulation task, we treat it as an intermediate step to achieve the manipulation goal. Furthermore, we take advantage of the start and goal constraints to guide our selection of a handover pose that maximizes the manipulability metric [5], which represents the dexterity of both arms while performing the handover action.

II. Algorithm

In sections II-A and II-B we present the 2 pre-processing steps our planner requires while Section II-C details the core

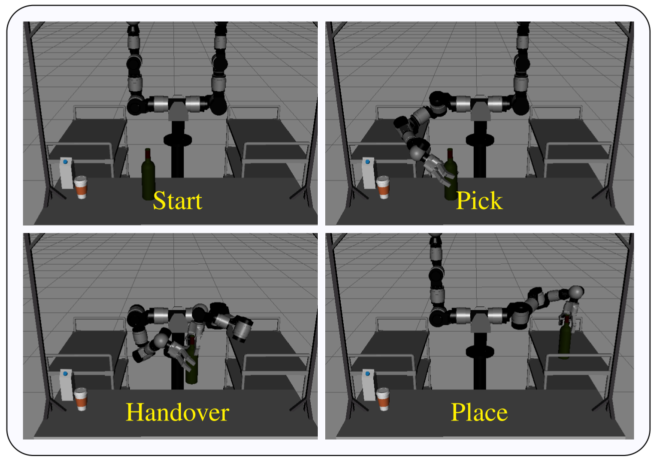

Fig. 1: Bimanual manipulation task: Transporting a bottle from the table to a utility cart at the right of the robot

of our bimanual planning strategy. In the rest of this paper, we will use the following notation: T_s, T_g and T_h refer to the poses for the target object at start, goal and handover steps. A_s and A_g denote the arms used for picking the object from T_s and placing it on T_g respectively.

A. Reachability space generation ($\mathcal{R}$)

We generate offline a 3D discretized representation of the reachability space $\mathcal{R}$ for our system [4]. We fill $\mathcal{R}$ by sampling a large number of random joint configurations for each arm and storing the average manipulability [5] of each sample in the voxel corresponding to the Tool Center Point (TCP) position of the end effectors (an entry of 0 means that the arm cannot reach that location) . Since our system is a fixed dual-manipulator, $\mathcal{R}$ will provide us with a manipulability metric for both left and right arms at each voxel.

B. Task Evaluation

Given a task, our planner must initially determine if a bimanual strategy is actually needed. For this to be the case, T_s and T_g must not be reachable for the same arm, in which case a single-arm strategy would suffice. We use the information stored in $\mathcal{R}$ to determine if either a *Left-Handover-Right* or *Right-Handover-Left* strategy is required. Our planner evaluates the entries in $\mathcal{R}$ corresponding to T_s and T_g: If both entries have positive values for either arm, then the task can be accomplished with a single manipulator. If the entries have

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positive values only for different arms, a bimanual strategy is required. Otherwise, our planner declares the task infeasible.

C. Bimanual Planning

Presented in Algorithm 1, this strategy consists on 4 steps:

1) Handover pose selection (T_h): We trace a line joining T_s and T_g in order to identify the 3D positions (p) in $\mathcal{R}$ that are reachable for both arms and that are within close vicinity of this line. The translation part of T_h is chosen as the point with the highest average manipulability. The rotation part of T_h is set as the interpolated rotation between T_s and T_g, using $\mathbf{p}$ as a reference.

As an example, Fig. 2 shows two candidate handover poses. According to our selection criterion, our algorithm would choose the handover pose at the right over the one at the left.

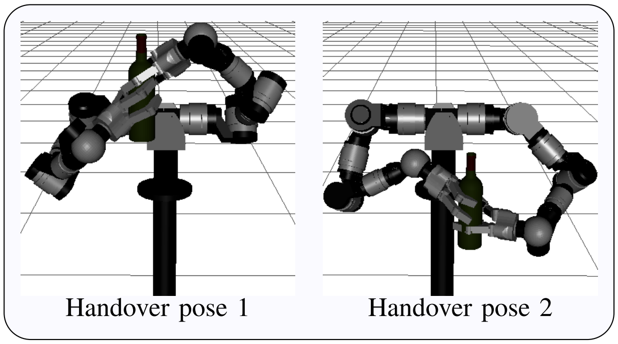

Fig. 2: Sample candidate handover poses for a test object.

2) Candidate Grasp Generation (T_s to T_h): We produce a candidate set of executable, collision-free grasps to pick the object and move it from T_s to T_h according to Algorithm 2, which generates 2 grasp sets considering the object placed in T_s and T_h($\mathcal{G}_S$ and $\mathcal{G}_G$ respectively). Both grasp sets are intersected and only the grasps that have a collision-free IK solution in both T_S and T_G are kept. The output $\mathcal{G}_I$ is an ordered set in which priority is given to grasps that arise arm configurations with higher manipulability in T_G.

3) Candidate Grasp Generation (T_h to T_g): Next, our algorithm finds grasps to move the object from T_h to T_g while avoiding collisions with the first hand during the handover step.

4) Transfer and transit path generation: We use the IK-BiRRT algorithm [1] to generate arm trajectories. We chose this sample-based planner to exploit the fact that A) We have a pseudo-analytical IK solution for the manipulators considered and B) The goals are defined by grasps (end-effector poses), which allows some freedom to explore the final arm configuration.

Figure 1 shows some frames of the plan generated by the algorithm we have introduced in this section considering the task of moving a wine bottle to a utility cart. The simulation setup replicates our actual physical robotic system.

Algorithm 1: DualArmPlanner($\mathcal{R}$, T_s, T_g, A_s A_g)

$\mathbf{p} \leftarrow \arg\max_{p\in\Re^3} m(p)$
$T_h \leftarrow$ `GenerateTransform`$(\mathbf{p}, T_s, T_g)$
$\mathcal{G}_s \leftarrow$ `GraspGeneration`(A_s, T_s, T_h)
foreach $\mathbf{x} \in \mathcal{G}_s$ **do**
  `Simulate`$(\mathbf{x}, A_s, T_h)$
  $\mathcal{G}_g \leftarrow$ `GraspGeneration`(A_g, T_h, T_g)
  if $\mathcal{G}_g \neq \emptyset$ **then**
    $\mathbf{x}_s \leftarrow \mathbf{x}$
    $\mathbf{x}_g \leftarrow \mathcal{G}_G$`.front()`
    break
$\Delta_s \leftarrow$ `SingleArmPlanner`$(\mathrm{A}_s, \mathbf{x}_s, T_s, T_h)$
$\Delta_g \leftarrow$ `SingleArmPlanner`$(\mathrm{A}_g, \mathbf{x}_g, T_h, T_g)$
return $\{\Delta_s, \Delta_g\}$

Algorithm 2: GraspGeneration(A, T_S, T_G)

$\mathcal{G}_S \leftarrow$ `SampleGrasps`(A, T_S)
$\mathcal{G}_G \leftarrow$ `SampleGrasps`(A, T_G)
$\mathcal{G}_I \leftarrow \mathcal{G}_S \cap \mathcal{G}_G$
foreach $\mathbf{x} \in \mathcal{G}_I$ **do**
  $\mathcal{M} \leftarrow \mathcal{M} \cup m(\mathbf{x})$
return `Sort`$(\mathcal{G}_I, \mathcal{M})$

III. CONCLUSION

In this paper, we introduced an approach for planning bimanual manipulation tasks. The approach focuses on maximizing the robot dexterity between manipulation steps by considering the manipulability metric to prioritize the selected grasps. Currently, we are working on the implementation of our approach in our physical bimanual robot. As future work, we seek to compare our presented approach with other methods using different criteria to select the handover pose of the object.

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