Towards Stacking Objects with a Mobile Manipulator

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***Abstract*— Grasping is an active research topic in robotics, however the potential of manipulation capabilities that a robot can exhibit by utilizing non-prehensile actions such as pushing and sliding still remain virtually untapped. In this work, we implemented a particular book-stacking scenario in an attempt to pinpoint the challenges in this body of work. We used human-inspired sliding motion to facilitate grasping books. The low success rate of our experiments revealed that closed-loop sensing and acting, manipulation with multiple action types and active grasping are necessary elements for robust execution.**

***Index Terms*— manipulation, non-prehensile, sliding**

I. Introduction

In service robotic tasks such as object pick and place, the robot need to first acquire the object before placement. When the grasping motion is executable and within reach of the robot, a direct reach-to-grasp motion is sufficient. However, in some configurations and for some objects, direct grasping is not available, such as when manipulating books or plates on the table. In such cases, pre-grasp motions such as sliding [1] and pushing [2] can enable the robot to grasp those object.

In previous work [3], we studied pushing tabletop objects to clear up space for other objects. In this work, we explore applying sliding motions to enable grasping. We focus on an implementation of stacking books by using sliding motions to enable grasping on a PR2 robot. By implementing a first approach, we aim to identify key challenges that need to addressed that claim to solve the problem. This work is hence about providing insights rather than offering a complete or general solution.

First we describe how the table and book objects are detected in Section II. We explain how the robot navigates around the table in Section III. In Section IV we explain how certain manipulation behaviors, including sliding, grasping and placing, are implemented. We report the success rate in Section V and conclude with our insights in Section VI.

II. Object Detection

We use the tilting Hokuyo laser scanner for the detection of the table and books. Since we detect low-profile objects such as books, higher resolution in z direction is needed, so the tilting period is set to 15 seconds. First, the laser hits corresponding to the robot and floor are removed from the point cloud. A RANSAC based approach is used to find the most dominant horizontal plane in the scene. The laser points above the convex hull of the tables are clustered and designated as book objects. Both the table and the books are represented with their centroids and convex hulls in the world frame.

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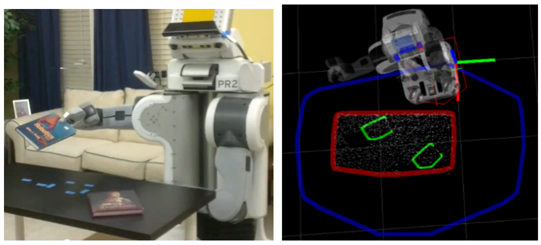

Fig. 1. The PR2 robot is manipulating a book.

III. Navigation

The robot is localized using odometry. Table and object positions are updated in odometry frame every time a scan is made. In the first scan the table is detected, we find waypoints around the table by extending the convex hull, as shown as the blue line in Figure 1.

The robot base velocity between waypoints is calculated using a P controller. The orientation of the robot is always selected to be facing the table center. There is no obstacle avoidance, however the robot stops and waits if a close obstacle is detected by the base laser scanner.

When a manipulation request is received, the robot first navigates to the waypoint closest to the object of interest. Then, it moves to a position so that the object centroid is in the middle of the arm workspace. The center of the workspace is found offline: On a discretized 3D grid, Inverse Kinematics (IK) results are logged if it resulted in success or not, and the center of 2D slices in the z direction are found.

IV. Manipulation

We use three action primitives for manipulating book-like objects: sliding, grasping and placing.

A. *Sliding*

If the book that will be grasped is not already on the edge of the table, the robot slides it to the edge by applying pressure and dragging it. The sliding action involves moving the arm to a pre-slide pose just above the book, lowering the end-effector until there is contact between the book and the fingers of the robot, moving the end effector in a linear trajectory on the table and then retracting the arm. A successful sliding action is shown in Figure 2. To find the sliding direction, first the object centroid and the robot arm base positions are projected to the 2D table plane. The sliding is applied on the line segment defined from the projected object centroid to projected robot arm base. The sliding distance is calculated by extending this line segment toward the edge of the table convex hull and and finding the point where it exceeds the table boundaries. The fingers of the PR2 gripper are equipped with force sensors. While the end effector is being lowered from the pre-slide pose, the fingertip sensors are checked for an impulse. If the derivative of the force exceeds a threshold, then the sliding action begins. This threshold is hard-coded and may not be optimal for every book-like object.

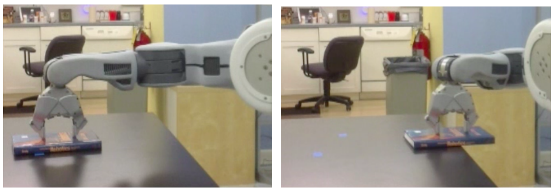

Fig. 2. Sliding motion primitive using parallel grippers.

B. Grasping

After the books are sled to the edge of the table, they are grasped by using a pre-defined grasp pose. Similar to the sliding action, the grasping action is executed first by moving the arm to a pre-grasp pose, then to the grasp pose while fingertip sensors are watched, then closing the gripper. Before the robot starts manipulating the object, first the end-effector trajectory for the sliding and grasping actions are planned. This trajectory is then linearly sampled and checked for IK solutions. This allows the robot to reason about the feasibility of manipulation.

C. Placing

For placement, while holding the book object, the robot places its end effector so it over the centroid of the target object and tilting down 45°. After this pose, the end effector is lowered in a linear trajectory, the gripper is opened and the arm is retracted quickly. If the arm doesn't move fast enough, we observed that the object is dragged with the gripper due to the high-friction fingertips of the PR2.

V. Results

In order to evaluate the approach, the robot was asked to place a book on top of another with different initial robot and book positions. We considered the experiment as a success if the two books were on top of each other in the final configuration, regardless of their orientations. Out of 12 trials, only 4 resulted in success. The success cases are shown in Figure 3.

Fig. 3. Successful run results from the trial runs. Final book configurations are not aligned in current implementation.

Experiments failed due to 3 main sources:

- Perception (3/12): Could not detect books or table borders correctly
- Manipulation (3/12): Failed to grasping the book or book fell to ground while robot base is moving.
- Navigation (2/12): Could not find a feasible base position to manipulate book

Perception errors were due to detection uncertainties or non-detections. Open-loop execution after an initial detection in general leads to significant uncertainties. We think using closed-loop solutions such as visual servoing [4] or active manipulation methods such as push-grasping [2] will help reduce this type or errors. Low-profile books were the reason for non-detections for our application. A good strategy for the robot might be to first move around to maximize its knowledge about the objects in the environment as in [5].

Manipulation errors were mainly due to open-loop execution of grasping. We used force sensing for sliding but did not utilize active grasping. An alternative to active grasping is to learn the affordances of objects on the fly [6]. It was interesting to note that one of runs failed because the robot dropped the book from its fingers while it was navigating towards the second object. Therefore one has to account for such unexpected errors.

Navigation errors happened because the robot could not find a base position where there is an IK solution to manipulate the book. For our application, we mandate that the sliding motion is executed from the centroid of the object. If our manipulation approach was more flexible (i.e. allowing pushes from any contact point), the execution would have likely continued.

VI. Conclusion

Pre-grasp such as pushing and sliding have the potential to facilitate object manipulation. By implementing a first approach, we aim to identify key challenges that need to be addressed in this field. Our implementation described a PR2 robot manipulating books using sliding as a pre-grasp motion. However, as Barry [7] also pointed out, perception uncertainties contribute to much of the problems. Limited manipulation capabilities also can lead to failures. We also note that using mobile manipulator introduces localization errors. We claim that uncertainties and errors are inevitable for this domain. Error detection and recovery behaviors thus should be further investigated.

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