Vision-based Stable 2D Planar Pushing of Dishware with 6-DOF Manipulator

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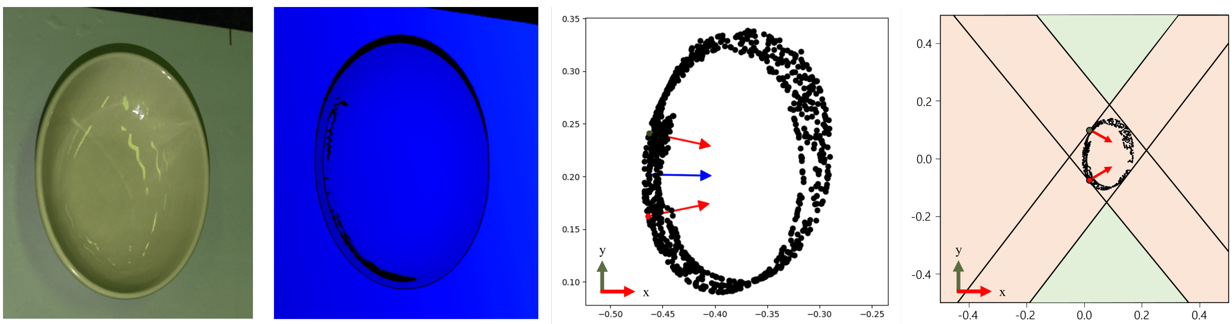
EXTENDED ABSTRACT

1 Introduction

Object relocation is a critical aspect of the field of robotics. From industrial automation to domestic applications such as flexible manufacturing, delivery, and table cleaning, the ability to move objects from one place to another accurately and efficiently is vital to achieving desired outcomes. There are circumstances when pushing is more advantageous than grasping when relocating the object, such as when the object is too big to be grasped by a gripper in a restaurant [1]. Pushing objects on the table for repositioning with real-time object position tracking was introduced [2], whereas pushing objects without object position tracking or sensing contacts is challenging due to complicated interaction between multiple bodies such as a table, object, and robot. Object relocation can be achieved by using analytic push planning [3] if physical properties are known. This is realized by deriving a stable push of dishware from a depth image, which is robust to pressure distribution. In this work, we present a vision-based stable pushing manipulation method that enables the end-effector of the manipulator to maintain contact points with the object. Then, we use hybrid A* algorithm [4] to plan a stable push path according to the path planning constraints given by the analytic pushing strategy to relocate the object to the target location.

2 Vision-Based Stable ICR Region Estimation Algorithm



(a) (b) (c) (d)

Figure 1: Stable ICR region derivation process through depth image; (a) Color image of a dish; (b) Depth image of a dish; (c) Two-point contact with the surface normal with cartesian coordinate. Red arrows indicate the surface normal of each contact point, and the blue arrow denotes the contact direction. (d) ICR region with cartesian coordinate. Regions are labeled as stable (green) or unstable (red)

The proposed algorithm aims to calculate the stable Instant Center of Rotation (ICR) region for the pusher, which represents the pusher's motion. As general dishware has properties such as symmetric shape, uniform density, and low height/width ratio, we assume that object's the center of friction is the 2D centroid of its shape. Also, we assume quasi-static and two-point contact pushing. We estimate the object's shape from the depth image. Push contact candidates with contact friction cones are then sampled based on gripper width. Under the assumptions above, we can derive stable ICR regions for a given push contact as shown in Figure 1 [5]. The stable ICR region is determined by multiple conditions regarding the object's physical property. First, the stable ICR should be within the region determined by the friction cone and the object's 2D shape. Second, it should be within the region between the tip line and the bisector between the contact point and the center of friction. Since these conditions are valid regardless of pressure distribution, pushes are robust to pressure distributions.

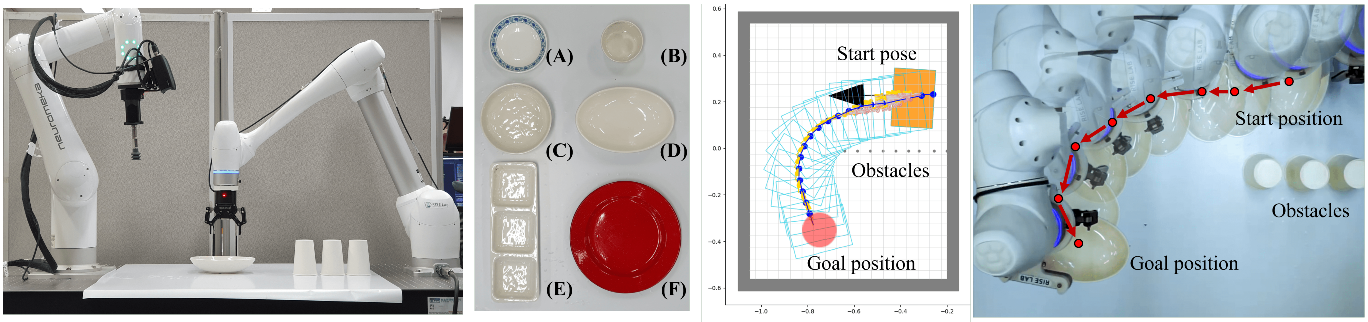
3 Hybrid A* Algorithm for Stable Push Planning

We utilize hybrid A* algorithm that accounts for linear and rotational motions for stable push planning. Hybrid A* algorithm takes into account the maximum steering angle obtained in section 2, as a constraint for push planning. We attempt to search the path eight times with different start directions uniformly and select the shortest path among the candidates as illustrated in Figure

2 (c). Our approach allows the robot to move the dishware to the desired location without needing additional re-approach during the push.

4 Experiment and Discussion

We evaluated the reliability of our vision-based stable push planning algorithm through a real pushing experiment on six dishes of different shapes and sizes. (b) of Figure 2 illustrates the objects used for the experiment. All these objects were selected to be wider than the gripper's maximum width. The stable push path was planned from a depth image captured with a structured light camera (Zivid Two) as shown in Figure 2 (c) and was executed by a 6-DOF manipulator (Doosan Robotics M1013) equipped with a parallel-jaw gripper (Robotiq 2f-85) as shown in (d) of Figure 2. Pushes that relocate the objects to the desired goal position are deemed successful. Our results, summarized in Table 1, indicate that the algorithm was effective for objects of smaller sizes (objects of (A) to (D)) but not for larger ones (objects (E) and (F)). In the future, we intend to improve the push path planning algorithm to handle larger objects by minimally shifting push positions and eventually realize 3D pushing by considering the toppling of the object.



(a) (b) (c) (d)

Figure 2: Experiment settings and push planning results; (a) Experiment setting; (b) Objects used for pushing experiment; (c) Output of push path planning of hybrid A^* algorithm; (d) Actual pushing of object (D) according to the path in (c)

Table 1: Push results for dishware of different lengths

Objects	A	B	C	D	E	F
Longest diameter (mm)	100	140	165	230	330	260
Push result	success	success	success	success	fail	fail

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