Scooping Manipulation via Motion Control with a Two-Fingered Gripper and Its Application to Bin Picking

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Abstract—This letter introduces a new method for scooping manipulation in constrained environments. The presented technique lends itself to relatively thin objects, with a large width-to-thickness ratio, which are commonly seen in many domestic and industrial tasks yet can cause considerable difficulty in handling. We present a novel approach to scooping based on a mobility analysis that leads to a new way to perform the operation via motion control with a two-fingered gripper. Our method thus expands the ways in which the manipulation of scooping can be performed, without necessitating underactuated control or a compliant mechanism. Our variable-length digit is suggested as a key facilitator for realizing the motion-controlled scooping maneuver. We present an extensive set of experiments showing the effectiveness of our approach in various scenarios featuring a constrained workspace, including bin picking from clutter.

Index Terms—Grasping, Grippers and Other End-Effectors

I. INTRODUCTION

Thin objects can be quite challenging to handle. For example, consider the situation depicted in Fig. 1 showing a robot trying to pick a plastic card lying on a flat support surface. We humans accomplish that task by taking advantage of our marvelous hand, with a high mobility and a sophisticated hybrid rigid-soft architecture, as well as advanced multi-modal sensing and robust control skills. These capabilities as a whole, which we almost take for granted, have no parallel in the robots at present. A careful arrangement is necessary to enable a common robot, such as the one with only two fingers shown in Fig. 1 to accomplish the picking task. Suction gripping, or any other means of exerting bilateral “sticking” forces, can be effective in some cases; however, these also have limitations, such as the necessity of a custom end-effector, the dependence on contact surface conditions, the difficulty with secondary manipulation after successful picking, among others.

This study presents a robotic scooping technique that is effective for the card picking task, for example. Fig. 1(a) shows how our scooping manipulation proceeds with a two-fingered gripper. While the blue finger presses down on the card, the yellow thumb gets through the space between the card and the support surface. A pinch grasp on the card’s faces is finally obtained. This way of manipulation, scooping, has been a topic of interest. What makes our approach unique is a novel mobility analysis that enables motion-control-based scooping, which can be implemented with a common two-fingered gripper retrofitted with our variable-length digit (the length of the thumb in Fig. 1(a) is controllable). Underactuated control or a compliant mechanism is not needed.

Through a series of experiments performed autonomously, the advantages of our method will be clarified over ad hoc picking approaches such as the one shown in Fig. 1(b) where the robot was controlled to directly pinch-grasp the edge pair of the card. These experiments feature a range of practical yet challenging settings with a constrained workspace, from an object of interest lying on a support surface to bin picking tasks in which the object to pick is placed on an unordered cluster of other object instances.

II. BACKGROUND AND RELATED WORK

The challenges of handling objects with a thin profile have motivated many interesting robotic manipulation solutions to develop. One notable recent approach is to take advantage
of compliance and underactuation. Although these give rise to increased system complexity and unconstrained mobility, the resulting passive and natural dynamics has proved useful for improving the robustness of picking operations. The effectiveness of a soft fingertip in thin object picking was demonstrated in [1]. Underactuated hands with a compliant mechanism were used for the manipulation of scooping in [2], [3] by inducing suitable interaction between the fingers and the environment, and for a human-inspired process of the flip-and-pinching manipulation in [4] which was shown to be effective in picking various thin objects. In [5], the energy interaction modeling between a deformable thin object and a soft gripper facilitated picking a sheet of paper in a dynamic manner. In [6–8], grippers with movable contact surfaces that are capable of picking thin objects were presented. Beyond picking, dexterous insertion of thin objects through in-hand manipulation was investigated in [9], with applications to dry cell battery insertion, small part assembly, etc.

Our presented manipulation technique for object scooping is applicable not only to an isolated object lying on a support surface but also to a workspace cluttered with a multitude of object instances. Therefore, it can facilitate bin picking—singulating and picking items out of a cluttered bin. The importance of bin picking is proved by its ubiquity: the situation is very common in a wide variety of material/part handling scenarios. However, the complexity of bin picking has still to be fully addressed by the robot systems at present. One critical issue in bin picking is to choose the right gripper. The combination of a multi-fingered and a suction gripper, which can be applied to multi-affordance grasping [10], proved useful in a competition setting (for example, Amazon Picking Challenge). As for object detection and grasp planning for bin picking, learning-based, data-driven approaches have recently received considerable attention [11]–[15]. In the practice of bin picking, our recent work [16] showed that interacting with the clutter directly, in the form of a controlled quasistatic push, can facilitate singulating and securing each item.

III. FRAMEWORK FOR MOTION-CONTROLLED SCOOPLING

In [2], the manipulation of scooping is modeled using a planar manipulation setting illustrated in Fig. 2. Here a linear thumb is controlled to slide on a flat surface with an angle of attack $\psi$ and to push a relatively thin object lying on the surface, against a wall formed by another fixture, shown as the linear finger. The thumb then penetrates under the object held by the finger. A pinch grasp is finally obtained as the thumb and the finger move closer. In this section, we study a more generalized case and perform a mobility analysis that enables our novel motion-control-based scooping.

A. Key Assumption

Before presenting our generalized technique, we first make a key assumption. Successful scooping is contingent on the thumb being able to initially get through between the object and the support surface, that is, the transition from Fig. 2(a) to (b). This seems to happen quite reproducibly in practice with a thumb that is motion-controlled to simply push the object horizontally; see the video attachment. However, rigid body mechanics alone is inadequate to explain how it is conceptually possible for the motion-controlled thumb to take the object off from the surface vertically and then penetrate into the space between the object and the surface, without deliberate force control to exert forces with a nonzero vertical component on the object. Rigorously speaking, the workable initial penetration in practice may be accounted for by the dynamics of microscopic deformation at the point of contact between the thumb, the object, and the surface. A detailed examination of the phenomenon lies beyond the scope of this study. Instead, our framework for scooping will be based on rigid body mechanics and the following key assumption that the initial penetration is achievable:

Assumption 1. Consider a planar rigid manipulation setting, shown in Fig. 2(a), featuring a motion-controlled linear thumb pushing a flat-bottomed object on a flat, level support surface against another fixture that blocks the object. If the thumb’s angle of attack $\psi$ is sufficiently small, it can penetrate into the space between the object and the surface.

Similar assumptions have been made in the literature (for example, [2]), though implicitly.

B. Mobility Analysis for Scoopability

In this work, we investigate a situation depicted in Fig. 3(a), generalized from Fig. 2(a) by allowing the finger to make contact on top of the object. The finger is thus represented simply by the contact point $F$ in Fig. 3(a). This generalization is motivated by the observation that a contact placed on top of the object is also able to counterbalance the thumb’s pushing force, as the finger wall does in Fig. 2 by means of both friction (contact force tangent to the object’s surface) and geometry (contact normal with a nonzero horizontal component due to curved object shape). Consequently, Assumption 1 is also applicable to the transition from Fig. 3(a) to Fig. 3(b), during which the thumb tilts up the object after a push similarly to Fig. 2(b). This scooping situation with $F$ on top of the object in Fig. 3 has also been studied in the literature, e.g., [3].

Contrary to that study, which presented a force analysis and then investigated the applicability of an underactuated,
compliant mechanism, here we perform a mobility analysis for motion-control-based scooping manipulation. More specifically, we examine when it would be possible for the object to be caught and finally pinched without getting lost while $F$ is kept fixed, which is promising for scooping using the minimalistic gripper model—the system of the linear thumb and the point finger controlled by relative repositioning. The shaded triangular area in Fig. 3(b), with the minus sign "−", represents the collection of the feasible twists of the object resolved according to Reuleaux’s method [17] (see [18], [19] for examples in different contexts). The triangle is delimited by the three contact normals at $F$, $T$, and $G$, and is interpreted as the region of the allowable centers of rotation for the object on the plane, to the first order due to the use of the contact normals. The "−" sign denotes the sense of the rotation, that is, into the page. Therefore, at the contact configuration of Fig. 3(b), the object can only rotate clockwise instantaneously about a point belonging to the triangular region without penetrating into the thumb, the finger, or the surface. In other words, if the gripper is held fixed, it is impossible for the object to escape from the gripper through the gap between $F$ and $G$ because the point coincident with $G$ is not allowed to move toward the halfspace on the right of its current contact normal. Our definition of scoopability conceptualizes this observation:

**Definition 1.** At the contact configuration of the three contacts $F$, $T$, and $G$ modeled in Fig. 3(b), the object is said to be scoopable if the motion of the point at $G$ is forbidden toward the halfspace on the right of the normal at $G$.

If the object moves with a feasible twist at a scoopable configuration, in general the point coincident with $G$ moves toward the thumb while the contacts $T$ and $F$ break free from the gripper. One way to induce the feasible motion is then to apply a pushing force at $T$ or $F$ by “closing” the gripper, for example, moving the thumb horizontally toward the fixed finger. The object can then be captured and pinch-grasped finally as it is forced to slide upward on the thumb. This accounts for what happened in Fig. 1(a).

Fig. 3(c) presents another example of a scoopable object with a semi-elliptical cross section. It can be seen that the convexity of the object’s geometry at $F$ helps to secure the desired mobility: the shaded area could have been much smaller without the convex geometry. In contrast, Fig. 3(d) shows an object configuration that is not scoopable due to the concavity at $F$. In this case, it is not possible for $G$ to move toward $T$ using any of the allowed twist in the areas signed “−” and “+”, and thus the gripper may lose hold of the object. The object will become scoopable by switching the thumb’s location to the opposite, thick end of the object where $G$ is currently located. We note that the mobility analysis in Fig. 3(b-c) shows (1) the benefit of a small attack angle $\psi$, which can enlarge the shaded area, and (2) the challenge of an object’s flat bottom, which will locate $G$ as far as possible to the right, and will thus minimize the area if other conditions are the same.

### C. Effect of Compliance and Friction

Compliance and friction at contact, which are unavoidable in practice, are ignored in the mobility analysis above. Will they facilitate scooping? We answer this affirmatively based on empirical evidence. We performed scooping experiments in an end-to-end manner all the way from the fulfillment of Assumption 1. A test object (see Table I) was initially placed on a flat surface, and then a scoop was attempted with a two-fingered gripper, similarly to Fig. 1(a) (Sec. V has full details of the experiment protocol). We then compared the performance of three fingertip materials to make the contact $F$ while other conditions were the same. When a soft, high-friction material (silicone rubber) was used, no failures happened out of 150 scooping attempts. With a hard, low-friction (hard plastic) and a hard, high-friction material (sandpaper), respectively, the success rates were 52/150 and 146/150. Almost all the failed cases were caused by unsuccessful initial penetration. In other words, once Assumption 1 was fulfilled, successful scooping happened highly reliably. The results verify the augmented robustness brought by compliance and friction in fulfilling the key assumption, as well as the viability of the mobility analysis. We reconfirmed these points through another set of experiments performed with again the three types of materials for the support surface at $G$. The witnessed benefit of the softer, higher-friction materials actually comes as no surprise, since it has been discovered repeatedly in the literature.

Despite the advantage of robustness, the object may get stuck because of friction and compliance. That is, wedging [17] can happen due to force-closure [17]. See Fig. 4 where $F$ is modeled as a frictional contact with a friction cone, which
can also model compliance \[^{[1]}\]. The object is in force-closure in Fig. 4(a) even with frictionless \(T\) and \(G\). Solutions to avoiding force-closure include reducing the angle of attack: no force-closure in Fig. 4(b) with decreased \(\psi\).

IV. PRACTICE OF MOTION-CONTROLLED SCOOPING WITH A PARALLEL-FINGER GRIPPER

This section presents the logistics of our scooping process by elaborating gripper design, planning, and control.

A. Design

Our mobility analysis in Sec. III necessitates a two-fingered gripper, composed of a finger and a thumb, with two degrees-of-freedom (DOF) such that the fingertip \(F\) can be placed freely with respect to the thumb. Fig. 3 shows our customized gripper to be used in our experiments. It is essentially a parallel-finger gripper retrofitted with a variable-length digit. Therefore, it is possible to place one fingertip freely relative to the other finger by opening/closing the gripper and by extending/retracting the variable-length digit. According to the lesson from Sec. III-C, a soft material is applied to one fingertip.

B. Pre-Scoop Planning

Procedure 1 below describes the steps of pre-scoop planning for testing scoopability and for determining how to initially configure the gripper by fixing the location of \(F\) and the thumb’s angle of attack \(\psi\). It takes as input the 3D model of an object and returns feasible pre-scoop configurations.

**Procedure 1: PRE-SCOOP PLANNER**

<table>
<thead>
<tr>
<th>Data: 3D Object model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Result: Feasible pre-scoop configurations</td>
</tr>
</tbody>
</table>

1. FindAntipodalPairs()

2. Repeat for each antipodal pair
   1. GetCrossSection()
   4. TestScoopability()

The planner starts with FindAntipodalPairs. The given object model, with a large width-to-thickness ratio, is first approximated as an \(n\)-sided convex polygon by disregarding its thickness, and then its antipodal pairs, which can be a vertex-vertex, vertex-edge, or edge-edge pair, are found. This is a classic computational geometry problem with a range of solution approaches.

For each antipodal pair, the following is repeated. First, in GetCrossSection method, the 2D cross section of the object model on the plane normal to that of the approximated polygon and aligned with the antipodal pair is obtained. A computational geometry package that can handle polygonal meshes can be applied here, for example, ‘trimesh’ in Python. Then in TestScoopability method, the mobility analysis in Sec. III-B is performed with the cross section by solving the following linear programs that execute Reuleaux’s method at the configuration whereby Assumption 1 is applied with a small nonzero \(\phi\) and a chosen angle of attack \(\psi\) (Fig. 3(b)):

\[
\begin{align*}
\text{find } x & \quad (1) \\
\text{subject to } a_i^T x < a_i^T x_i, & \quad i \in \{T, G, F\} \quad (2) \\
\text{find } x & \quad (3) \\
\text{subject to } a_i^T x > a_i^T x_i, & \quad i \in \{T, G, F\} \quad (4)
\end{align*}
\]

The programs (1-2) and (3-4) are for finding the areas signed “−” and “+,” respectively. These collectively represent the set of the allowable centers of rotation for the object. \(a_i\) denotes a vector orthogonal (rotated 90° counterclockwise) to the contact \(i\)’s normal. \(x_i\) denotes the initial point of \(a_i\), on the line of the contact normal at \(i\). See Fig. 3(b) showing \(a_T\) and \(x_T\) for example. Subsequently, scoopability (Definition 1) is verified by checking the direction of the allowed velocity at \(G\). TestScoopability itself can be repeated to obtain the collection of the acceptable locations of \(F\) given \(\psi\), which can testify the suitability of scooping with the object. Fig. 6 shows examples obtained with our software[^2].

C. Scooping via Motion Control

Based on the resulting pre-scoop plan, a scoop is executed through motion control using the gripper, as can be previewed in Fig. 7. First, the gripper is aligned with the selected

[^1]: According to [20], “For planar problems, a point contact with friction and a soft contact are identical.”

[^2]: Available at https://github.com/HKUST-RML/Scooping
antipodal pair and the finger contact \( F \) is made on top of the object by the fixed-length digit, according to the mobility analysis (Fig. 6). The thumb as a variable-length digit is then controlled to slide on the support surface toward \( F \). This maneuver leads to successful scooping while the object slides upward on the thumb’s face. Our software\(^2\) keeps the thumb attack angle \( \psi \) constant, the fingertip at \( F \) fixed, and the thumb’s tip in contact with the surface as the gripper closes, by coordinating the motions of our entire manipulator system—the base gripper, the variable-length finger, and a six-DOF arm. The necessity of the whole-arm motion coordination is accounted for by the fact that the mechanism of the base gripper (by Robotiq Inc.) is arranged such that the fingertips move distally as the fingers close. The software also takes advantage of wrist force-torque sensing to detect initial contacts on the tips of the digits, which will trigger the scooping motion.

Alternatively, it is conceivable to control the gripper such that the thumb remains fixed and the fingertip \( F \) moves toward the thumb. In this case, the object will necessarily slide at \( G \) all the way through for successful scooping, against the maximum possible friction force at \( G \) in the direction away from \( T \). We therefore expect this finger-driven scooping to be outperformed by the thumb-driven scooping explained above, whereby \( G \) does not need to slide constantly. Our experiments in Sec. [V] will confirm this. Another issue is whether to use the variable-length digit as the thumb or the finger. Our experiments will provide the empirical evidence that the preferred option is to use the variable-length digit as the thumb.

V. PICKING BY SCOOPING: IMPLEMENTATION, EXPERIMENTS, AND DISCUSSION

This section presents the results of a series of experiments performed autonomously in a range of scenarios featuring a constrained workspace: scooping from a flat surface and bin picking via scooping.

A. Scooping from a Flat Support Surface

![Fig. 7: Scooping operations performed on a flat surface: (a) Domino block (widthwise), (b) Domino block (lengthwise), (c) Go stone, (d) Triangular prism. See also the video attachment.](image)

We first examined the performance of our scooping manipulation in the task of picking objects lying on a flat surface. The objects that we tested are a plastic card, a domino block, a Go stone, and a flat triangular prism, all with a large width-to-thickness ratio, as can be seen in Table I. These all feature a flat bottom face that can pose a challenge, as discussed in Sec. [III-B]. For example, the Go stone has a semi-elliptical cross section; if it were fully-elliptical, it would be easier to scoop. According to the pre-scoop planning (Fig. 6), a parallel edge pair, an antipodal vertex pair, and a vertex-edge pair were selected to accommodate feasible pre-scoops for the rectangular objects (the plastic card and the domino block), the circular Go stone, and the triangular prism, respectively. Following initial localization by a fiducial marker, a scoop was then performed as instructed in Sec. [IV-C]. See Fig. 7.

The lessons from the results reported in Table I featuring the success rates (a success is defined as a successful final pinch grasp) of scooping under various conditions, are:

- A small angle of attack \( \psi \) can facilitate scooping, as discussed in Sec. [III-B] and [III-C]. The values of \( \psi \) in the experiments were determined such that the somewhat bulky motor box (Fig. 5) does not interfere with the support surface.
- When the thumb was controlled to approach to the fixed finger (the columns labeled “thumb-driven” in the table), the success rates were higher. This confirms our discussion in Sec. [IV-C].


<table>
<thead>
<tr>
<th>Object</th>
<th>Dimensions (mm)</th>
<th>Thumb attack angle $\psi$ (°)</th>
<th>Success rate (successes/trials) Variable-length digit as finger</th>
<th>Success rate (successes/trials) Variable-length digit as thumb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Go stone</td>
<td>23</td>
<td>60</td>
<td>25/30</td>
<td>16/30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>45/30</td>
<td>30/30</td>
</tr>
<tr>
<td>Domino block (widthwise)</td>
<td>44</td>
<td>60</td>
<td>24/30</td>
<td>5/30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>45/30</td>
<td>6/30</td>
</tr>
<tr>
<td>Domino block (lengthwise)</td>
<td>20</td>
<td>60</td>
<td>24/30</td>
<td>0/30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>45/30</td>
<td>24/30</td>
</tr>
<tr>
<td>Plastic card</td>
<td>thickness 0.75</td>
<td>60</td>
<td>22/30</td>
<td>0/30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>45/30</td>
<td>7/30</td>
</tr>
<tr>
<td>Equilateral triangular prism</td>
<td>30</td>
<td>60</td>
<td>28/30</td>
<td>18/30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>45/30</td>
<td>30/30</td>
</tr>
</tbody>
</table>

- When the variable-length digit was used as the thumb, the success rates were higher, as stated in Sec. IV-C.

The table also presents the minimum values of $F$’s dimensionless position that can guarantee the reproducibility of the results, i.e. all the way from the fulfillment of Assumption 1 to successful picking, with the soft material (silicone rubber) fingertip. The value ranges from 0 to 1. When it is closer to 1, $F$ is closer to $G$. These values confirm the conservativeness of the mobility analysis, as compared in Fig. 6.

By comparison, an ad hoc approach to picking a thin object lying on a flat surface proved ineffective, as shown back in Fig. 1(b). Here, the fingers were controlled to slide on the surface toward each other in an effort to obtain a pinch grasp on an edge pair of the object, a plastic card. Out of 30 picking attempts, none were successful.

B. Bin Picking

The next set of experiments are concerned with picking items out of a cluttered bin. The lessons confirmed in Sec. V-A are exploited by adopting the variable-length digit as the thumb, moving the thumb toward the fixed finger, positioning $F$ in accordance with the minimum threshold, and finally running the same control software.

Given a 2D image of an object cluster seen from above, we identify each instance through instance segmentation and then its pose is estimated using standard vision techniques. The instance with the largest detected footprint and the most distant from the bin’s wall is heuristically selected as the one to pick at the time. A scoop is then executed after the robot finds a feasible pre-scoop configuration with no collision with the wall of the bin. Fig. 8(a-c) illustrates the process.

We evaluated the bin picking performance while varying the size of the clutter: we set a maximally allowed number of items and topped the bin up occasionally. Table II provides two evaluation metrics, success rates and PPH (picks per hour) values. PPH is obtained by multiplying the success rate and the rate of picking, which is inclusive both perception and manipulation time. Since our implementation is not based on a highly-optimized hardware/software setting, the metrics are meant for comparing relative performance. It can be seen that the best performance is obtained when there are just a few items around, which may be accounted for by the decreased pose uncertainty when an item is supported by a flat, hard bottom surface, rather than a cluster of other items.

C. Complete Bin Picking

Finally, the robot is tasked with complete bin picking: given a bin filled with a homogeneous group of the test objects, pick all of them one after the other out of the bin.

1) Autonomous complete bin picking via scooping: First, Fig. 8(d) presents some snapshots during the complete bin picking of plastic cards, advanced from our recent work [21] that necessitated dual-arm manipulation. This was performed autonomously using the same vision and control procedure explained in Sec. V-B. By repeating multiple sets of the experiments, we were able to achieve 73 PPH. Second, the complete bin picking of 25 domino blocks was also executed autonomously, in a collision-aware manner such that the robot avoids collision with the wall of the bin. In one trial, it took 829 seconds at 108 PPH to pick all the blocks one by one. Here, the robot was also programmed opportunistically...
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Fig. 8: (a-d) Scooping applied to the bin picking of dominoes, Go stones, triangular prisms, and plastic cards, respectively. The object instance being picked is identified through vision, as shown on the leftmost panels. See also the video attachment.

(1) to get a direct pinch grasp in case both the two largest opposite faces of a block are reachable and (2) to relocate a block by simply pushing toward the center of the bin if a collision-free path can be found in case a small number of blocks are around, which can facilitate initial positioning of the gripper on the object. The video attachment provides the coverage of these capabilities too.

2) Complete bin picking via scooping and dig-grasping: Our recent study [16] presents the method of dig-grasping, which is also applicable to bin picking. A dig-grasp is executed by “digging” the clutter in the form of a controlled push maneuver. Although this is distinct from the way an item is scooped using the presented technique here, both dig-grasping and scooping are implemented using the gripper with adjustable finger lengths (Sec. IV-A). We have discovered that dig-grasping generally outperforms scooping in terms of PPH, provided other conditions (e.g. vision) are the same. However, it is not possible to complete bin picking using only dig-grasping because a nonzero positive digging depth is needed; for example, it cannot be applied to the tasks in Fig. 7 which can be accomplished easily with scooping, because the finger cannot dig the hard support surface. We thus tried to integrate the two, in order to accelerate the pace of bin picking. Our strategy is to start off with dig-grasping (Fig. 9(a)) and to switch to scooping (Fig. 9(c)) as the remaining amount of items becomes insufficient to dig-grasp. Note, dig-grasping is facilitated by a rigid fingertip, unlike scooping. This is because a softer fingertip is more likely to give rise to stable pushing [22], according to the mechanics of pushing, instead of a successful dig-grasp—quickly rotating the object and funneling it into the gripper’s workspace. Therefore the mechanism in Fig. 9(b) proved useful. We applied the strategy to the complete bin picking of bowl-full, 115 Go stones. Out of 128 picking attempts in total, reported in our multimedia material submitted,[3] there were 101 successful singulation and subsequent picking events, 7 attempts in which two stones were simultaneously captured, and 20 picking failures. Dig-grasping was executed 37 times at 158 PPH. This helped achieve 138 PPH throughout the whole process, close to the best performance that our scooping can accomplish, according to Table II.

VI. CONCLUSION

In this study, we presented an approach to motion-control-based scooping that is suitable for picking relatively thin objects in a constrained workspace. Our mobility analysis justifies the novel use of a motion control scheme for scooping, and our system is arranged to implement the required motion, with demonstrated effectiveness and robustness.

3Full video available at https://youtu.be/A1oetsxHKOY
feedback for detecting contact geometry. Shown in this work, is conceivable using fingertip tactile with anthropomorphic, multi-phalanx fingers. Reactive and other than the one shown in this work, for example, a gripper point finger is motion-controlled with respect to the face of ing. The adoption of the simple gripper model, in which a advantage of a contact on the face also makes it possible to an object, as featured in this study, can be easier to target terms of gripper positioning, a contact on the top face of lends itself to a conventional motion-controlled gripper, with- out underactuated control or a compliant mechanism. In terms of gripper positioning, a contact on the top face of an object, as featured in this study, can be easier to target and reach than the side edges, as can be seen in Fig. [1] Taking advantage of a contact on the face also makes it possible to pick objects larger than the gripper’s opening range.

Our method does have limitations. If Assumption 1 is violated, although its viability has been demonstrated, a successful scoop will not happen. The mobility analysis requires accurate information about the object’s geometry.

B. Generalization

Possible directions for generalization include the follow- ing. The adoption of the simple gripper model, in which a point finger is motion-controlled with respect to the face of a thumb, makes it possible to apply a wide range of grippers other than the one shown in this work, for example, a gripper with anthropomorphic, multi-phalanx fingers. Reactive and spontaneous scooping, rather than the planned approach shown in this work, is conceivable using fingertip tactile feedback for detecting contact geometry.

REFERENCES


