Geometry-Based Manipulation through Robotic Caging

Yusuke MAEDA[1], Tomohiro ASAMURA[2], Tomohiro EGAWA[3], and Yuuri KURATA[4]

***Abstract*— Caging is a method to confine object configurations by a closed region made by robot bodies. It can be used as a substitute for or a complement to conventional grasping in robotic manipulation. Because caging is a geometrical concept, manipulation via caging falls into a class of "geometry-based manipulation." Geometry-based manipulation can be performed by position-controlled robots according to only geometrical information, which is a merit for the present level of robot technology. In this paper, we discuss three forms of geometry-based manipulation via caging: caging manipulation by robots and walls, in-hand caging manipulation, and caging-based grasping by robot fingers with soft skins. We present basic ideas and some experimental results of them.**

I. INTRODUCTION

Robotic caging [1] has been studied by many researchers [2]–[14]. and is becoming popular for real-world robotic manipulation [15] [16]. Recent advances in depth sensors and CAD technology enable robots to use accurate geometric models of objects, and robots are superior in position control. Thus robotic caging can be performed much easier than conventional grasping.

The easiness can be attributed to the geometric nature of caging. Even though manipulation is inherently mechanical, robots can cage objects geometrically under some assumptions. We call it "geometry-based manipulation." In this paper, we describe some examples of geometry-based manipulation via caging, which would expand robots' repertoire of manipulation.

II. ADVANTAGES OF CAGING

Caging has several advantages due to its geometric nature. Here we mention the following two among others:

Caging with Local Object Features. Objects can be caged with their local geometric features. For example, even if a part of the shape of an object is occluded and unknown, caging of its visible part may be possible. This would be useful to deal with real-world manipulation with imperfect knowledge. Moreover, we can make "caging-friendly" objects by adding small local features such as bumps and cavities.

Margin-Based Robust Caging. Considering margins of robot positions to guarantee caging, we can achieve robust caging to errors in robot control and geometric information of objects. Today's robots have high accuracy in their position control, relatively small margins would make caging very robust.

*This work was supported by JSPS KAKENHI Grant Number 22700200 and JKA's promotion funds from KEIRIN RACE.

[1]Yusuke MAEDA is with Division of Systems Research, Faculty of Engineering, Yokohama National University, 79-5 Tokiwadai, Hodogaya-ku, Yokohama, Japan maeda@ynu.ac.jp

[2]Tomohiro ASAMURA is with Mitsubishi Electric Corp., Japan

[3]Tomohiro EGAWA is with Okuma Corp., Japan

[4]Yuuri KURATA is with Graduate School of Engineering, Yokohama National University, Japan

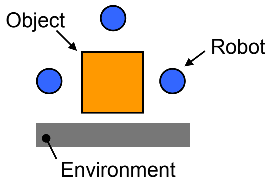


Fig. 1: Caging an object by robots and a wall

(a) (b) (c)

Fig. 2: Manipulation along a wall and a corridor

(a) (b) (c)

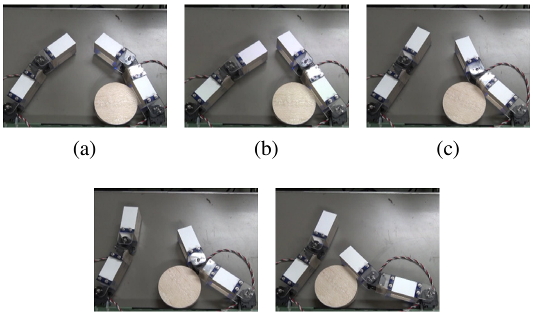
Fig. 3: Manipulation in an L-shaped corridor

III. CAGING BY ROBOTS AND WALLS

Caging is usually performed only by robots. However, objects can be caged not only by active robots, but also by passive entities such as walls (Fig. 1). Walls can help reduce the number of necessary robots for caging. Moreover, in narrow passages, robot-only caging may not be possible but robots with walls may be able to cage objects. Thus the authors studied robotic caging with walls [17] [18].

Using passive walls elicits the manipulability problem in caging. In robot-only caging performed with a fixed robot formation, manipulation is always possible and therefore the manipulability problem is trivial. On the other hand, in caging by robots and walls, a fixed robot formation is obviously not good enough; caging can be broken and manipulation may fail.

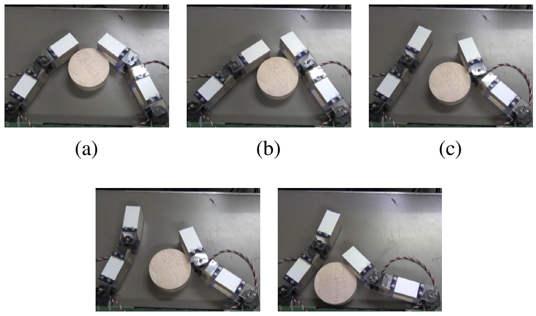
In [17] we derived a condition for the manipulability in caging by robots and walls. It formulates the manipulability in a broad sense; due to the difficulty in dealing with the



(a) (b) (c)

(d) (e)

Fig. 4: In-hand caging manipulation (right-to-left)



(a) (b) (c)

(d) (e)

Fig. 5: In-hand caging manipulation (top-to-left)

manipulability of the object, we formulated the changeability of the closed caging region. We developed an RRT-based motion planner based on the derived condition to manipulate objects to goal regions.

Fig. 2 and 3 show examples of manipulation by circular mobile robots. A bag on a circular tray was manipulated successfully. All the motions of the robots were generated by the above-mentioned motion planner. The robot formations were not fixed but caging was maintained throughout manipulation. Note that the object position was not sensed in the experiments; we do not need it for manipulation as far as caging is guaranteed.

In order to avoid jamming, contacts between the object and the robots and those between the object and the walls should be slippery.

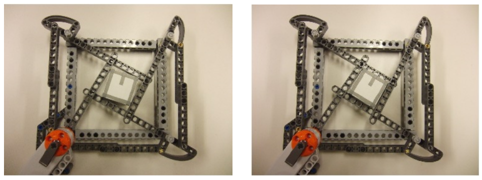
IV. In-Hand Caging Manipulation

In the previous section, we presented caging by mobile robots and walls. If we replace the robots and the walls with robot fingers and palms, respectively, another application of caging can be found. We call it "in-hand caging manipulation."

An object must be caged by robot fingers and a palm for in-hand caging manipulation. The fingers are position-controlled and change their configurations maintaining caging. As a result, the object can be manipulated in the hand. It does not require external sensors and can be used as a variant of sensorless manipulation [19].

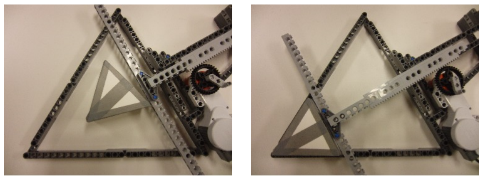
Fig. 4 and 5 shows examples of planar in-hand caging manipulation. A circular object was manipulated by a two-fingered hand. The finger motions were generated by our developed RRT-based planner. In the figures, the robot motions were identical but the initial positions of the object were different. Without sensing the object position, the object was successfully manipulated to the left-bottom corner in the hand in both cases. In order to reduce jamming, a heuristic algorithm was introduced in our RRT planner.

We also studied different special hands with lower degrees of freedom for in-hand caging manipulation. Some prototypes with LEGO Mindstorms can be found in Fig. 6 and 7. In these "hands," errors in the initial configuration of the object are tolerable to some extent and its possible configurations are narrowed through in-hand caging manipulation. Such minimalistic hands would be useful in some applications such as parts feeders. The hands can also be attached on robot arms to manipulate objects to arbitrary configurations.



(a) Initial (b) Goal

Fig. 6: 1-DOF hand for square objects



(a) Initial (b) Goal

Fig. 7: 1-DOF hand for triangular objects

V. Caging-Based Grasping by Rigid Fingers with Soft Skins

Objects in caging are freely movable in their caged regions, which may cause collisions in manipulation and inaccuracy in placing. A possible solution to the problem is transition from caging to grasping [13] [14]. However, grasping by position-controlled robot hands may lead to excessive internal force.

We proposed a different simple approach to grasping by position-controlled robot hands with the advantage of caging: caging-based grasping by a robot hand with rigid and soft parts [20] [21]. In our caging-based grasping, we use a robot hand with rigid fingers covered with soft skins (Fig. 8). When the following conditions hold, we call the situation "caging-based grasping":

1) Rigid-part caging condition: The object is caged in a closed region formed by the rigid parts of the robot hand.

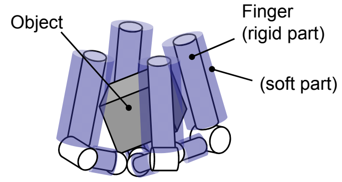
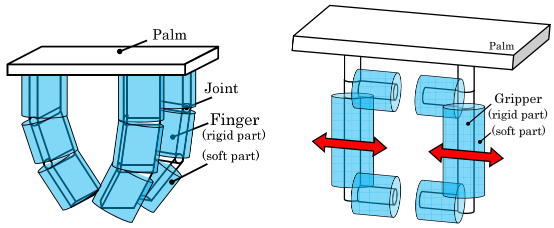


Fig. 8: Caging-based grasping



(a) Three-fingered articulated hand (b) Two-jaw parallel gripper

Fig. 9: Robot hands for caging-based grasping

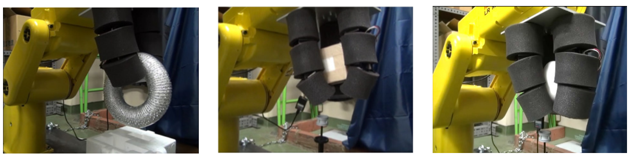
2) Soft-part deformation condition: Assuming that the soft parts of the robot hand become rigid, the closed region for caging becomes empty.

From the latter condition, the soft parts cannot keep their original shape and therefore deform as a reaction to the object. Thus the object is in compliant grasp by reaction forces of the deformed soft parts. Note that both of the above conditions can be tested geometrically and explicit mechanical analysis is not necessary.

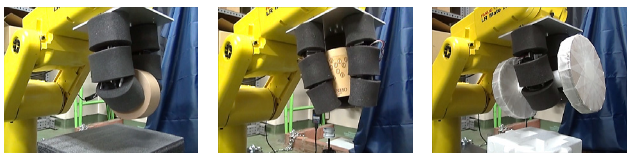
We derived concrete forms of the above conditions for many combinations of hands and objects in 2D and 3D (Fig. 9). Then the derived conditions were validated in experiments. A variety of objects were grasped and manipulated easily (Fig. 10 and 11).

VI. CONCLUSION

In this paper, we presented some forms of manipulation via caging. Those are not humanlike but suitable to today's robots due to their geometry-based nature. We hope such geometry-based manipulation techniques will lead to a wider variety of dexterity of robots.



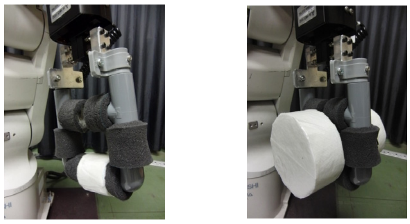
(a) Torus (b) Cuboid (c) Ellipsoid



(d) Hollow cylinder (e) Solid cylinder (f) Dumbbell-shaped

Fig. 10: Caging-based grasping by a two- or three-fingered articulated hand

(a) Sphere (b) Torus (c) Hollow cylinder



(d) Bottomed hollow cylinder (e) Dumbbell-shaped

Fig. 11: Caging-based grasping by a two- or four-jaw gripper

REFERENCES

[1] E. Rimon and A. Blake, "Caging planar bodies by one-parameter two-fingered gripping systems," *Int. J. of Robotics Research*, vol. 18, no. 3, pp. 299–318, 1999.

[2] A. Sudsang, J. Ponce, and N. Srinivasa, "Grasping and in-hand manipulation: experiments with a reconfigurable gripper," *Advanced Robotics*, vol. 12, no. 5, pp. 509–533, 1998.

[3] ——, "Grasping and in-hand manipulation: Geometry and algorithms," *Algorithmica*, vol. 26, no. 4, pp. 466–493, 2000.

[4] J. Spletzer, A. K. Das, R. Fierro, C. J. Taylor, V. Kumar, and J. P. Ostrowski, "Cooperative localization and control for multi-robot manipulation," in *Proc. of 2001 IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, 2001, pp. 631–636.

[5] A. Sudsang, F. Rothganger, and J. Ponce, "Motion planning for disc-shaped robots pushing a polygonal object in the plane," *IEEE Trans. on Robotics and Automation*, vol. 18, no. 4, pp. 550–562, 2002.

[6] Z. Wang and V. Kumar, "Object closure and manipulation by multiple cooperating mobile robots," in *Proc. of IEEE Int. Conf. on Robotics and Automation*, 2002, pp. 394–399.

[7] J. Erickson, S. Thite, F. Rothganger, and J. Ponce, "Capturing a convex object with three discs," *IEEE Trans. on Robotics*, vol. 23, no. 6, pp. 1133–1140, 2007.

[8] M. Vahedi and A. F. van der Stappen, "Caging polygons with two and three fingers," *Int. J. of Robotics Research*, vol. 27, no. 11-12, pp. 1308–1324, 2008.

[9] S. Makita and Y. Maeda, "3D multifingered caging: Basic formulation and planning," in *Proc. of IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, 2008, pp. 2697–2702.

[10] R. Fukui, T. Mori, and T. Sato, "Application of caging manipulation and compliant mechanism for a container case hand-over task," in *Proc. of IEEE Int. Conf. on Robotics and Automation*, 2010, pp. 4511–4518.

[11] S. Makita, T. Watanabe, and Y. Maeda, "3D multifingered caging —derivation of sufficient conditions for four kinds of simple-shaped objects by a symmetric robot hand—," *J. of Robotics Soc. of Japan*, vol. 28, no. 5, pp. 599–605, 2010, (in Japanese).

[12] P. Pipattanasomporn and A. Sudsang, "Two-finger caging of nonconvex polytopes," *IEEE Trans. on Robotics*, vol. 27, no. 2, pp. 324–333, 2011.

[13] A. Rodriguez, M. T. Mason, and S. Ferry, "From caging to grasping," *Int. J. of Robotics Research*, vol. 31, no. 7, pp. 886–900, 2012.

[14] W. Wan, R. Fukui, M. Shimosaka, T. Sato, and Y. Kuniyoshi, "Grasping by caging: A promising tool to deal with uncertainty," in *Proc. of IEEE Int. Conf. on Robotics and Automation*, 2012, pp. 5142–5149.

[15] S. S. Srinivasa, D. Ferguson, C. J. Helfrich, D. Berenson, A. Collet, R. Diankov, G. Gallagher, G. Hollinger, J. Kuffner, and M. V. Weghe, "HERB: a home exploring robotic butler," *Autonomous Robots*, vol. 28, no. 1, pp. 5–20, 2010.

[16] J. A. Stork, F. T. Pokorny, and D. Kragic, "A topology-based object representation for clasping, latching and hooking," in *IEEE-RAS Int. Conf. on Humanoid Robots*, 2013.

[17] R. Yokoi, T. Kobayashi, and Y. Maeda, "2D caging manipulation by robots and walls," in *Proc. of IEEE Int. Symp. on Assembly and Manufacturing*, 2009, pp. 16–21.

[18] R. Yokoi, Y. Maeda, and T. Kobayashi, "Formulation and planning of planar caging manipulation by robots and walls," *Trans. of Japan Soc. of Mechanical Engineers, Series C*, vol. 76, no. 770, pp. 2671–2677, 2010, (in Japanese).

[19] M. A. Erdmann and M. T. Mason, "An exploration of sensorless manipulation," *IEEE J. of Robotics and Automation*, vol. 4, no. 4, pp. 369–379, 1988.

[20] Y. Maeda, N. Kodera, and T. Egawa, "Caging-based grasping by a robot hand with rigid and soft parts," in *Proc. of 2012 IEEE Int. Conf. on Robotics and Automation*, 2012, pp. 5150–5155.

[21] T. Egawa and Y. Maeda, "2D and 3D caging-based grasping of objects in various shapes," in *IROS2013 Workshop on Caging and Its Applications in Grasping/Multi-agent Cooperation*, 2013.