Two- and Three-dimensional Caging-Based Grasping of Objects of Various Shapes with Circular Robots and Multi-Fingered Hands

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Background: Grasping vs. Caging

- **Conventional Grasping**
  - Object is localized
  - Need for force control

- **Conventional Caging [Rimon 99]**
  - Object is movable
  - No need for force control
Caging

- Easily executed by today’s robots
- But… object movement is not allowed in some applications
  - Possible inaccurate object placement
  - Possible collisions
Motivation

- To establish a new approach to grasping with the merit of caging:

  “Caging-based grasping”

  [Maeda 2012 ICRA]
What is caging-based grasping?

- A robot hand with rigid and soft parts is used
  - Rigid parts cage the object
  - Soft parts achieve a complete grasp by their deformation
Merit of caging-based grasping

- Grasping by position-controlled hands
  - No need for force sensing/control
  - Only **geometrical analysis** is necessary to achieve grasping
Previous studies on grasping by position-controlled hands

- Compliant grasps
  (e.g., [Cutkosky and Kao 89] [Inoue and Hirai 08])

- No need for force sensing or explicit force control
- **Mechanical analysis** on grasp stability is necessary to guarantee successful grasping
Objective

• Only two cases are considered in our previous study [Maeda 2012 ICRA]

2D Grasping of circular objects by three circular robots

3D Grasping of spherical objects by a three-fingered hand

Caging-based grasping of various objects by various hands
Robot hands considered (for 2D grasps)

• Two or three circular robots (circular “fingers”)
Robot hands considered (for 3D grasps)

- For 3D grasps
  - Two- or three-fingered articulated hands
  - Two- or four-jaw parallel grippers (1 DOF)
Objects considered

- For 2D grasps
  - Graspable
  - Appropriate as shape primitives

- For 3D grasps
  - Graspable
  - Appropriate as shape primitives
Definition of caging-based grasping

- **Rigid-part caging condition**
  - To make the object caged
    - Closed-region formation
    - Object inside
    - No interference

- **Soft-part deformation condition**
  - To complete grasping
Rigid-part caging condition

- **Closed-region formation**
  The closed region through which the object cannot pass is formed by the rigid parts of the hand.

- **Object inside**
  The object is in the closed region formed by the rigid parts of the hand.

- **No interference**
  The rigid parts of the hand do not overlap with the object.
Soft-part deformation condition

Assuming that the soft parts of the hand become rigid, the object cannot exist in the closed region for caging.

1. Soft parts deform
2. Reaction forces are applied to the object
3. Grasping is achieved
Derivation of concrete conditions of caging-based grasping

- We need conditions of caging-based grasping in a concrete form for each combination of a robot hand and an object
- Sufficient conditions were derived
- Example: 2D grasp of a T-shaped object by three circular robots
Sufficient condition for 2D caging-based grasping of a T-shaped object (1/2)

Rigid-part caging condition

Closed region formation

- Robot (rigid part)
- Inter-robot distance must be upper-bounded

Object inside

- The robots must be in each of the shaded regions

Closed region formation

Closed region

Object inside

Closed region
Sufficient condition for 2D caging-based grasping of a T-shaped object (2/2)

No interference

Gap between the soft parts

(width of the T-shaped object)

(soft part)

(checked by a collision detection library)
Experiments of 2D caging-based grasping by circular robots

- iRobot Create covered with polyurethane foams
- Moving the robots concurrently by open-loop control
Experiments of 2D caging-based grasping of objects in various shapes

Caging-based grasping was achieved based on our derived conditions:

- L-shaped
- square U-shaped
- rectangle
- H-shaped
- cross-shaped
- triangle (approximated by circle)
Experimental setup of multifingered articulated hands

- 6-DOF Manipulator (Fanuc LR Mate 200i)
- Articulated hand
  - Two or three 2-DOF fingers
  - Soft parts: urethane foam
Experiments of 3D caging-based grasping by articulated multifingered hands

- Conventional caging
- Caging-based grasping

Hollow cylinder
Solid cylinder
Experiments with articulated multifingered hands

Caging-based grasping was achieved based on our derived conditions

cuboid
dumbbell-shaped
bulb-shaped (sphere + cylinder)
torus
egg-shaped (approximated by sphere)
Experimental setup of multi-jaw grippers

- 6-DOF manipulator
  (Mitsubishi RV-1A)
- 1-DOF gripper
  (Mitsubishi 4A-HM01)
- Rigid parts: PVC pipes
- Soft parts: polyurethane foam
Experiments with multi-jaw grippers

conventional caging

![Image of conventional caging]

caging-based grasping

![Image of caging-based grasping]

torus

cuboid
Experiments with multi-jaw grippers

Caging-based grasping was achieved based on our derived conditions
Conclusion

- We achieved caging-based grasping of various objects by circular robots, multi-fingered articulated hands and multi-jaw grippers
- Grasping based on only geometrical information is possible using theoretically driven conditions

Future Work

- Stable picking and placing
- How to select appropriate soft parts
- Application to various tasks