Caging-Based Grasping by a Robot Hand with Rigid and Soft Parts

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Background: Grasping vs. Caging

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

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

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

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

  "Caging-based grasping"
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 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 achieve grasping
Definition of caging-based grasping

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

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

Both of the above geometrical conditions hold

Grasping is achieved
An example of 2D caging-based grasping

- Grasping a circular object by three circular robots

![Diagram showing three circular robots forming a cage around a circular object.](image-url)
Rigid-part caging condition

\[
\left\{ \begin{array}{l}
2r_{\text{rigid}} \leq d_{ij} \\
< 2(R_{\text{obj}} + r_{\text{rigid}}) \\
\theta_{12} + \theta_{23} + \theta_{31} \leq \pi
\end{array} \right.
\]
Soft-part deformation condition

\[ r_{\text{soft}} + R_{\text{obj}} \]

\[ \theta'_{12} + \theta'_{23} + \theta'_{31} > \pi \]

\[
\begin{cases}
2r_{\text{rigid}} \leq d_{ij} < 2(R_{\text{obj}} + r_{\text{rigid}}) \\
(i \neq j)
\end{cases}
\]

\[
\theta_{12} + \theta_{23} + \theta_{31} \leq \pi
\]

\[
\theta'_{12} + \theta'_{23} + \theta'_{31} > \pi
\]
2D caging-based grasping: Experiments

Mobile robots: iRobot Create
Object: styrene foam (used as a pallet)
Soft parts: Urethane foam
Typical types of 3D multifingered caging [Makita et al. 10]

Envelope-type Caging

Ring-type Caging

Waist-type Caging
Typical types of 3D caging-based grasping

- Envelope-type caging-based grasping
- Ring-type caging-based grasping
- Waist-type caging-based grasping
Caging-based grasping using local geometric features

- Example: local hollows on the object enable caging-based grasping

Ring-type caging-based grasping
An example of 3D caging-based grasping

- Grasping a sphere by a symmetric hand
  - Rigid parts: cuboid links
  - Soft parts: cylindrical skins

![Diagram of caging-based grasping](image-url)
Derivation of sufficient condition for caging-based grasping

Focus on the cross section that has the maximal gap between fingers

- link (rigid part)
- soft part
A sufficient condition for rigid-part caging

\[ L < 2R_{\text{obj}} \]

\[ d_{\text{tip}} < \sqrt{3}R_{\text{obj}} \]
A sufficient condition for soft-part deformation

\[ \sqrt{3}(a + R_{\text{obj}}) > D \]
A sufficient condition for caging-based grasping

\[ R_{\text{obj}} > \max \left( \frac{d_{\text{tip}}}{\sqrt{3}}, \frac{L}{2}, \frac{D}{\sqrt{3}} - a \right) \]

\[ L < 2R_{\text{obj}} \]

\[ \sqrt{3}(a + R_{\text{obj}}) > D \]

\[ d_{\text{tip}} < \sqrt{3}R_{\text{obj}} \]
3D caging-based grasping: Experiments

- Three-fingered hand with semicylindrical soft parts
Pick-and-place demonstration

Caging

Caging-based grasping
Summary

- A new and simple approach to grasping by position-controlled robot hands: “caging-based grasping” was proposed.
  - Conditions for 2D and 3D caging-based grasping were derived.
  - Experimental validation of caging-based grasping was performed for a 2D case (with mobile robots) and a 3D case (with a multifingered hand).
Future work

- Application to objects in various shapes
- Application to various robot hands