3D Multifingered Caging: Basic Formulation and Planning

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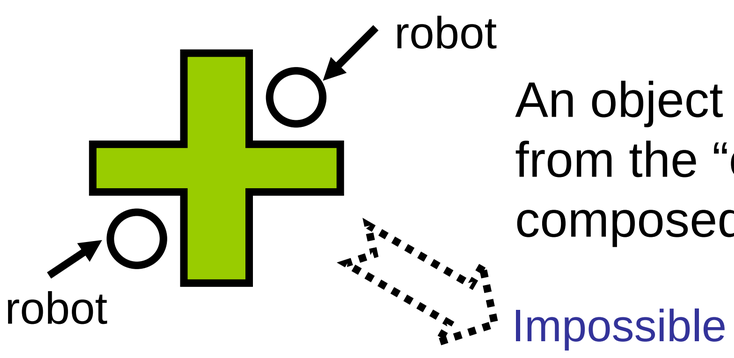
What is "Caging"?

⇨ A kind of object constraining



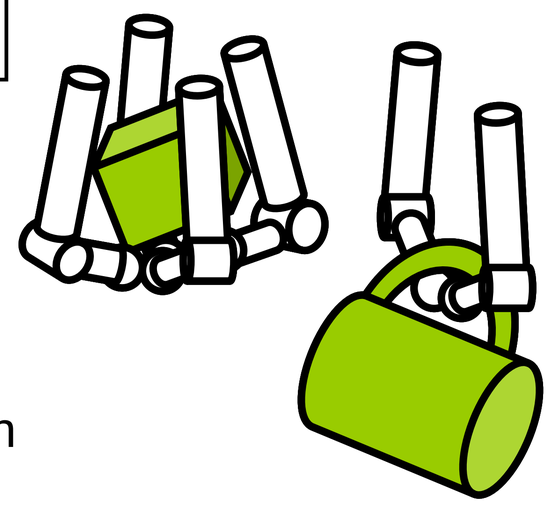
An object cannot escape from the "cage" composed of robots

Previous works:
only 2D caging and 2D-approximated 3D caging
(Using mobile robots or circular fingers)

What is "3D Multifingered Caging"?

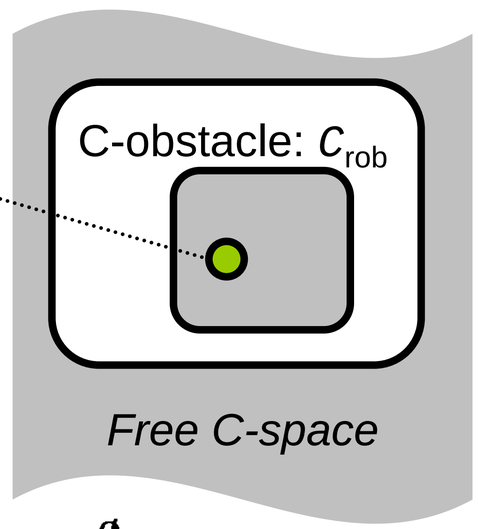
Completely 3-dimensional caging by a multifingered hand

- Position-controlled hand can constrain an object **(Force control is not necessary)**
- A hand with low degrees of freedom can constrain an object
- Errors of modeling and/or position control are allowed to some extent considering caging margin



Formulation

Object configuration: $\boldsymbol{q}_{obj}$



A subset of free C-space including $\boldsymbol{q}_{obj}$, C_{free_obj}, is entirely closed by C-obstacle, C_{rob}

⇨ $\mathcal{C}_{free\_obj} \cap \mathcal{C}_{free\_inf} = \emptyset$

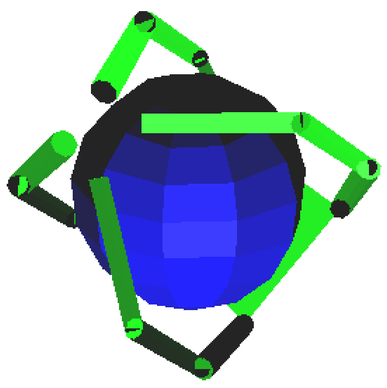
C_{free_inf} is a subset of free C-space including a point at infinity

Planning procedure (RRT-based)

1. Set initial configuration of path branches, $\boldsymbol{z}_{ini}$
2. Generate a random configuration, $\boldsymbol{z}_{rand}$
3. Find the nearest neighbor, $\boldsymbol{z}_{near}$ from the path branches
4. Generate a candidate configuration, $\boldsymbol{z}_{cand}$, between $\boldsymbol{z}_{rand}$ and $\boldsymbol{z}_{near}$
5. Check whether a robot has collision with an object at $\boldsymbol{z}_{cand}$
6. Add $\boldsymbol{z}_{cand}$ to the path branches as a new configuration, $\boldsymbol{z}_{new}$
7. Repeat the steps from 2 to 6 until $\boldsymbol{z}_{new}$ satisfies **sufficient conditions for caging**

Planning of robot hand configuration

Caging a sphere



[Sufficient conditions]

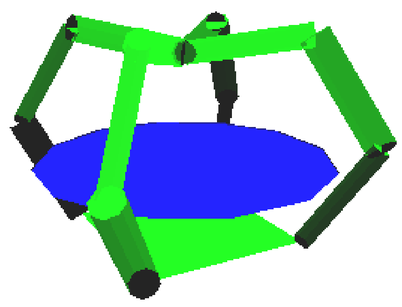
Every face among robot fingers is covered by obstacle region

$$\frac{r_{sphere}}{\sqrt{1-\left(\frac{d_j(\bar{\theta})-d_{j+1}(\bar{\theta})}{2l_j}\right)^2}} > \max\left(\frac{d_j(\bar{\theta})}{2}, \frac{d_{j+1}(\bar{\theta})}{2}\right)$$

[Results]

$$\bar{\theta} = [1.06, 1.10, 0.55]^T \text{[rad]}$$

Caging a disk

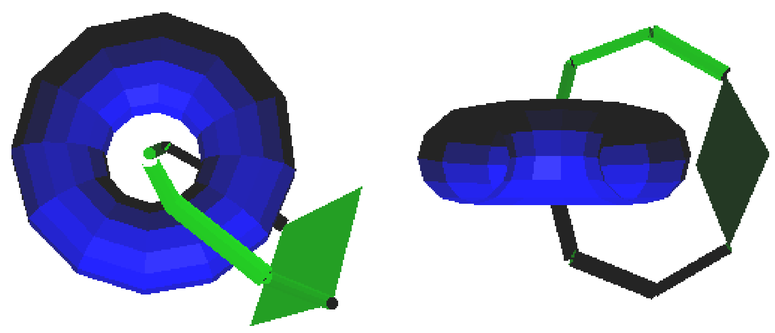


Every distance between each joint and/or each fingertip is shorter than the diameter of the disk

$$d_{ijik}(\bar{\theta}) < 2r_{disk} \quad (k \neq j)$$
$$d_{ij(i+1)k}(\bar{\theta}) < 2r_{disk}$$

$$\bar{\theta} = [0.99, 1.16, 1.15]^T \text{[rad]}$$

Caging a ring-like object (torus)



The distance between each fingertip is shorter than the diameter of the ring

$$d_{L+1}(\bar{\theta}) < d_{ring}$$

$$\bar{\theta} = [1.08, 0.88, 0.93]^T \text{[rad]}$$

Ongoing and future work

- Caging a complex-shaped object
- Planning both hand approaching motion and finger configuration
- Caging in practical environment with a manipulator and a hand