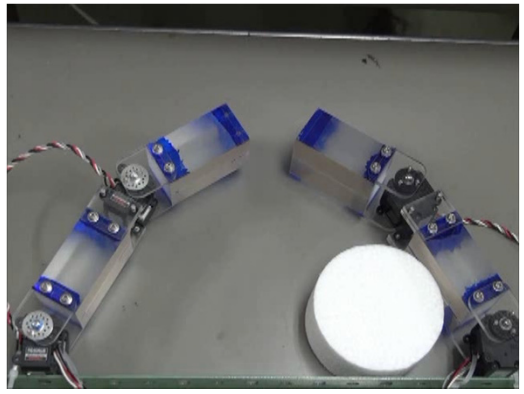
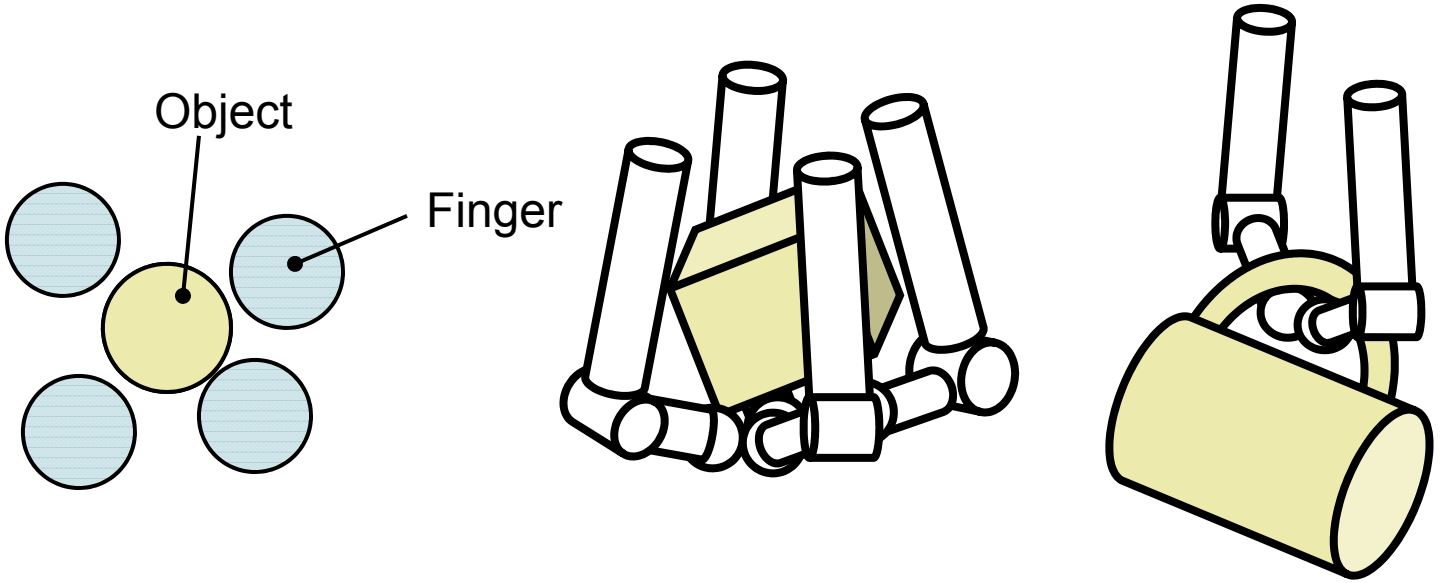
Sensorless In-hand Caging Manipulation

*Yusuke MAEDA
(Yokohama National University)
Tomohiro ASAMURA
(Mitsubishi Electric Corp.)



Robotic Caging

- Caging: To capture an object in a closed region composed by robot bodies
  - Geometry-based
  - No need for force control or force sensing



Geometry-based Manipulation

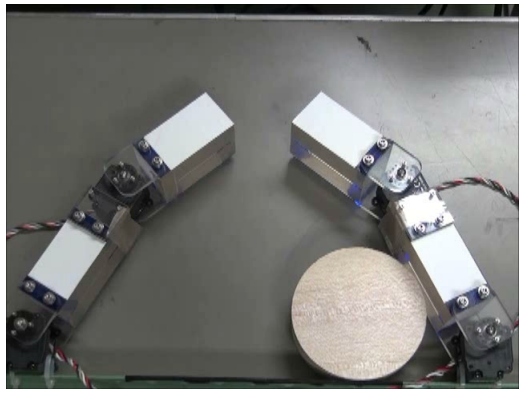
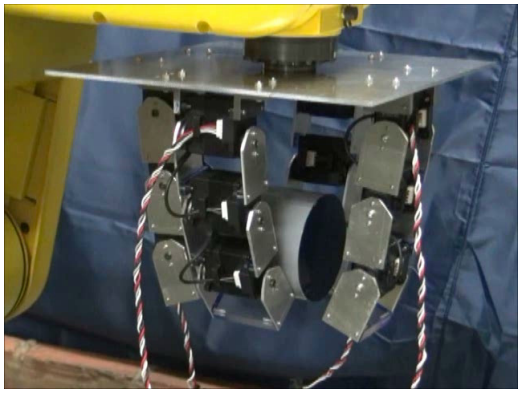
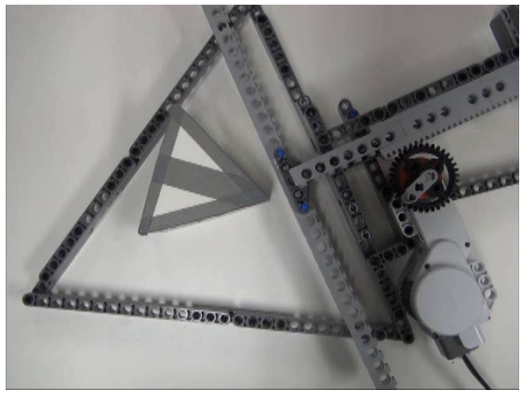
- Geometry-based manipulation like caging is easy and useful
  - Superiority of robots in position control
  - Recent advances in cameras, depth sensors, CAD technologies, etc.
- Force sensing/control is still difficult

Motivation

- Explore **new** forms of geometry-based manipulation via caging
  - would expand robots' repertoire of manipulation
  - may not be humanlike, but can be suitable to today's robots

In-hand caging manipulation

- In-hand manipulation with objects caged

Objective

Formulate a new manipulation methodology:
"in-hand caging manipulation"

- In-hand manipulation of a caged object by changing the shape of the cage

⇨
- In-hand manipulation with position control
- "Sensorless": Without exteroceptive sensors

Related Works (Caging with dynamic robot formation)

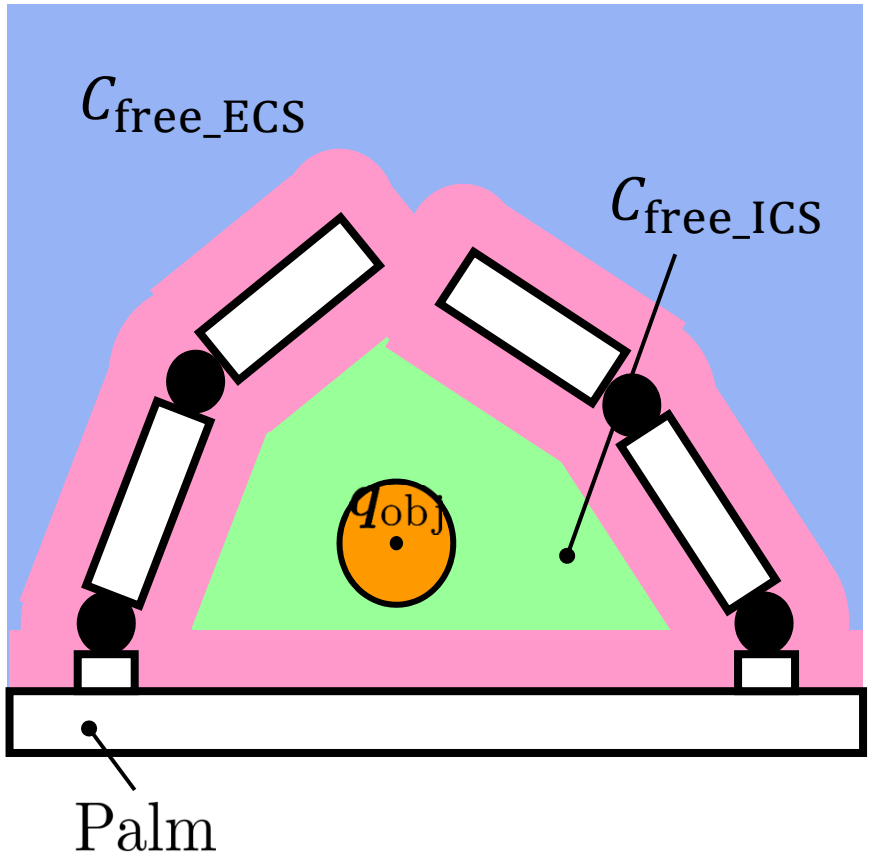
- [Sudsang et al. 2002]
  Caging manipulation by disk-shaped robots
- [Yamawaki and Yashima 2013]
  Planar whole arm manipulation in which caging is used partially
- [Yokoi et al. 2009] Caging manipulation by disk-shaped robots and walls

Caging Condition

$$\begin{cases} \mathcal{C}_{\text{free\_ICS}} \neq \emptyset \\ \boldsymbol{q}_{\text{obj}} \in \mathcal{C}_{\text{free\_ICS}} \end{cases}$$

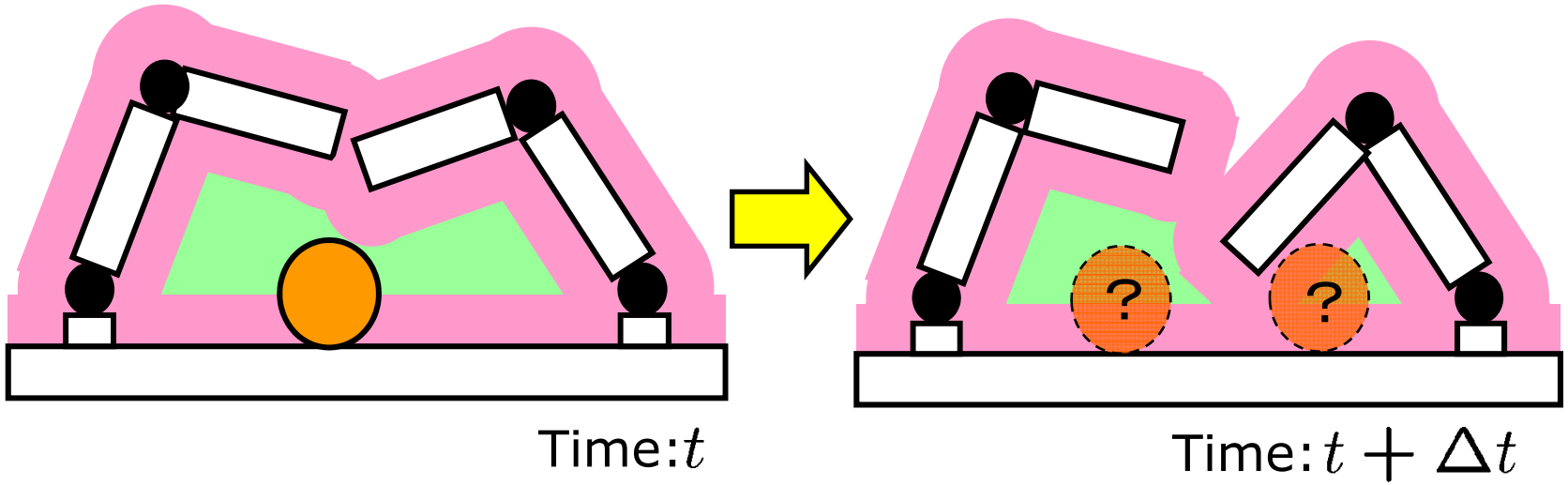
$\mathcal{C}_{\text{free\_ICS}}$: (free) inescapable configuration space of object

$\mathcal{C}_{\text{free\_ECS}}$: (free) escapable configuration space of object

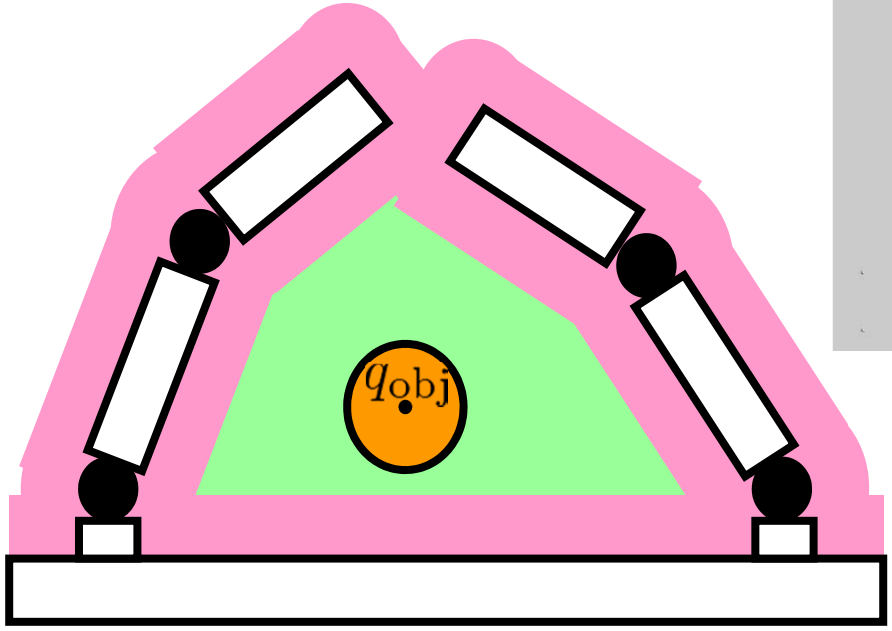


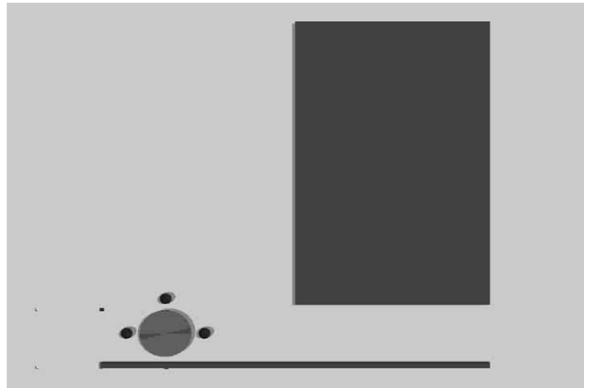
Possible Manipulation Failures

- Discontinuous shrinkage or split of ICS may lead to manipulation failures
  - Note: system is sensorless



Manipulability Condition [Yokoi 2010 ISAM]



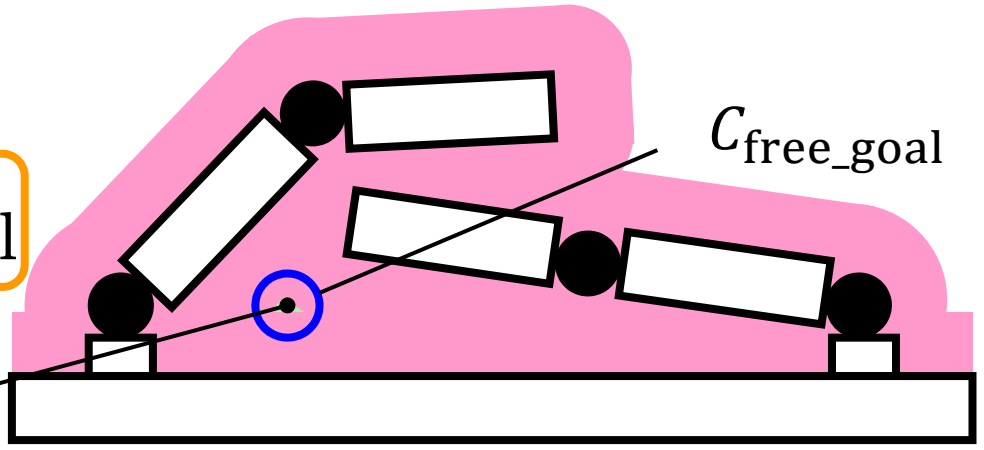


$$\lim_{\Delta t \to +0} \left(\mathcal{C}_{\mathrm{free\_ICS}}(t) \cap \mathcal{C}_{\mathrm{free\_ICS}}(t + \Delta t) \right) = \mathcal{C}_{\mathrm{free\_ICS}}(t)$$

Manipulation Planning: Problem Statement

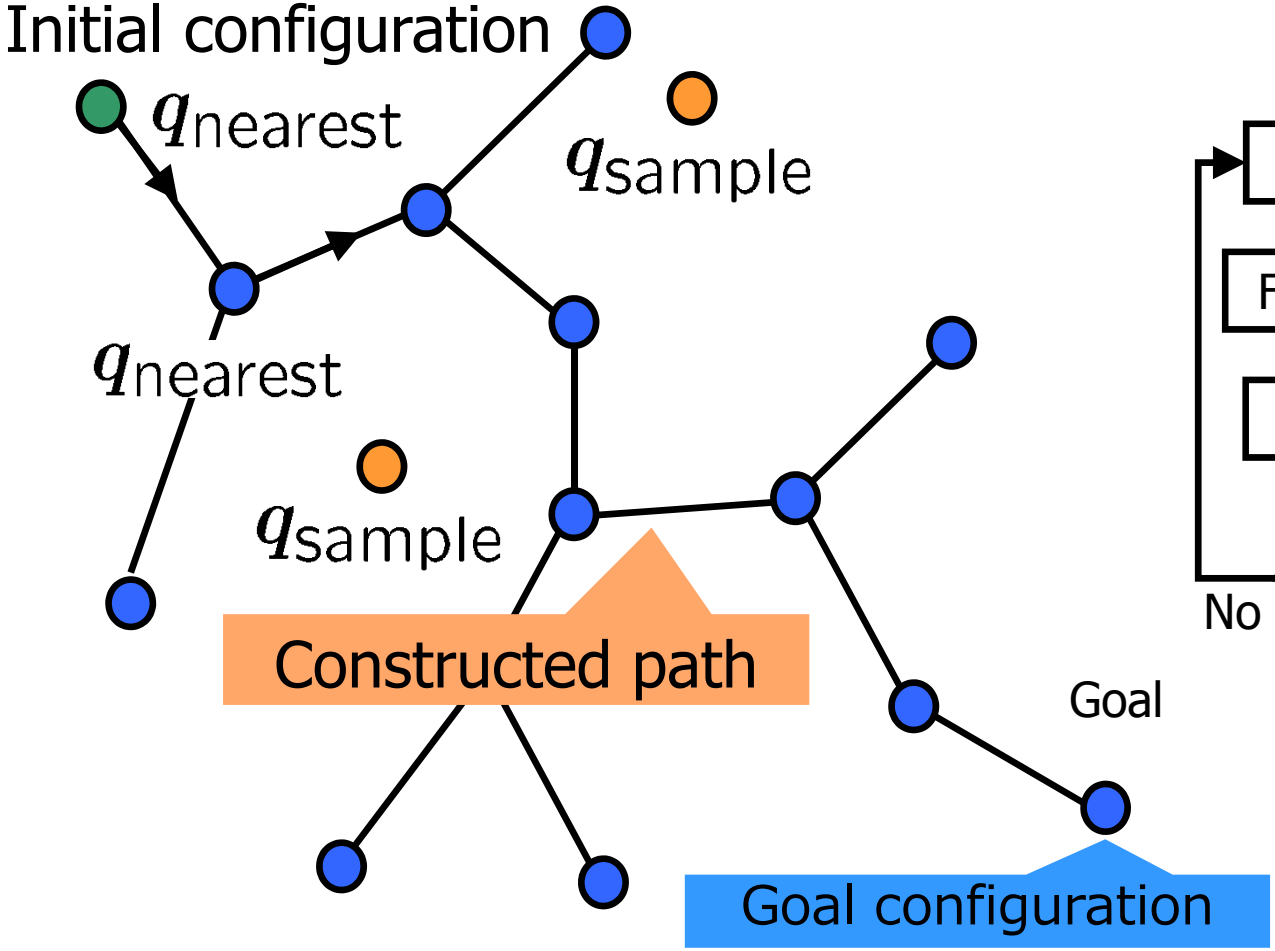
- Assumptions
  - Planar two-fingered hand (4 dof)
  - Circular object
  - The object is initially caged but its position is unknown
- Goal

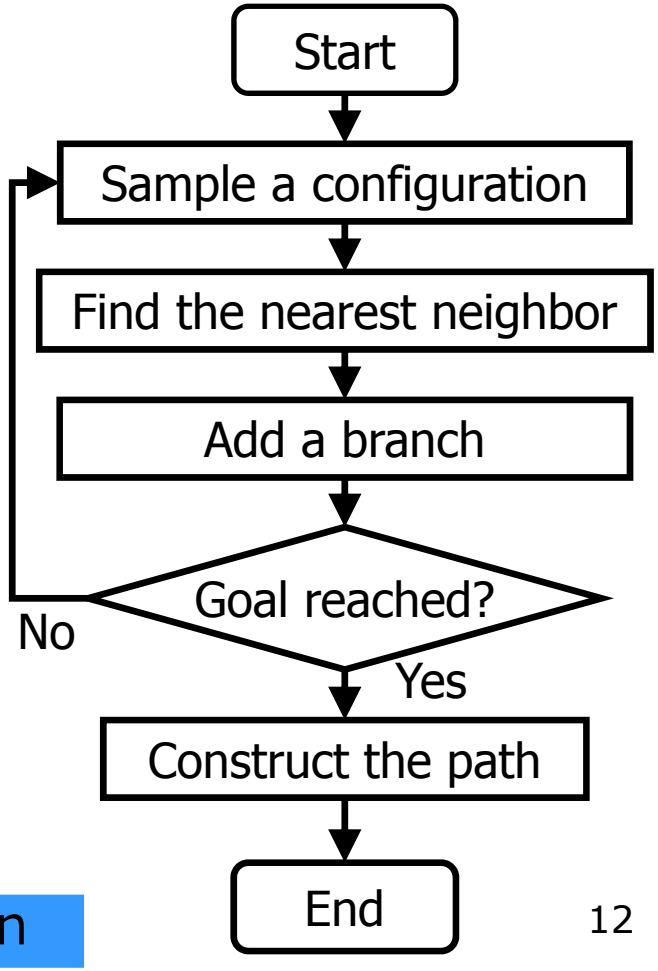
$$\mathcal{C}_{\text{free\_ICS}} \subseteq \mathcal{C}_{\text{free\_goal}}$$



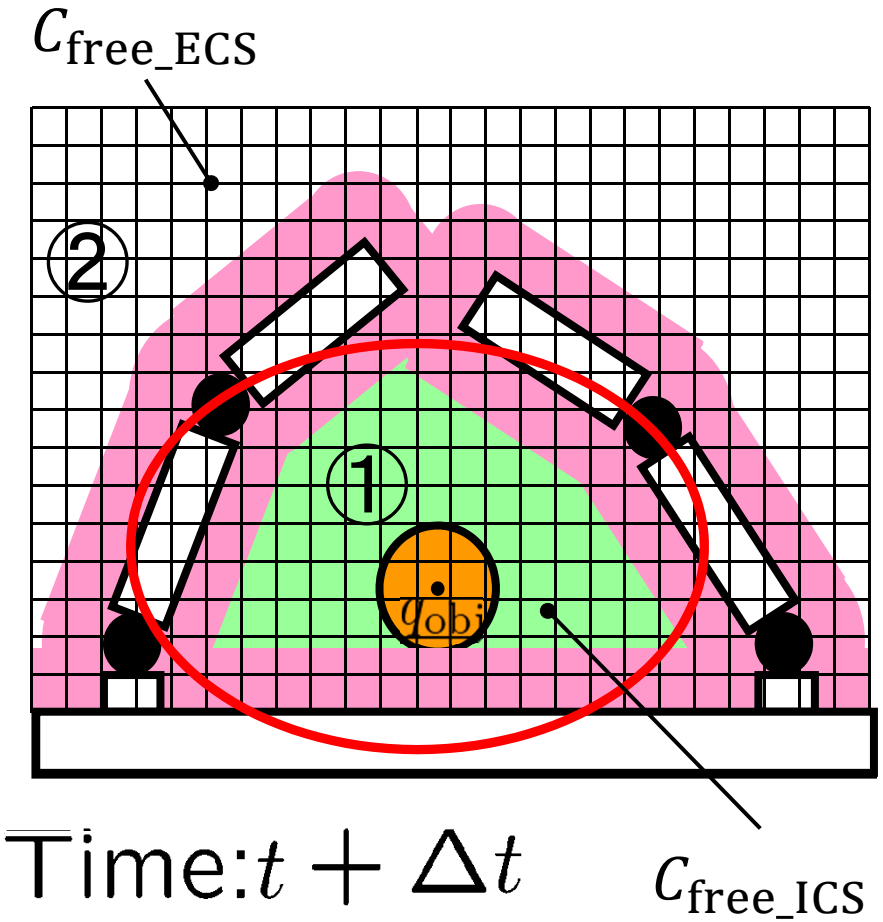
Manipulation Planning: RRT-based Algorithm

RRT: Rapidly-exploring Random Trees [LaValle 01]





Grid-based Caging and Manipulability Test



Identify C_{free_ICS} at Time t by labeling

⇩

Identify C_{free_ICS} at Time $t+\Delta t$ by labeling (Caging Test)

⇩

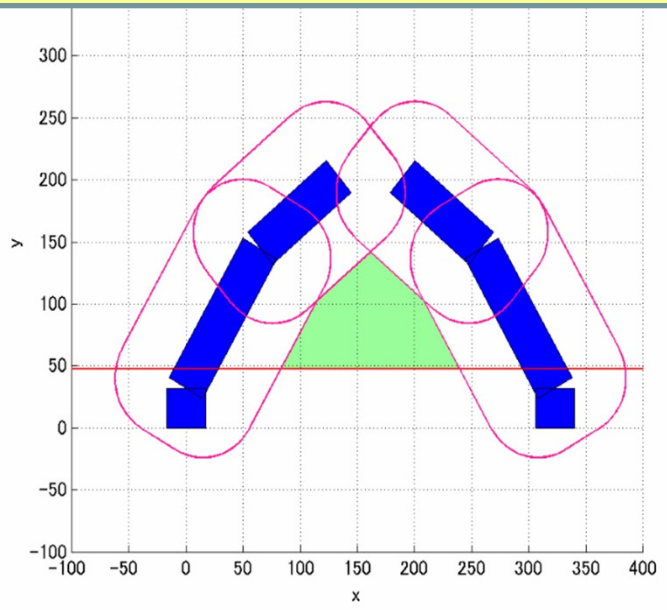
Calculate intersection between $C_{free\_ICS}(t)$ and $C_{free\_ICS}(t+\Delta t)$

⇩

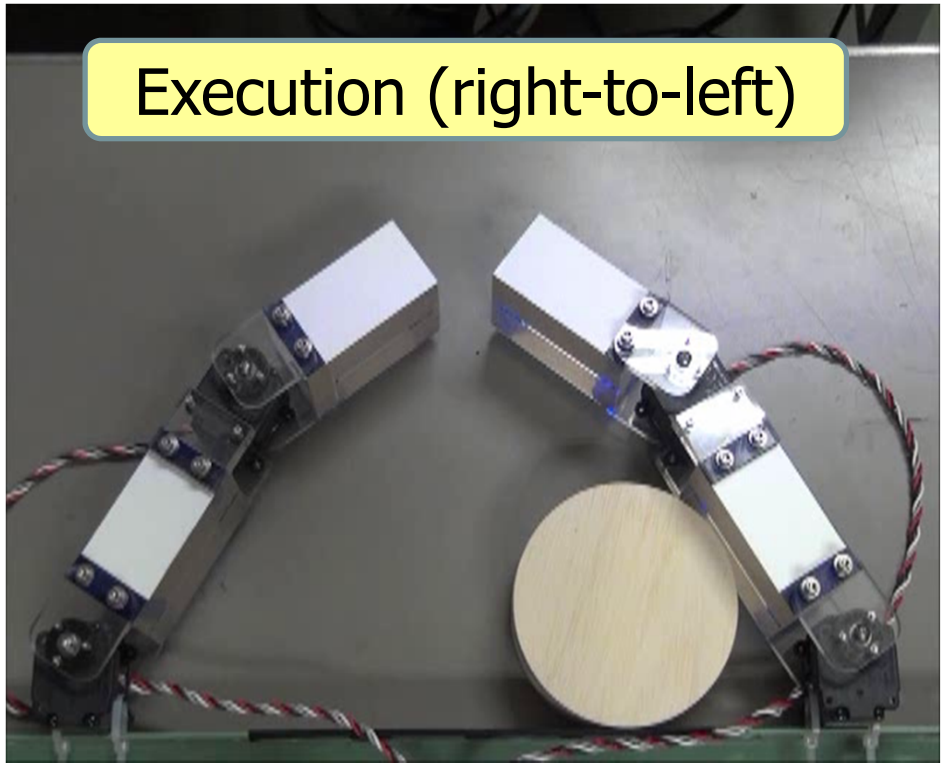
Check discontinuous shrinkage and split of C_{free_ICS} (Manipulability test)

Preliminary Experimental Result

Planned Manipulation (to left)



Execution (right-to-left)



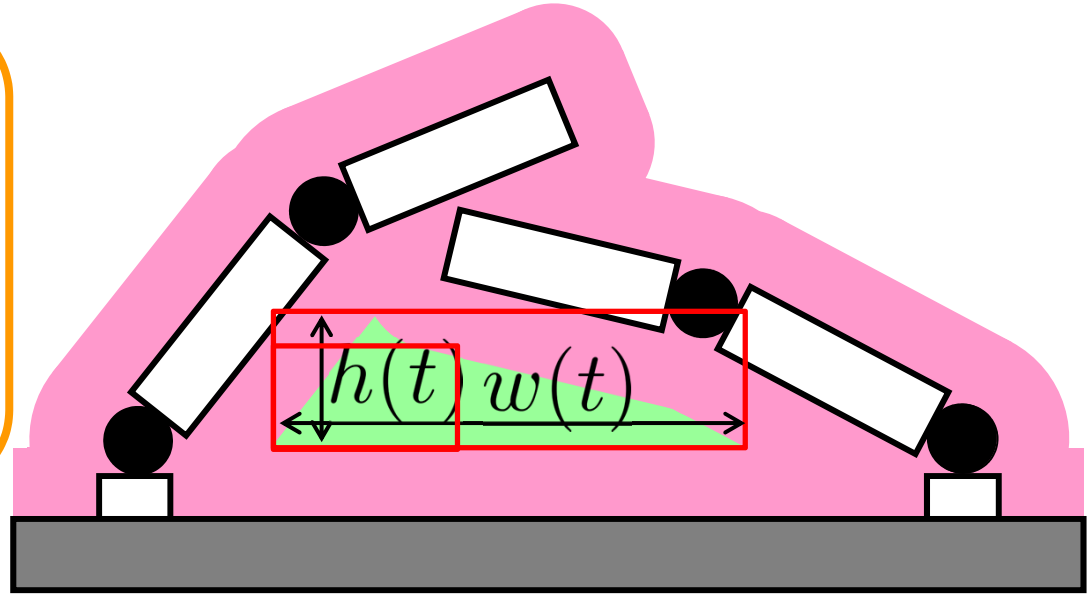
Jamming
(initial position dependent)

×4

Heuristics for Jamming Avoidance

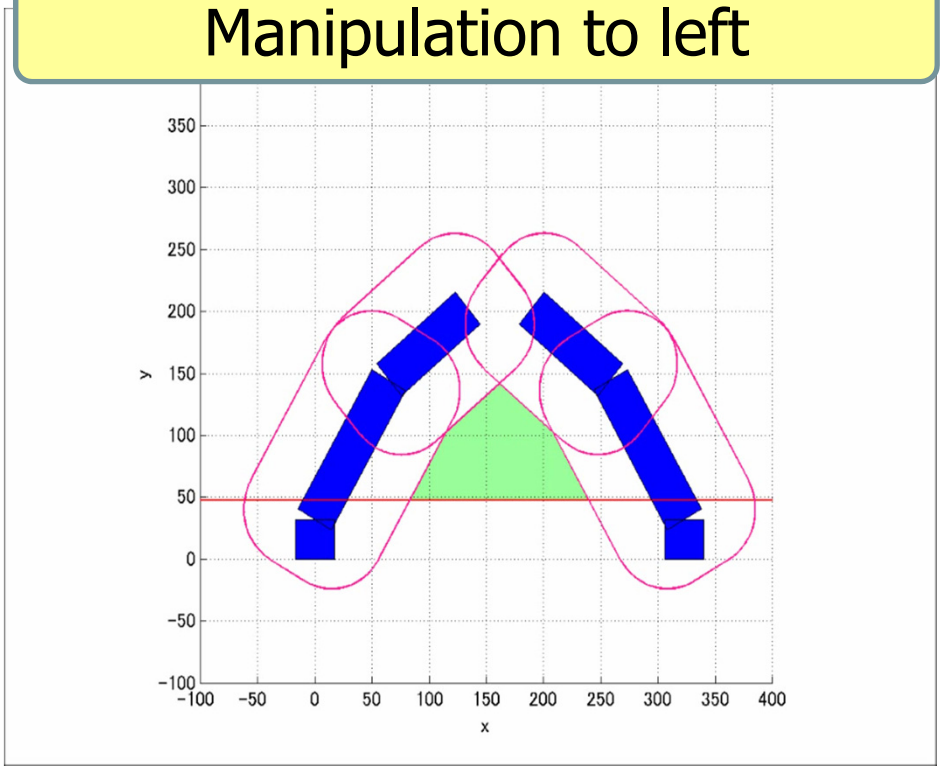
- Necessary condition on bounding box of ICS

$$\begin{cases} \dfrac{w(t+\Delta t)}{w(t)} > b \\ \dfrac{h(t+\Delta t)}{h(t)} > b \end{cases}$$

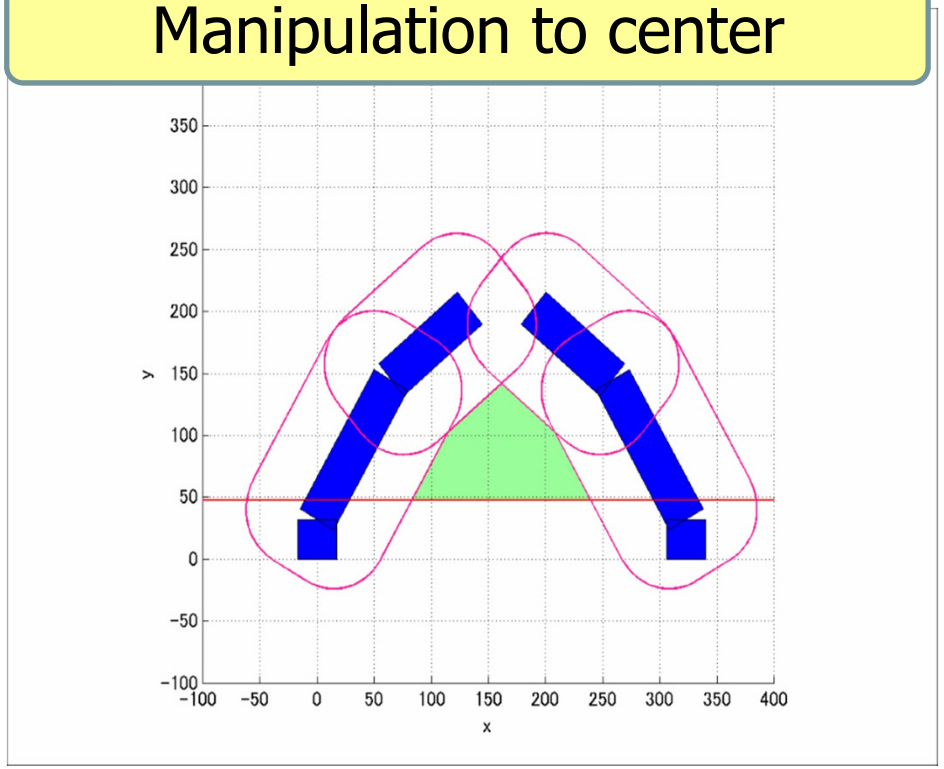


Example Manipulation Plans

Manipulation to left

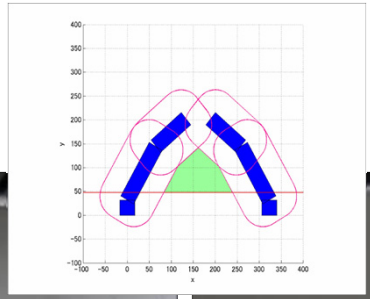


Manipulation to center

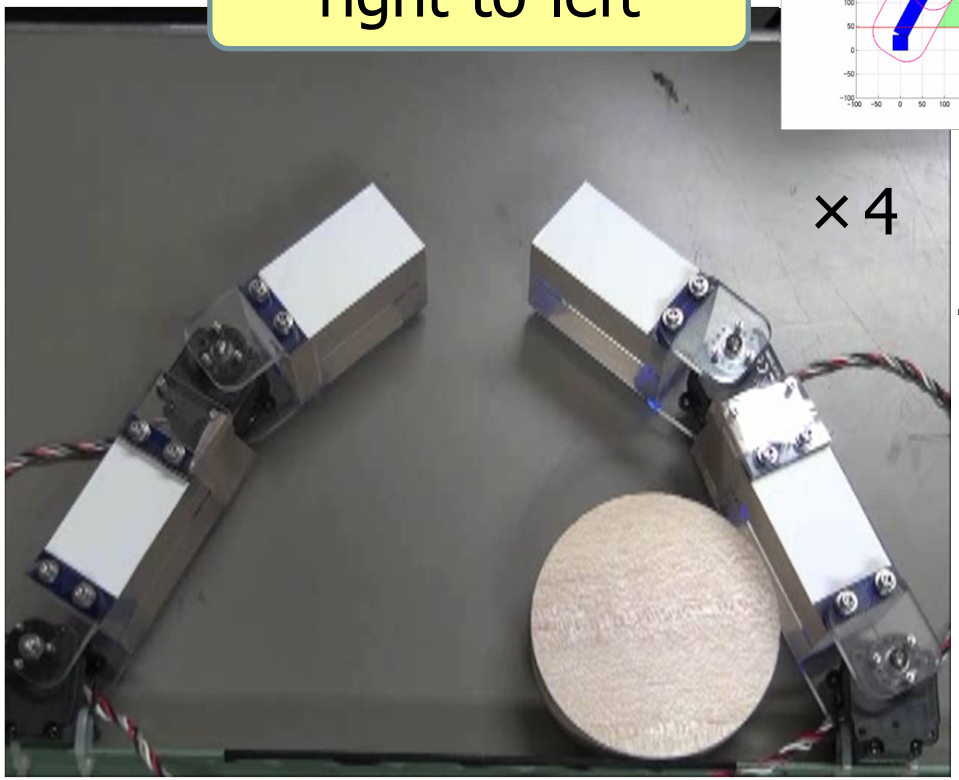


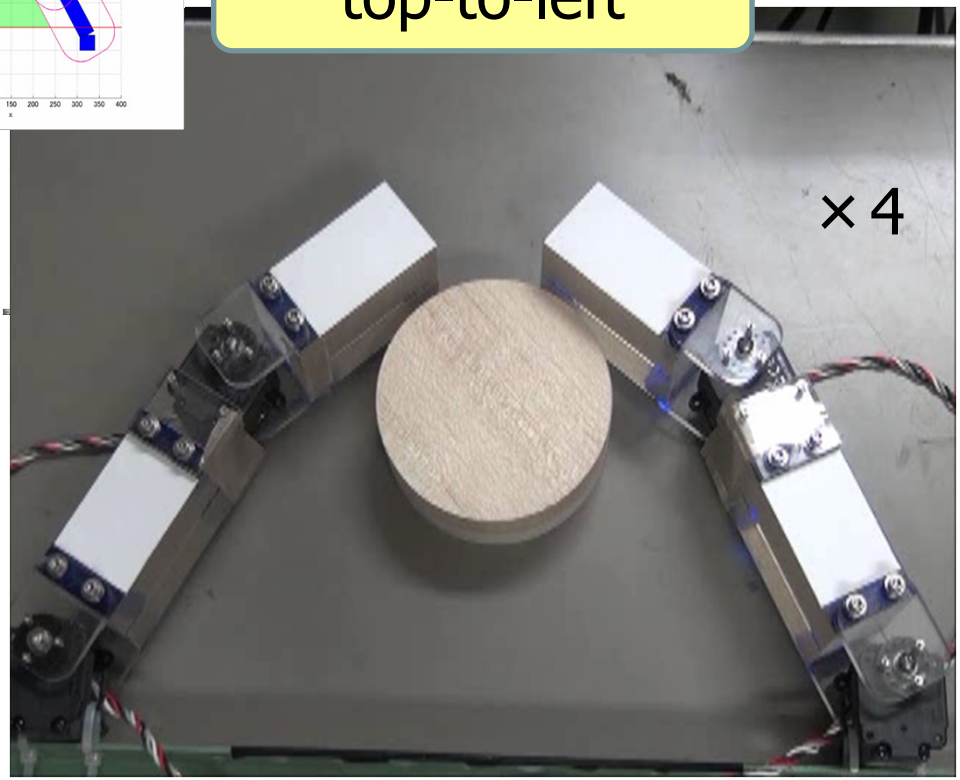
Experimental Verification (1/2)

right-to-left



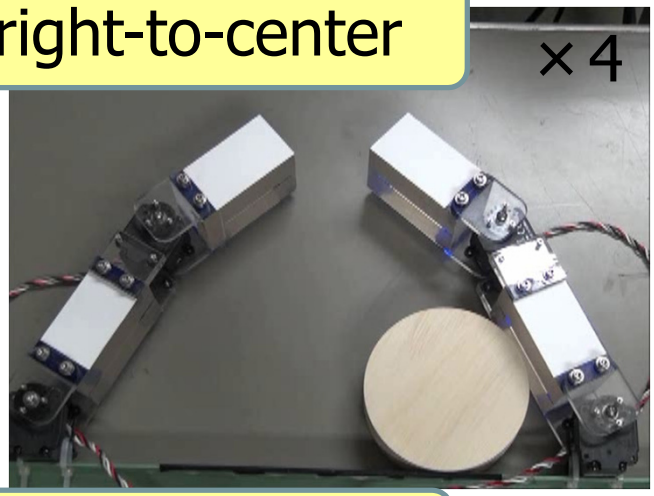
top-to-left



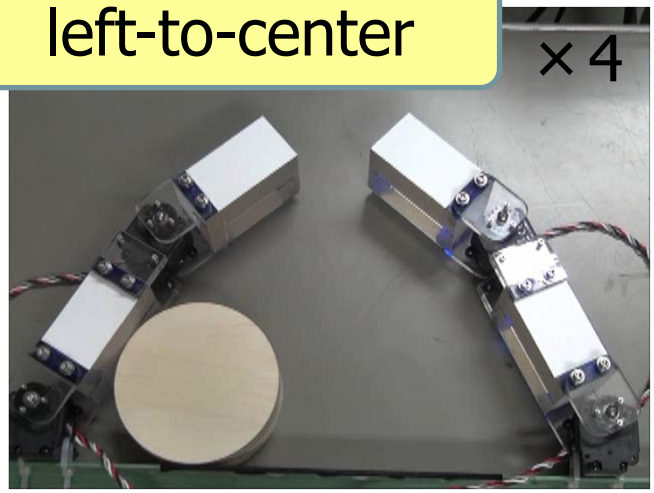


Experimental Verification (2/2)

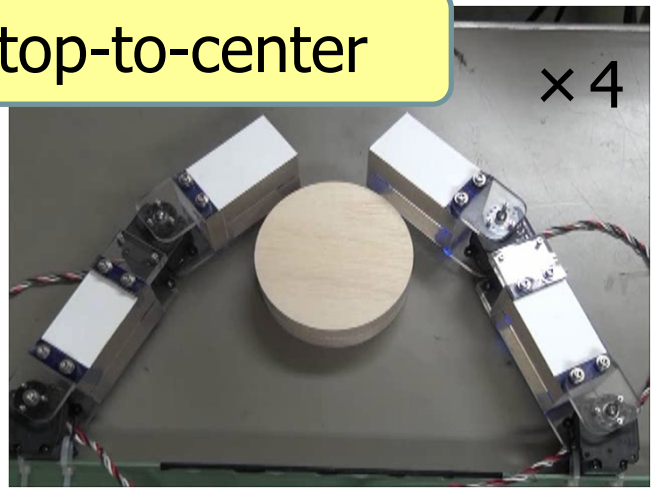
right-to-center

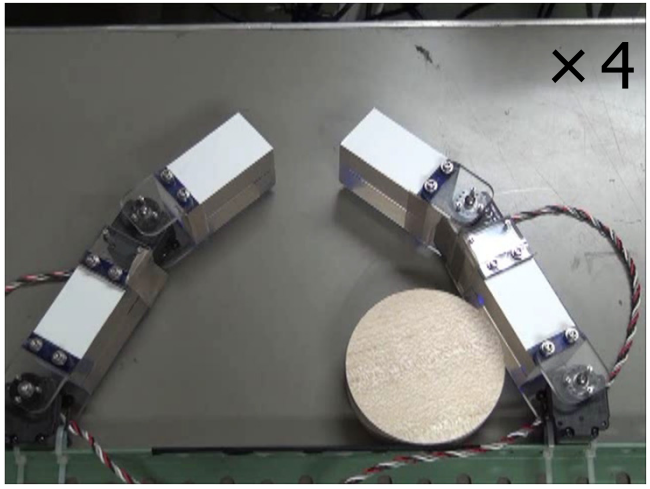


left-to-center

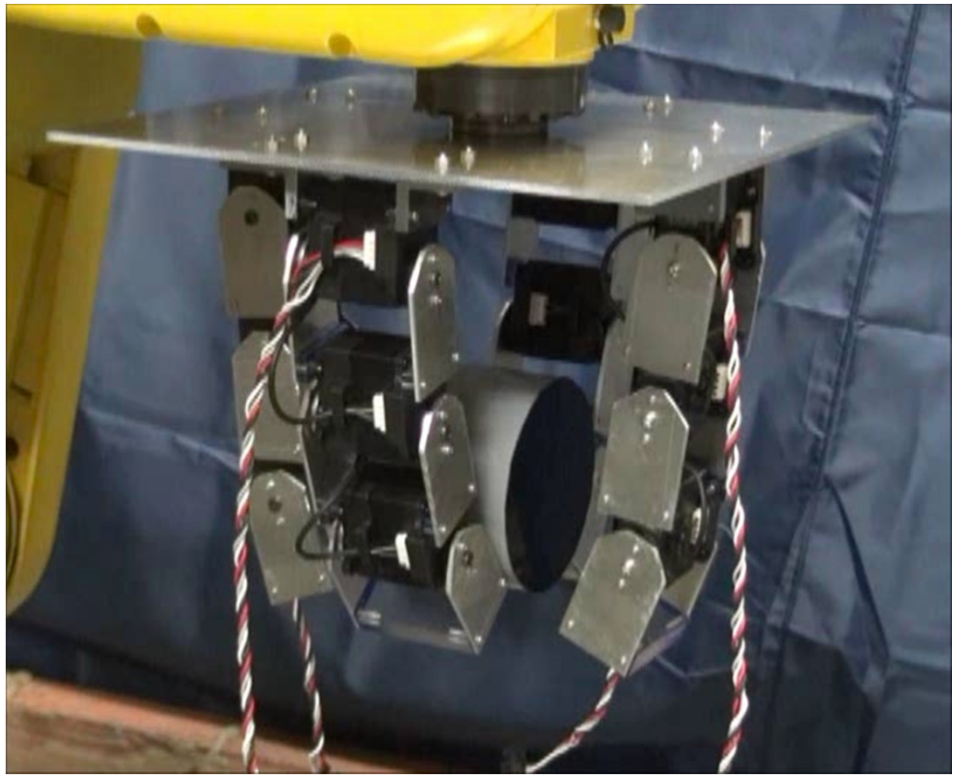


top-to-center

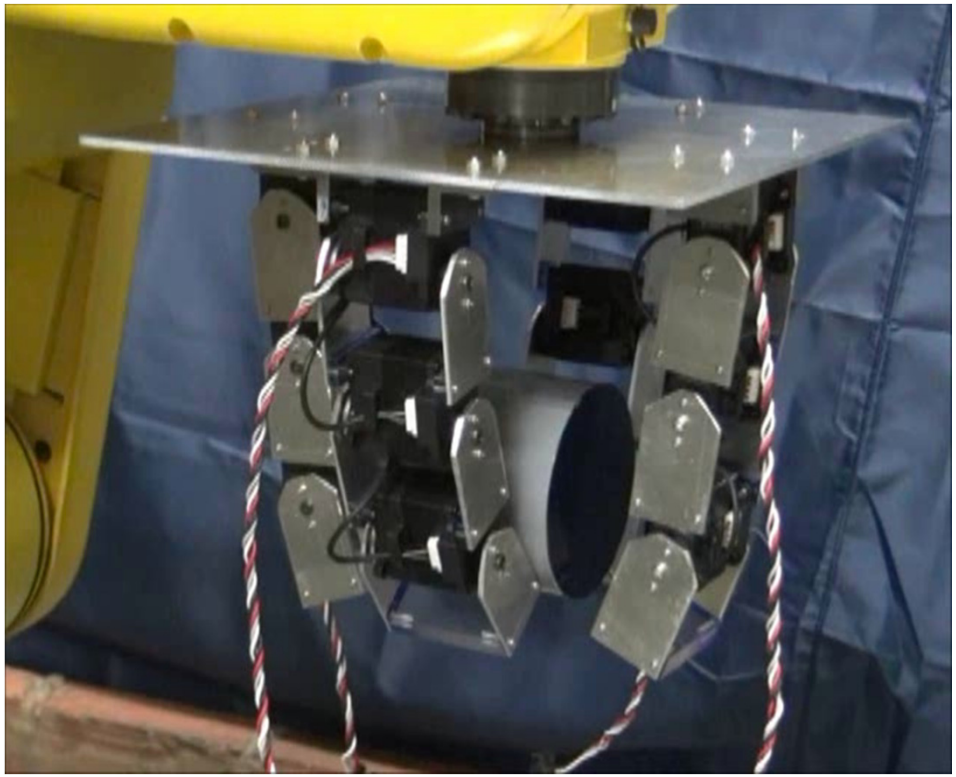




3D In-hand caging manipulation by a four-fingered hand



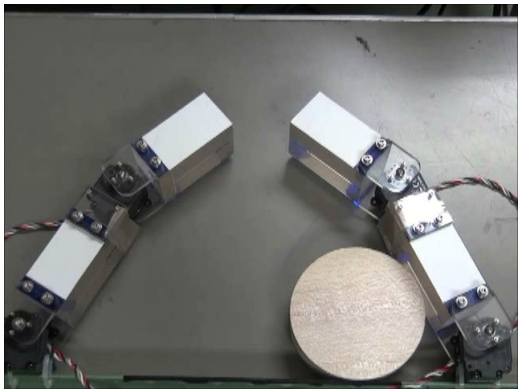
(to center) ×4

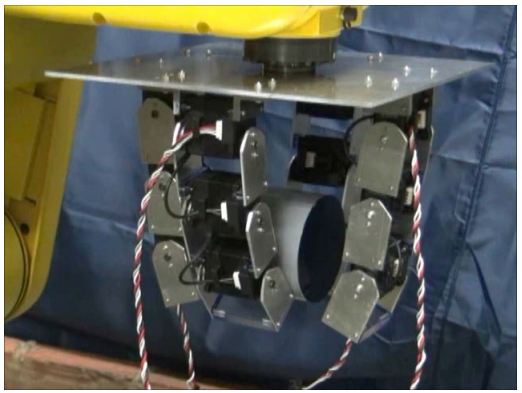


(to rear side) ×4

Conclusion

- A new manipulation methodology: "sensorless in-hand caging manipulation" was formulated
  - RRT-based manipulation planning
  - Experimental verification in 2D/3D setups





Future Work

- Effective jamming avoidance
- Wider variety of objects and robot hands