Object Assembly using Dual-Arm Robot and Dexterous Robot Hands

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Robot Cognition and Control Lab. (RCCL)
Korea Institute of Industrial Technology (KITECH)

Contents

I. Robot Cognition and Control Lab. (RCCL)

Robot Cognition and Control Lab.

Control


Dr. J.-H. Bae

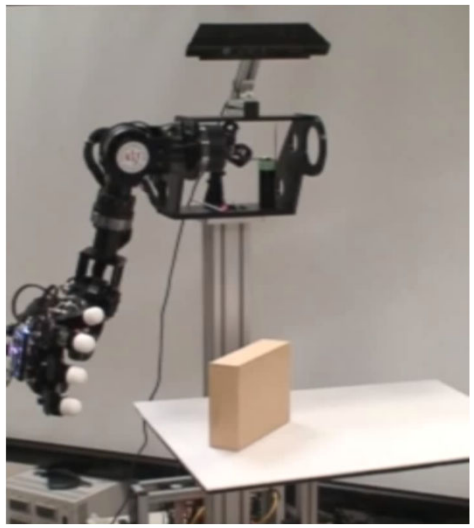

Dr. D.-H. Lee


Mr. H. Park


Mr. M.-S. Choi


Mr. Y.W. Shin


Mr. S. D. Seo



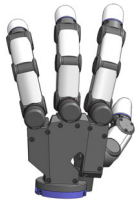
Cognition


Dr. J.-H. Park


Mr. G.-R. Jang

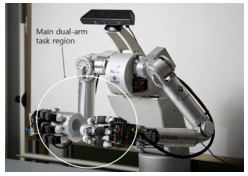

Mr. J. M. Noh

Dexterous Robot Hand



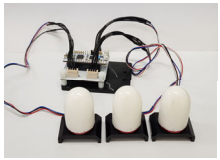
Smart Gripper

Dual-arm Robot

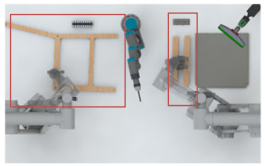


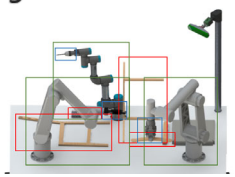
High-Level Grasping and Manipulation

Force/Tactile Sensor

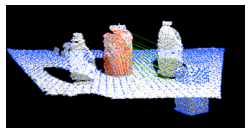


2D Object Recognition

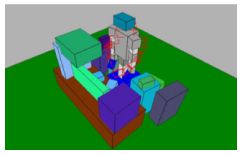




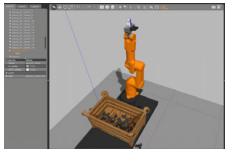
3D Recognition



Planning



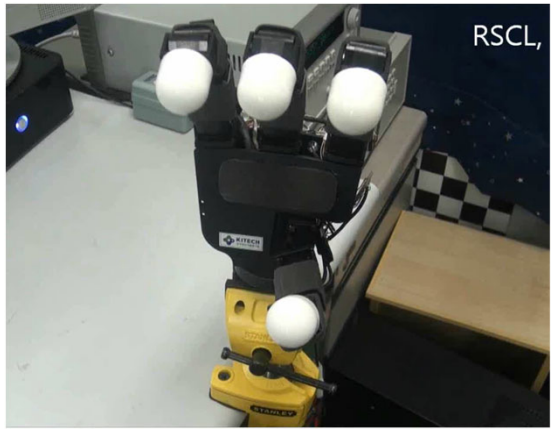
Multi-Physics Simulation



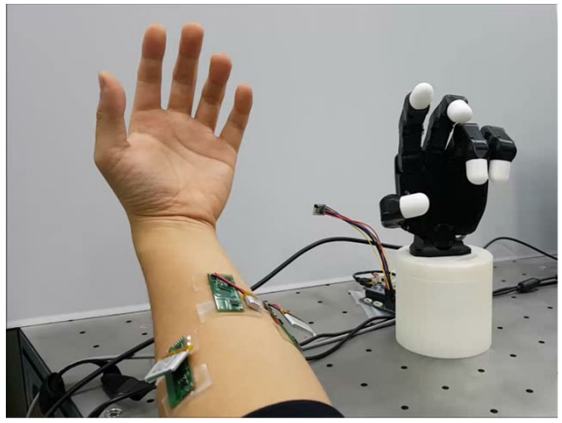
Cyber Physical System (CPS)

Robot Cognition and Control Lab.

- Dexterous robot hands

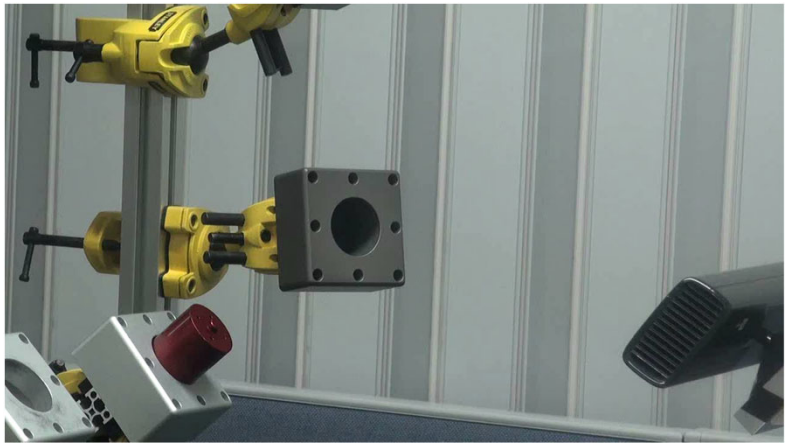


KITECH-Hand (Allegro Hand)

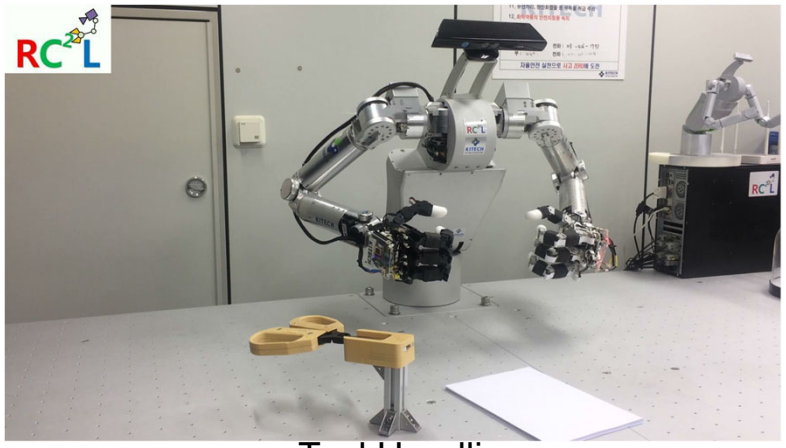


KITECH-Hand R

- Manipulation and assembly



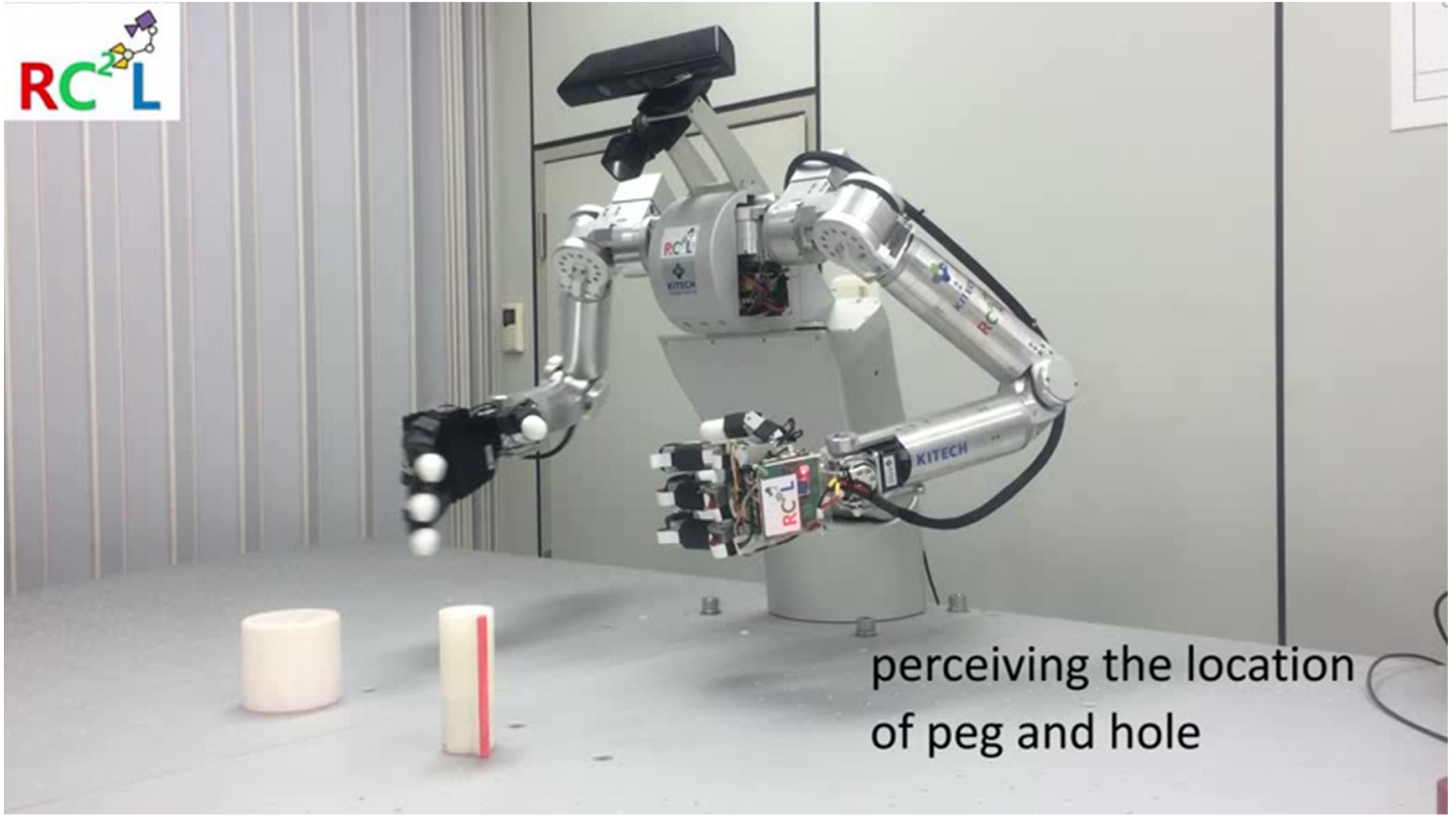
Peg-in-Hole Demonstration



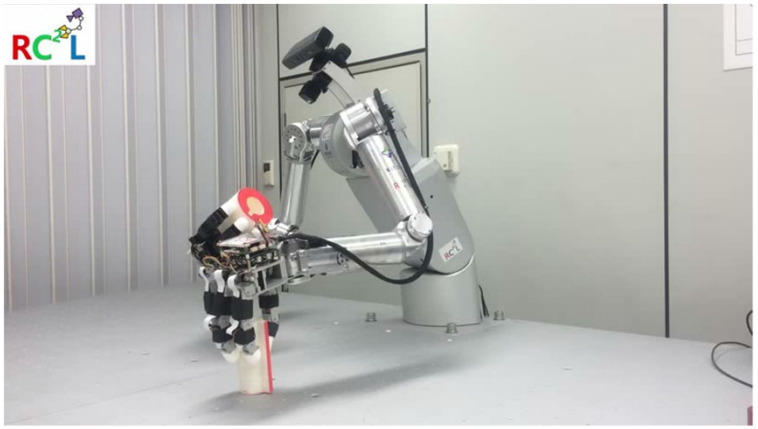
Tool Handling

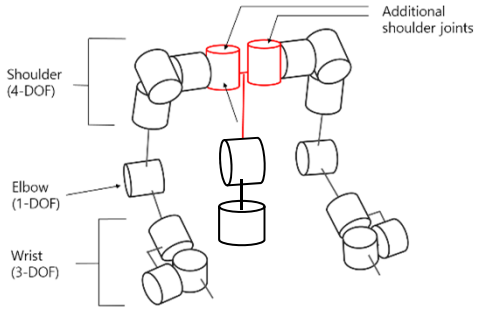
I. Bimanual Peg-in-Hole Assembly

Bimanual Peg-in-Hole Assembly

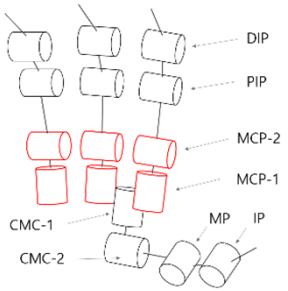


How Is It Done?





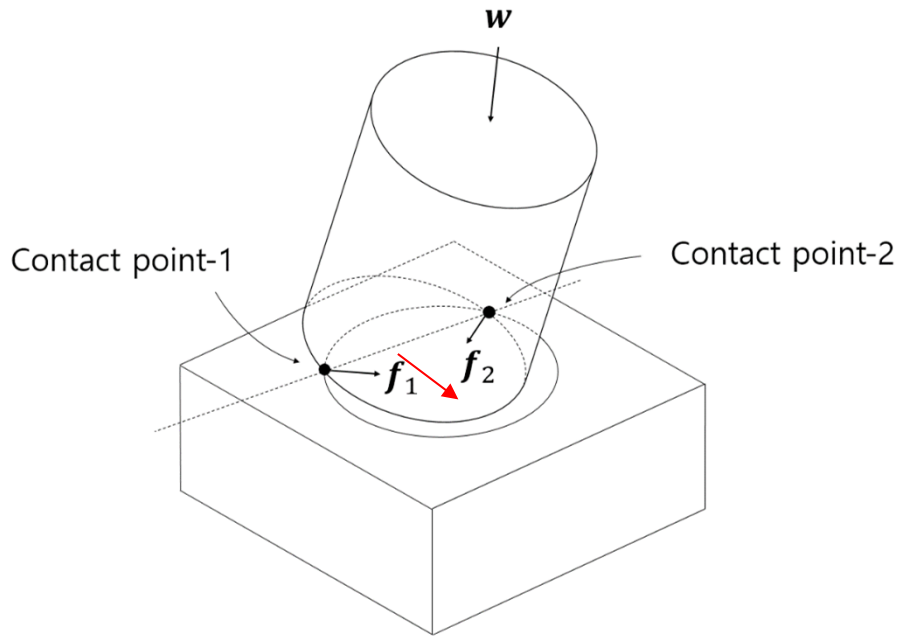
18-DOF dual-arm robot



16-DOF dexterous robot hand

- No force sensors are used
- The arms and hands are controlled separately
- Hybrid force-position controller is used for arms (force control is feedforward)
- Advanced blind controller is used for the robot hands

Main Idea



- Apply (Properly designed) Random force => Perturbation
- Reaction force always is naturally generated towards center of the hole
- Sum of perturbation and reaction force gradually draw the peg into the hole

Control Scheme

Hybrid Force-Position Control

Task-space position control

Force control (feedforward)

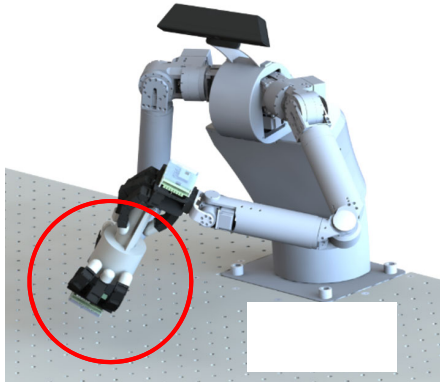
$$\boldsymbol{\tau} = \boldsymbol{J}^{\mathrm{T}} \begin{bmatrix} \boldsymbol{\Omega} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{I} \end{bmatrix} \boldsymbol{K}_{\mathrm{p}} \Delta \boldsymbol{x} + \boldsymbol{J}^{\mathrm{T}} \begin{bmatrix} \boldsymbol{R}_{\mathrm{h}} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{R}_{\mathrm{h}} \end{bmatrix} \boldsymbol{w} - \boldsymbol{D}\dot{\boldsymbol{q}} + \boldsymbol{\tau}_{\mathrm{g}} + \boldsymbol{\tau}_{\mathrm{f}}.$$

Suppress null-motion

Gravity comp.

Friction comp.

$$\boldsymbol{\Omega} = \boldsymbol{R}_{\mathrm{h}} \boldsymbol{\Sigma} \boldsymbol{R}_{\mathrm{h}}^{\mathrm{T}}$$
$$\boldsymbol{\Sigma} = \mathrm{diag}([0 \;\; 1 \;\; 1])$$



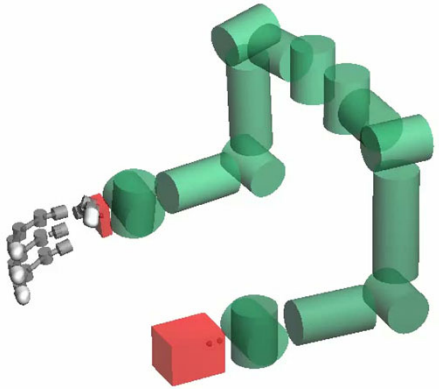
Position Control

$$\boldsymbol{\tau} = \boldsymbol{J}^{\mathrm{T}} \begin{bmatrix} \boldsymbol{\Omega} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{I} \end{bmatrix} \boldsymbol{K}_{\mathrm{p}} \Delta \boldsymbol{x} + \boldsymbol{J}^{\mathrm{T}} \begin{bmatrix} \boldsymbol{R}_{\mathrm{h}} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{R}_{\mathrm{h}} \end{bmatrix} \boldsymbol{w} - \boldsymbol{D}\dot{\boldsymbol{q}} + \boldsymbol{\tau}_{\mathrm{g}} + \boldsymbol{\tau}_{\mathrm{f}}.$$

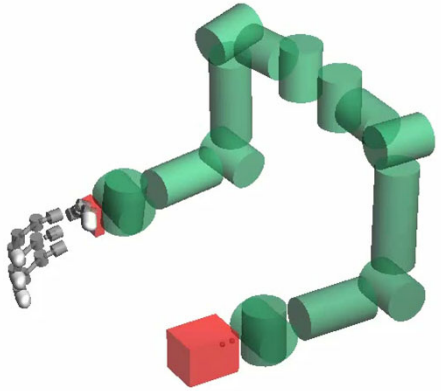
$$\boldsymbol{\Omega} = \boldsymbol{R}_{\mathrm{h}} \boldsymbol{\Sigma} \boldsymbol{R}_{\mathrm{h}}^{\mathrm{T}}$$

$$\boldsymbol{\Sigma} = \mathrm{diag}([0 \;\; 1 \;\; 1])$$

- With all axes on

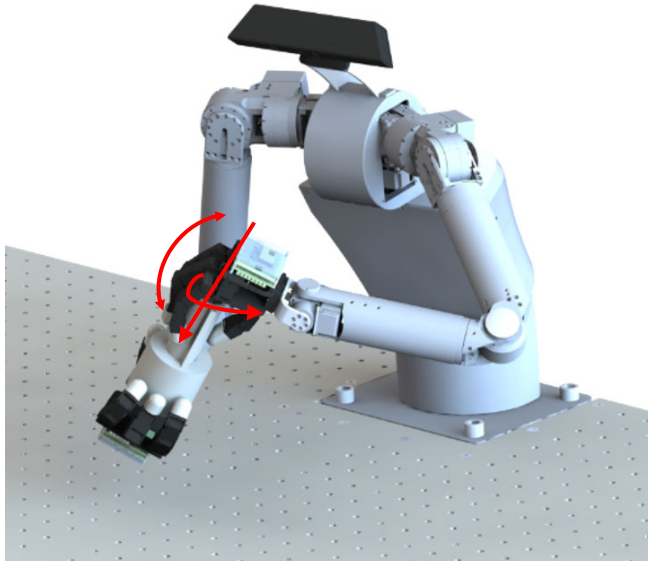


- With X-axis free



Force Control

$$\boldsymbol{\tau} = \boldsymbol{J}^{\mathrm{T}} \begin{bmatrix} \boldsymbol{\Omega} & \mathbf{0} \\ \mathbf{0} & \boldsymbol{I} \end{bmatrix} \boldsymbol{K}_{\mathrm{p}} \Delta \boldsymbol{x} + \boldsymbol{J}^{\mathrm{T}} \begin{bmatrix} \boldsymbol{R}_{\mathrm{h}} & \mathbf{0} \\ \mathbf{0} & \boldsymbol{R}_{\mathrm{h}} \end{bmatrix} \boldsymbol{w} - \boldsymbol{D}\dot{\boldsymbol{q}} + \boldsymbol{\tau}_{\mathrm{g}} + \boldsymbol{\tau}_{\mathrm{f}}.$$



- Perturbation is a wrench vector in 6-dimensional Cartesian space

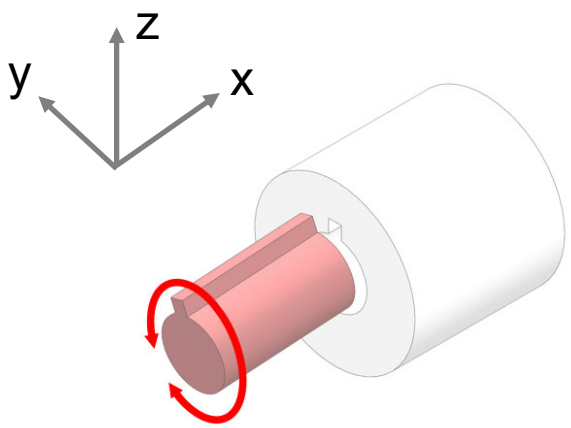
$$\boldsymbol{w} = [w_1 \ w_2 \ w_3 \ w_4 \ w_5 \ w_6]^{\mathrm{T}}$$

- The wrench vector is expressed using 4 parameters

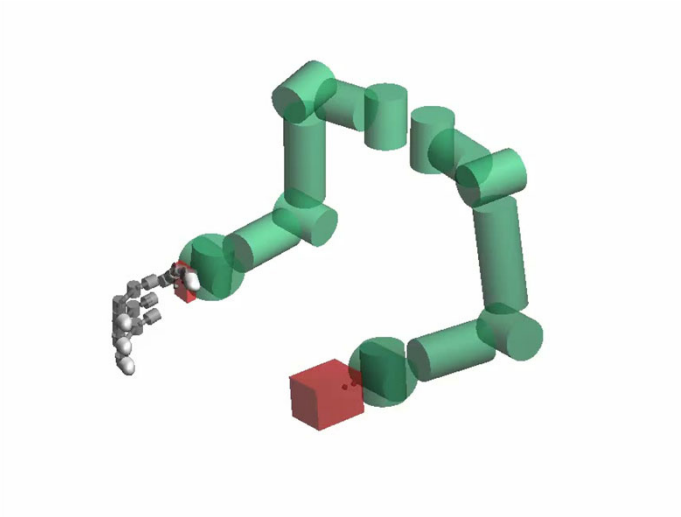
$$w_i = a_i \sin(b_i t + c_i) + d_i, \quad i \in \{1, 2, \ldots 6\},$$

Unit Motions

Rubbing



$$w_i = a_i \sin(b_i t + c_i) + d_i, \quad i \in \{1, 2, ...6\},$$



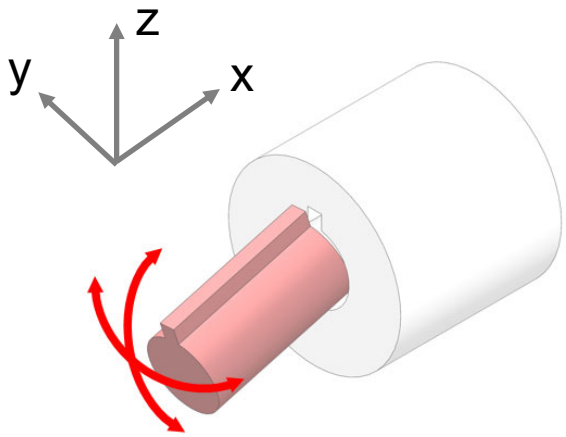
$$\boldsymbol{a} = [\ 0\ 0\ 0\ 0\ 0\ f_{\text{rub}}\ ]^{\text{T}}$$

$$\boldsymbol{b} = [\ 0\ 0\ 0\ 0\ 0\ v_{\text{rub}}\ ]^{\text{T}}$$

$$\boldsymbol{c} = \boldsymbol{d} = \mathbf{0}^{\text{T}}$$

Unit Motions

Wiggling



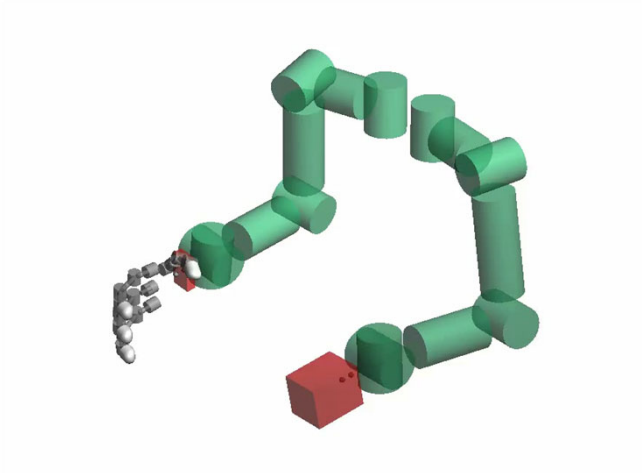
$$w_i = a_i \sin(b_i t + c_i) + d_i, \quad i \in \{1, 2, ...6\},$$

$$\boldsymbol{a} = [\ 0\ 0\ 0\ f_{\text{wiggle}}\ f_{\text{wiggle}}\ 0\ ]^{\text{T}}$$

$$\boldsymbol{b} = [\ 0\ 0\ 0\ v_{\text{wiggle}}\ v_{\text{wiggle}}\ 0\ ]^{\text{T}}$$

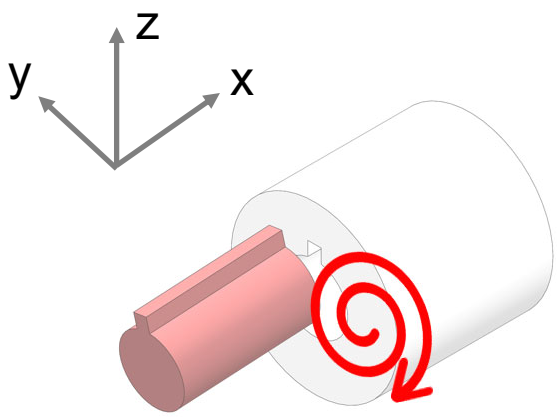
$$\boldsymbol{c} = [\ 0\ 0\ 0\ 0\ \pi/2\ 0\ ]^{\text{T}}$$

$$\boldsymbol{d} = \mathbf{0}^{\text{T}}$$



Unit Motions

- Spiral motion



$$w_i = a_i \sin(b_i t + c_i) + d_i, \quad i \in \{1, 2, ...6\},$$

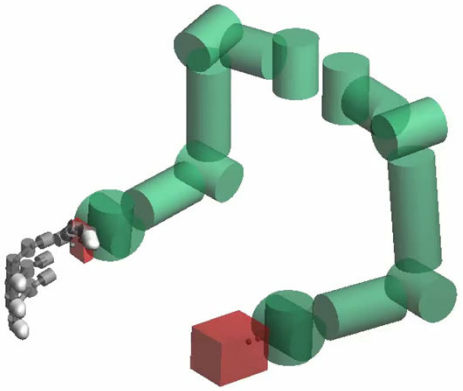
$$\boldsymbol{a} = [\ f_{\text{spiral}}(t)\ \ f_{\text{spiral}}(t)\ \ 0\ \ 0\ \ 0\ \ 0\ ]^{\text{T}}$$

$$\boldsymbol{b} = [\ v_{\text{spiral}}\ \ v_{\text{spiral}}\ \ 0\ \ 0, 0\ \ 0\ ]^{\text{T}}$$

$$\boldsymbol{c} = [\ 0\ \ \pi/2\ \ 0\ \ 0\ \ 0\ \ 0\ ]^{\text{T}}$$

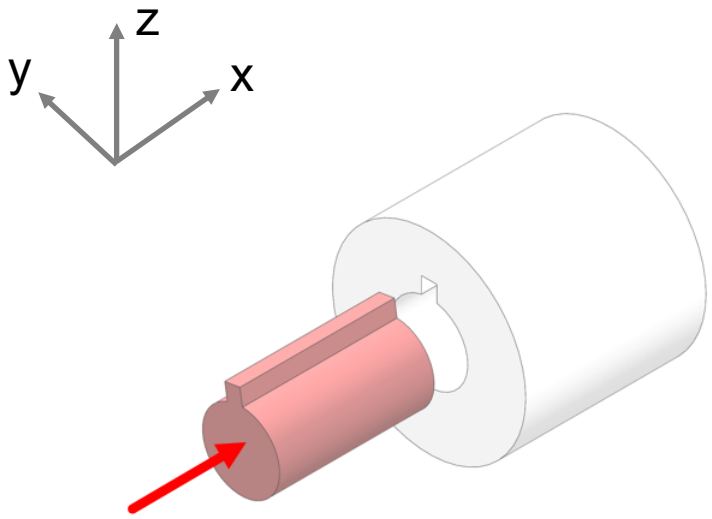
$$\boldsymbol{d} = \mathbf{0}^{\text{T}}$$

$$f_{\text{spiral}}(t) = \alpha \sin(v_{\text{spiral}} t) + \beta$$



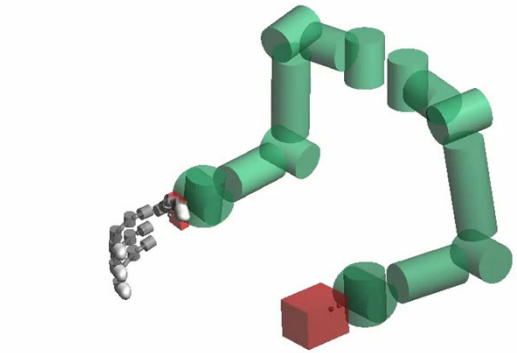
Unit Motions

- Unit motions : Pushing



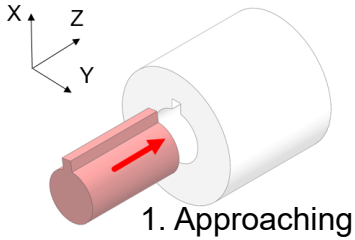
$$w_i = a_i \sin(b_i t + c_i) + d_i, \quad i \in \{1, 2, ...6\},$$

$$\boldsymbol{a} = \boldsymbol{b} = \boldsymbol{c} = \mathbf{0}^{\mathrm{T}},$$
$$\boldsymbol{d} = [\ 0\ 0\ f_{\mathrm{push}}\ 0\ 0\ 0\ ]^{\mathrm{T}}.$$



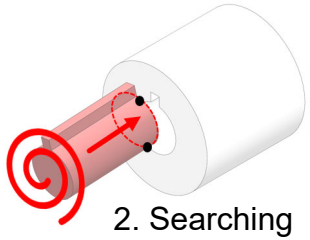
Peg-In-Hole Procedure

$$\tau = J^{\mathrm{T}} \begin{bmatrix} \Omega & 0 \\ 0 & I \end{bmatrix} K_{\mathrm{p}} \Delta x + J^{\mathrm{T}} \begin{bmatrix} R_{\mathrm{h}} & 0 \\ 0 & R_{\mathrm{h}} \end{bmatrix} w - D\dot{q} + \tau_{\mathrm{g}} + \tau_{\mathrm{f}}.$$



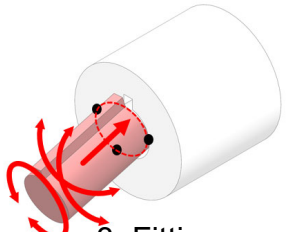
1. Approaching

$$w_{\text{approach}} = w_{\text{push}}$$



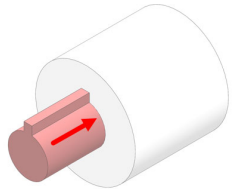
2. Searching

$$w_{\text{search}} = w_{\text{push}} + w_{\text{spiral}}$$



3. Fitting

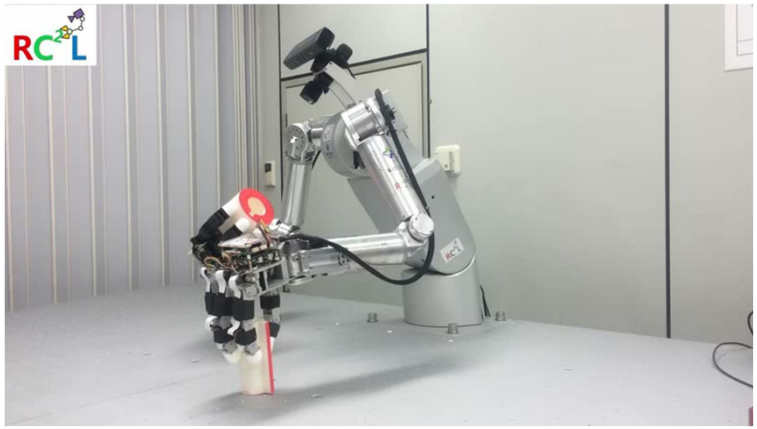
$$w_{\text{align}} = w_{\text{push}} + w_{\text{wiggle}} + w_{\text{rub}}$$

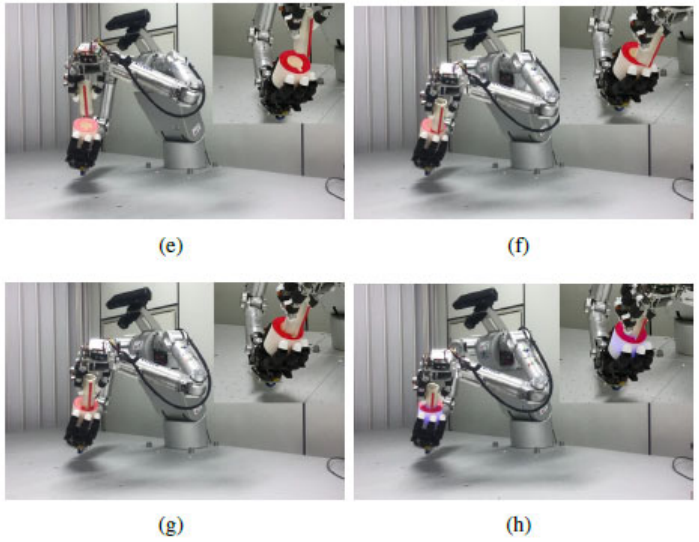


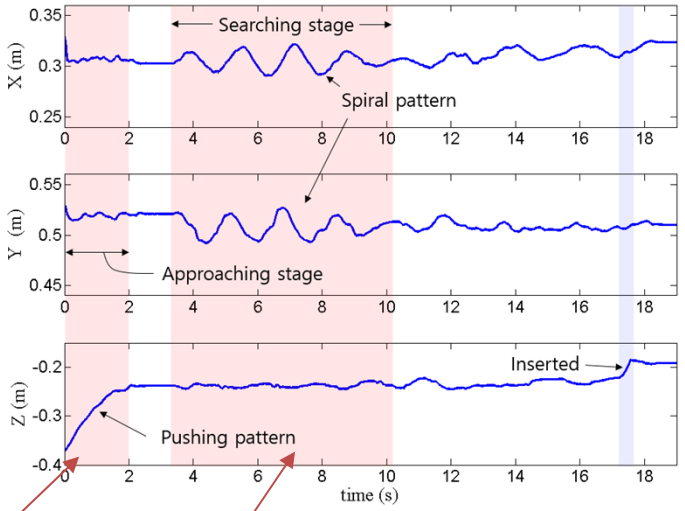
4. Inserting

$$w_{\text{insert}} = w_{\text{push}}$$

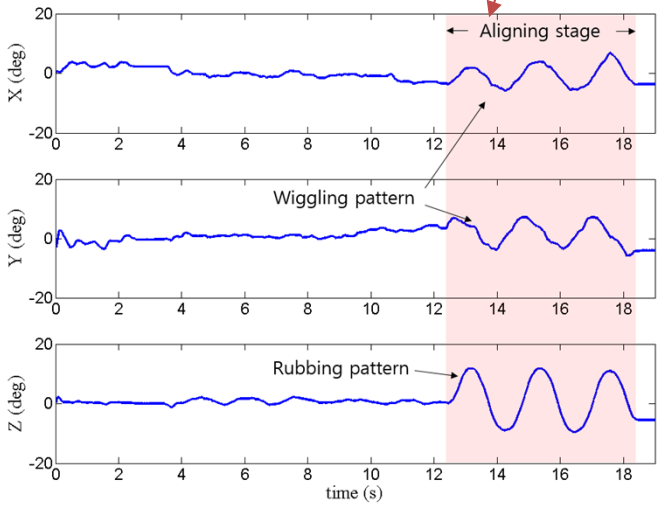
Experiment





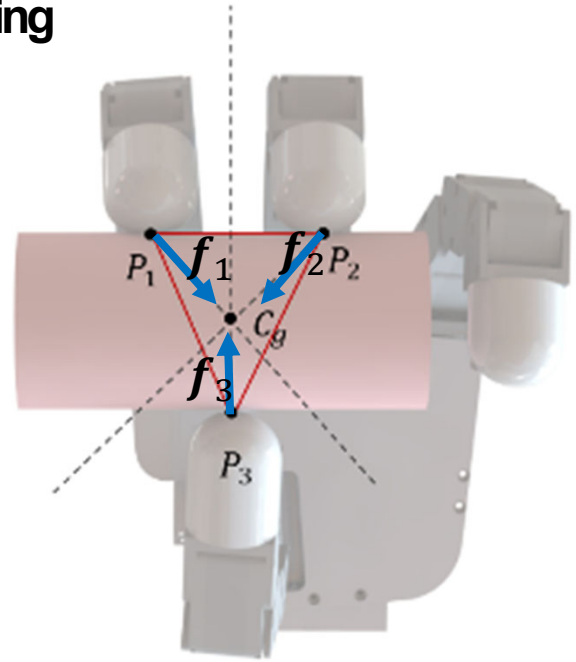


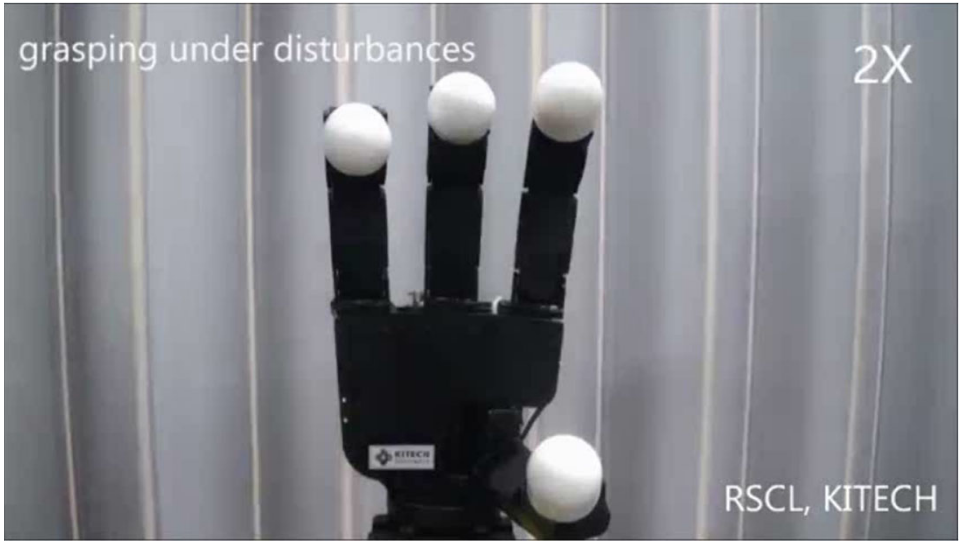
Approaching Searching Fitting



Advanced Blind Grasping

Grasping





No tactile sensor!

Desired force:

$$\hat{\boldsymbol{f}}_i = \frac{C_g - P_i}{||C_g - P_i||}.$$

$$\alpha_1 \hat{\boldsymbol{f}}_1 + \alpha_2 \hat{\boldsymbol{f}}_1 + \alpha_3 \hat{\boldsymbol{f}}_1 = \mathbf{0}.$$

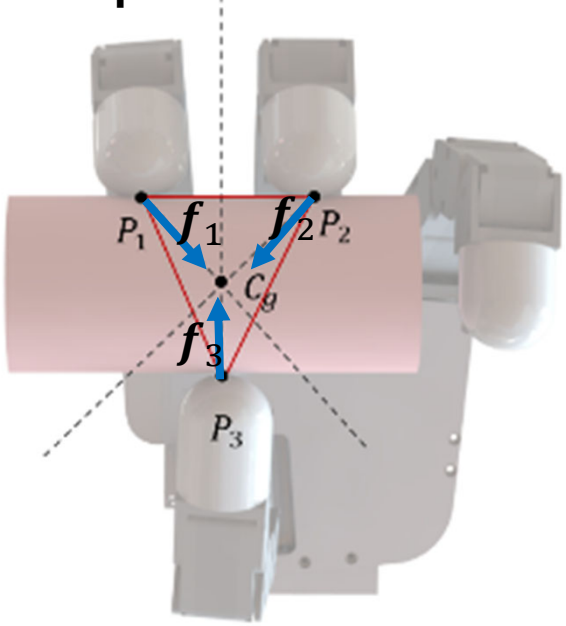
Control Law:

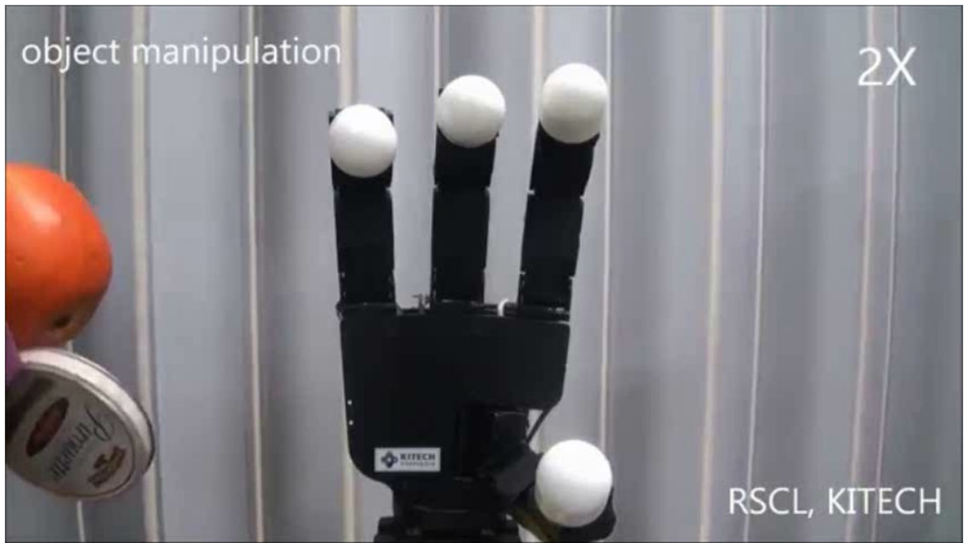
$$\boldsymbol{\tau}_{\mathrm{d}} = -\boldsymbol{D}\dot{\boldsymbol{q}} + \alpha_i \boldsymbol{J}^{\mathrm{T}} \hat{\boldsymbol{f}}_i$$

J.-H. Bae, el al, “A grasp strategy with the geometric centroid of a groped object shape derived from contact spots,” in Proc. IEEE Int. Conf. Robot. Autom., May 2012, pp. 3798-3804.

Advanced Blind Grasping

In Hand Manipulation





Translation:

$$f'_i = f_i + K_t \Delta C_g$$

Rotation:

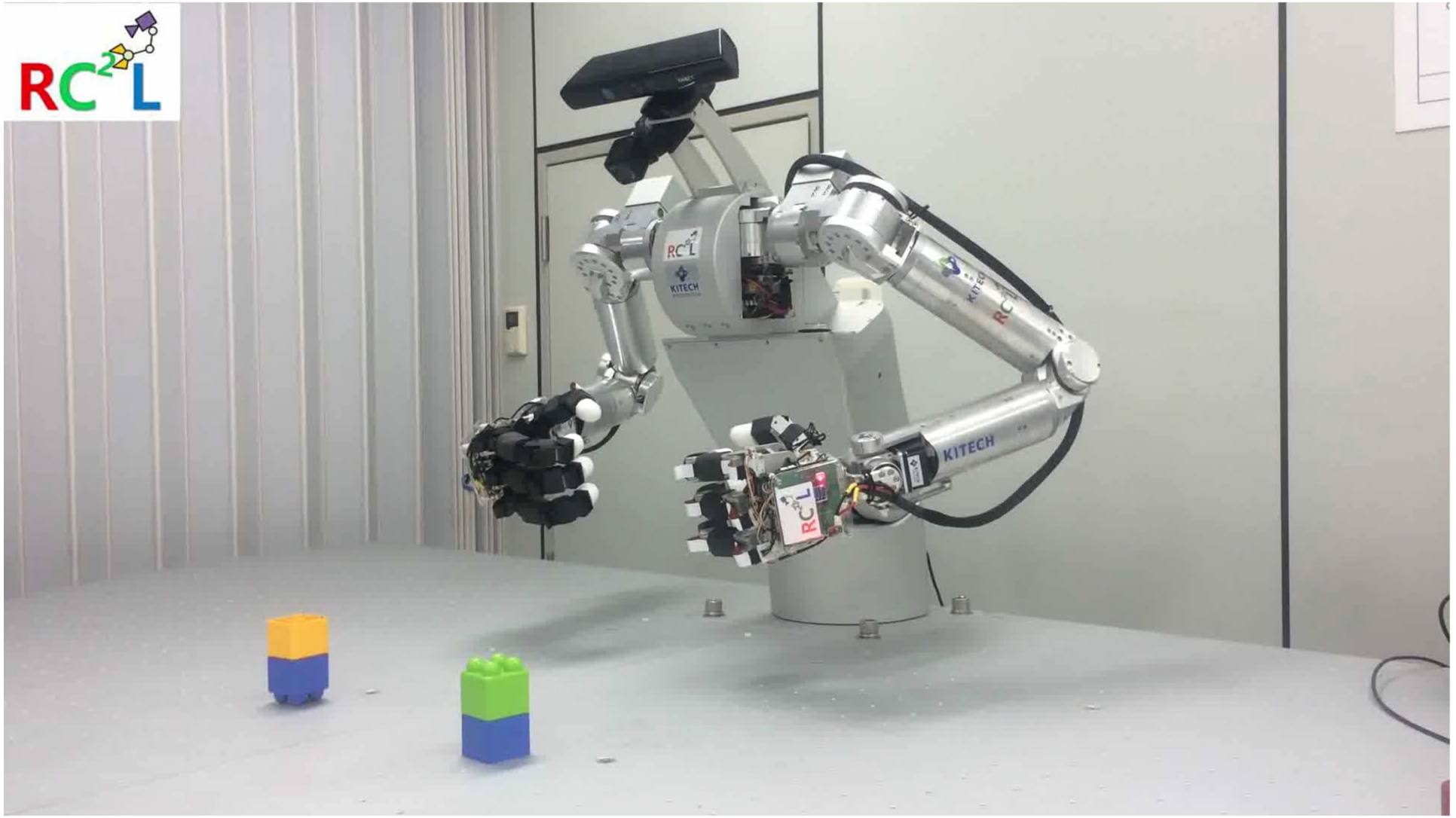
$$f'_i = f_i + f_{ri}.$$
$$f_{ri} = \hat{z}_C \times (P_i - C_g)$$
$$\|f_{ri}\| = \frac{K_r \theta}{\|P_i - C_g\|}$$

Control Law:

$$\tau_d = -D\dot{q} + \alpha_i J^T \hat{f}_i$$

J.-H. Bae, el al, “A grasp strategy with the geometric centroid of a groped object shape derived from contact spots,” in Proc. IEEE Int. Conf. Robot. Autom., May 2012, pp. 3798-3804.

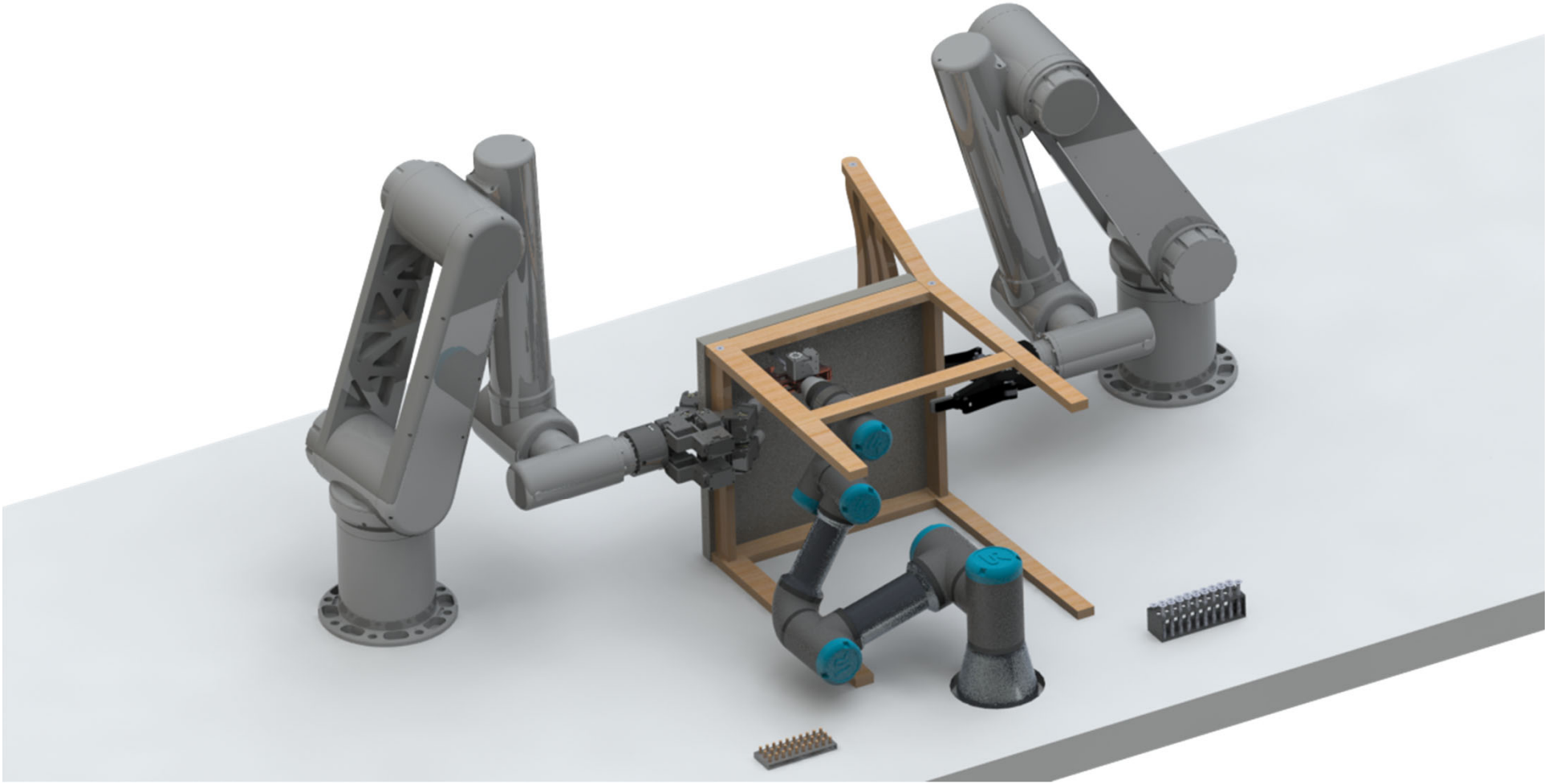
Application: Block Assembly



III. On-going Researches in RCCL

- Furniture Assembly
- Peg-in-Hole with Smart gripper
- Reinforcement Learning based Peg-in-Hole

Furniture Assembly

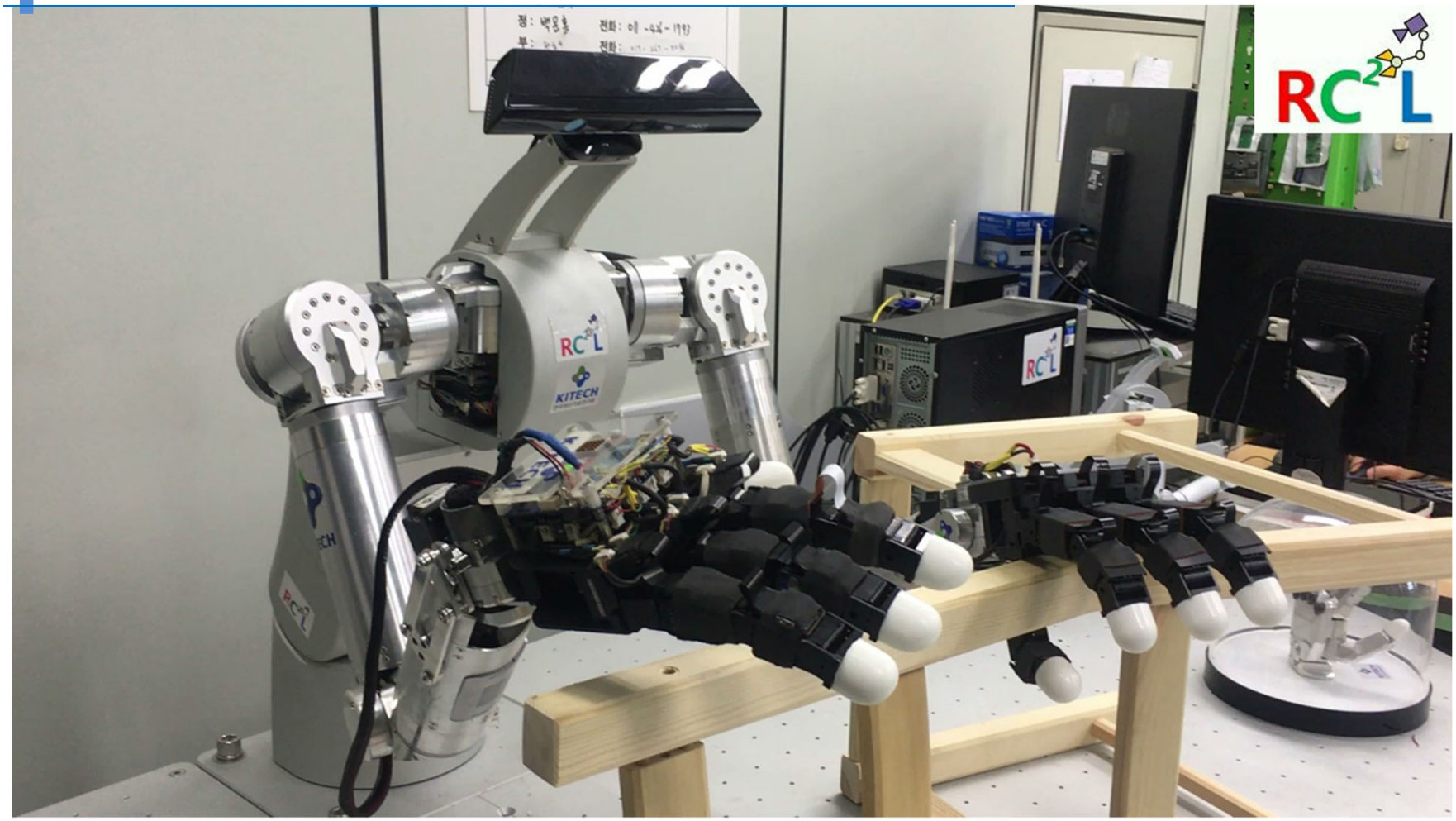


Furniture Assembly

Challenge 1: Single Frame Assembly

Furniture Assembly

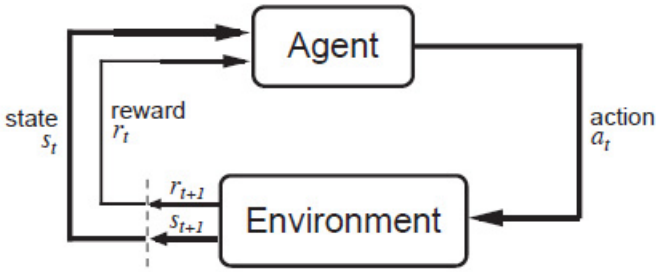
Challenge 2: Multi Frame Assembly



Furniture Assembly

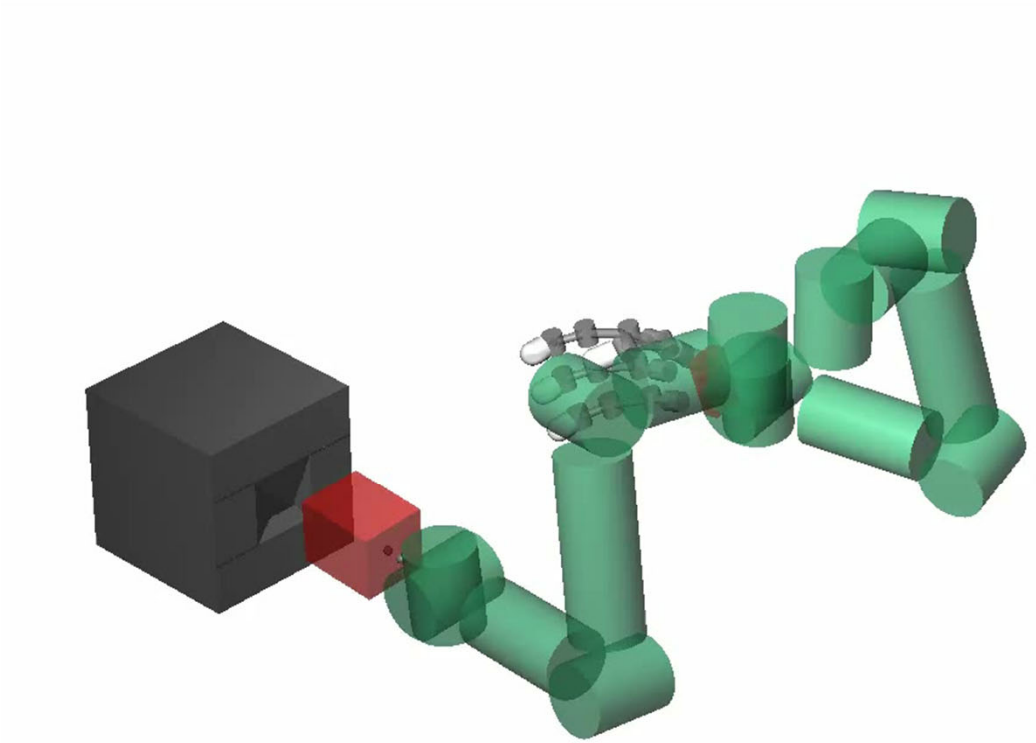
Challenge 3: Using Screw Driver

Reinforcement Learning based Peg-in-Hole



- Algorithm:
  DQN

- Actions:
  X_d +5mm
  X_d -5mm
  Y_d +5mm
  Y_d -5mm
  Z_d +5mm
  Z_d -5mm
  Do nothing



After 1000 episode

Thank You

Q & A