Control and Motion Planning for Flexible Parts Assembly

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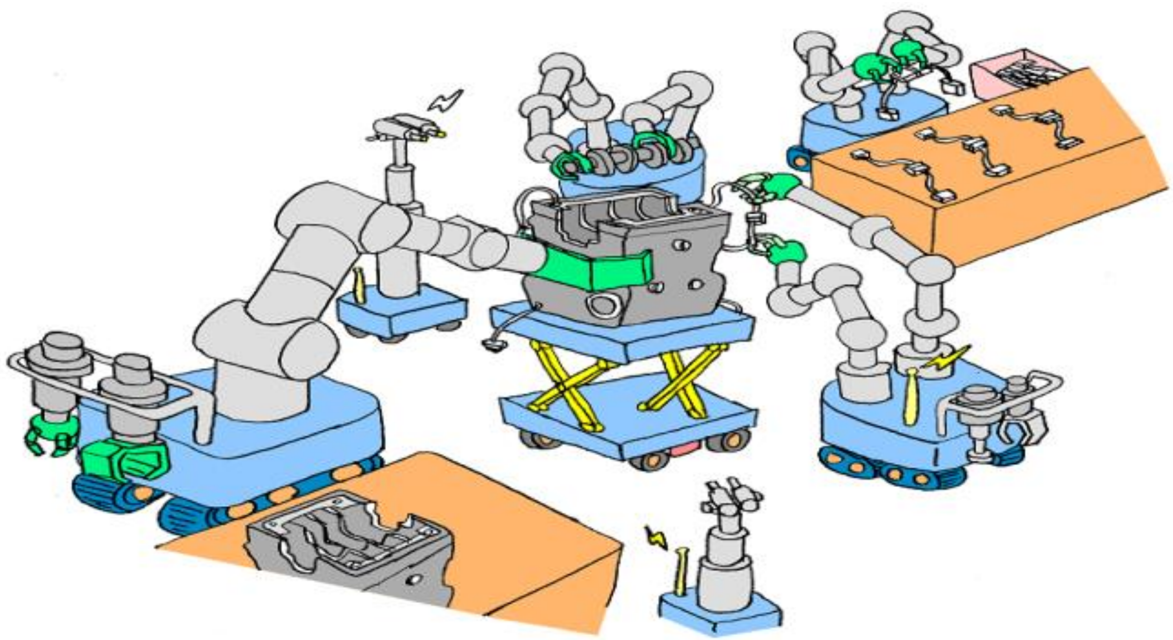
Introduction



From Mass Production System to On-demand Production System

Basic Research ⟷ Application Research

Outline

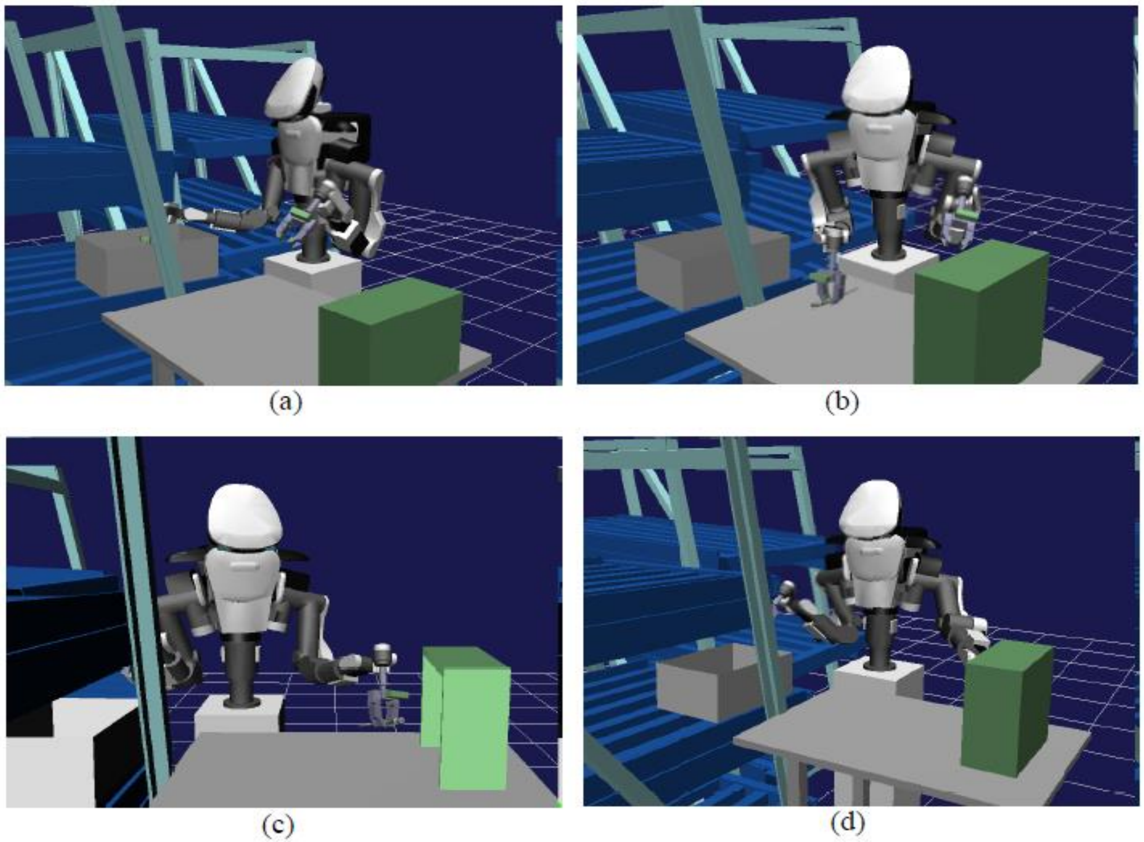
- Motion Planning of Dual-Arm Industrial Manipulators
- Snap Assembly
- Assembly Planning of Elastic Parts

A Manipulation Motion Planner for Dual-Arm Industrial Manipulators

Harada, Tsuji, and Laumond, ICRA 2014

Introduction

- Dual-Arm Manipulator Introduced in Industry
- Labor Cost to Generate Robot Motion

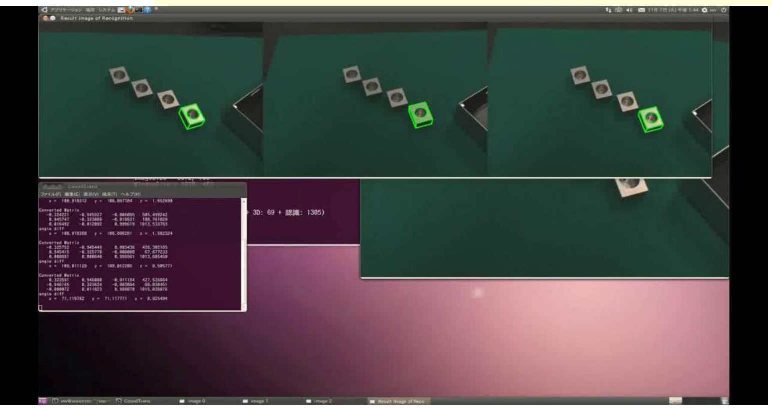


An example of dual-arm motion

Pick and Place by using Dual-Arm Manipulator

- Right Pick - Right Place
- Right Pick - Regrasp - Left Place
- Right Pick - Right Place - Left Pick - Left Place
- Right Pick - Right Place - Right Pick - Right Place

Etc..



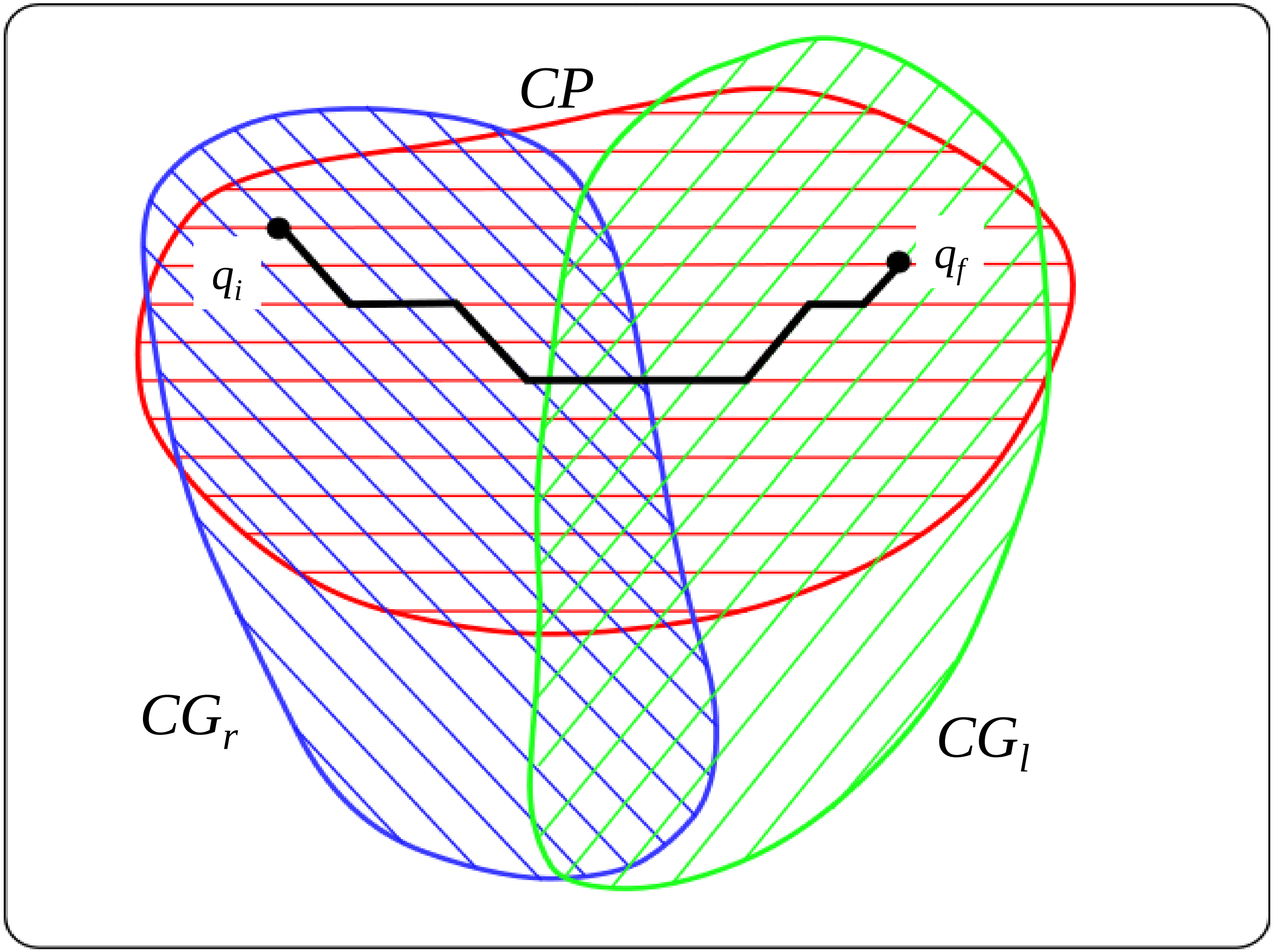
Harada et al. (ICRA '12)

Manipulation Planner for Dual-Arm Manipulators

Several Styles of Pick-and-Place motion :
Right Pick – Right Place, Right Pick – Regrasp – Left Place, etc
can be realized according to the context of task.

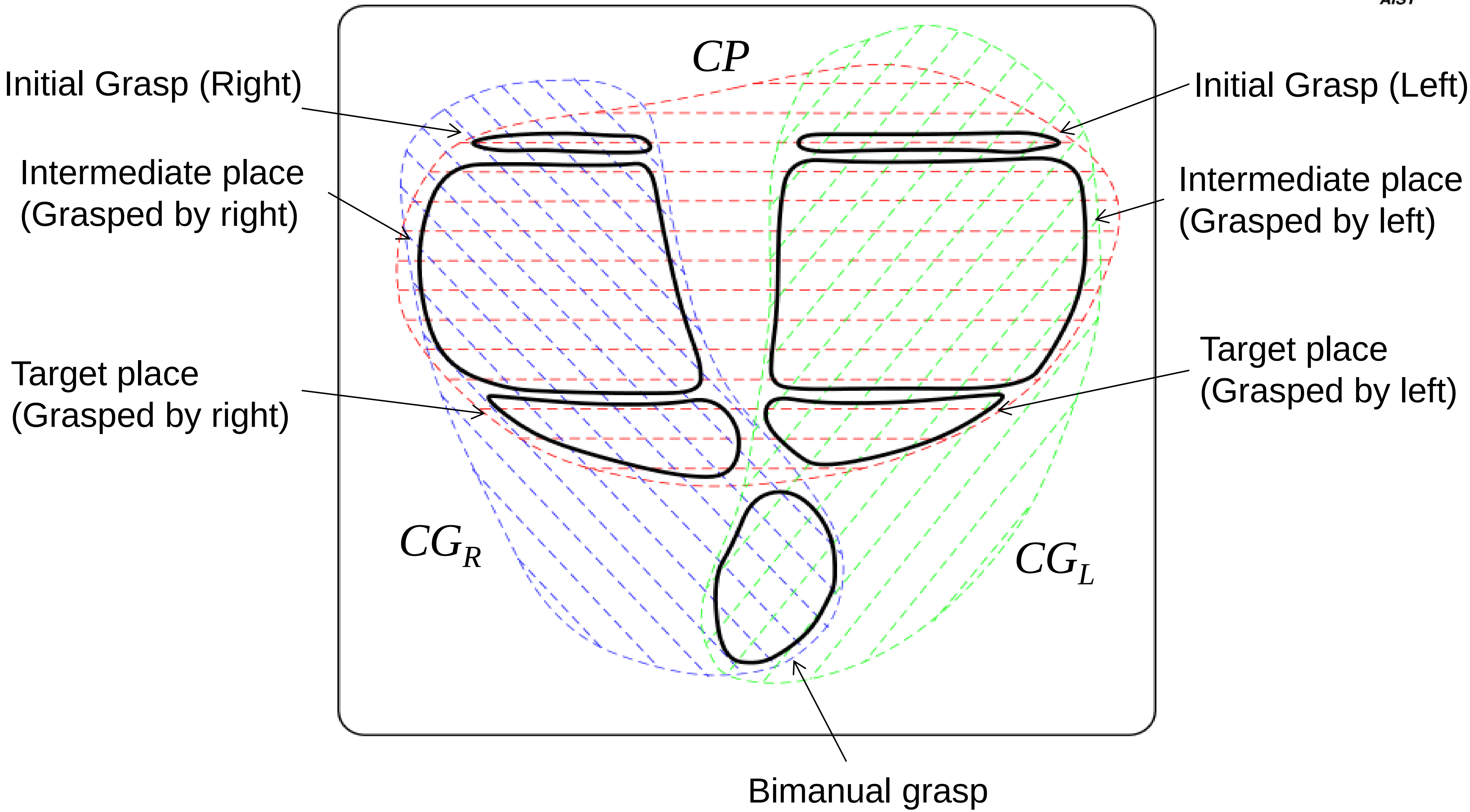
Configuration Space for Dual-Arm Manipulator

$$CS = CS_r \times CS_l \times CS_o$$



Basic Structure

$$CS = CS_r \times CS_l \times CS_o$$



Manipulation Graph

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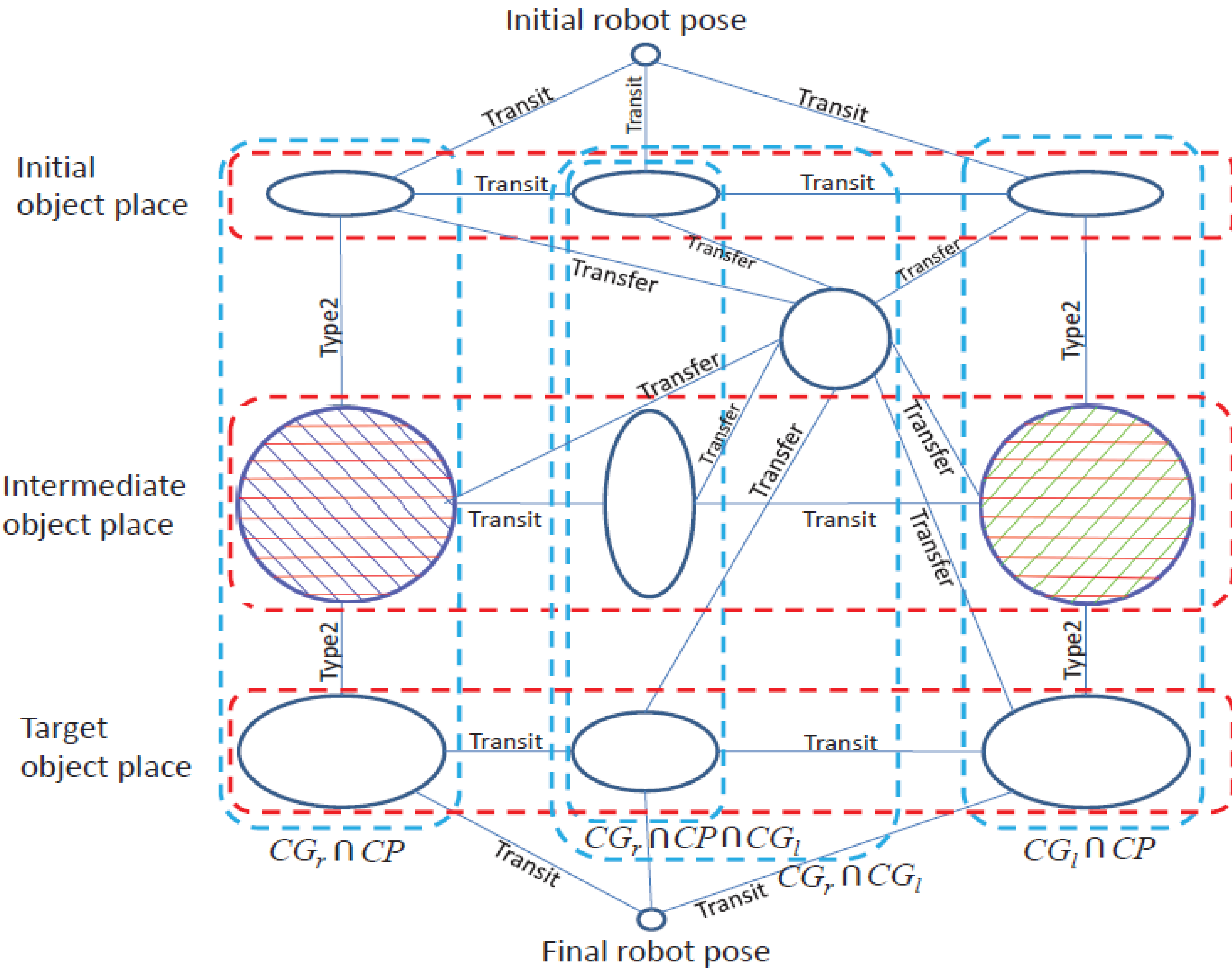

Manipulation Graph Search

- Each component is connected with edges.
- Each edge is constructed by using a random sampling based planner (Motion Planning Kit)
- Intermediate Object Posture is composed of a graph constructed by using Visibility-PRM.
- Motion will change in accordance with the order of edge construction

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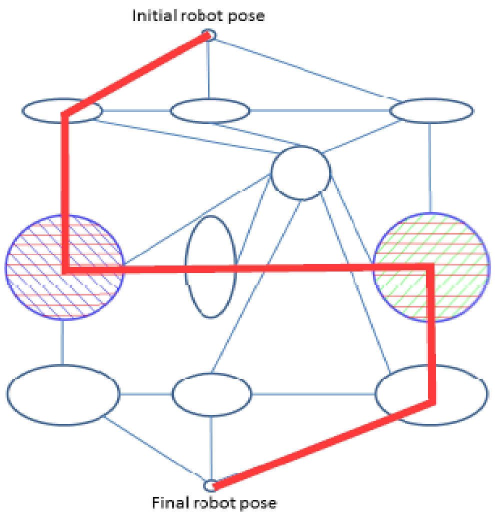
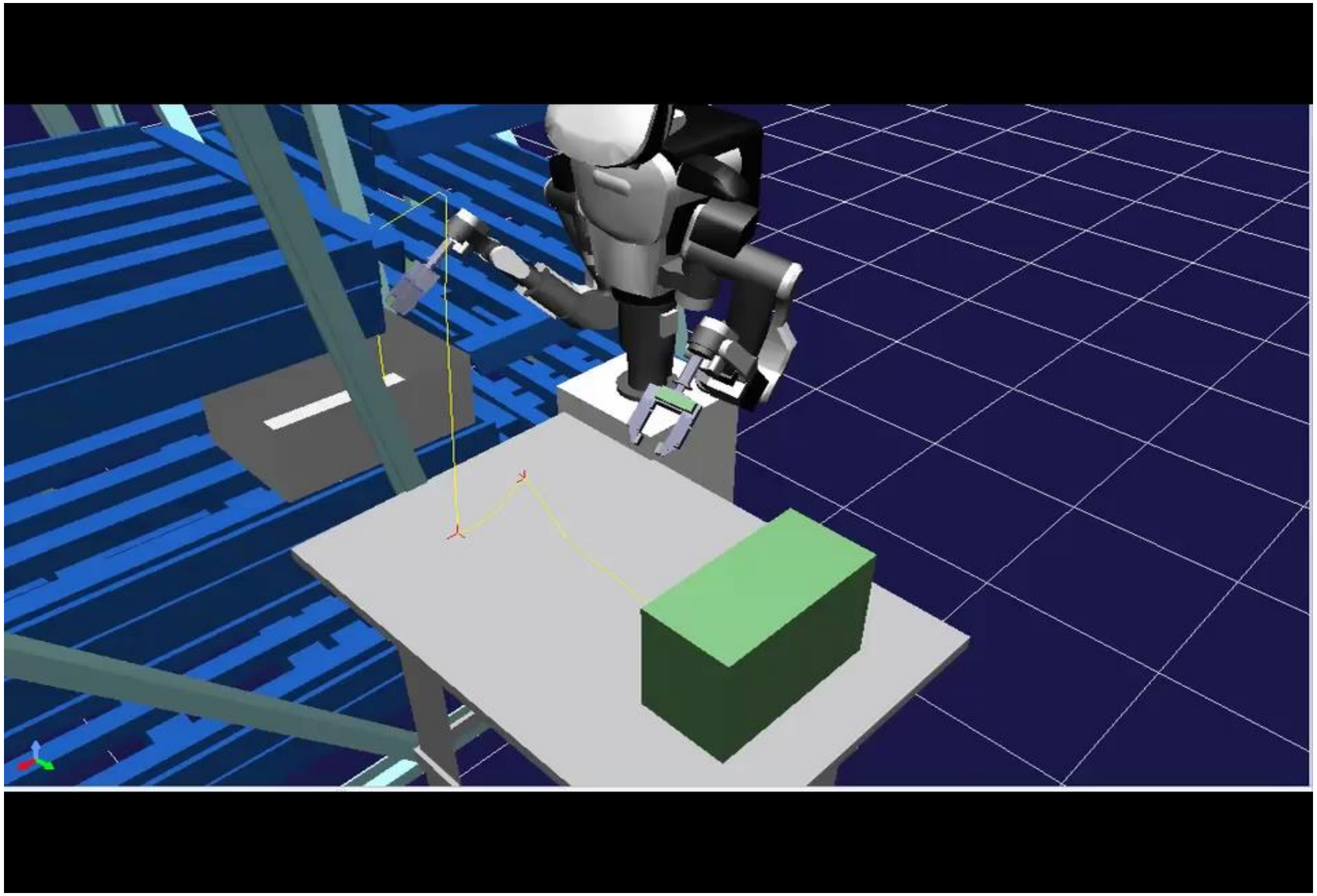
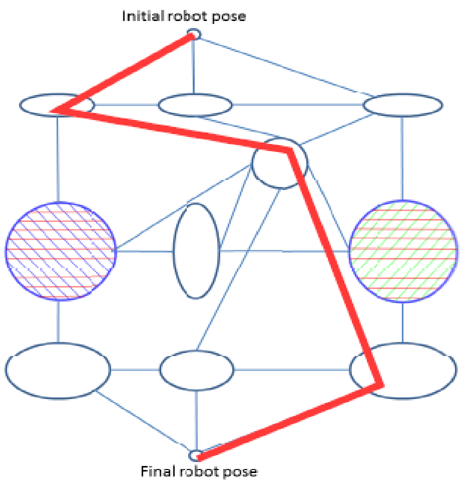
Examples 1



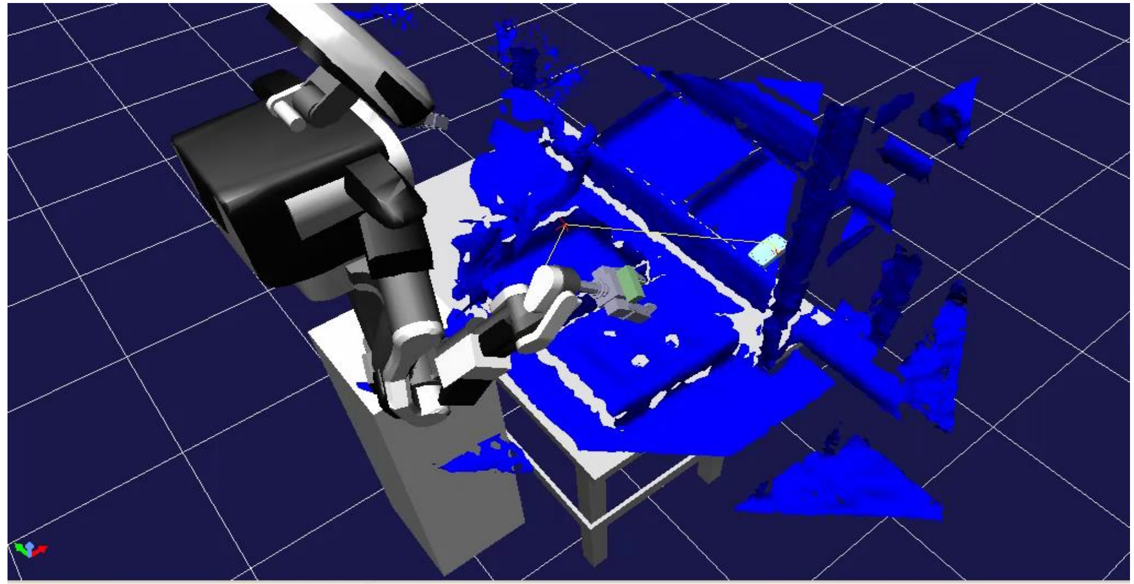


Place Object on Table
Regrasp bw Right and Left

Examples 2



Regrasp bw Right and Left



Robotic Snap Assembly

Research on Snap Assembly

- Force Controlled Snap Assembly
- Identification of Assembly State
- Failure Characterization

Rojas, Harada, Yoshida et al., ICMA 2012
Rojas, Harada, Yoshida et al., IROS 2012
Rojas, Harada, Yoshida et al., Humanoids 2012
Rojas, Harada, Yoshida et al., ICRA 2014

Dr. Juan Rojas
AIST Post-Doc 2011-2012

Snap Assembly Automation

- Snapping Mechanisms
  Pervasive in factories, homes, industries.

Cantilever Snaps

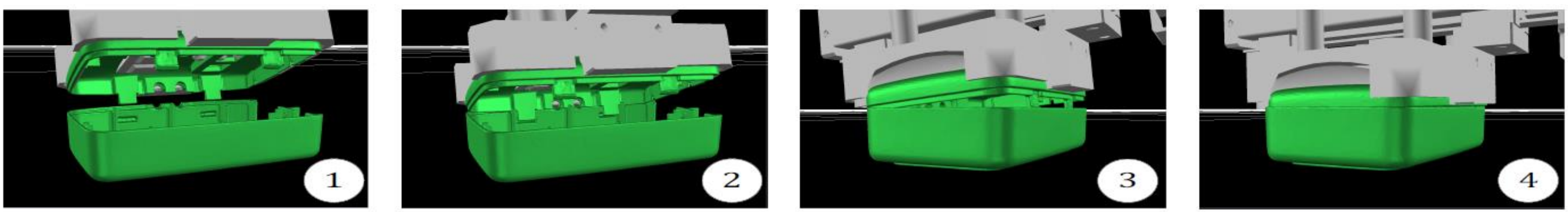
Force Controlled Snap Assembly

(Rojas, Harada Yoshida et al. ICMA' 12)

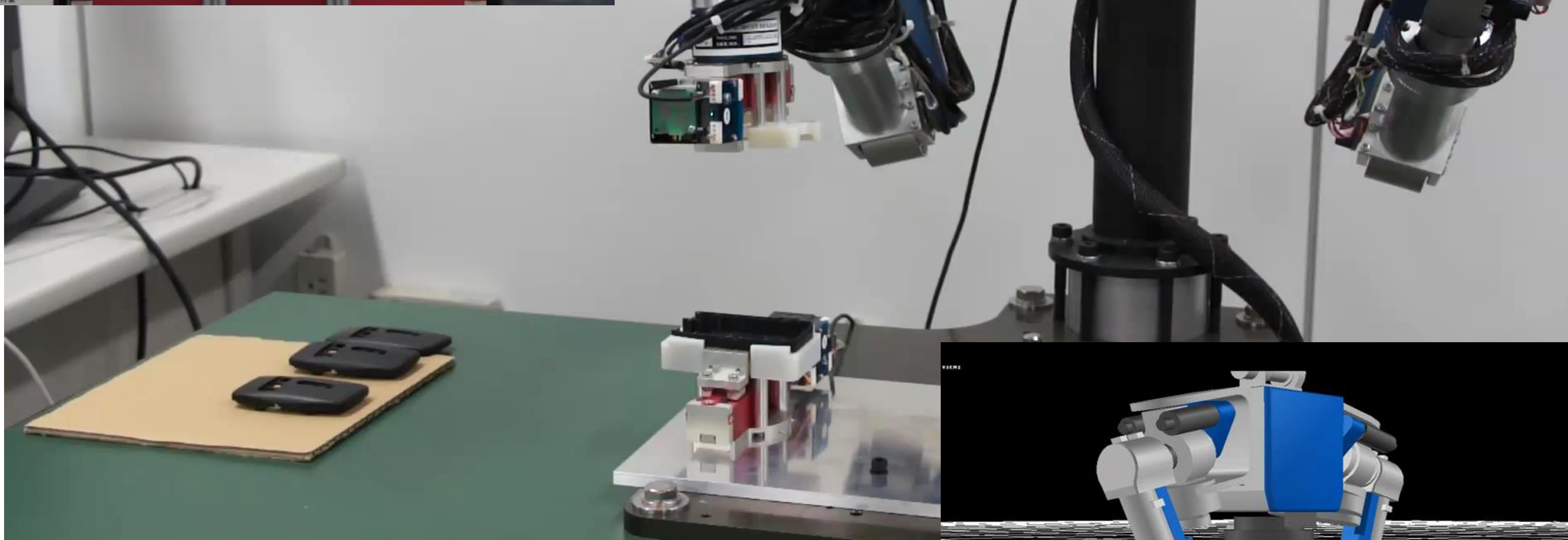
- Switching the Force Controlled Mode

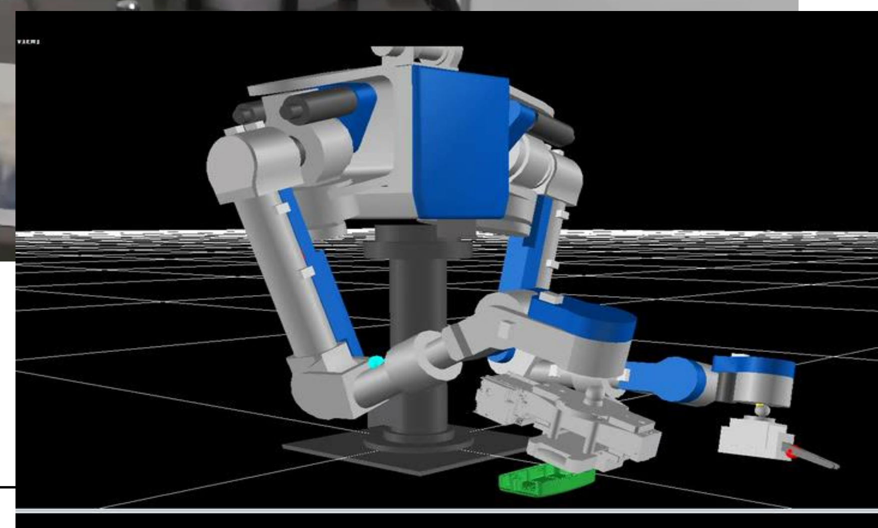
– Control Basis Approach

Approach	Position Control	
		}Force Condition
Rotation	Position Control	
		}Force Condition
Alignment	Moment Control	
		}Position Condition
Snap Insertion	Force Control	
Mating		



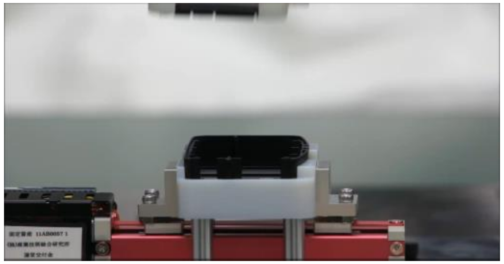
Simulation/Experiment



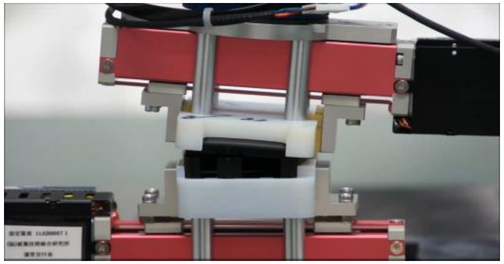


Methods: Pivot Approach Strategy

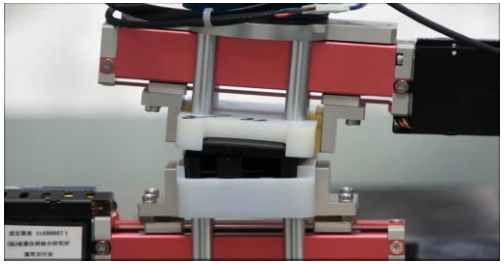
Approach



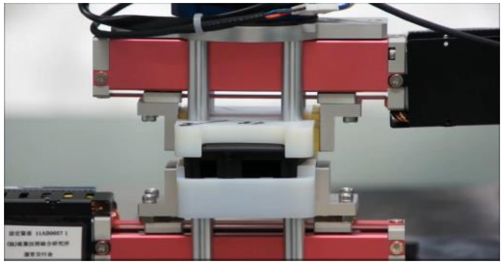
Rotation

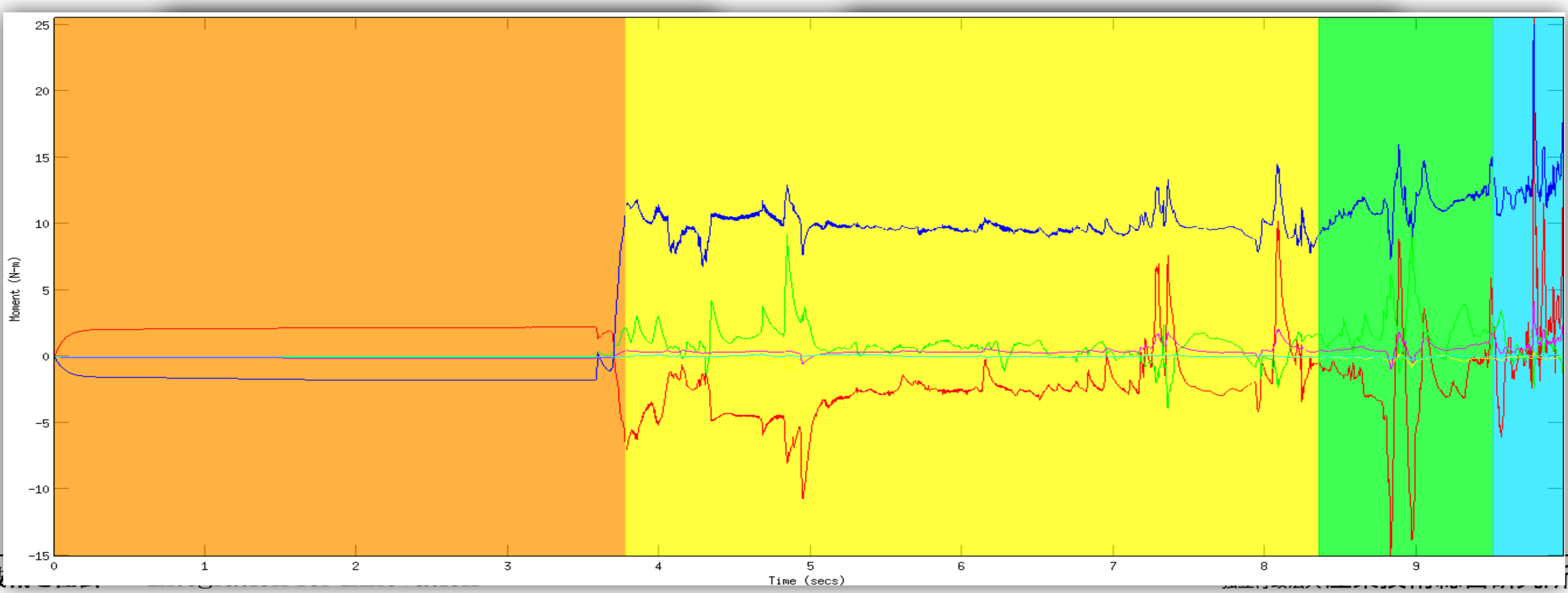


Insertion

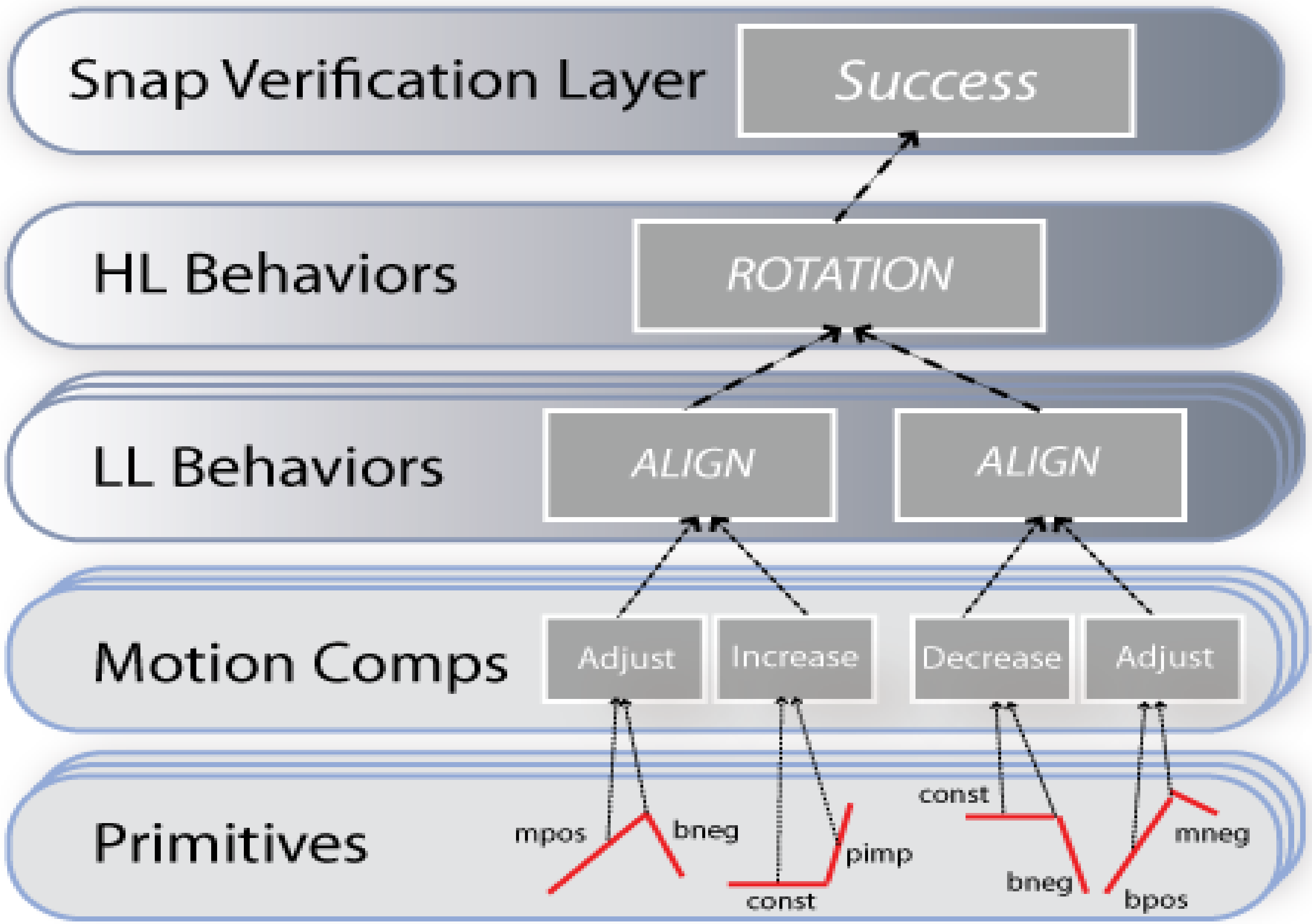


Mating

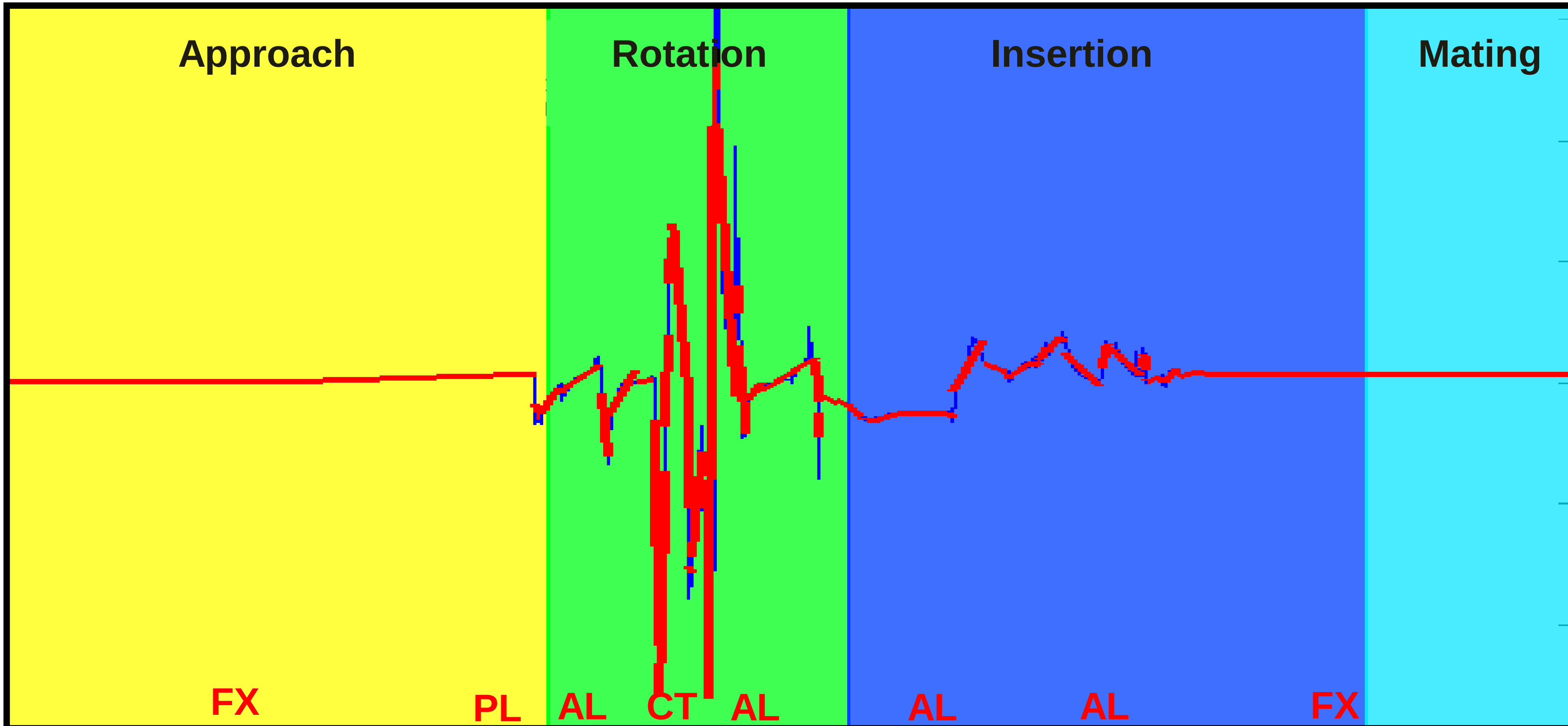




Identification of Assembly State:
The Relative Change-Based Hierarchical Taxonomy (RCBHT)

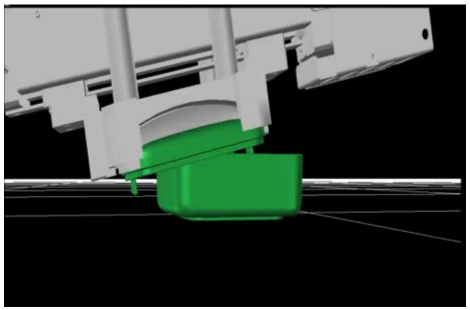


Identification Result

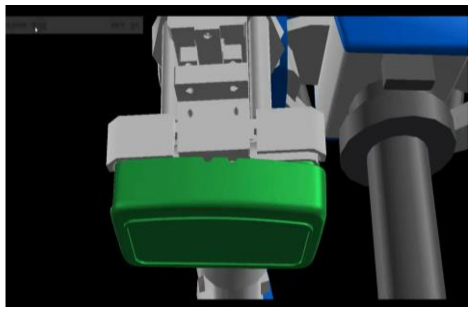


Failure Characterization

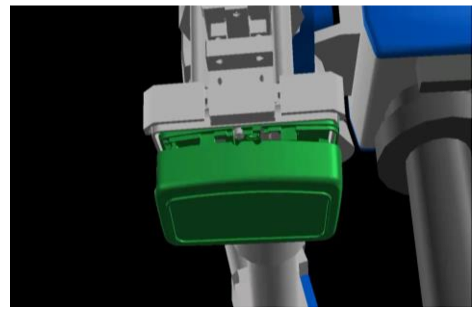
- Approach trajectory deviated in 1 of 3 directions.



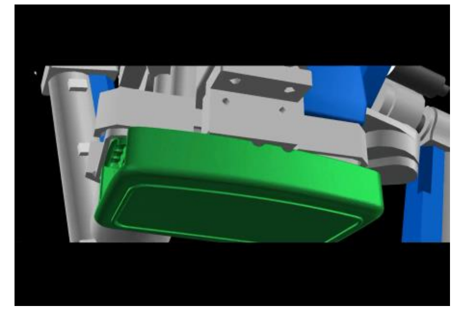
X-Deviation



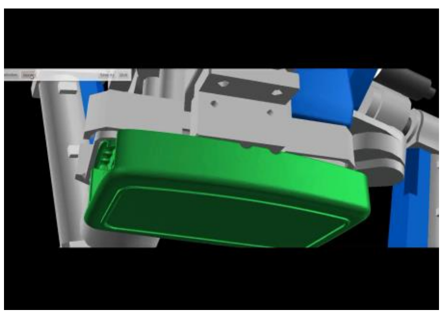
Y-Deviation



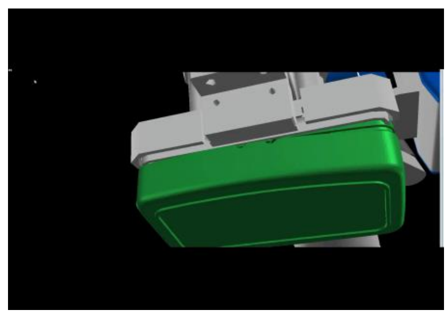
Yaw-Deviation



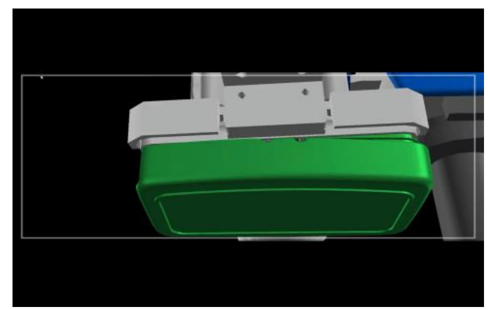
XY-Deviation



XYaw-Deviation



YYaw-Deviation



XYYaw-Deviation

- Assumed “small” deviations → local error correction motions.

Methods: FC Training

- Measure statistical parameters: $\{\mu, max, min\}$ for tasks that have deviations in 1, 2, or 3 simultaneous directions.

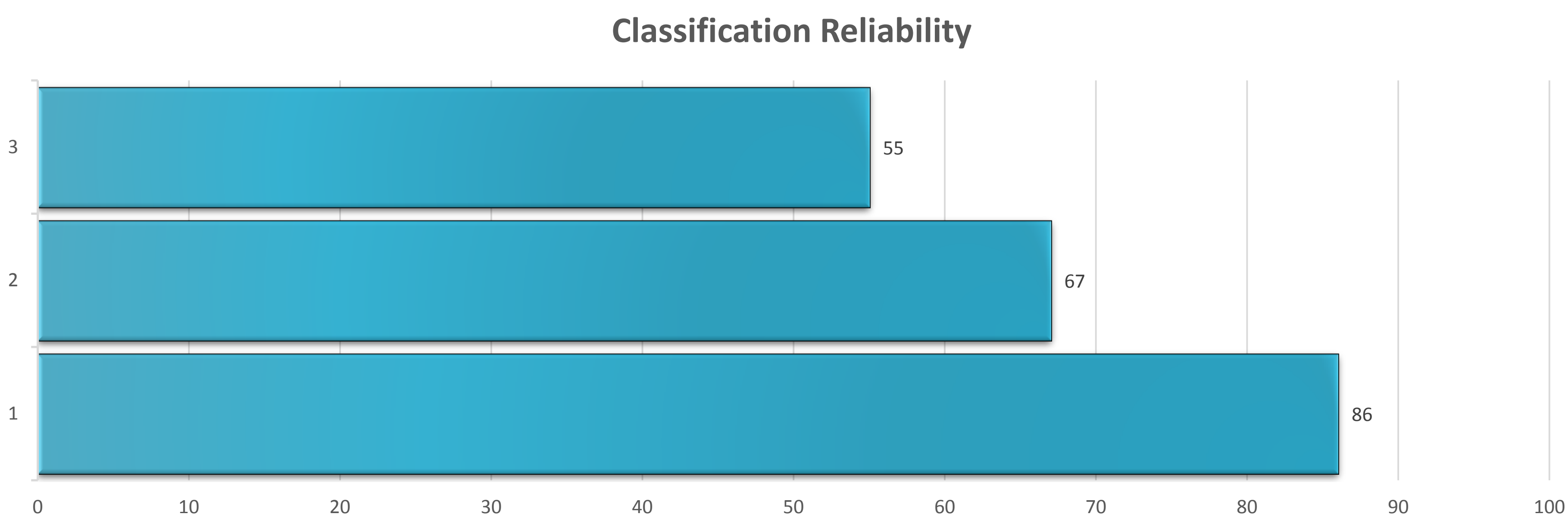
- 7 deviation classes for deviations in: x-axis (Δx), y-axis (Δy), and yaw-axis ($\Delta \phi$).

1-deviation	$\{\Delta x, \Delta y, \Delta \phi\}$
2-simultaneous deviations	$\{\Delta xy,\ \Delta x\phi,\ \Delta y\phi\}$
3-simultaneous deviations	$\{\Delta xy\phi\}$

- Training samples organized by equally spaced intervals.

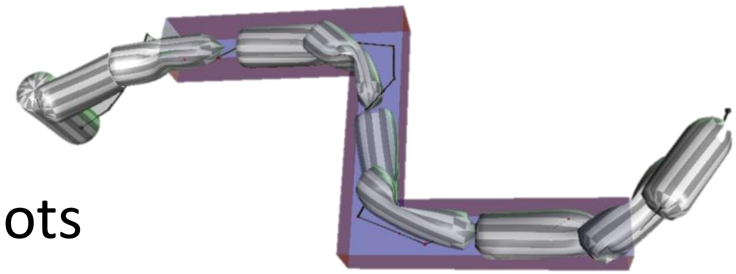
Experiments Testing

- Tested with 32 trials:
  - 1Dev:18 trials, 2Dev:12 trials, 3Dev: 4 trials.



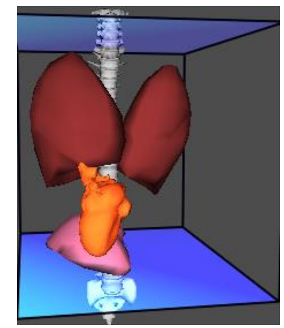
Assembly Planning of Elastic Parts

Motion planning of flexible parts



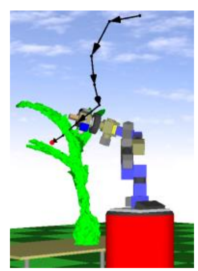
- Previous work
  - Application: medical robots, flexible robots
  - Flexible robot [Lamiraux 2001], [Bayazit 2002], [Gayle 2005, 2006], [Mahoney 2009] [Tang 2010]

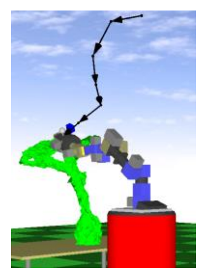
    Approximation, model reduction, smooth transition

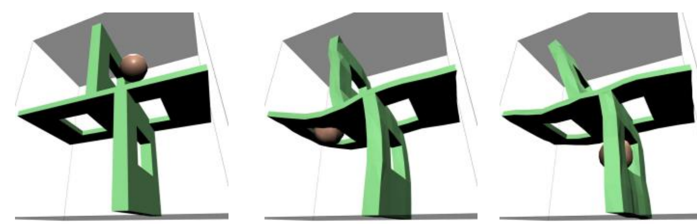


  - Flexible environment [Rodriguez 2006], [Frank 2011]

    Approximation, learning in advance





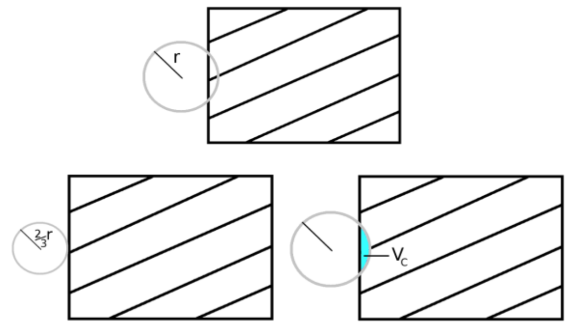


- Planning for assembly
  - Arbitrary deformation
  - More precise model
  - Including drastic status change (e.g. snapping)

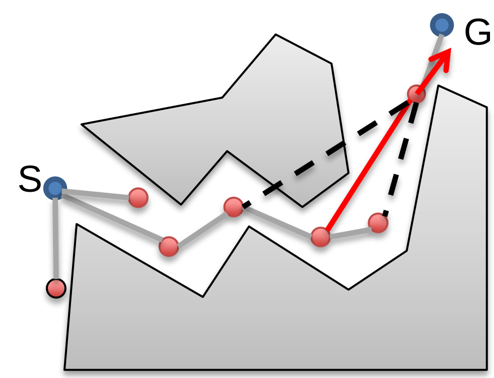
Motion planning of deformable objects

- Issues on previous methods

  - Arbitrary deformation at any place
    → Planning non-deformable area to be grasped by a robot



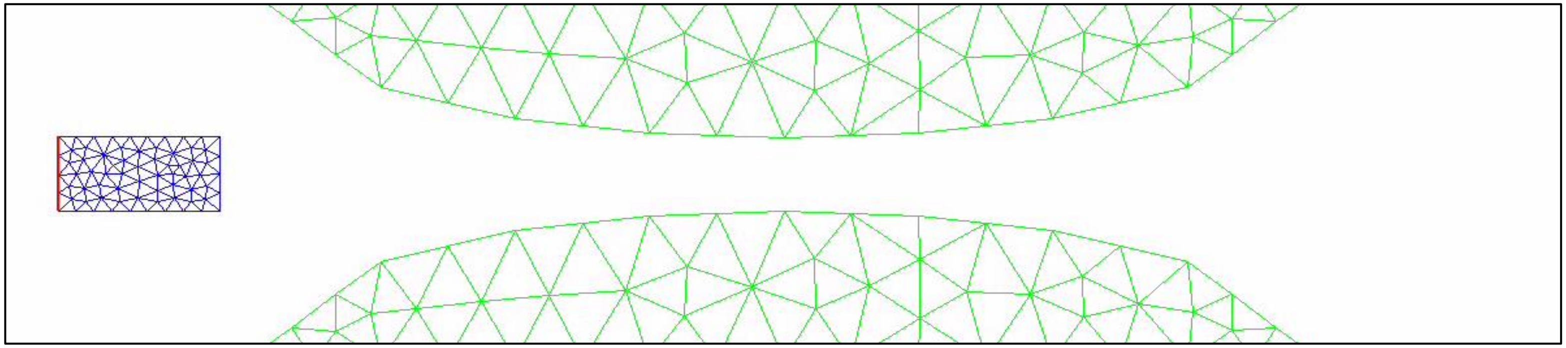
  - Needs for simple measure for deformation
    →Ratio of nodes inside the obstacle
    Higher feasibility with smaller measure
    Used for orientation correction during planning



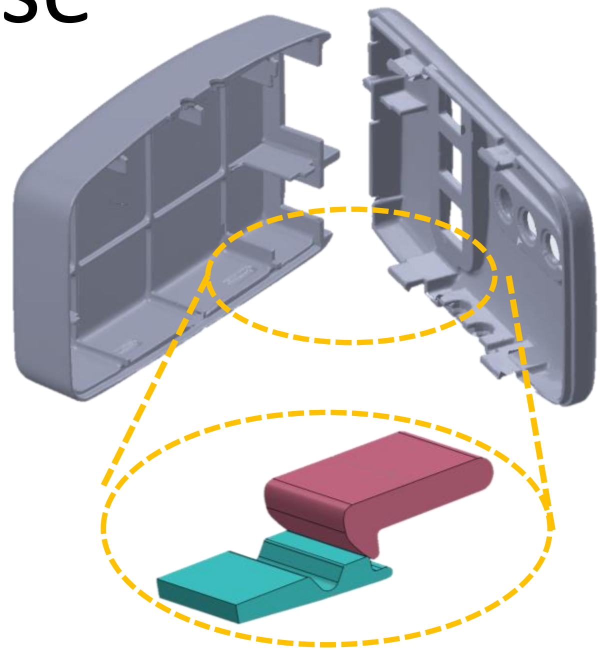
  - Fluctuation of configuration in planned path
    → Leading towards less fluctuated direction :
    A “guide” path with visibility-like method

2-D Case

- Motion planning of deformable objects
  - Planning grasped object instead of allowing arbitrary deformation
  - Sampling-based planning with minimal deformation based on simple measure
  - The deformation is more precisely computed based on FEM
- Simulation
  - Basic 2-D problem
  - Planning for narrow passage that intrinsically requires deformation

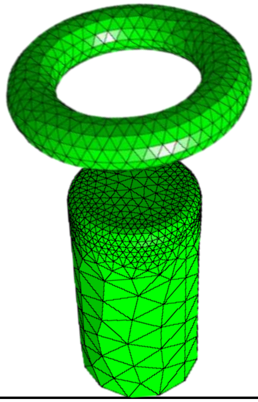


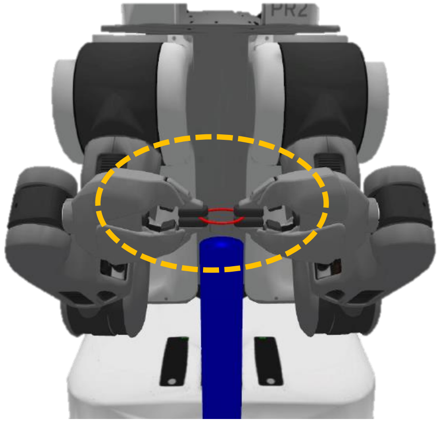
Extension to 3-D case



- Including possible larger status change
  - Snapping assembly: fast status change
  - O-ring fitting: large deformation
- Integrating planner and simulation
  - Optimization-based planning (e.g. CHOMP)
  - Efficient FEM simulator (SOFA)

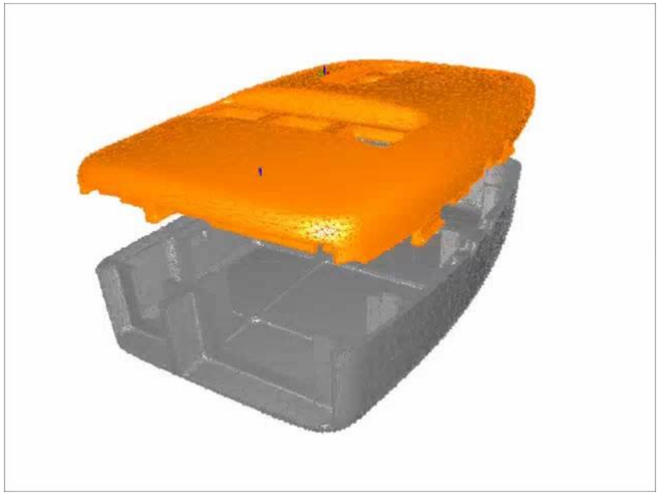
    http://www.sofa-framework.org/



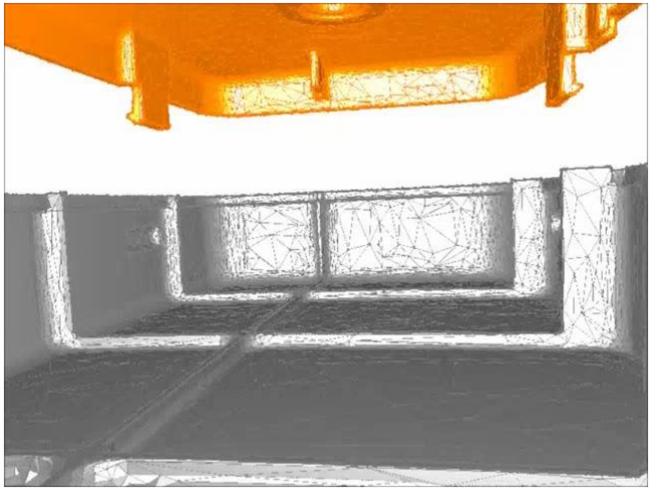


Simulation of snapping joints

- FEM-based model
  - Simulation: SOFA
  - Thousands of nodes
  - Deformable / rigid parts

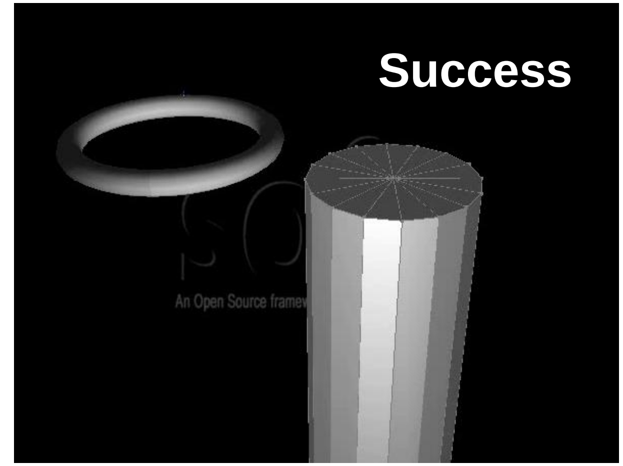


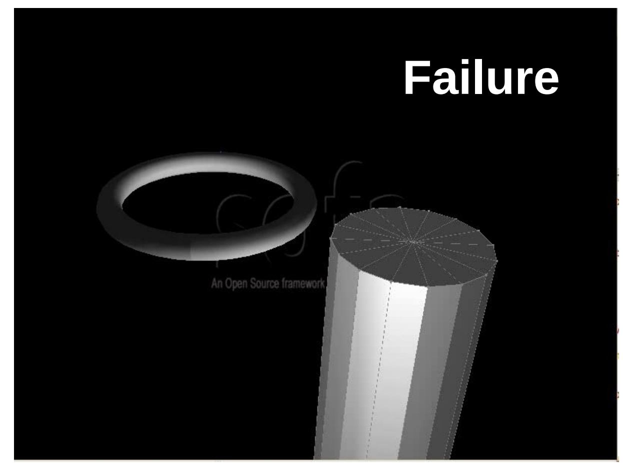
- First results
  - Assuming firm grasp
  - Snapping reproduced
  - Trajectory planned trial-and error basis



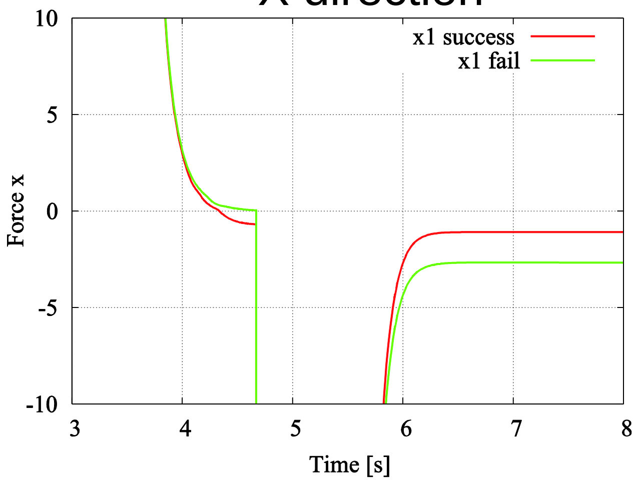
Simulation of O-Ring assembly

- Simulations
  - O-ring modeled by a segment and springs
  - Grasping at two points
  - CHOMP-based trajectory, modified try-and-error
  - Compare successful and failure trajectories – force difference observed.

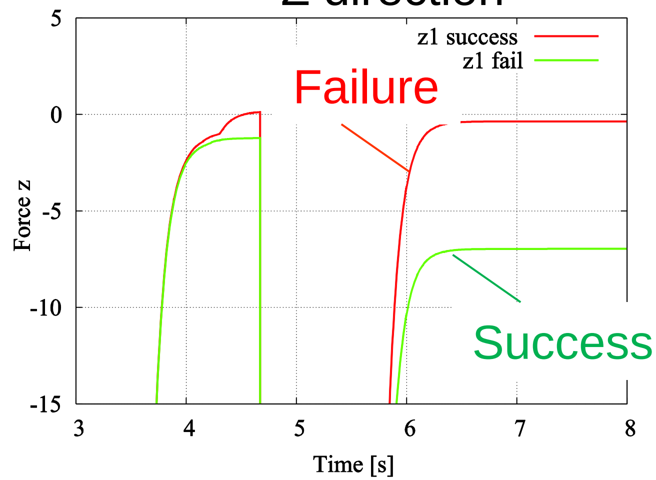




X direction



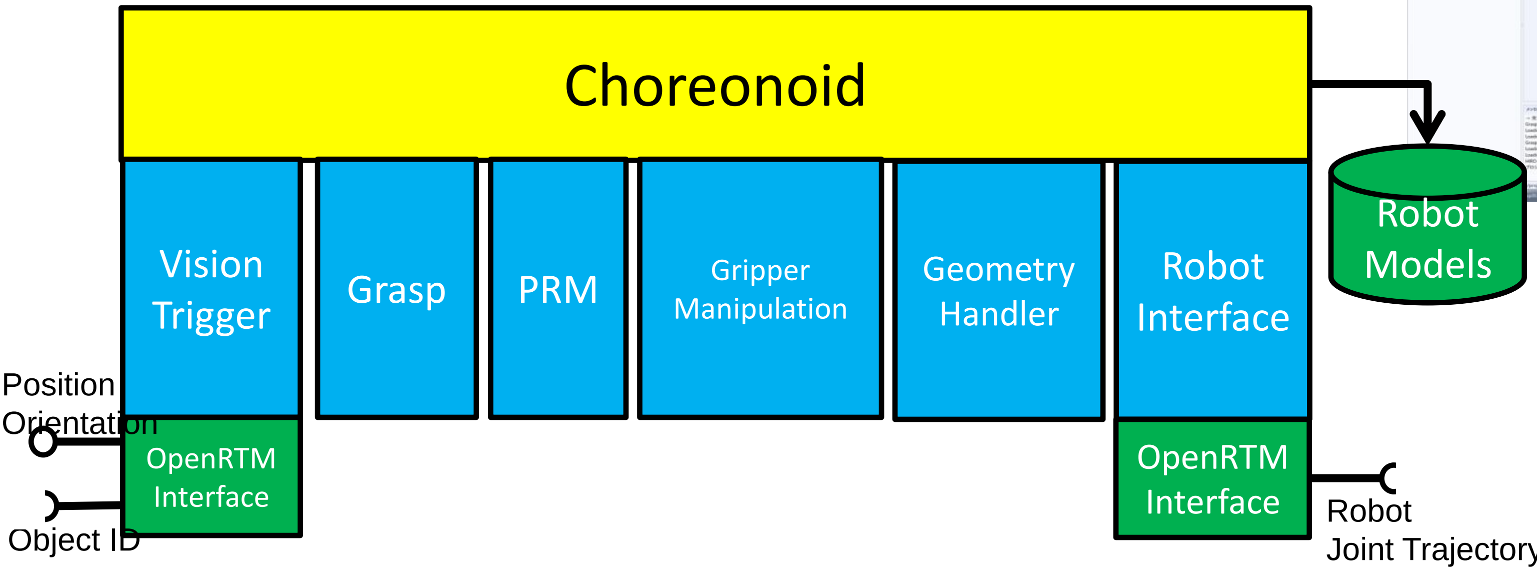
Z direction

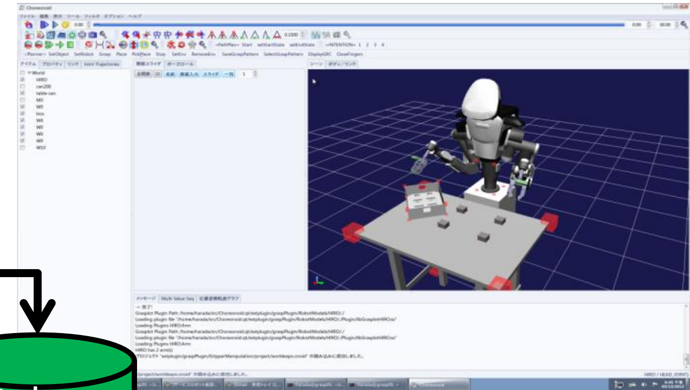


Implementation Issue

Available from http://choreonoid.org/GraspPlugin

Grasp Plugin for Choreonoid





Grasp: Grasp Planning
PRM: Trajectory Planning
GripperManipulation： Pick and Place Planning
GeometryHandler: Clustering of Polygon Models
VisionTrigger: Interface in Connection with Vision Sensor
RobotInterface: Interface in Connection with Robot Controller

Conclusions

- Motion Planning of Dual-Arm Industrial Manipulators
- Snap Assembly
- Assembly Planning of Elastic Parts