

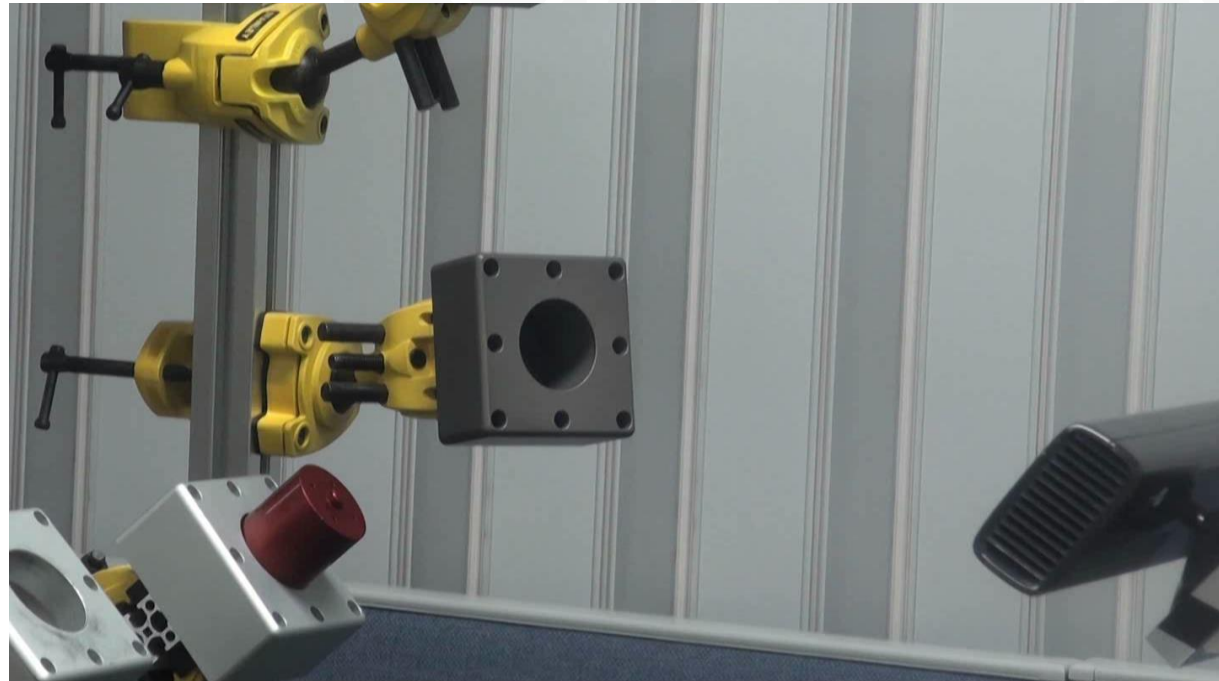
# **EXPERIMENTAL RESULTS OF WHOLE-BODY CONTROL FRAMEWORK ON TORQUE CONTROLLED HUMANOID LEGGED ROBOT AND DUAL ARM-HAND MANIPULATOR**

**Yisoo Lee, Hyeonjun Park, Jaeheung Park, Seoul National University**

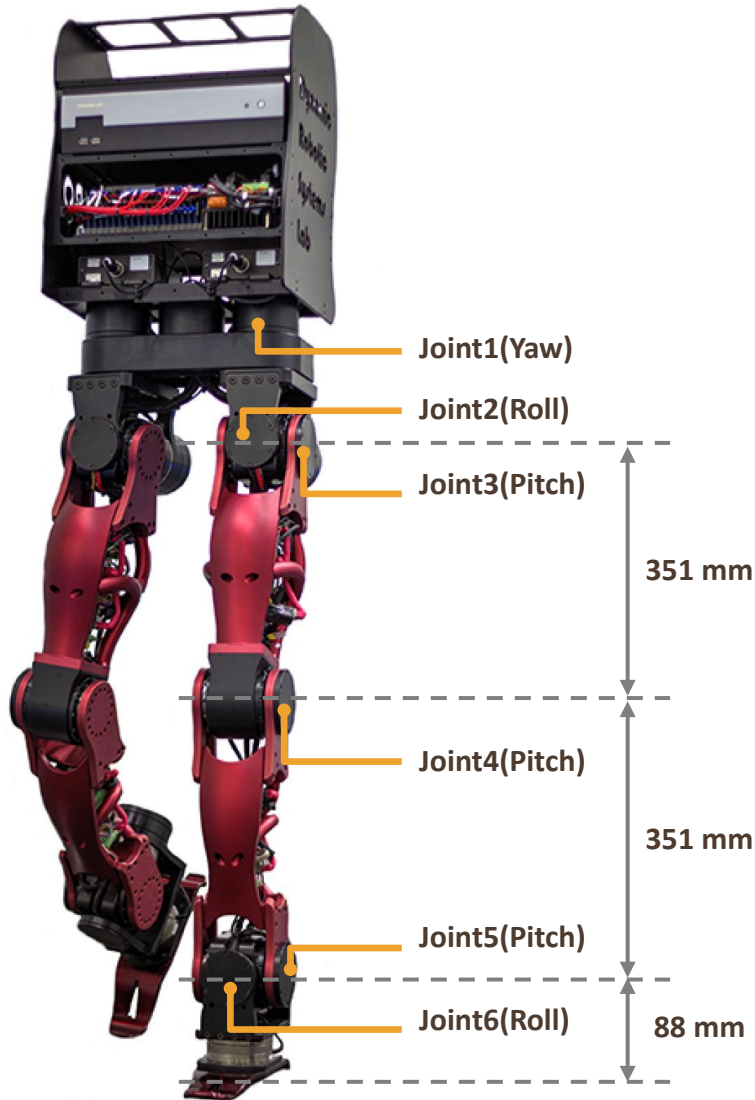
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**Ji-Hun Bae, Moon-Hong Baeg, KITECH**

# HUMANOID LEGGED ROBOT & ARM-HAND MANIPULATION



# SPECIFICATIONS OF THE ROBOT



- ❖ Degree of Freedom: 12
- ❖ Total Weight: 54.635kg (Legs 39.335Kg)
- ❖ Joint Range of Motion

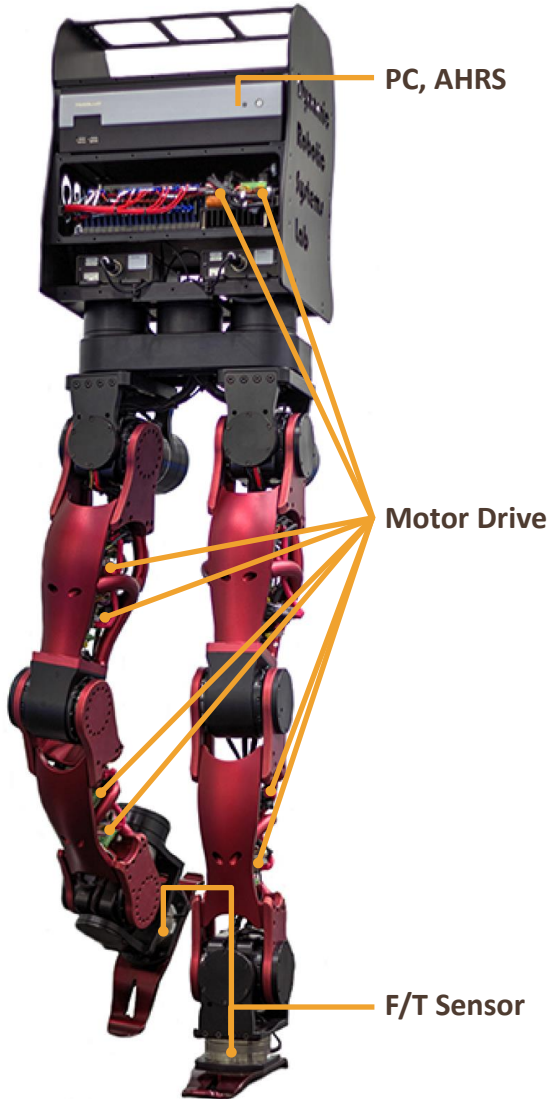
Joint		Range	
		Minimum	Maximum
Hip	Y	-47.3	46.5
	R	-33.4	111
	R	-103.1	31.6
Knee	P	-21.5	121.1
Ankle	P	-83.6	35.3
	R	-42.5	67.8

- ❖ Joint Specifications

Joint	Hip Yaw (1)	Hip Roll (2)	Hip Pitch (3)
Max Cont. Output Power(W)	300	364	427
Reduction Ratio	50	50	50
Cont. Torque after reduction(Nm)	42.8	61.0	77
Peak Torque after reduction(Nm)	152.0	231.0	307.5
Speed @ 48V after reduction(rad/sec)	7.92	5.24	6.13

Joint	Knee Pitch (4)	Ankle Pitch (5)	Ankle Roll (6)
Max Cont. Output Power(W)	427	427	209
Reduction Ratio	50	50	50
Cont. Torque after reduction(Nm)	77.0	77.0	21.45
Peak Torque after reduction(Nm)	307.5	307.5	76.5
Speed @ 48V after reduction(rad/sec)	6.13	6.13	15.73

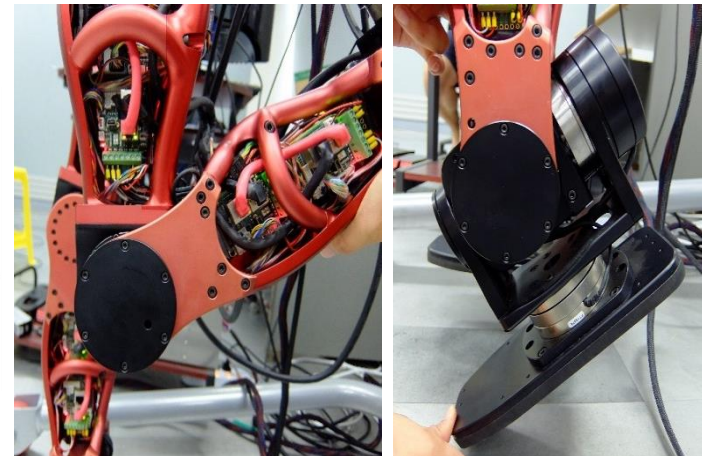
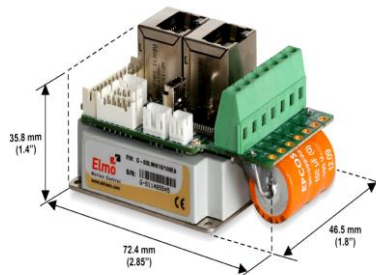
# DEVICES



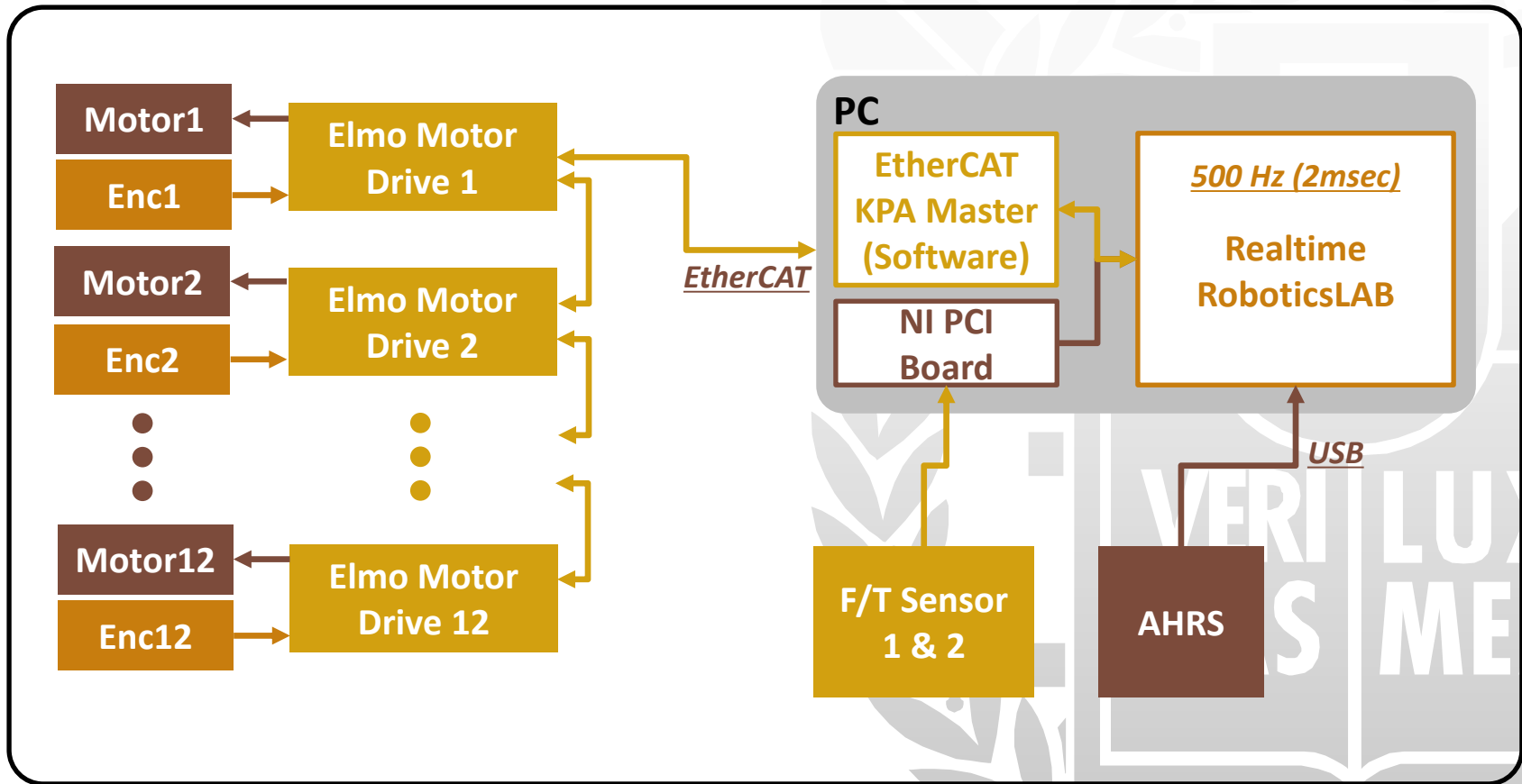
- ❖ PC : Intel I7-630m processor and 4Gbyte DDR3 RAM
- ❖ AHRS(Attitude Heading Reference System)  
: Microstrain 3DM-GX3-25 (x1)



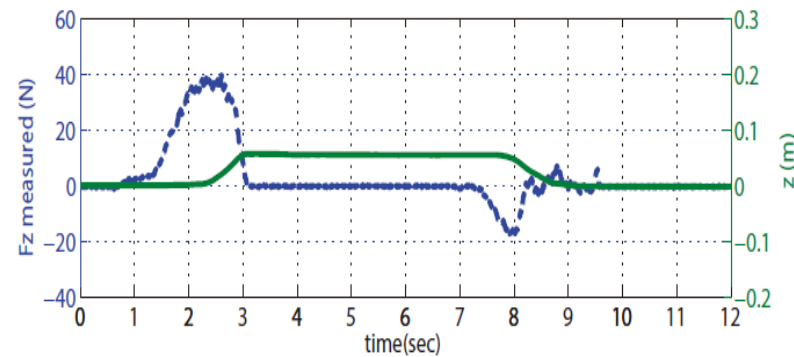
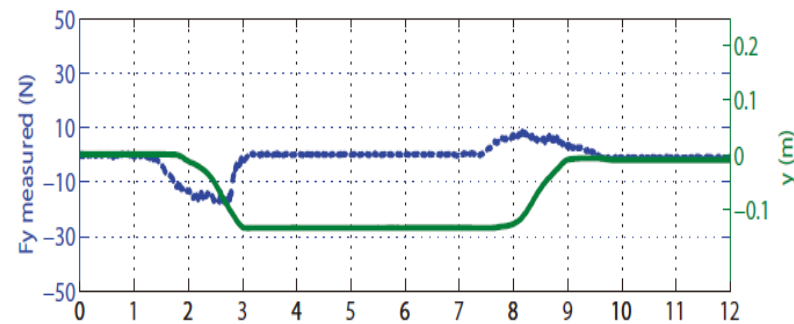
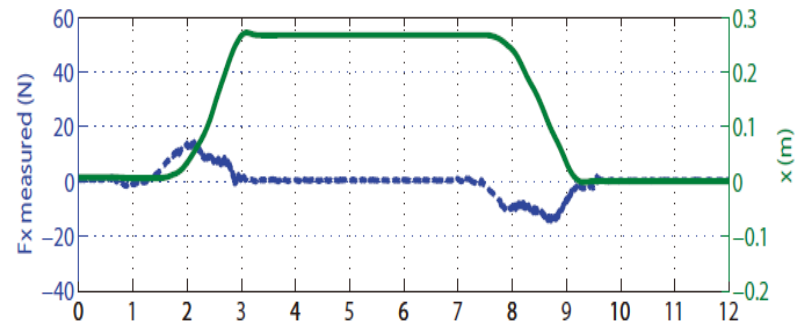
- ❖ Motor Drive  
: Elmo Gold Solo Whistle Digital Servo Drive (x12)
- ❖ F/T Sensor: ATI DAQ MINI85 (x2)



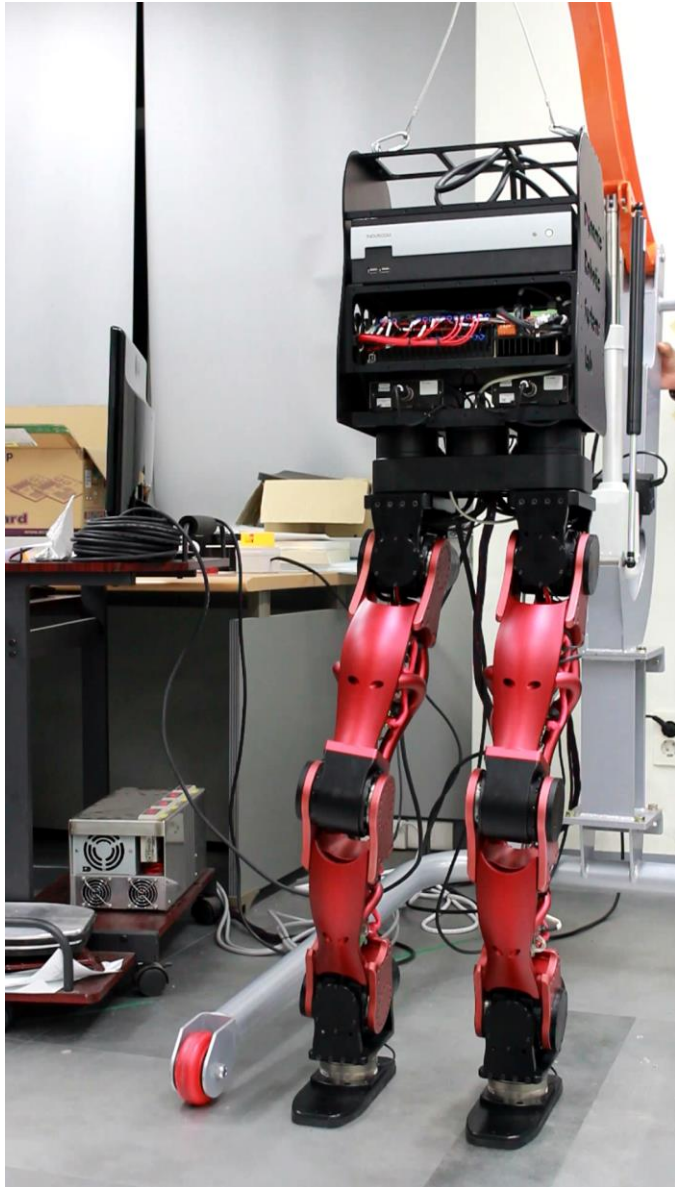
# SYSTEMS



# GRAVITY COMPENSATION

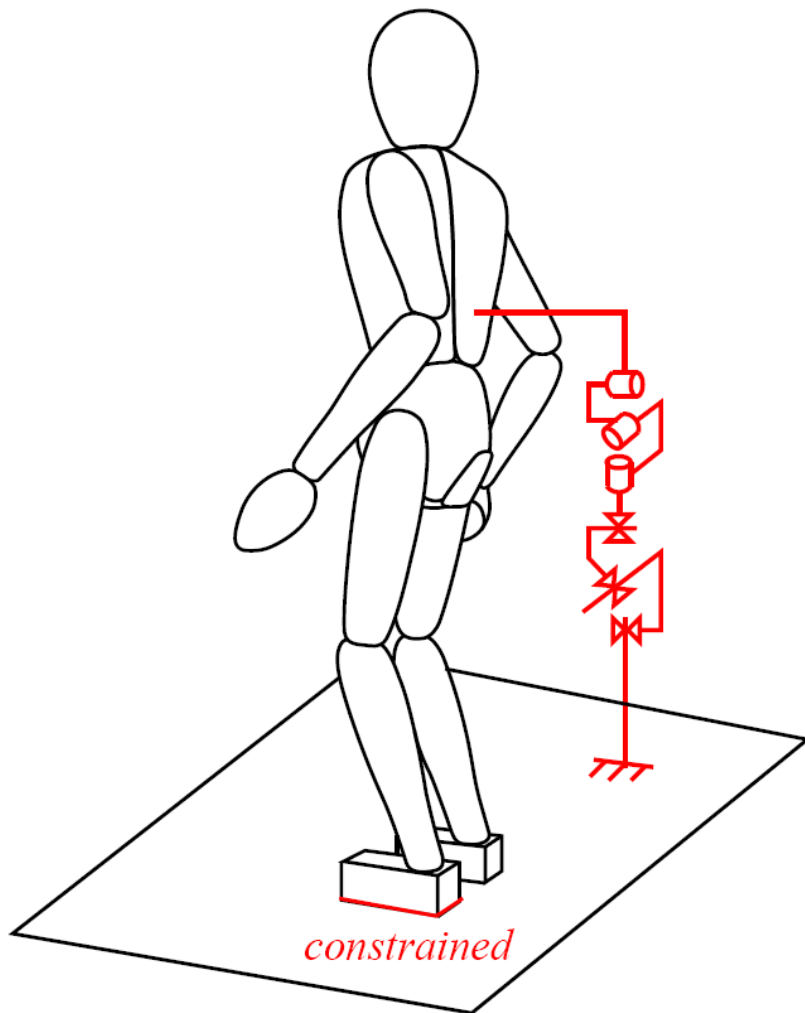


# OPERATIONAL SPACE WHOLE-BODY CONTROL



- ❖ **COM position  
& Body orientation control**
  - COM y : -0.05m -> 0.05m
  - COM x, z : Hold Initial Position
  - Orientation : Hold Initial Orientation
  - Task time : 7.5 sec

# ROBOT CONTROL IN CONTACT



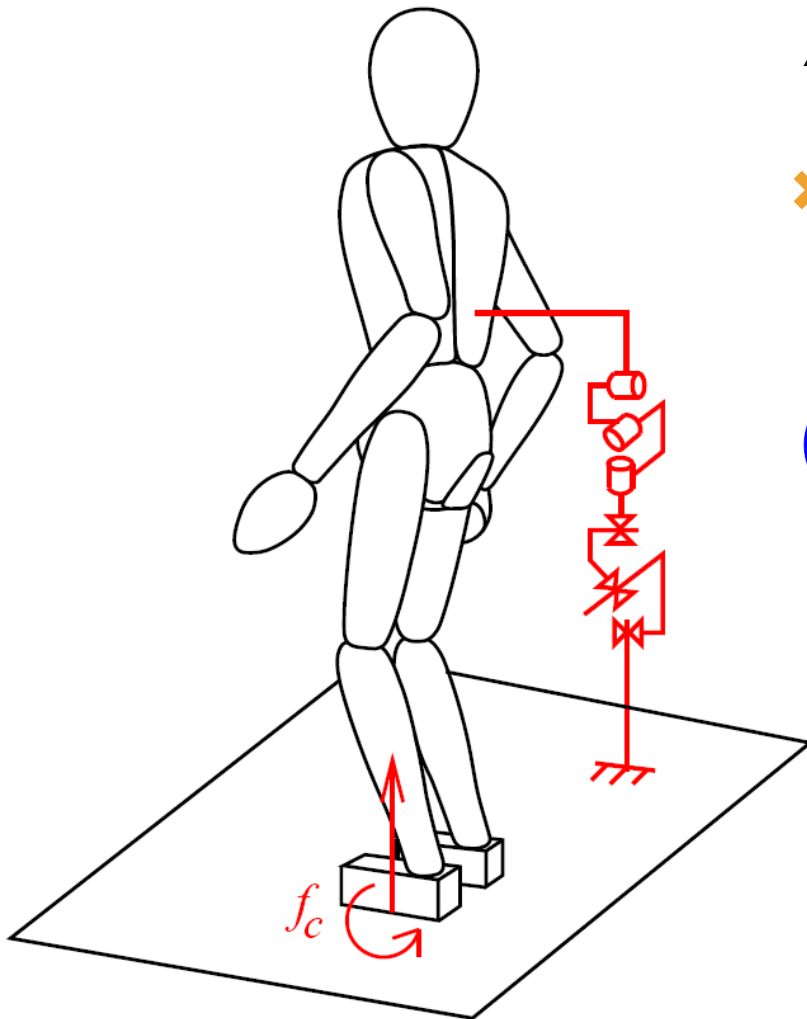
✘ Reaction forces are used for control



✘ Task Space Control using Whole-body Dynamics

VERI LUX  
TAS MEA

# DYNAMICS IN CONTACT



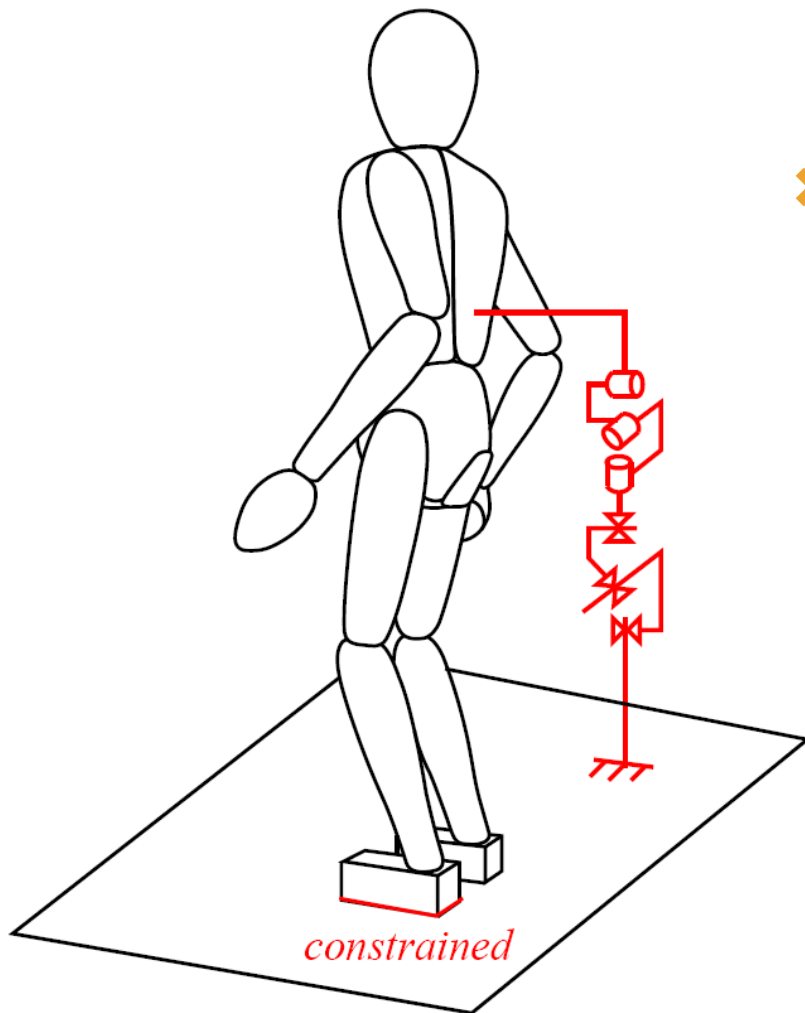
$$A(q)\ddot{q} + b(q, \dot{q}) + g(q) + J_c^T \mathbf{f}_c = \Gamma$$

✘ By treating the contacts as constraints,  $\ddot{x}_c = 0$   $\dot{x}_c = 0$

$$\mathbf{f}_c = \bar{J}_c^T(q)\Gamma - \mu_c(q, \dot{q}) - p_c(q)$$

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TAS MEA

# CONSTRAINED DYNAMICS



$$A(q)\ddot{q} + b(q, \dot{q}) + g(q) + J_c^T \mathbf{f}_c = \Gamma$$

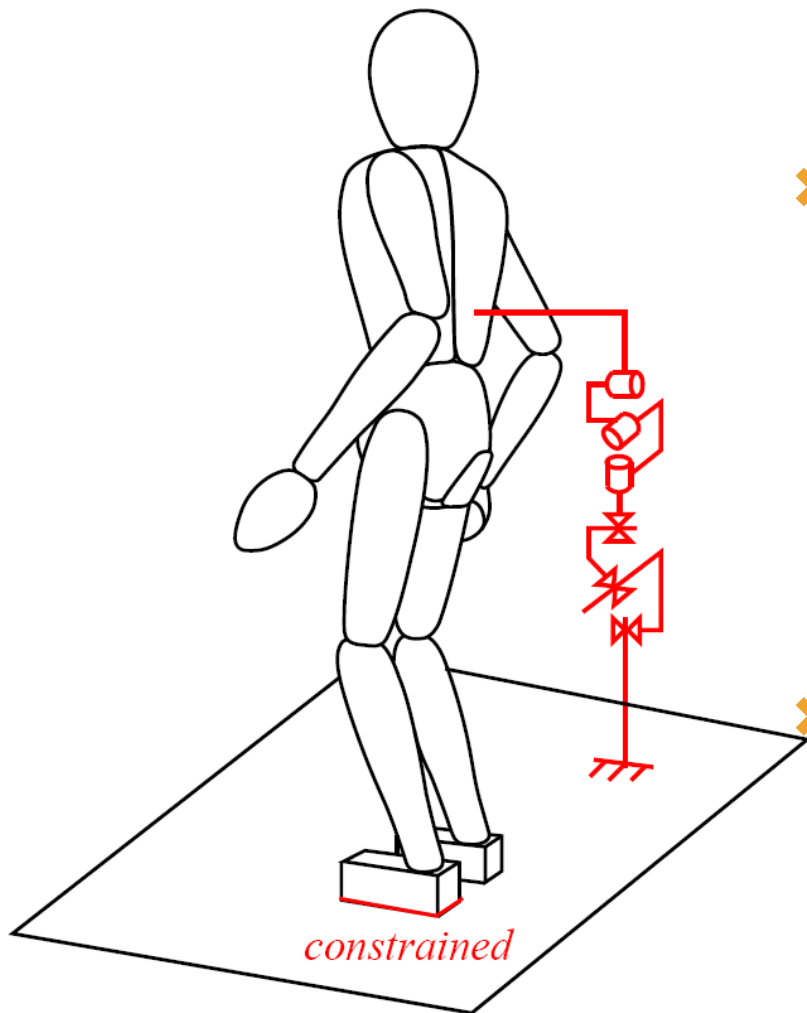
✘ By treating the contacts as constraints,  $\ddot{x}_c = 0$   $\dot{x}_c = 0$

$$\mathbf{f}_c = \bar{J}_c^T(q)\Gamma - \mu_c(q, \dot{q}) - p_c(q)$$

$$\begin{aligned} A(q)\ddot{q} + b(q, \dot{q}) + g(q) \\ - J_c^T(\mu_c(q, \dot{q}) + p_c(q)) \\ = (I - J_c^T \bar{J}_c^T)\Gamma \end{aligned}$$



# TASK CONTROL



- ✘ Constrained Task Dynamics

$$\Lambda \ddot{\mathbf{x}} + \mu(\mathbf{q}, \dot{\mathbf{q}}) + \mathbf{p}(\mathbf{q}) = \mathbf{F}$$

- ✘ Control Force

$$\mathbf{F} = \hat{\Lambda} \mathbf{f}^* + \hat{\mu} + \hat{\mathbf{p}}$$

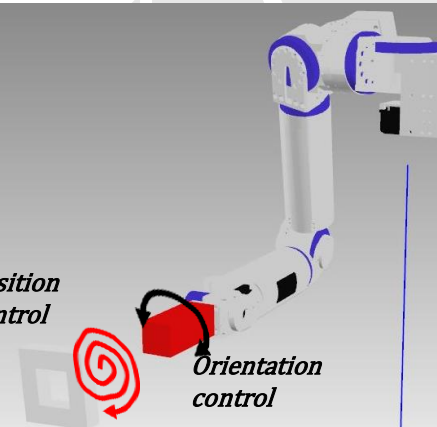
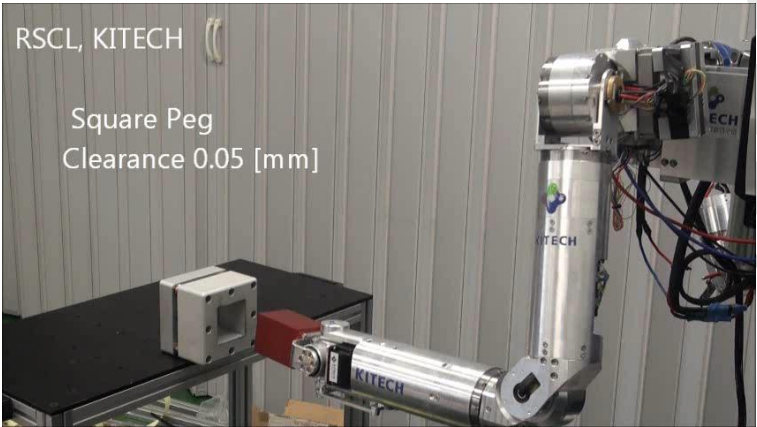
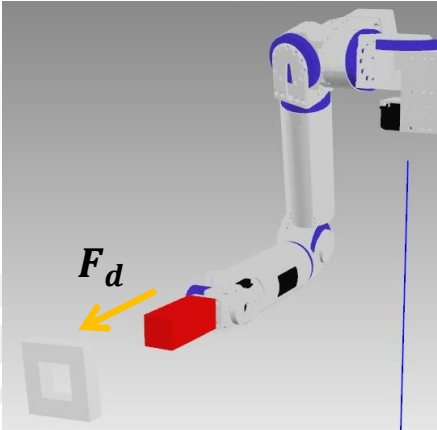
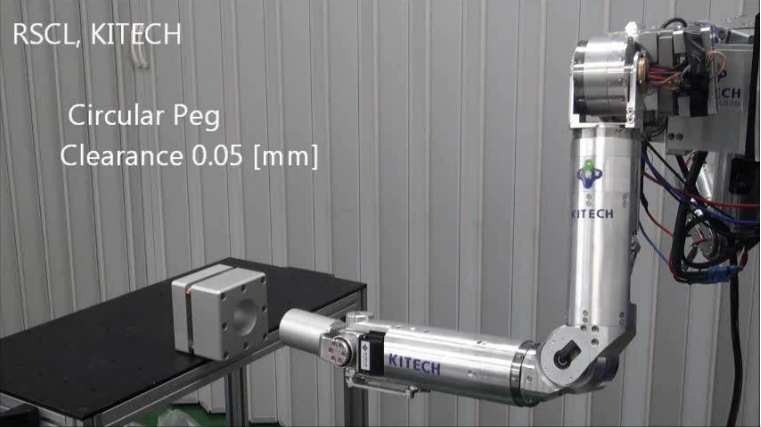
# ONGOING & FUTURE WORK

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- ❖ **Motion and Force Control in Various Contact States**
  - Contact force distribution
  - Change of contact state
- ❖ **Estimation of Contact State and Contact Environment**
- ❖ **Static/Dynamic Walking**
- ❖ **Upper Body...**



# PEG IN HOLE TASK LAST YEAR



LUX  
MEA

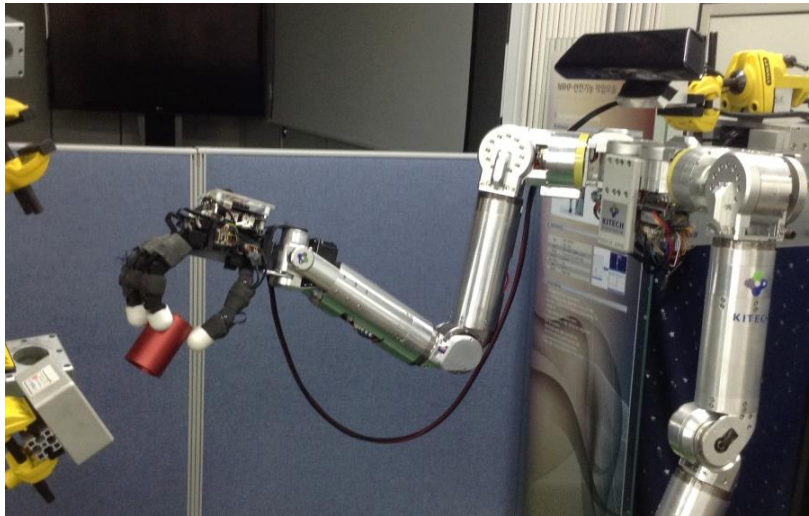
# PEG IN HOLE TASK WITH TWO HANDS



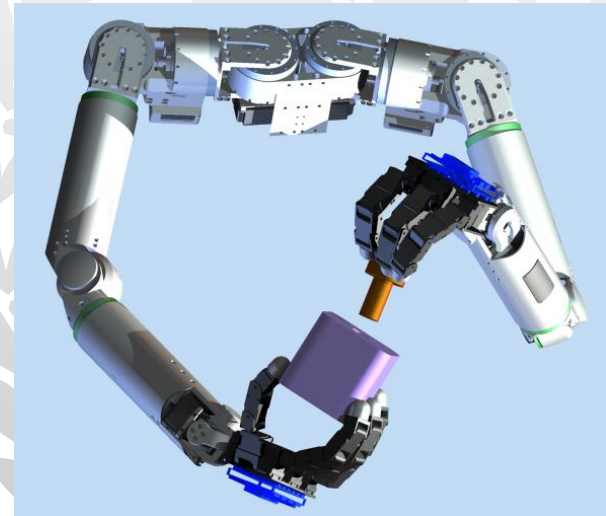
LUX  
MEA

# RESEARCH GOALS

- ❖ Peg-in-hole task with unified hand-arm system
- ❖ Using compliance, without force information feedback
- ❖ Developing robust peg-in-hole strategy for unstructured environment



Hand-arm system



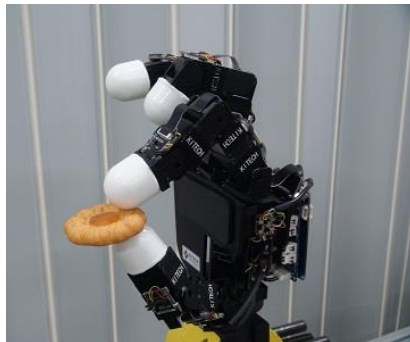
Dual-arm system

UX  
NEA

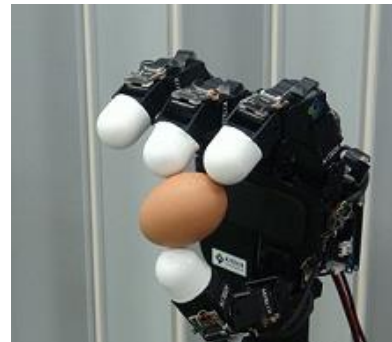
# ROBOTIC HAND

## ❖ Robotic grasping and manipulation

- Grasping
  - various grasping ex) pinching, 3/4 grasping, envelop
  - known or unknown and various object grasping
- Manipulation (In-Hand Manipulation)
  - object transition
  - object rotation
  - regrasping



Pinching



3 finger grasping



4 finger grasping



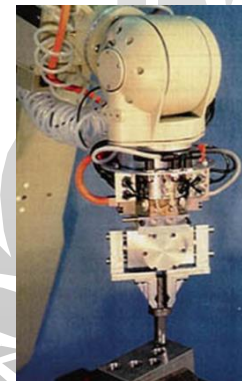
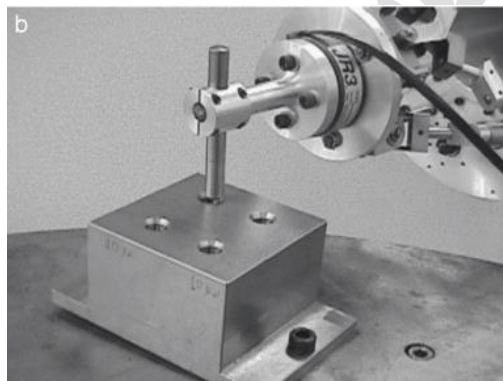
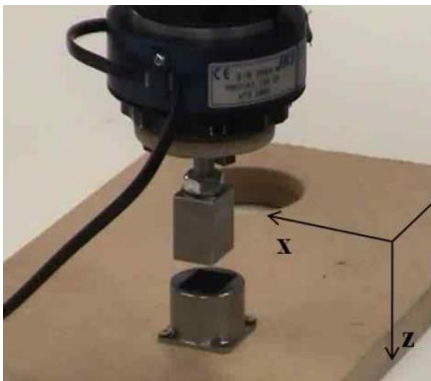
envelop

VERI LUX

A

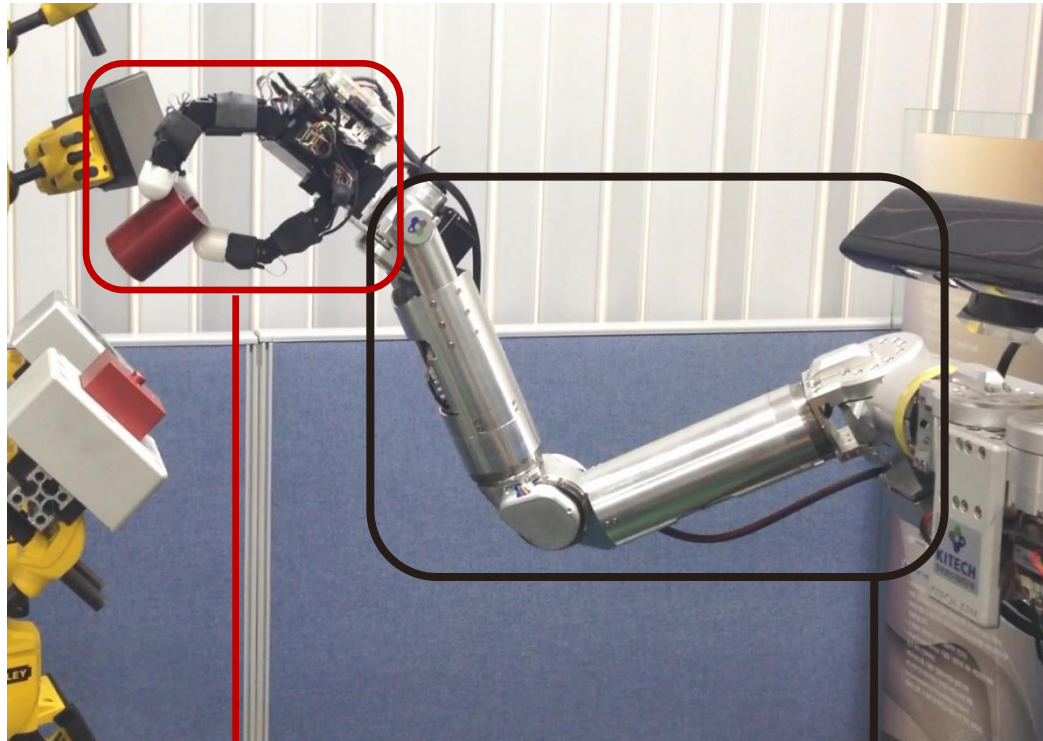
# PEG-IN-HOLE

- ❖ Peg-and-hole task is present in a major part of assembly operation and is therefore studied by many researchers
- ❖ The Peg in Hole problem has been extensively researched because it represents a contact task of manipulation that requires both position and force control
- ❖ Stiffness could make the peg-hole jam and peg-in-hole seems to require extremely careful consideration to perform well even with a good manipulator hardware



Peg in hole task with manipulator

# ROBOT HAND-ARM SYSTEM



Mini  
Robot hand

Macro  
8DOF-Manipulator

## ❖ Macro

- Robot arm
- Slow
- Strong

## ❖ Micro

- Robot hand
- Fast
- Weak

VERI LUX  
TAS MEA

# PEG-IN-HOLE STRATEGY

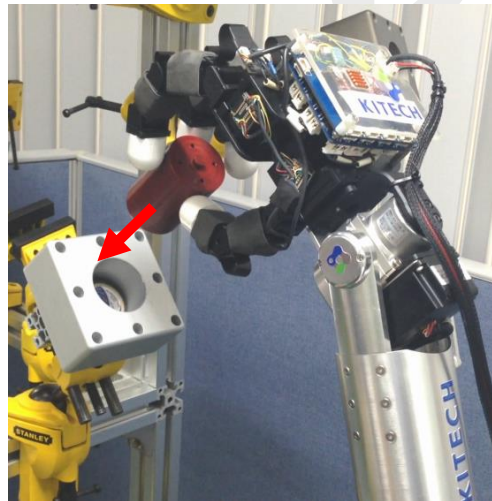
- ❖ Generating force on the peg toward the hole
- ❖ Searching the hole following spiral trajectory
- ❖ Rotating the peg for orientation fitting and friction decreasing

Robot hand

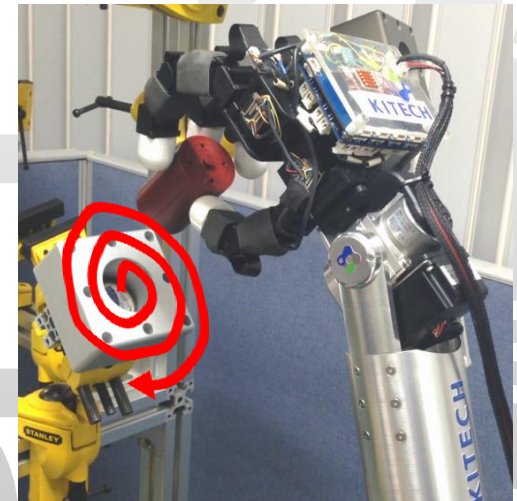


Screw motion

Robot arm

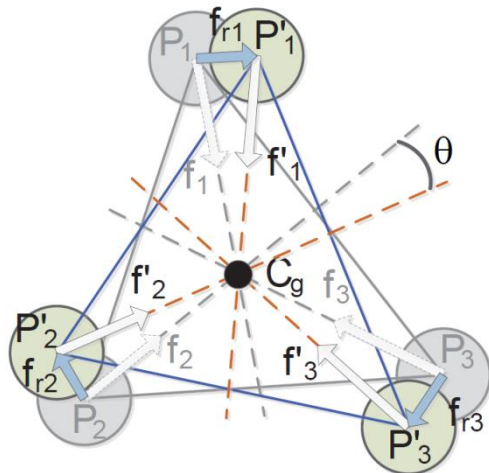
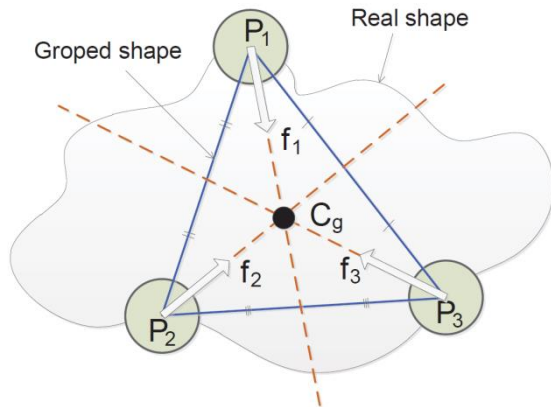


Generate force



Spiral motion

# OBJECT ROTATING AND MOVING WITH ROBOT HAND



## ❖ Each finger input

$$u_i = u_{gi} + u_{ti} + u_{ri} + g_i$$

## ❖ Object grasp input

$$u_{gi} = J_i^T f_i$$

$$\text{where, } f_i = k_i \frac{(C_g - p_i)}{\|C_g - p_i\|}, C_g = \frac{1}{3} \sum_{i=1}^3 p_i$$

## ❖ Object transition input

$$u_{ti} = J_i^T k_{ti} (p_{is} + \Delta C_g - p_i)$$

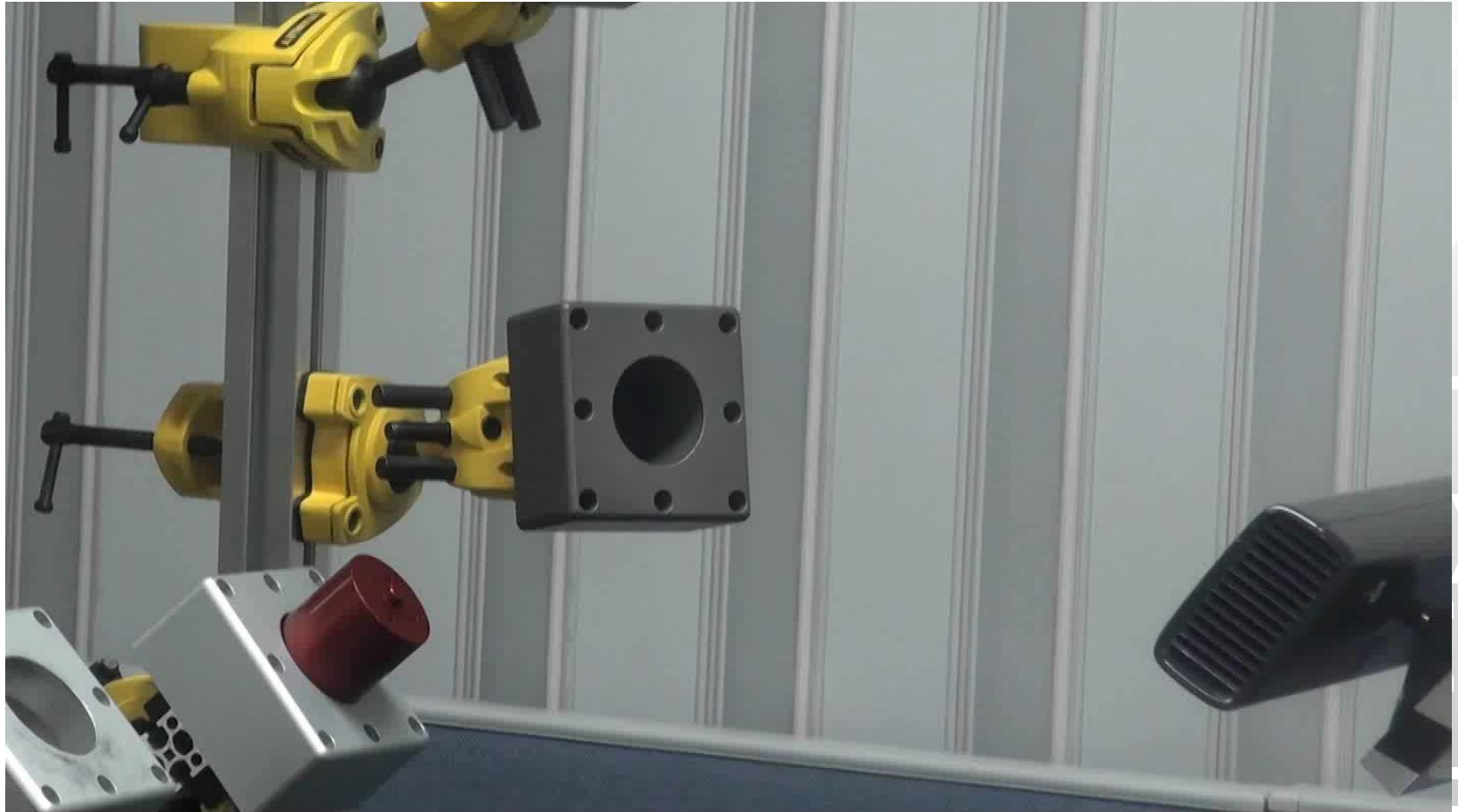
## ❖ Object rotation input

$$u_{ri} = J_i^T k_{ri} (p_{id} - p_i)$$

$$\text{where, } p_{id} = R_\theta (p_{is} - C_g) + C_g$$

# PEG-IN-HOLE USING ROBOT HAND

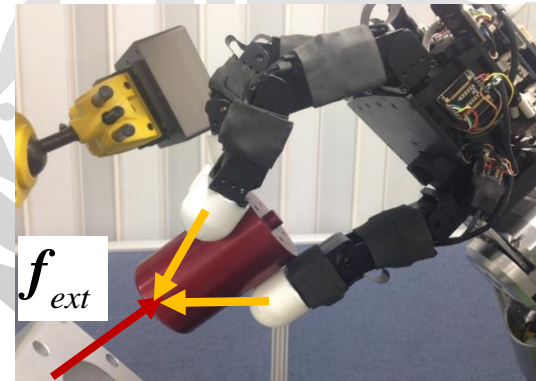
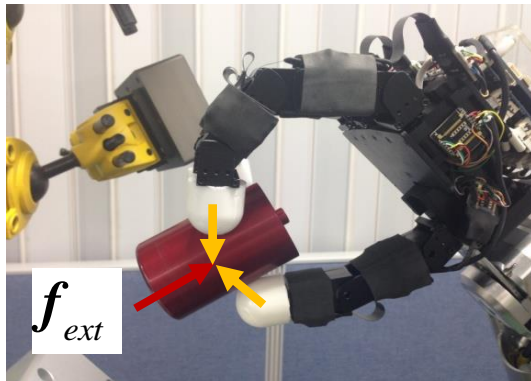
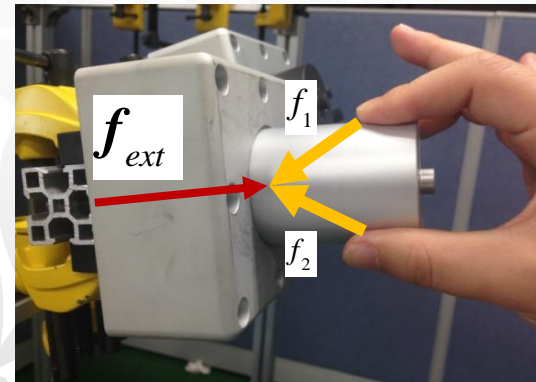
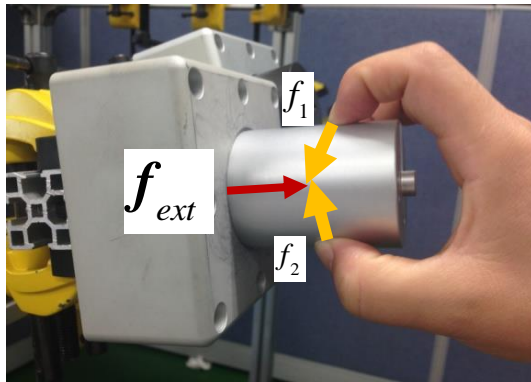
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X  
A

# REGRASPING

## ❖ Regrasping for inserting force



LUX  
MEA

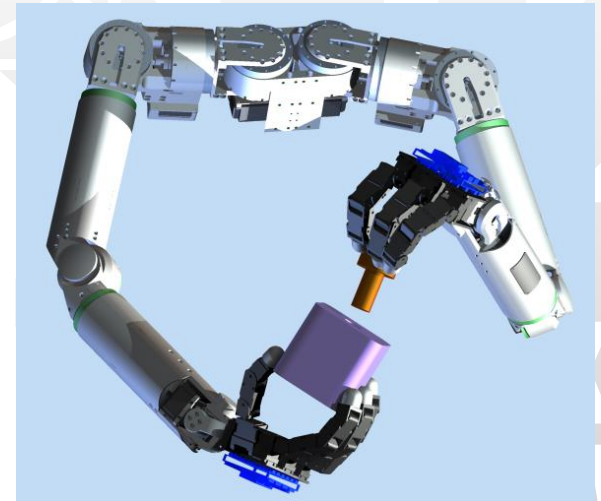
# CONCLUSIONS

## ❖ Conclusions

- High success rate in low tolerance
- Work without exact hole position/orientation information
- Object manipulation with unified hand-arm system

## ❖ Future works

- Assembly works with dual-arm-hand system
- Combine leg, arm, and hand
- Develop the control strategy for the whole system!



Future work