Consideration of Specification of our Collaboration

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Honda R&D

2013.2.12 Tentative Version

2013.2.18 Version 1

2013.5.09 Version 2

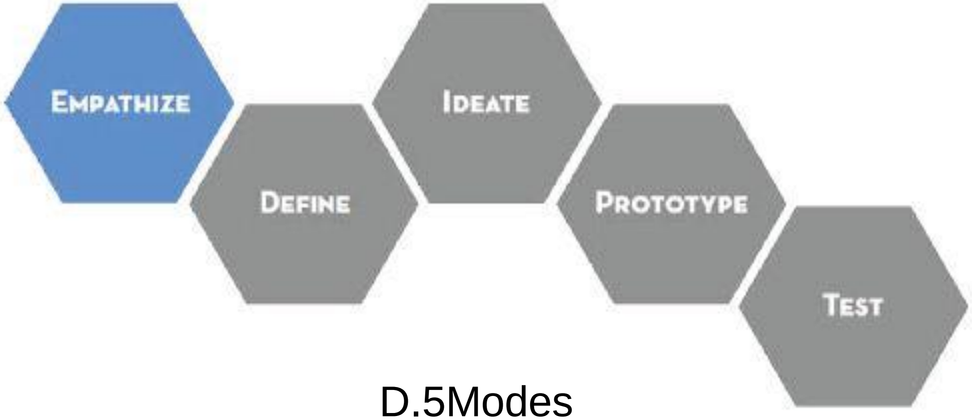
Stanford Mind?

Stanford Design Innovation Process.

Through the course of the project, students learn, apply, and experience the Stanford Design Innovation Process and many of its tool sets. Teams observe and interview users to better understand their needs, benchmark existing technologies and products to identify the design opportunities, extensively brainstorm to discover the obvious, crazy, and novel ideas, and iteratively prototype to quickly test their ideas and get a better understanding of their designs. The end result is a refined design concept backed with key insights.

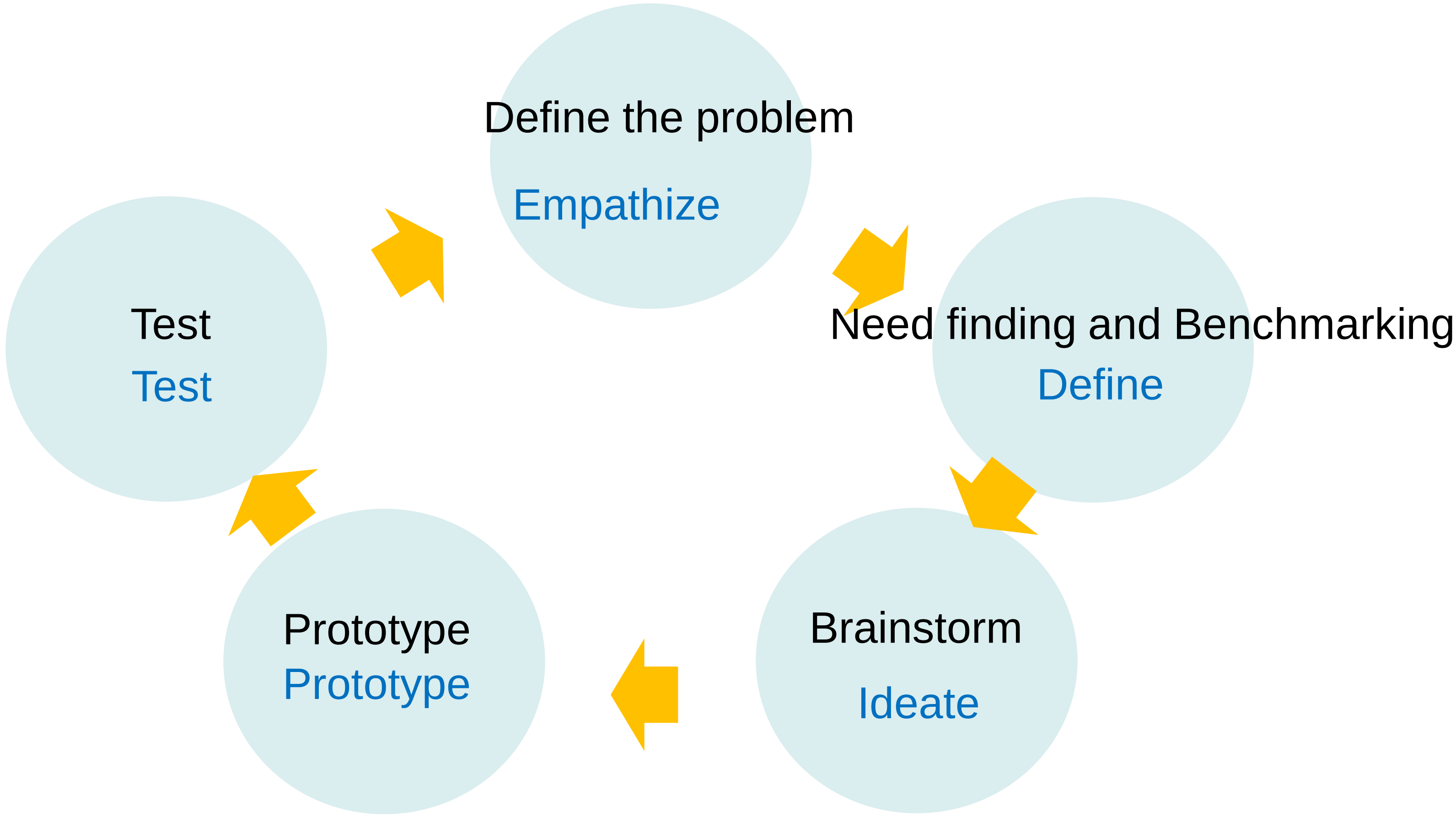
Click to Enlarge

About d.School



D.5Modes

Similar Process?



Agenda


Define the problem
Empathize
Need finding
and
Benchmarking
Define
Brainstorm
Ideate

Let's start from background

Define the problem
Empathize

Need finding and Benchmarking
Define

Brainstorm
Ideate

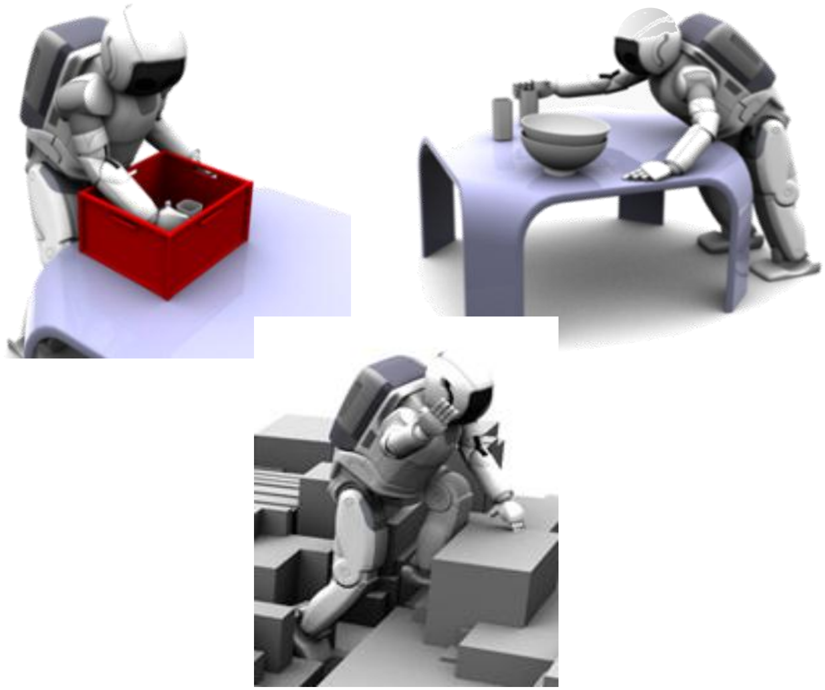
Background

Honda realized walking and a few handling Manipulation by using position based rigid robot

Our Target is

Working and Assisting with physical interaction in Human Ordinary Life

Comment by A.Orita
Too Weak to support
Our research needs
Big Vision is needed!!!



Compliant Robot is essentially needed to realize this!!

Large Impact was

What was changed?

- Honda has already tackled with making robot for Fukushima Nuclear Power Plant
  ⇒ However we think it takes quit a long time for us to realize good ability to bring humanoid into the plant.

1. We have to shrink our long story for next generous robot to catch up with world research level.

2. To realize 1., Collaboration should be an important role of the factors of research goal in short period (2 or 3 years).

Related Target

We have several target(milestone) to realize our purpose

2016 Model : Disaster Robot for real severe situation

Functions : Traveling on the real uneven terrain(rubble) with dynamic obstacles
Clear robot's way from unstructured rubble

One of the
Key Technology

Soft Actuator with Active/Adjustable Passive Compliance

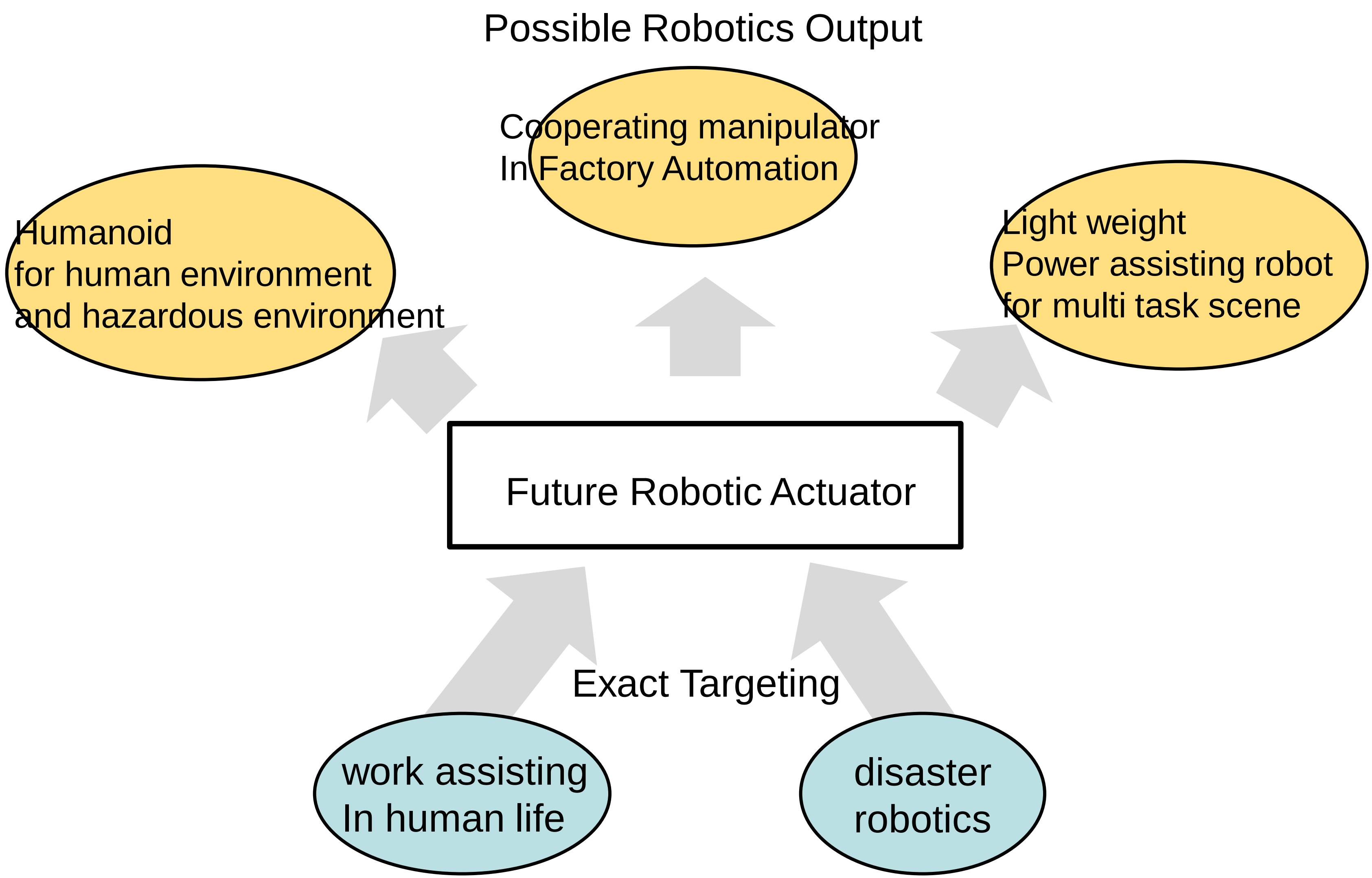
Pneumatic
Hydraulic
Electro Magnetic

\+

Variable Impedance Device

**Whichever we choose Active Compliance,
we need a Variable Impedance Passive Compliance**

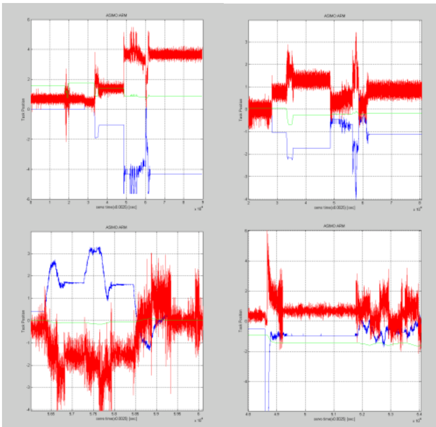
Summary of Background



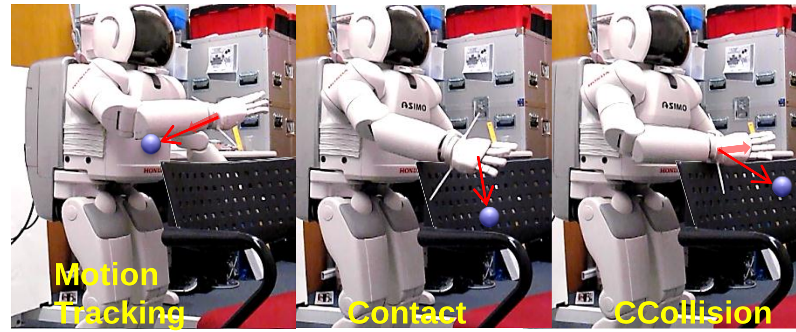
Past activities regarding compliant robot

Fundamental approach for compliant robot
(during collaboration with Prof. Oussama Khatib)

Open Loop Torque Controller in Asimo



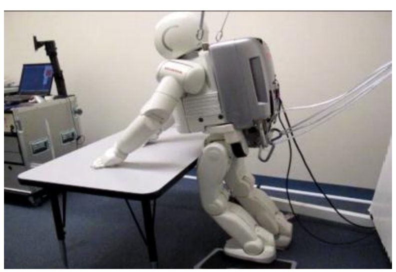
Trajectory tracking with contact

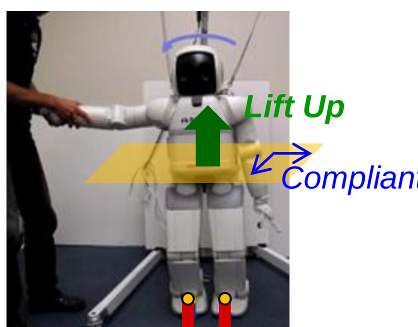


Online task position command

Operational Space Control validation

Whole-Body Multi-Contact and Control





<Achievement>

Possibility of torque based control for allowing collision and contact in motion control

Knowledge of using computed torque control with null-space projection

Developed tactile sensor and possibility of using it for the arm and body

Walking research of compliant robot from hardware to motion control

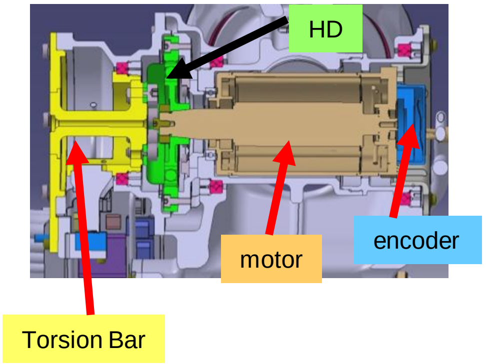
<High-performance torque control system>

Why we purse rapid torque tracking?

Good torque response leading

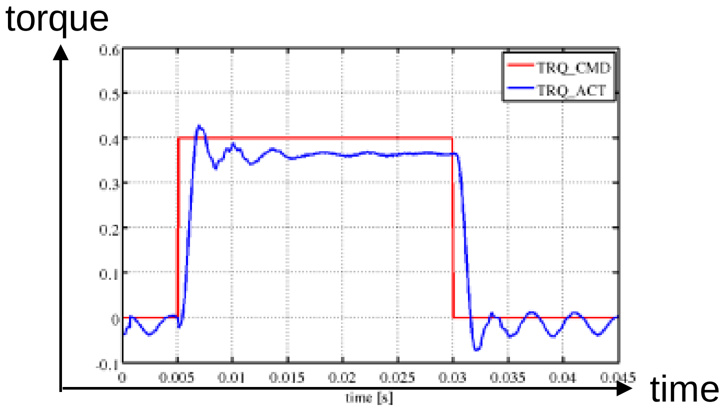
- **Good position tracking**
- **Good adapting disturbance**

Joint Torque Control System (FB)



SEA type torque control system

Step Torque Response



1ms time constant of step torque response

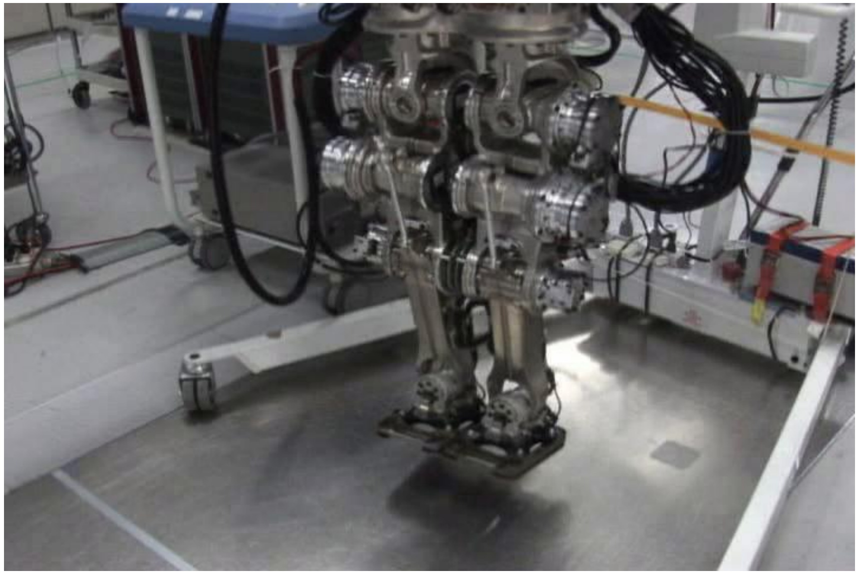
<Achievement>

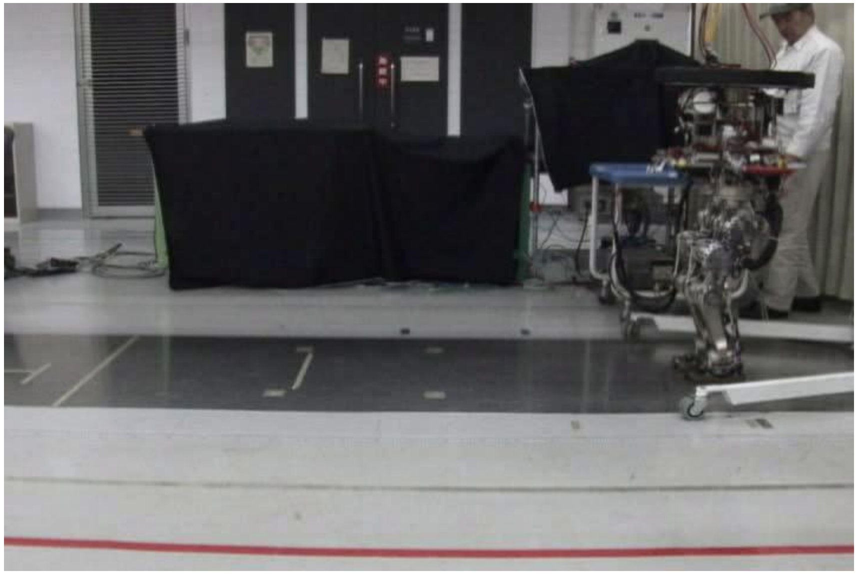
Rapid tracking joint toque system. Time constant of step torque response is 1ms.

Walking research of compliant robot from hardware

<Walking Experiment and Zero Torque Response>

We choose walking task because it's a very time critical task of handling Earth.





<Achievement >

Floating base computed torque and balance control is validated in biped-experiment with disturbance

Lastly, we developed fully joint torque biped robot and realized preliminary walking

Problems

After these researches, we have these problems

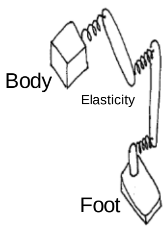
- Hardware
  Many kind of joint resonance vibrations are a big problem.
  Serial Elastic Actuator System is much heavier than normal position control system

- Stabilizing Control
  Highly estimation technique is needed for adjusting model to real robot
  Continuously tasks and constraints changing method

- Motion Planning
  Our planning method of walking is highly determined, but it easily reach the limitation in disturbance and robot falls down.

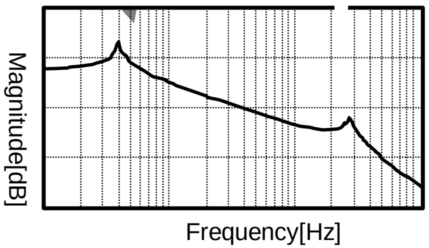
Our next subject for compliant robot

Joint Torque Actuation (hardware)



Each joint has
It's own resonance
Frequency.
And it's varied
According to contact

In our experimental validation,
joint resonance vibration is a big problem,
Because it reduce the tracking ability of task.
When disturbance let it arise, we have to suppress.



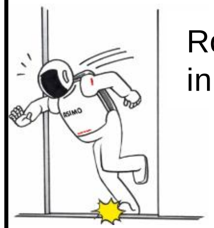
So far,
we tried local control and observer technology to suppress it.
However it turns out not enough for us to realize precise task such as walking.

- Variable Stiffness and Damping
- Smaller and lighter actuation
- Some more updates for local torque control

Materials for previous activities

Purpose

Demand 1



Robot should allow unexpected collision
in coexistence with human or hazardous environment

Robot needs **Softness**

Robotics **Joint Softness**
is inevitable to allow higher disturbance

Demand 2

Robot should move or work precisely
in coexistence with human or hazardous environment

Robot needs **Accuracy of Move**

Robotics **Joint Rigidity**
is inevitable to move
with suppression of disturbance

"Softness" and "Accuracy of Move" are contrary characters and can not be realized simultaneously

Changeable Stiffness of Robotic Joint according to situation

||

Robotic actuator with variable stiffness

Purpose

We realize Robotic Actuator with variable stiffness for robot to allow Unexpected collision and to do still accurate work and move.

Important Factors

Purpose

We realize Robotic Actuator with variable stiffness for robot to allow unexpected collision and to do still accurate work and move.

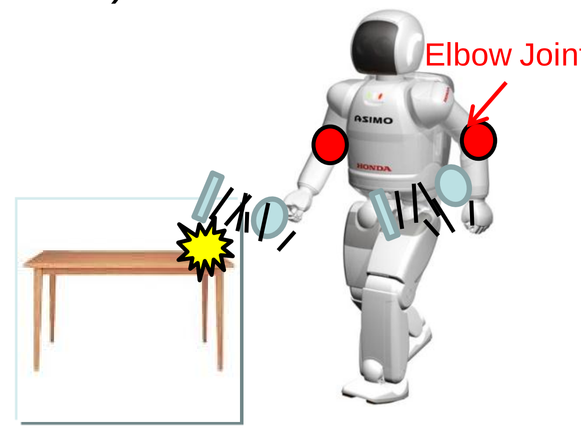
Factors	Reasons	Target Value for Asimo's Elbo
Wider stiffness range	Compatibility of Softness and Accuracy of move	80 – 400 Nm/rad
Change stiffness in real time	Maximum force is often occurred within 50ms in experimental robot collision data	Within 50ms
Lighter weight of device	Device weight affects linearly the energy of disturbance	Within 150g (device only)
Larger deflection of stiffness	To raise up the energy absorbance while collision	9 degree

Expected Specification of VSA

<Specification from Asimo working in human environment>

Supposing arm collision in maximum shoulder speed(not walk)
we focus on elbow joint specification

In this scene, we want to integrate hardware compliance and software compliance(joint torque control) into elbow joint



<Demands in detail>

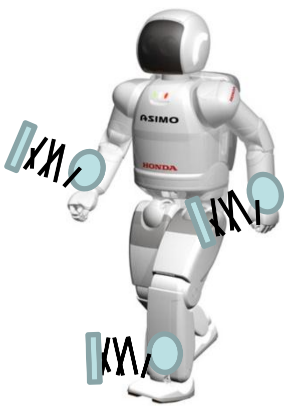
- In collision, joint must not be destroyed.
  And in usual work joint must work as precise as Asimo work.
- Robot can change stiffness in real time according to sensor data

[Needed Factor]

Stiffness Range	80 – 400 Nm/rad
Maximum Deflection	9 deg
Stiffness Change Time	Under 50ms
Maximum Torque	50Nm
Output Torque	25Nm
Device Weight	Under 150g (Joint as much as Asimo Elbow)

Collision Settings [stiffness] for Spec

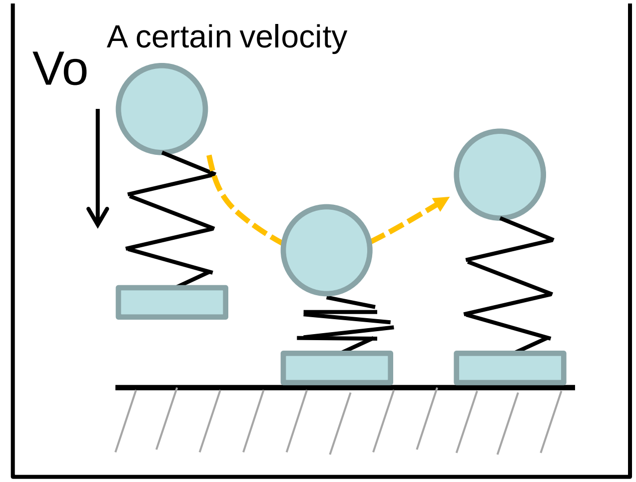
Supposition of end effector collision

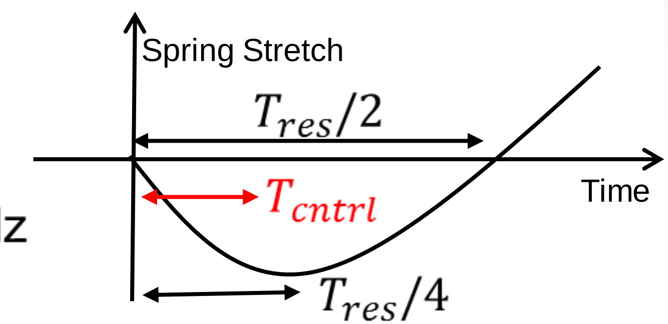


Arm and leg mass
Is aligned at end effector

This is about 5 % of
Total mass(suppose 40kg)
Link Length = 0.2m.

Basic assumption of collision





About stiffness in collision
Arm mass resonance frequency(time constant) is

$$T_{res} = 2\pi\sqrt{\frac{m_{arm}}{K_{edge}}}$$

Suppose that active control is effective less than 20 Hz
($T_{cntrl} = 50$ms)
And using a condition $T_{res}/4 > T_{cntrl}$

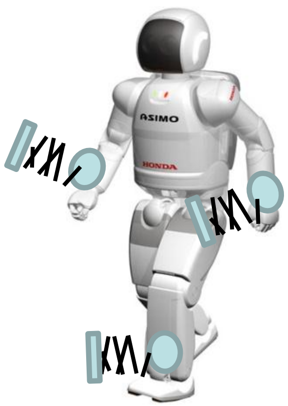
$$K_{edge} < \frac{1}{4}\pi^2 \frac{m_{arm}}{T_{cntrl}^2} = 2.4649 \cdot \frac{2}{0.05^2} = 1971.92 N/m$$

And using the relation $K_{joint} \cdot \Delta\theta = K_{edge} \cdot L_{link} \cdot (L_{link} \cdot \Delta\theta)$

$$K_{joint} = K_{edge} \cdot L_{link} \cdot L_{link} < 1971.92 \cdot 0.2 \cdot 0.2 \approx 80 Nm/rad$$

Collision Settings [stiffness] for Spec

Explanation about high stiffness specification
Supposition of end effector collision



Arm and leg mass
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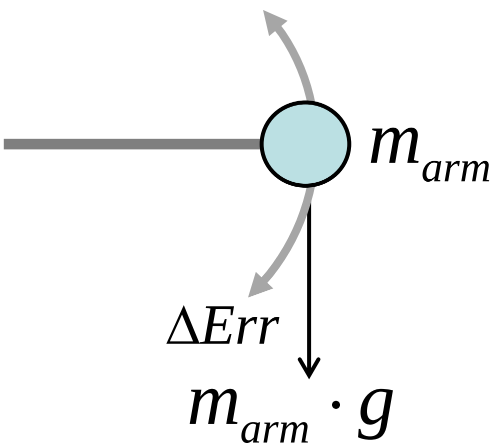
Total mass(suppose 40kg)
Link Length = 0.2m.



$$K_{edge} \cdot \Delta Err_{allowance} = m_{arm} \cdot g$$

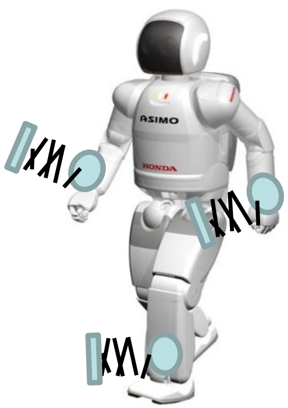
$$\Leftrightarrow K_{joint} / link^2 \cdot \Delta Err_{allowance} = m_{arm} \cdot g$$

$$\Leftrightarrow K_{joint} = m_{arm} \cdot g \cdot link^2 / \Delta Err_{allowance}$$

$$K_{joint} = 2 \cdot 9.81 \cdot 0.2^2 / 0.002 \approx 400 Nm / rad$$

Collision Settings for Spec

Supposition of end effector collision



Arm and leg mass
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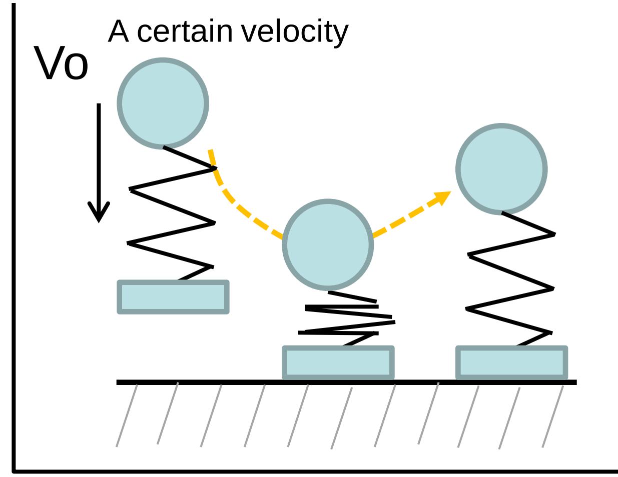
This is about 5 % of
Total mass(suppose 40kg)
Link Length = 0.2m.

Basic assumption of collision



About spring deflection in collision

Absorbing energy $\frac{1}{2} m v_{coll}^2 = \frac{1}{2} \cdot 2 \cdot 2^2 = 4J$

It should be equivalent to Spring Energy $\frac{1}{2} K_{edge} \cdot \Delta x^2$

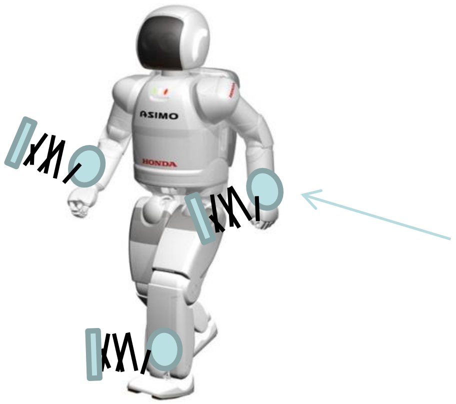
So, if we choose 200 Nm/rad for joint spring
Deflection is

$$\Delta\theta = \frac{v_{coll}}{L_{link}} \sqrt{\frac{m_{arm}}{K_{edge}}} = \frac{2}{0.2} \sqrt{\frac{2}{1971.92}} \approx 18 \deg$$

This is maximum deflection when VS absorbs all of energy

Collision Settings for Spec

Supposition of end effector collision



Arm and leg mass
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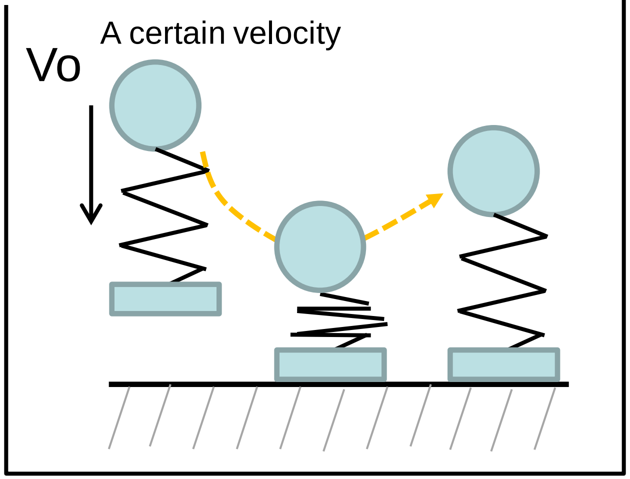
This is about 5 % of
Total mass(suppose 40kg)
Link Length = 0.2m.

Basic assumption of collision



About spring deflection in collision
However active control such as joint torque control relieve this deflection before reaching maximum deflection

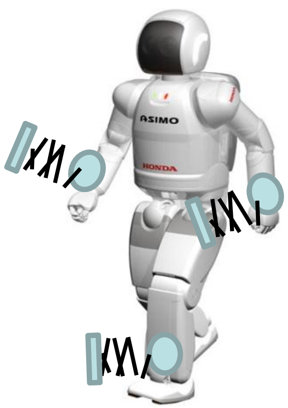
As active control's time constant should be faster than maximum deflection time,
More than 63.2％ (about 50 ％ in all case) of deflection is relieved by active control.

So, if we choose 200 Nm/rad for joint spring
Actual deflection of mechanical joint stiffness is

18 deg • 0.5 = 9 deg

Damping setting for spec

Supposition of end effector collision



Arm and leg mass
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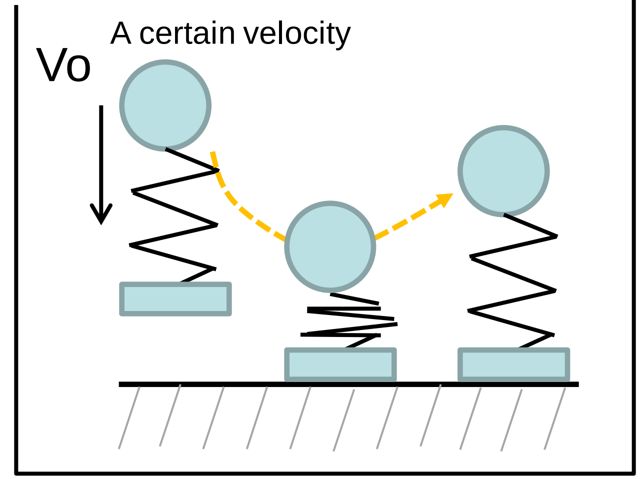
This is about 5 % of
Total mass(suppose 40kg)
Link Length = 0.2m.

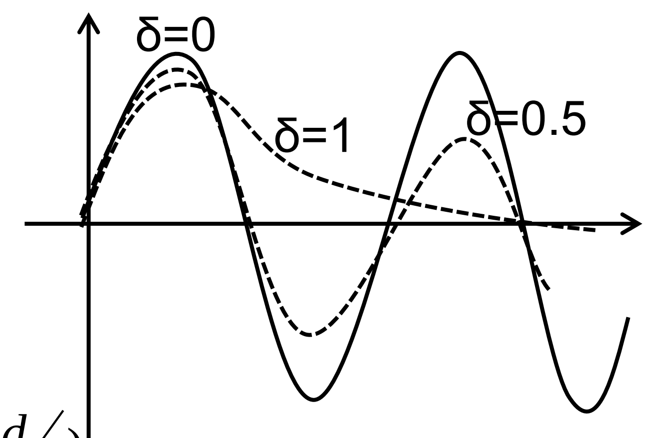
Basic assumption of collision



Damping effect in this assumption is expected according to δ

$$D_{edge} = 2 \cdot \delta \cdot \sqrt{m_{arm} \cdot K_{edge}}$$

$$D_{joint} = L_{link}^2 \cdot 2 \cdot \delta \cdot \sqrt{m_{arm} \cdot K_{edge}}$$



As the basic damping of joint, we set δ=0.1
for mechanical damping

$$D_{joint} = 0.2^2 \cdot 2 \cdot 0.1 \cdot \sqrt{2 \cdot 1971.92} \approx 0.5 Nm/(rad/s)$$

Research Contents and Possible Solutions

Research Content

Step 1 Variable Stiffness Device by using multi-layer EAP

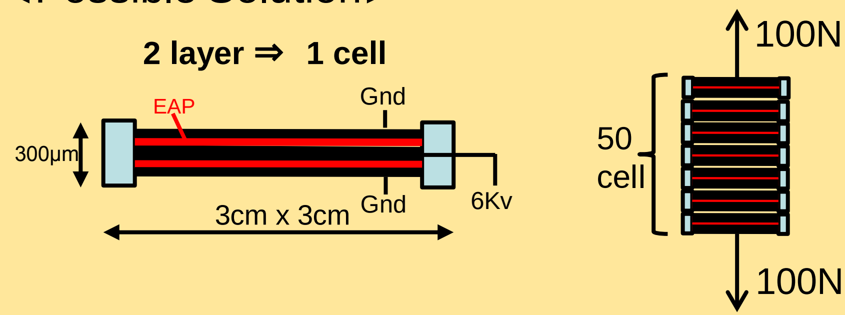
<Target>

- Endure more than 100N force
- Stiffness Range is about 1 order
- Changing Stiffness within dozens of ms

<Important Subjects>

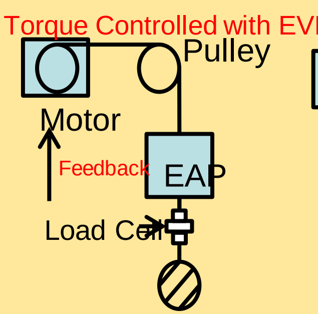
- Larger allowable force in 1 cell
- Lighter and Smaller design
- Reproductivity and efficiency

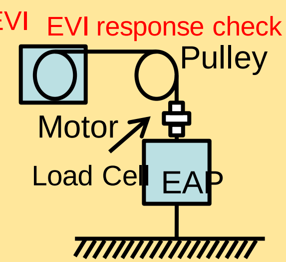
<Possible Solution>



<Validating items>

- How different between design and experiment
- Ability of reproductivity
  and mechanical repeatability
- Usability of mechanical characteristics

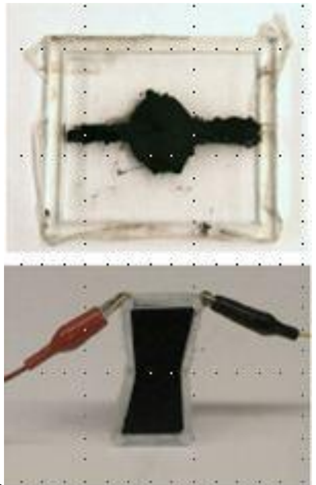




Priority Subjects and Solutions in Step 1

- Efficient fabrication

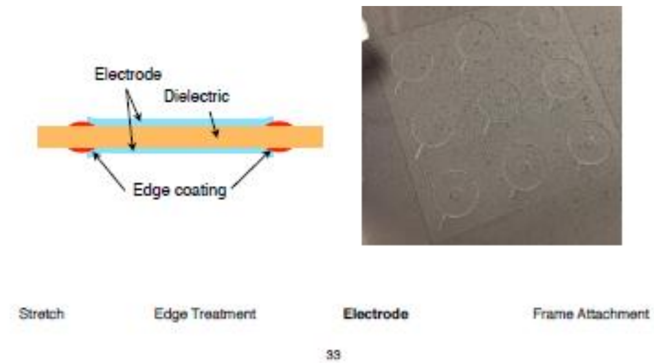
<SRI(Usual method)>



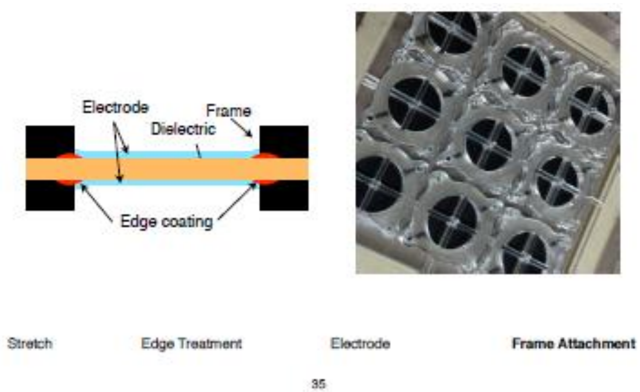
More than 12 hours
In fabrication
Fabrication of Masks, frames
Masking, spraying, gluing, curing
assembly

Under 10% yield
Low reliability

Reducing failure causes in assemble
Example(Solved):
Ununiformity of electrode
A flaw by edge of frame



Assemble with
Precise Position Correction



<Stanford EAP>

Within 1hour
fabrication

More than 70%
yield

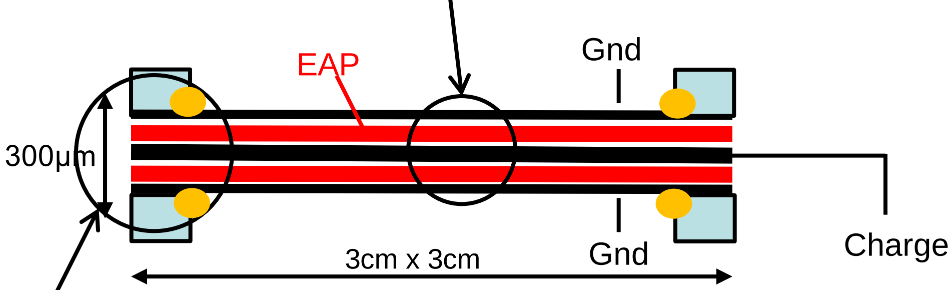
This enables us to produce more than hundreds of EAP cell.
However more upgrading in fabrication is needed to get reliability.

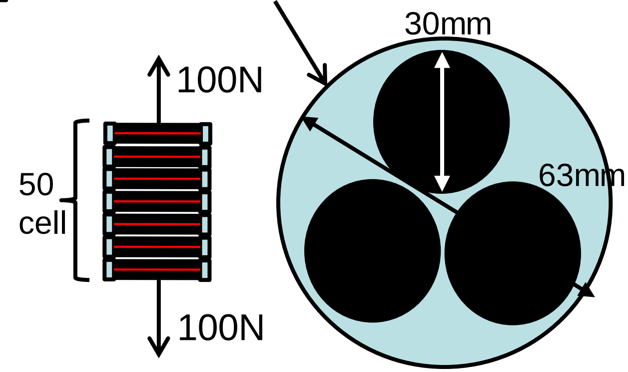
Priority Subjects and Solutions in Step 1

- Lighter and Smaller design
- Larger allowable force in 1 layer (The number of cells, cell shape)

1 EAP layer ⇒ 2 cell (twice as much as previous)
Reducing electrode ,Sharing frame

Parallelize(3cell)
Sharing frame





Plastic material for frame with soft edge coating
Reducing volume in 1 cell, and treating not to tunneling

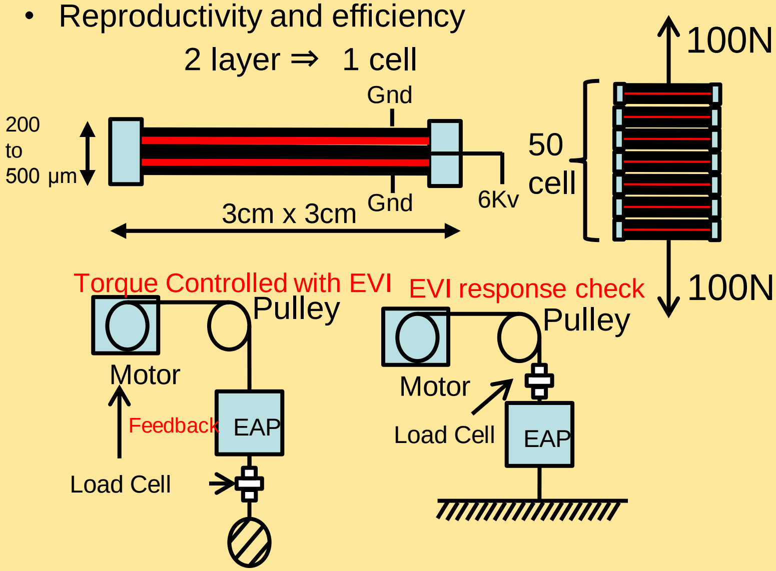
Utilizing rapid prototype method,
we evaluate and choose the best design of multiple ones in short time.

Research Steps

Step 1 Research Subject

Multi-Layered EAP for variable stiffness device

- Larger allowable force in 1 cell
- Lighter and Smaller design
- Reproductivity and efficiency



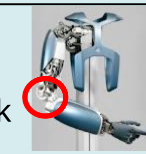
<Validating items>

- How different between design and experiment
- Ability of reproductivity and mechanical repeatability
- Usability of mechanical characteristics

Step 2 Research Subject

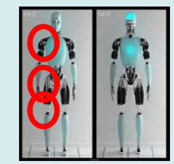
2.1 Variable Stiffness Actuator for robot manipulator

- Transition to rotational move
- Realizing integrated system
- Suitable stiffness rage for robot task
- Co-actuated with main actuator

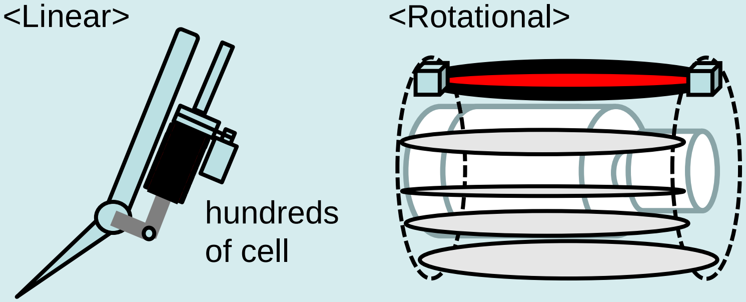


2.2 Large Torque VSA for humanoid

- 200Nm order allowable
- Super light device with material/electrode change
- Ensure electrical safety



Hybrid actuator system



<Validating items>

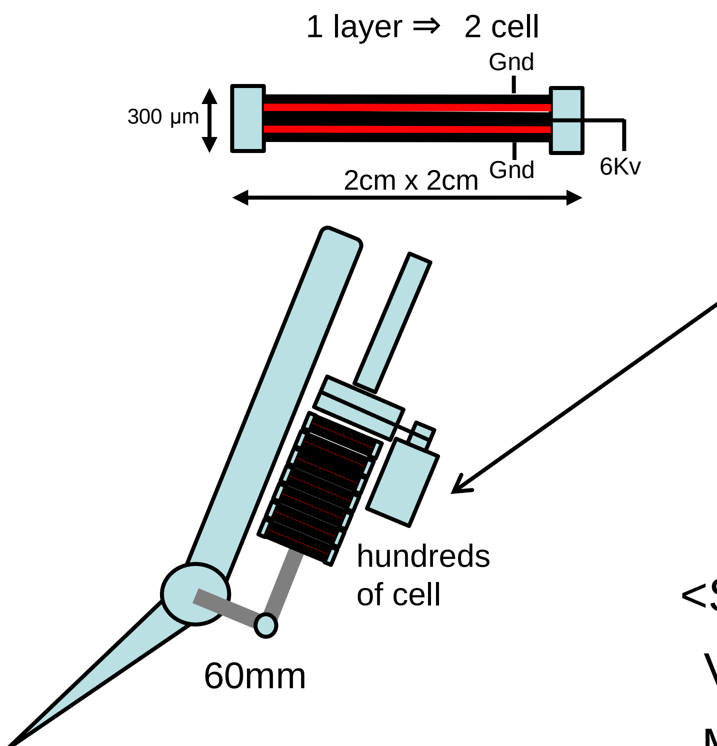
- Force limitation of current material and design
  ⇒Listing up the needed characters of newer material
- Getting the knowledge about relation of force, volume, weight
- Listing up the design demands for electrical safety

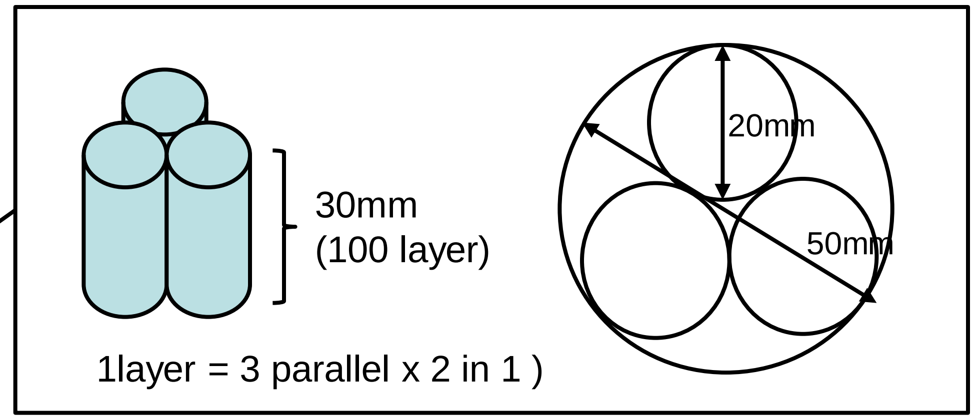
Firstly we do Step 1, and we judge whether we do Step 2 or not according to the result.

Step 2 Possible Configuration 1

Linear(for elbow joint)

Circle frame type





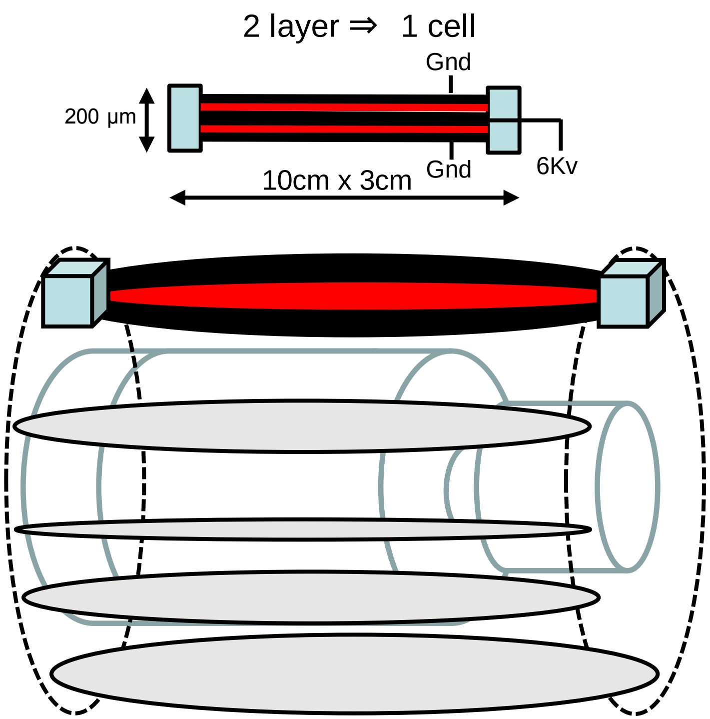
<Specification>

Variable Stiffness Range	80 – 400 Nm/rad
Maximum Deflection	9 degree
Maximum Torque	50 Nm
Electrical Safety(human)	3A / 1.1ms
Device Volume	59 cm3

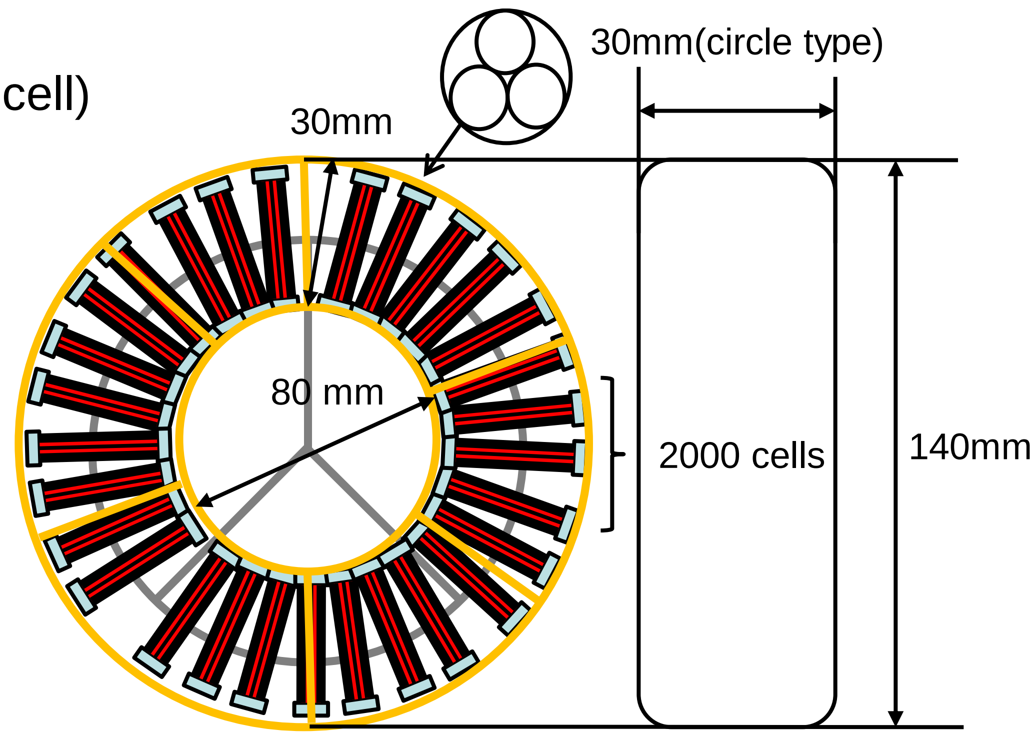
Step 2 Possible Configuration 2

Rotational(for larger torque)

Ellipsoid frame type (large force / cell)



Using 3cell/layer reduces the number of layer(D120mm)



<Specification>

Variable Stiffness Range	200 – 800 Nm/rad
Maximum Deflection	7 deg
Maximum Torque	110 Nm
Electrical Safety(human)	3A / 1.5ms
Device Volume	1243 cm3

Both types will be **possible** to realize, however **revolutionary design** will be needed

Research Schedule

2013/2-2013/5	2013/6-2013/9	2013/10-2014/1	2014/2-2014/5
Q1 report Review design concept Comparison with other research	Q2 report Intermediate report Demonstration of multi layer Listing up subjects and Solutions for them	Q3 report Review of final design And possibility of Realizing subjects	Q4 report Final report Demo of 50 layer Report of Achievement
Brushing up cell design	Making cells and validation	Multi-layer production	Validation of final proto
Fixing specification in detail Sharing knowledge of Stanford EAP Cell designs for multi layer and theoretical validation Fixing validating method, and test environment	Initial validation of multi-layer EAP (about 10 layers) Prototyping Several designs	Modeling of Newer cell design Calibrating model Listing problems And solution using model Validating 50 layer device Prototyping 50 layer EAP	Making final prototype Final validation of prototype Making report of results and Content of next Step

Executing resources

Stanford : Prof. Mark Cutkosky PosDoc Shiquan Wang(MS)

HondaR&D : Atsuo Orita HRI-US : Takeshi Yasui Takashi Bannai

Duration 1+1/4 year