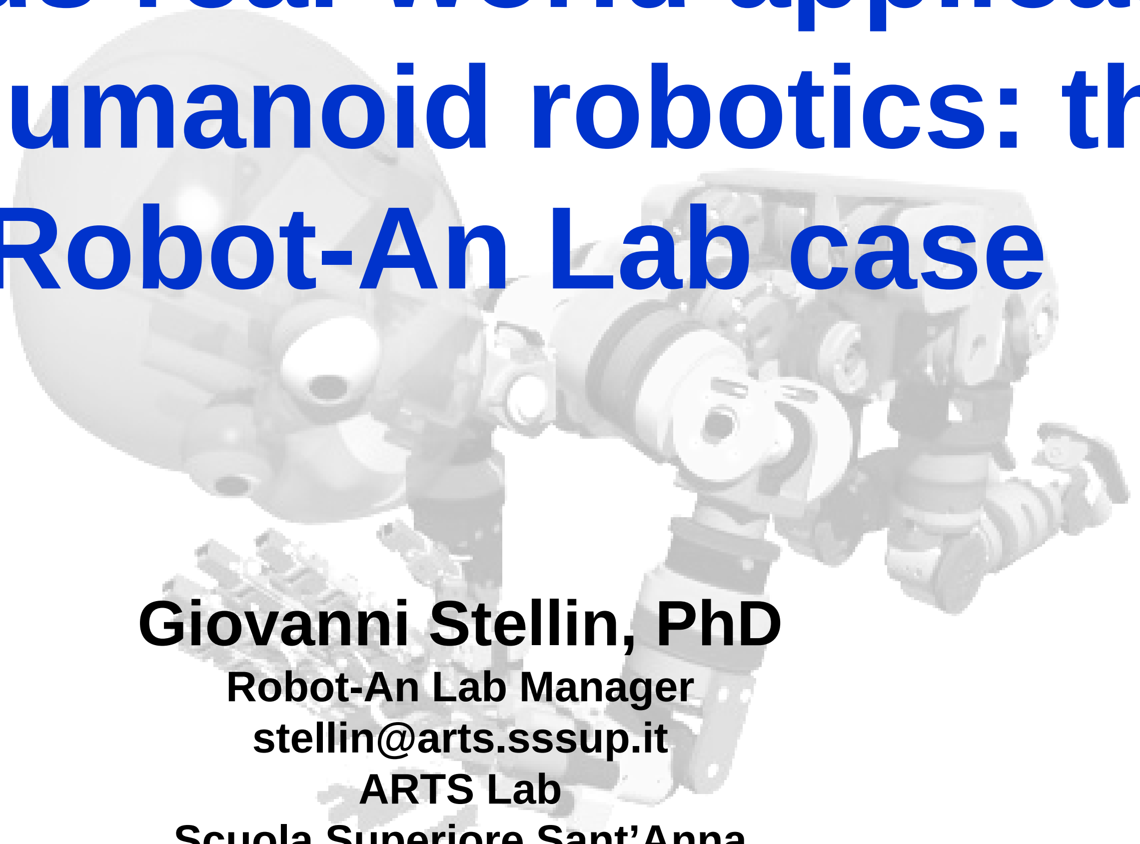
Towards real-world applications of humanoid robotics: the Robot-An Lab case



Giovanni Stellin, PhD

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ARTS Lab

Scuola Superiore Sant'Anna

First workshop for young researchers on

Human-friendly robotics

Napoli, October 24° 2008

Giovanni Stellin, PhD

Outline

- The Robot-An Lab
- The iCub
- The ARTS Humanoid
- The SABIAN: Technology Transfer Phase
- The SABIAN: Original Development Phase

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Welcome to Robot-An (established 2007)

Integrated Design Approach

Mechanical Design

Design of Sensors

Low-level Control Architecture

Software Development

Vision Modules for Object Tracking

Reaching and Adaptive Grasping

Biped Locomotion

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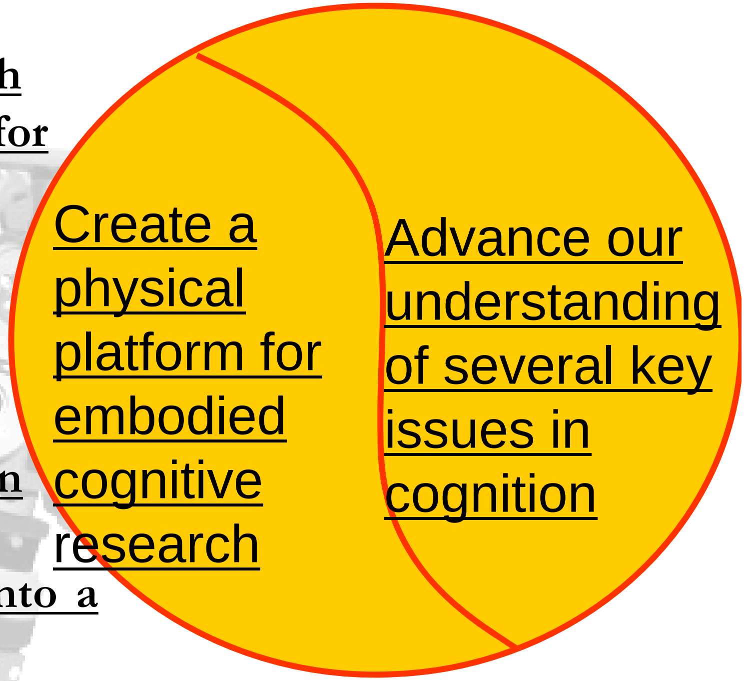
RobotCub Project (IST-2002-2.3.2.4)

(ROBotic Open-architecture Technology for Cognition, Understanding and Behaviour)

The robotic cub goals are:

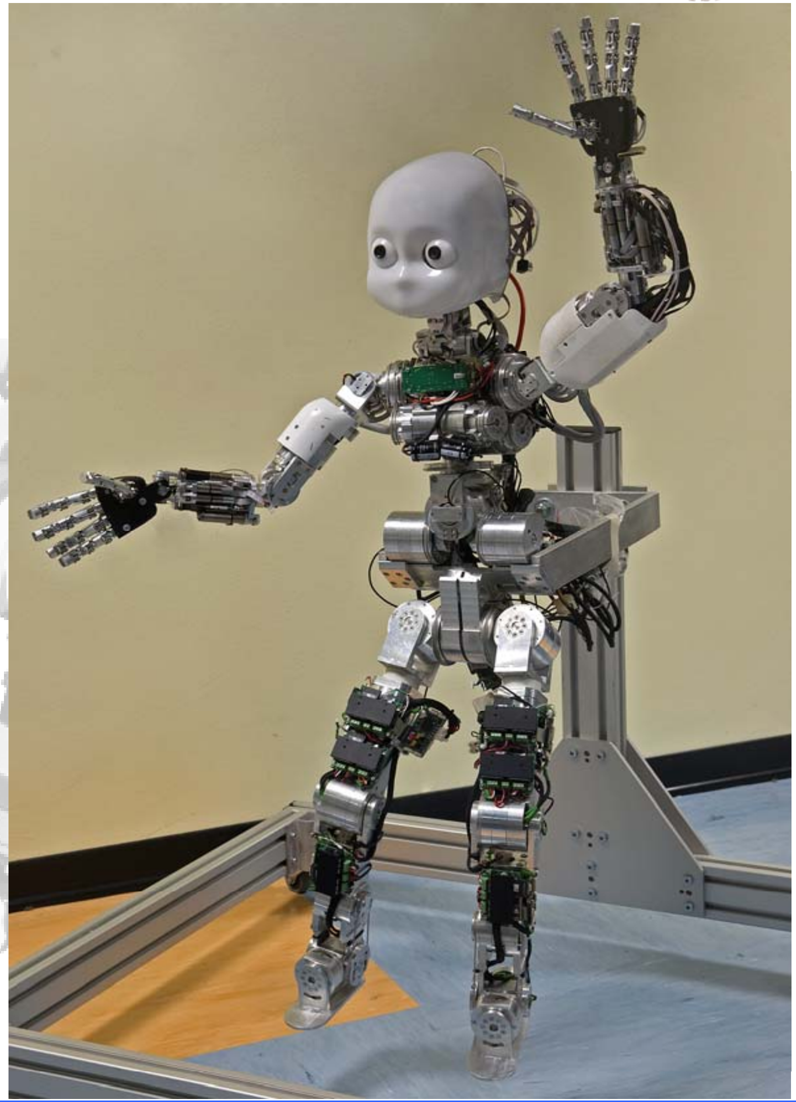
- Create an open physical platform for embodied research that can be taken up and used by research community for development of cognitive system
- Advance the understanding of several key issues in cognition:
  - how interact with the environment
  - how develop perceptual, motor and communication capabilities
  - how intelligence becomes the capacity to enter into a shared world rather than solve problems
  - how evolution replaces task-oriented design
  - how enaction subsumes emergence
  - how actions are initiated and maintained by a motivation



The iCub

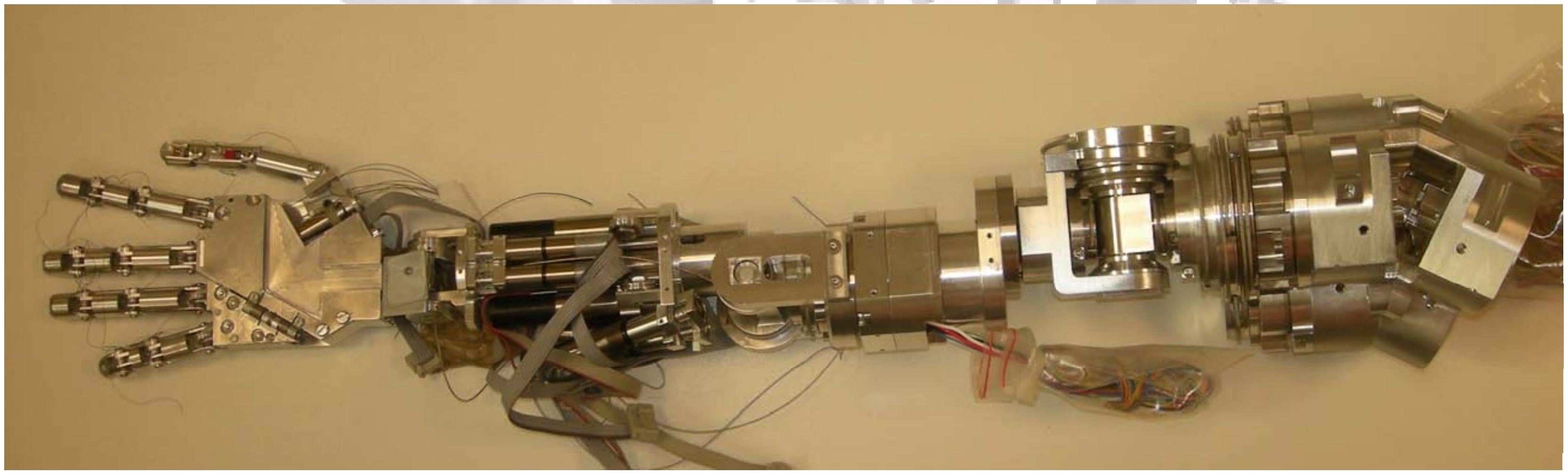
The iCub is a full humanoid sized and shaped as a child. The total height is estimated to be around 90 cm.

It has around 50(55) degrees of freedom (DOF), including articulated hands to be used for manipulation and gesturing. A study has been conducted for determining if and how many degrees of freedom are minimally required to produce/generate plausible facial expressions. The robot should be able to crawl and sit (to free the hands from supporting the body) and autonomously transition from crawling to sitting and vice-versa.



iCub SSSA Platform

Subsystem: Right upper limb	*DoFs*	*DoMs*
Shoulder (abduction/adduction, flexion on the sagittal plan and on the horizontal plan)	3	3
Elbow (flexion)	1	1
Forearm (abduction/adduction)	1	1
Wrist (flexion/extension and abduction/adduction)	2	2
Hand	20	9
Total	27	16



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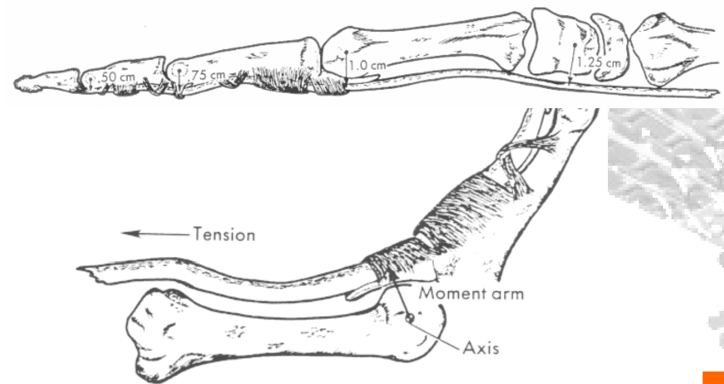
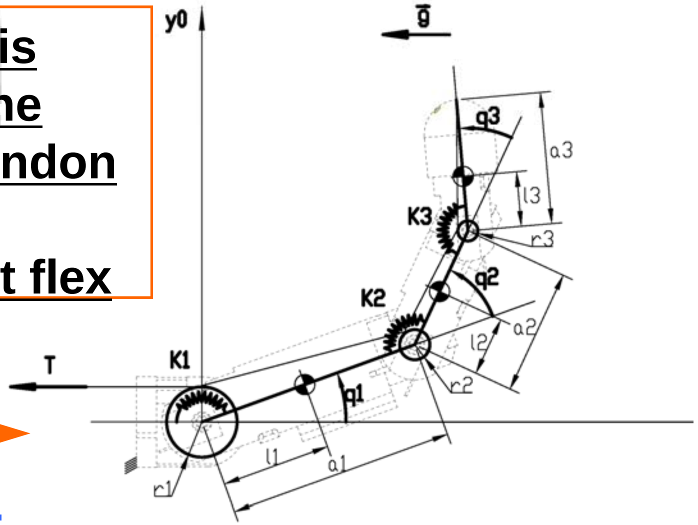
Bio-inspired Design Guidelines

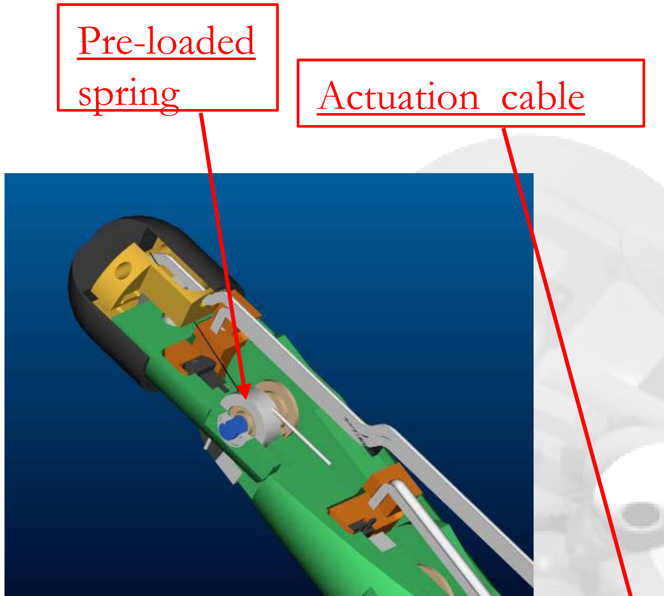
- Integrated design of head/neck-trunk-arm-hand
- Actuators in the preceding link
- Mechanical stops in the joints (no hyper-extension allowed)
- Tendon transmission (and synovial sheats/bowden cable) in the hand and gears or belt in the arm
- N joints of a manipulator means at least N+1 actuator (and tendons): one acts as antagonistic tendon. <u>Elastic elements, where allowed, are suitable (passive action)</u>
- Under-actuation exploited in the hand design



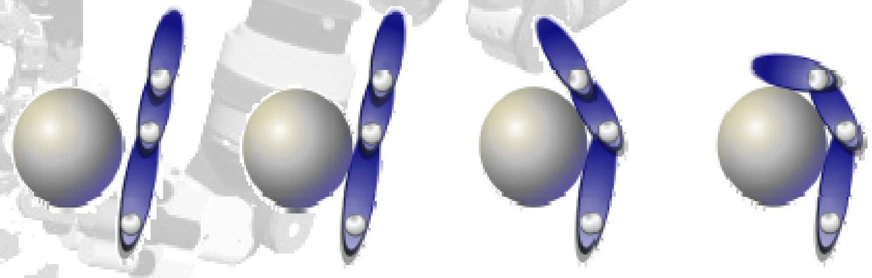
<u>The human finger is under-actuated: one muscle and one tendon (Flexor Digitorum Profundus) make it flex</u>



Underactuation

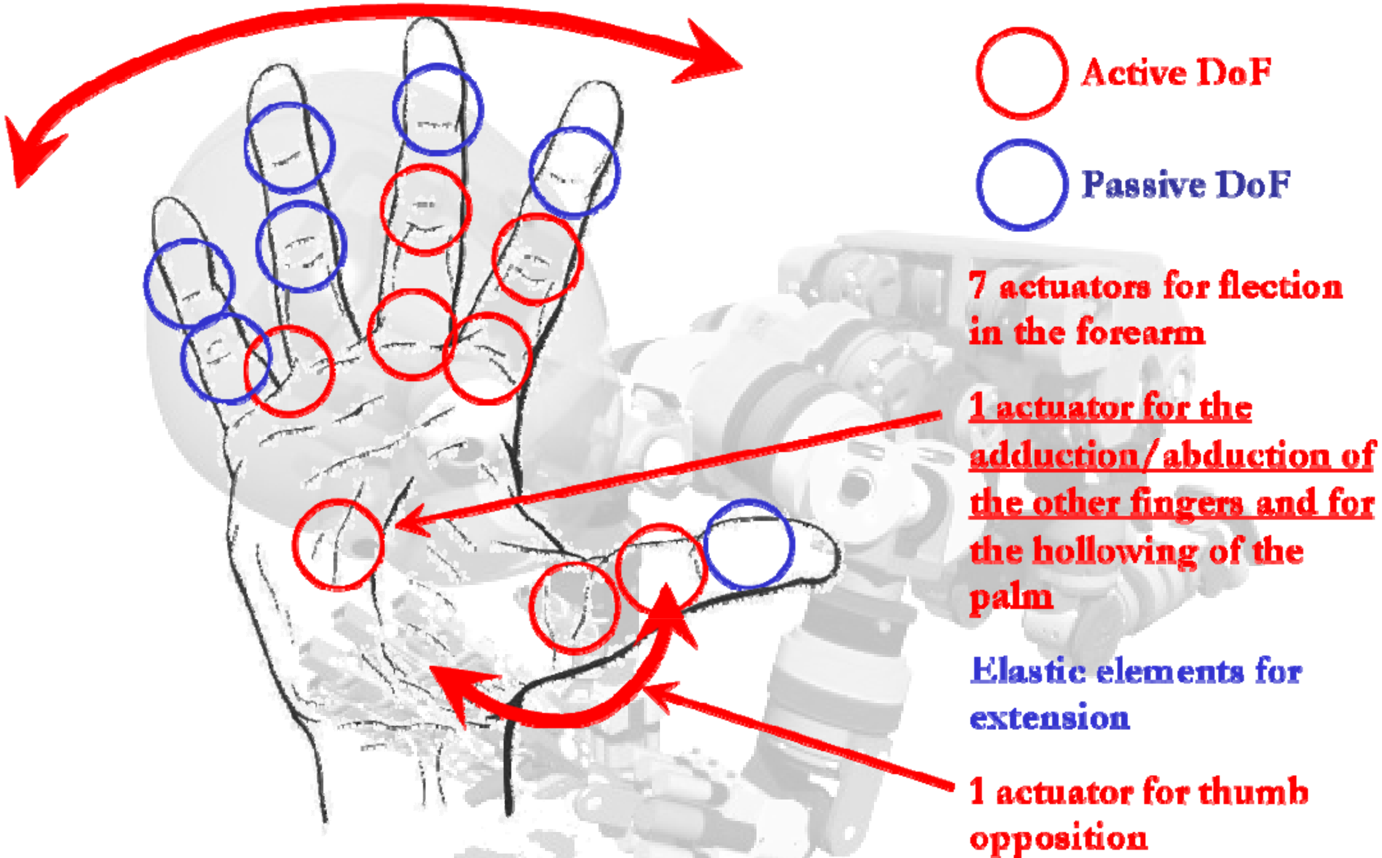


Underactuated mechanisms allow to decrease the number of active degrees of freedom by means of connected differential mechanisms in the system; when the underactuation concept is applied to grasping cable-driven devices, they become self-adaptive to the shape of the grasped object using less motors than DoFs. This solution reduces both the complexity of control and the overall size.



However, it is not suitable for manipulation

Hand Kinematics



Grasping and Manipulation

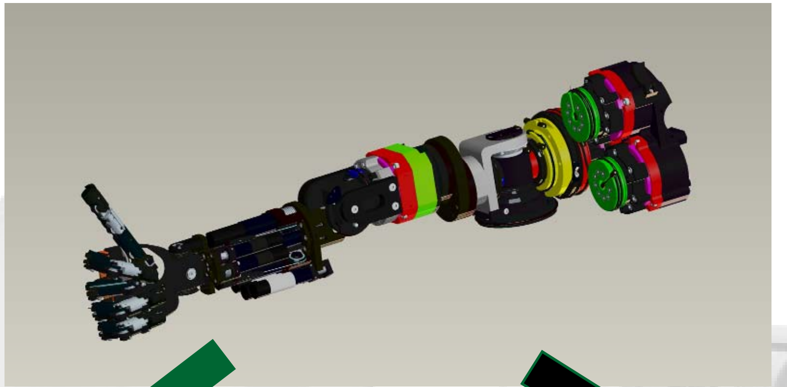
(20 DoF and 9 DoM)

The RobotCub Hand

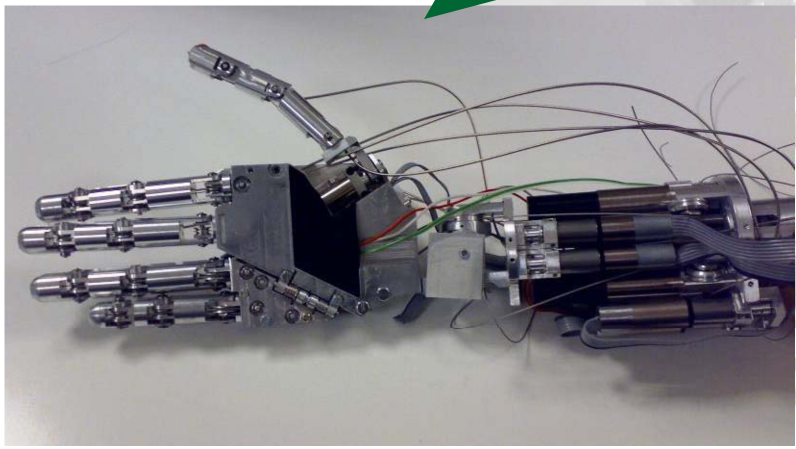
- N° of DoFs: 20 (9 motors)
- Weight: 160 grams
- Dimensions and range of movements:

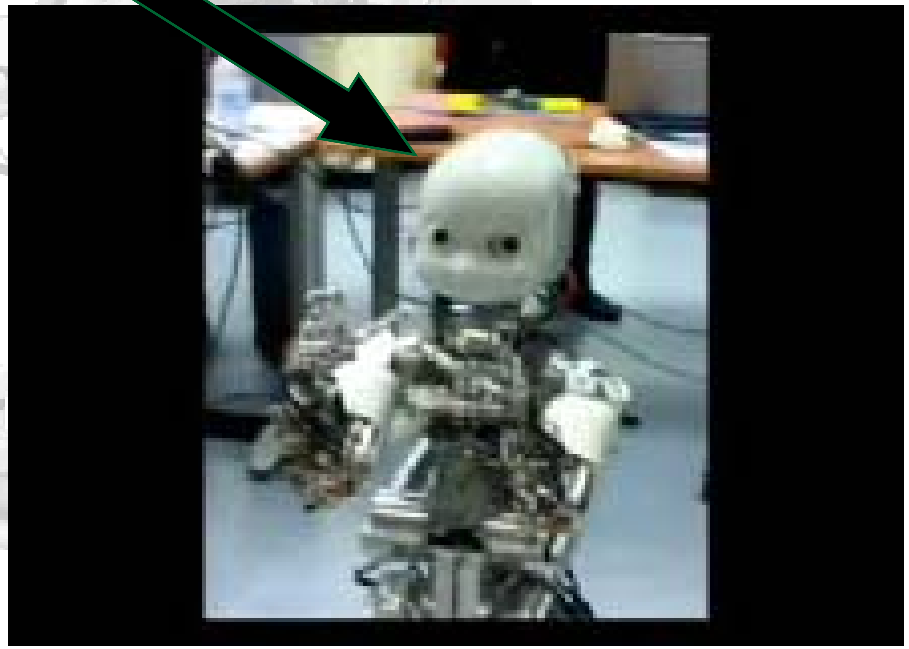
Finger	Length (mm)	Diameter (mm)	Range flection PIP,DIP, MP (°)	Range ab/adduction (°)
Index/Middle/Thumb	68	12	95	30 (only index)
Ring	68	12	95	30
Little	57	11	95	45

Two Hand Versions



SSSA Hand





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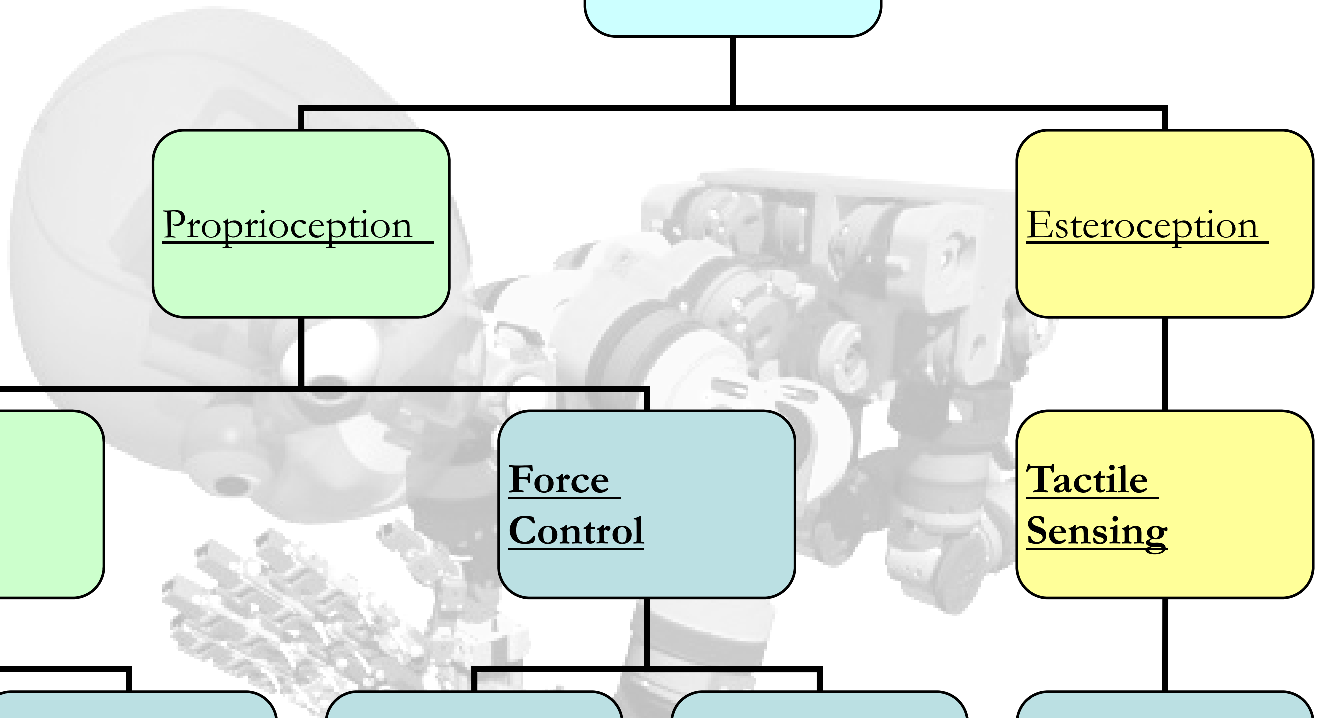
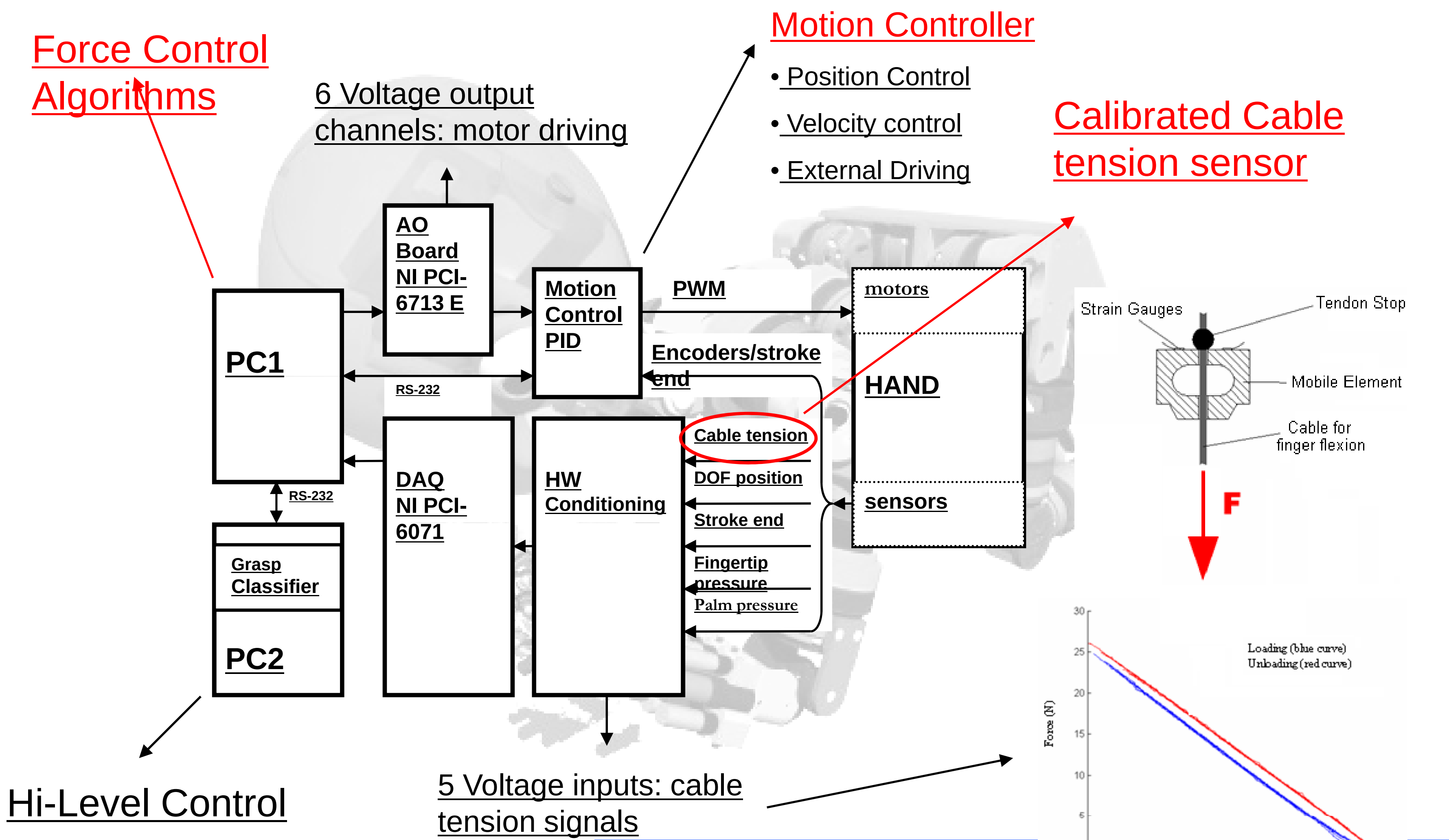
The Sensory System



- **The Sensory System**
  - Proprioception
    - **Position Control**
      - Encoders
      - 15 Hall Effect Angular Sensors (v.3)
    - **Force Control**
      - 5 Cable Tension Sensors (v.2)
      - Current Detection
  - Esteroception
    - **Tactile Sensing**
      - Optoelectronic Sensors

Control for Grasping



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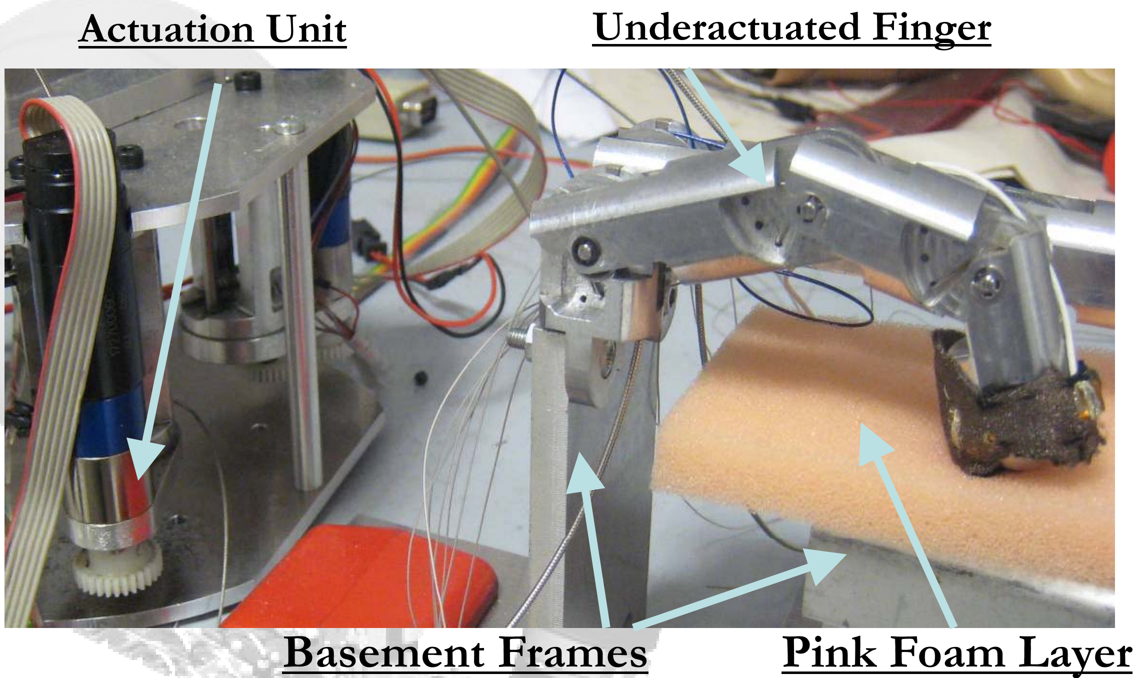
Object Softness and Friction Recognition: Sensor Fusion



Sensors involved:
- Motor Encoder
- Hall Effect Sensors (in all the joints)
- Cable Tension Sensor
- FingerTPS (only one tactile pad for the fingertip)

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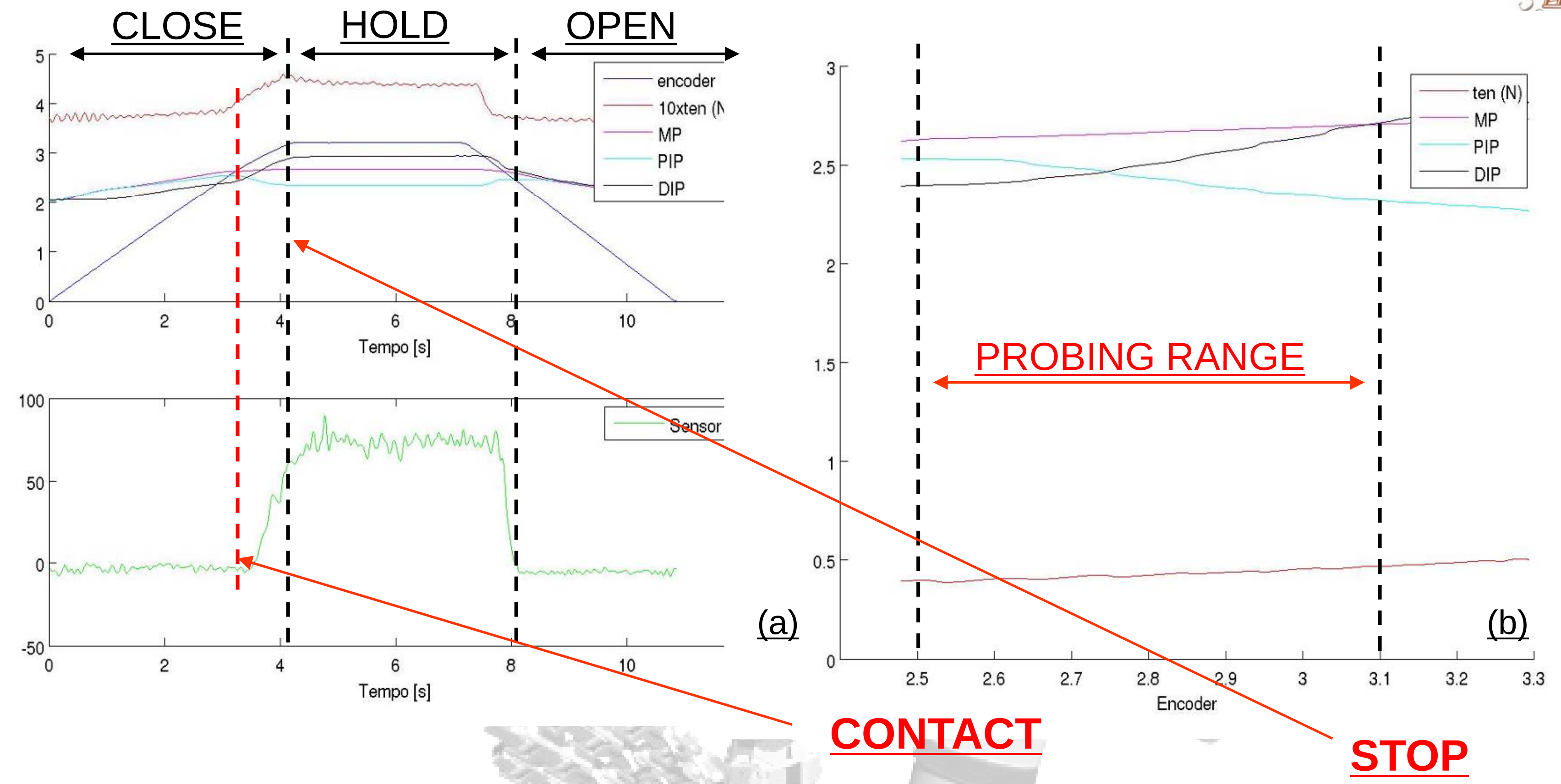
Sensor Output



- Motor Encoder: reference parameter
- Hall Effect Sensors (in all the joints): excellent results in softness detection
- Cable Tension Sensor: good results in contact detection
- FingerTPS (tactile on the fingertip): fair results in friction detection

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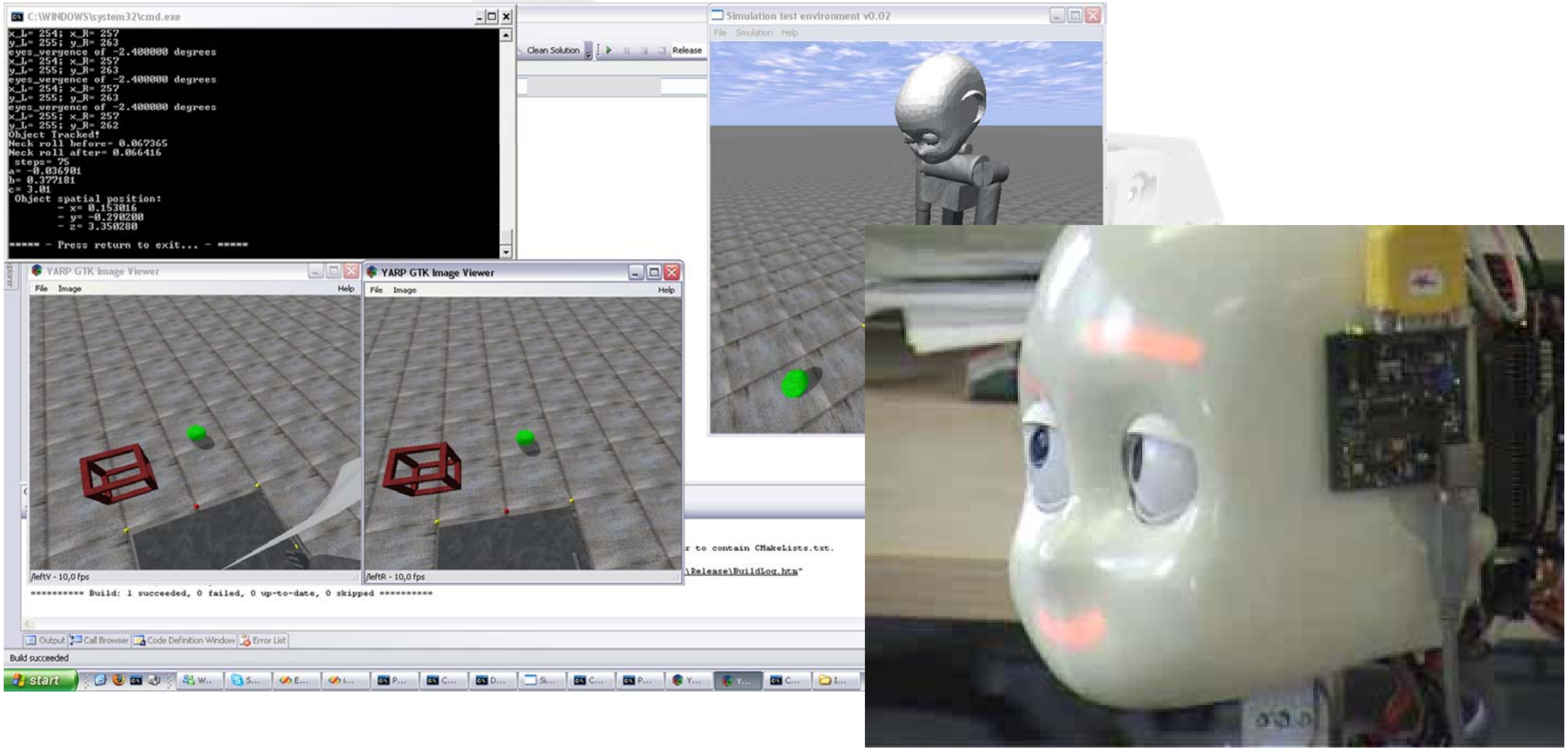
Vision Module

- 3D reconstruction of the ball's position:
  Triangulation --> geometrically detecting the ball's centroid into a 3D space (x,y,z) with the origin located within the robot's head.



Sensory-Motor Map Coordination for the Reaching

- It has been created a sensory-motor map of the robotic arm that lead us to create an **internal model of the arm.**
- The sensory motor map relates the joint position of the robotic manipulator with the information obtained from the vision system.
- The sensory motor map is constructed after a **babbling** phase (by means of a SANFIS - self-Adaptive Neuro-Fuzzy system) in which is stored information about the manipulator workspace.
- The data stored serves to generate the robotic arm forward model.

Babbling Motor Phase

- In this phase the robot will move its joints randomly through the manipulator workspace to make the robot discover and create its internal model about its own kinematics.
- It has been stored data that come from the angular joints position and the position of the end-effector in the image planes of the two cameras of the robot.
- The data stored serves to generate the robotic arm forward model.

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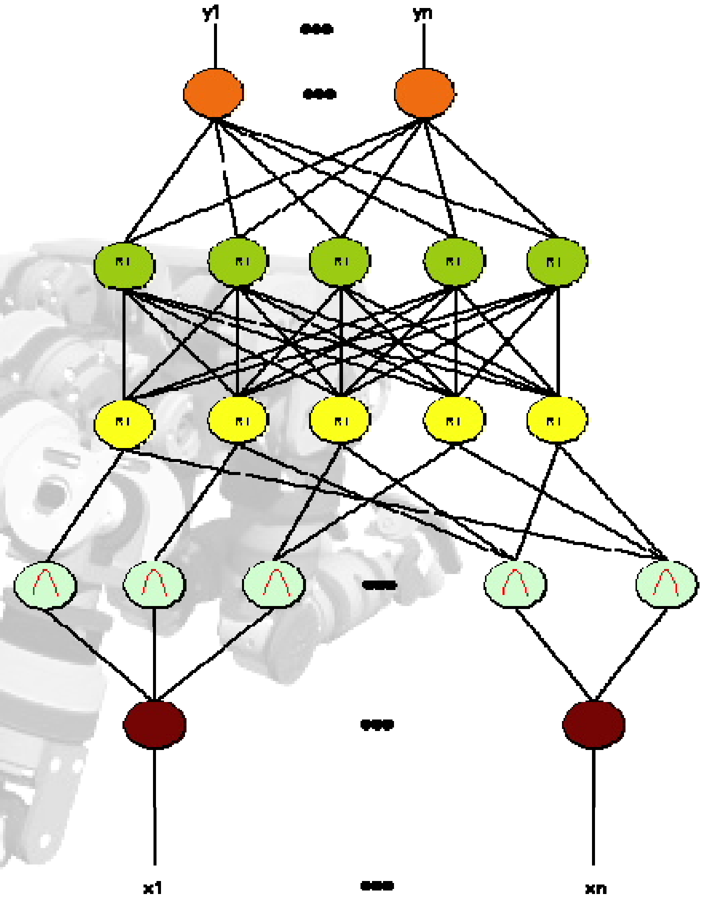
Neuro-fuzzy Systems

- A Neurofuzzy system is a fuzzy system that uses a learning algorithm derived from a neural network theory to determine its parameters(fuzzy sets and fuzzy rules).
- We use a Neuro-fuzzy system named) SANFIS(self-Adaptive Neuro-Fuzzy systems that clusterizes the input data to generate its structure and uses a backpropagation technique as learning algorithm, we are following the same structure described in (Lee et al, 2000).

End effector position in the image



Joints angles of the manipulator

C.S.G. Lee and Jeen-Shing Wang, "Self-Adaptive Neuro-Fuzzy Systems: Structure and Learning", Proc. Of 2000 IEEE/RSJ Int. Conf. On Intelligent Robots and Systems, Takamatsu, Japan, pp. 52-57, Oct.31-Nov.3, 2000.

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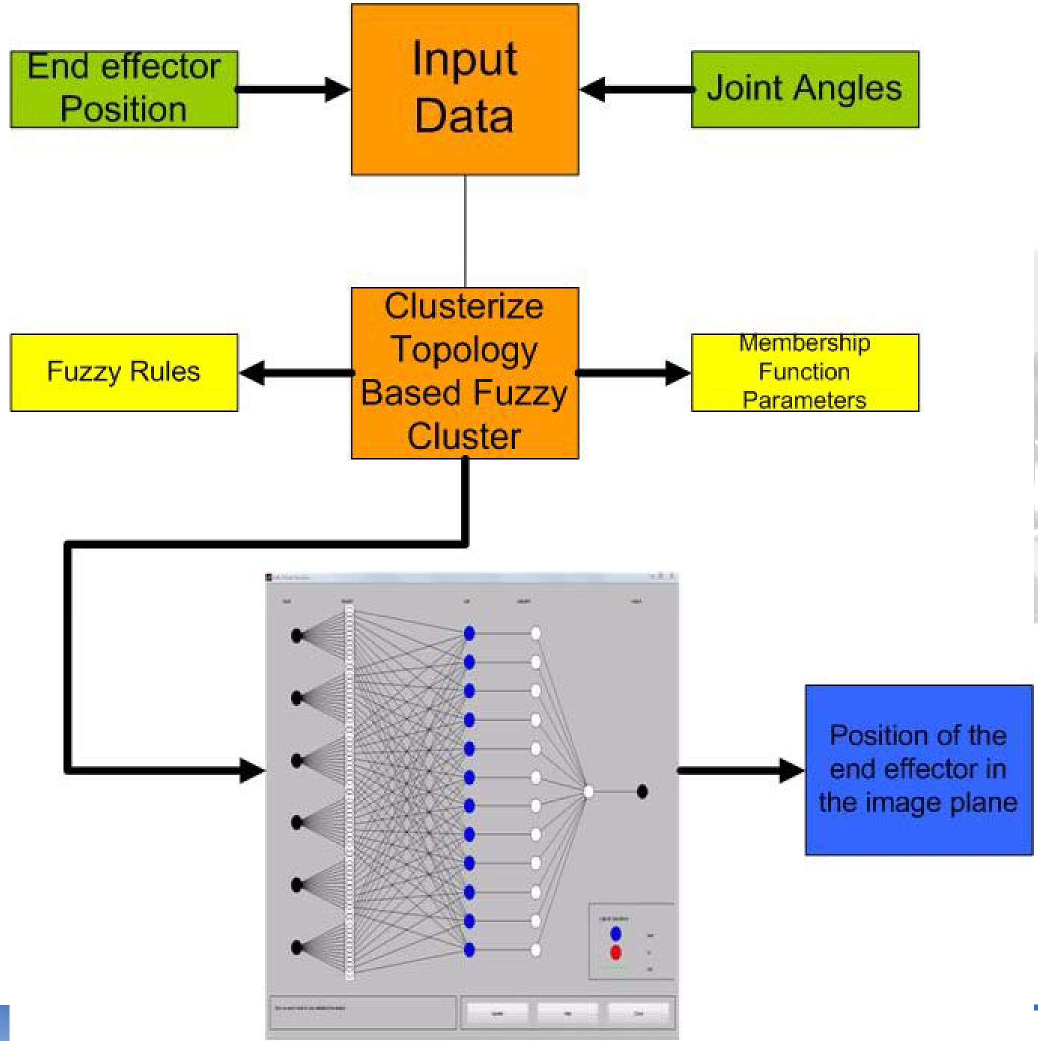
Forward Arm Model Generation



SANFIS

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Reaching Controller

- It is used a local Jacobian that is updated in every iteration with an extended least square algorithm.

$$\hat{J}_k = \hat{J}_{k-1} + (\Delta f - \hat{J}_{k-1} h_\theta)(\lambda + h_\theta^T P_{k-1} h_\theta)^{-1} h_\theta^T P_{k-1}$$

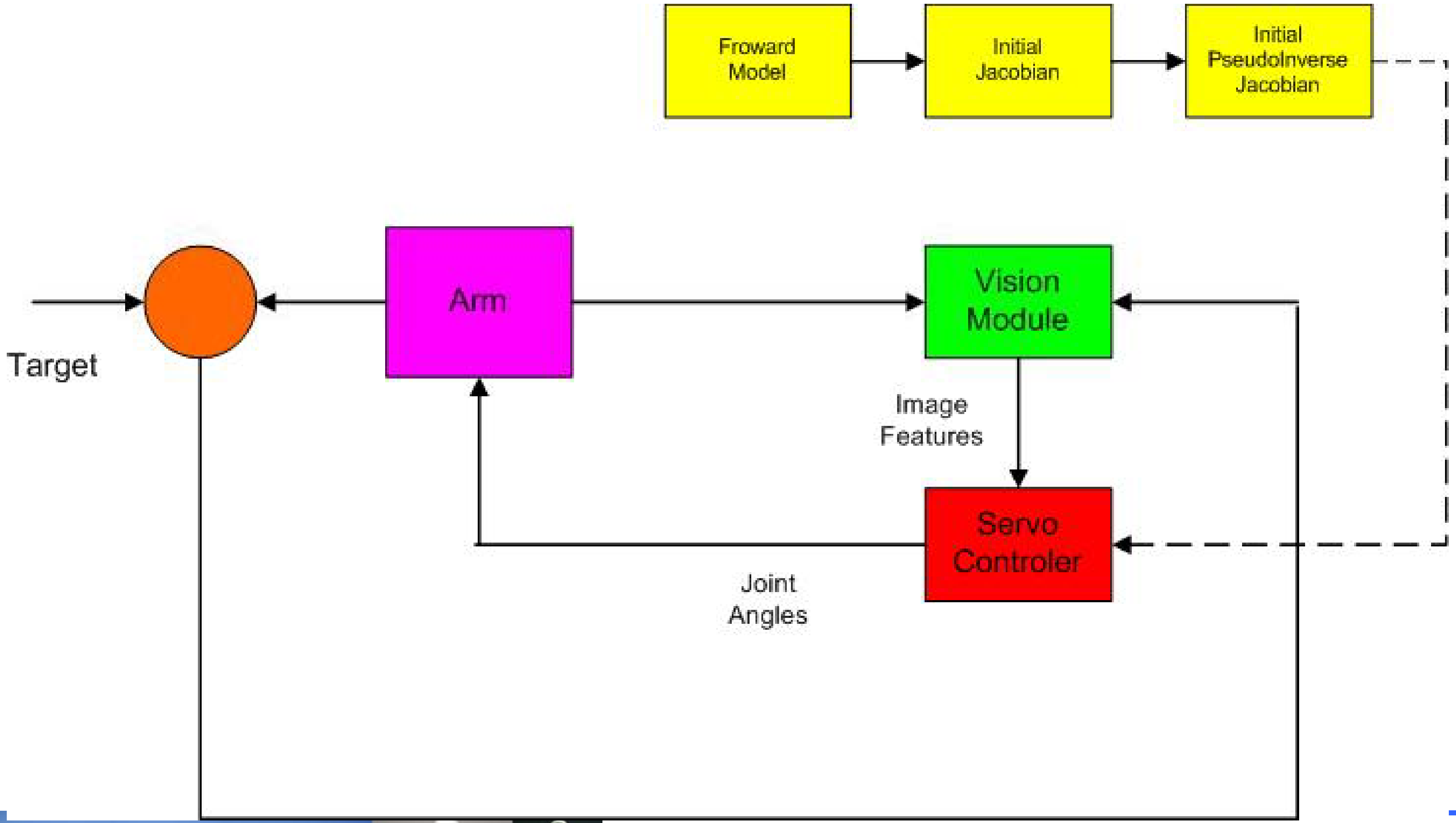
$$P_k = \frac{1}{\lambda}(P_{k-1} - P_{k-1} h(\Delta f - \hat{J}_{k-1} h_\theta)(\lambda + h_\theta^T P_{k-1} h_\theta)^{-1} h_\theta^T P_{k-1}$$

- The control signals are send to the joint in every iteration following the equation

$$\theta_{k+1} = \theta_k - (\hat{J}_k^T \hat{J}_k)^{-1} \hat{J}_k^T (f_k + \frac{\partial f_k}{\partial t} h_t)$$

J. A. Piepmeier, G. V. McMurray and H. Lipkin , "A Dynamic Jacobian Estimation Method for Uncalibrated Visual Servoing", *IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, September-1999, Atlanta, USA

The Reaching Controller Architecture



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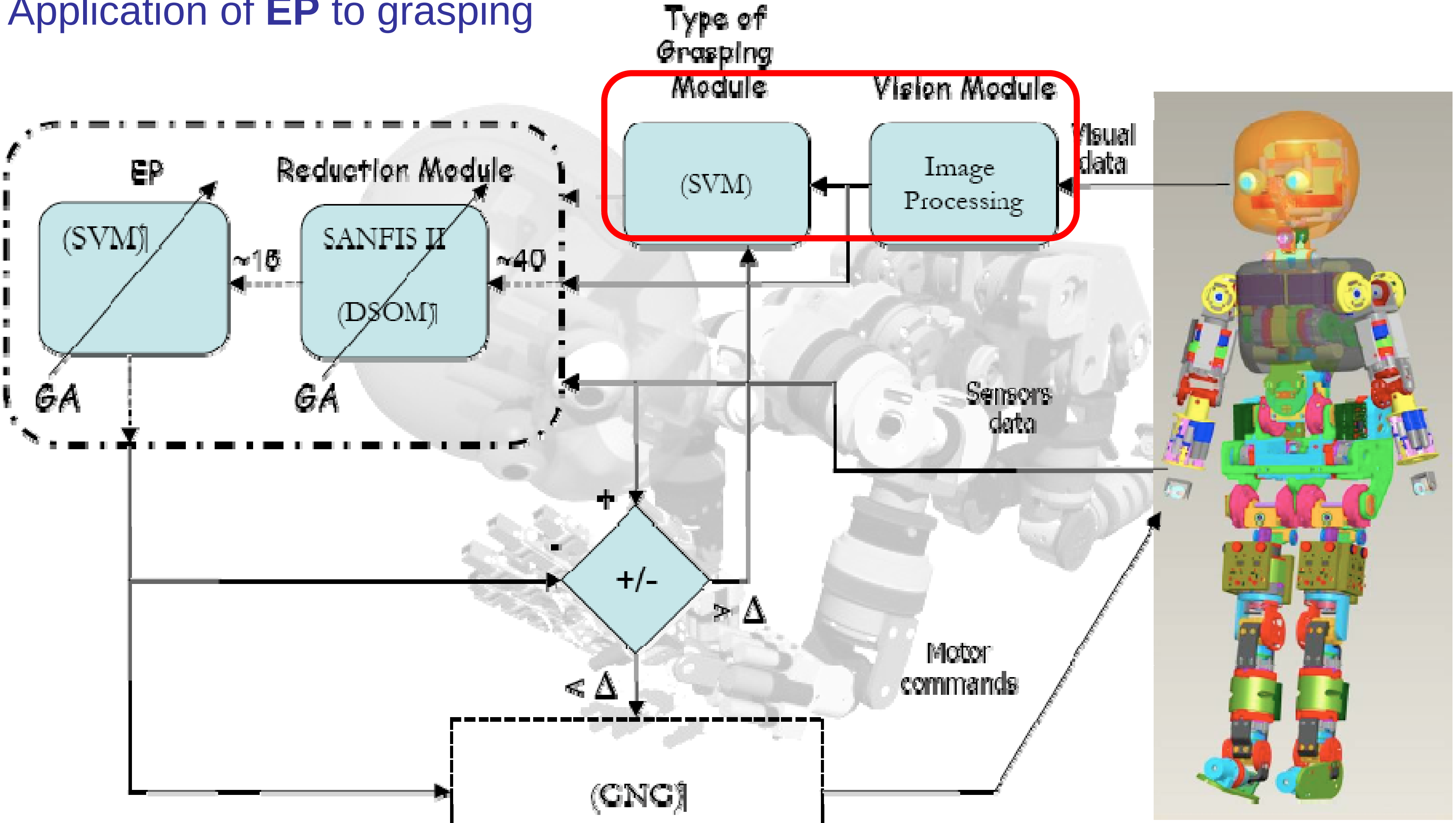
An EP scheme for iCub (Work in Progress)

Application of **EP** to grasping



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- The Robot-An Lab
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- The SABIAN: phase 1
- The SABIAN: phase 2

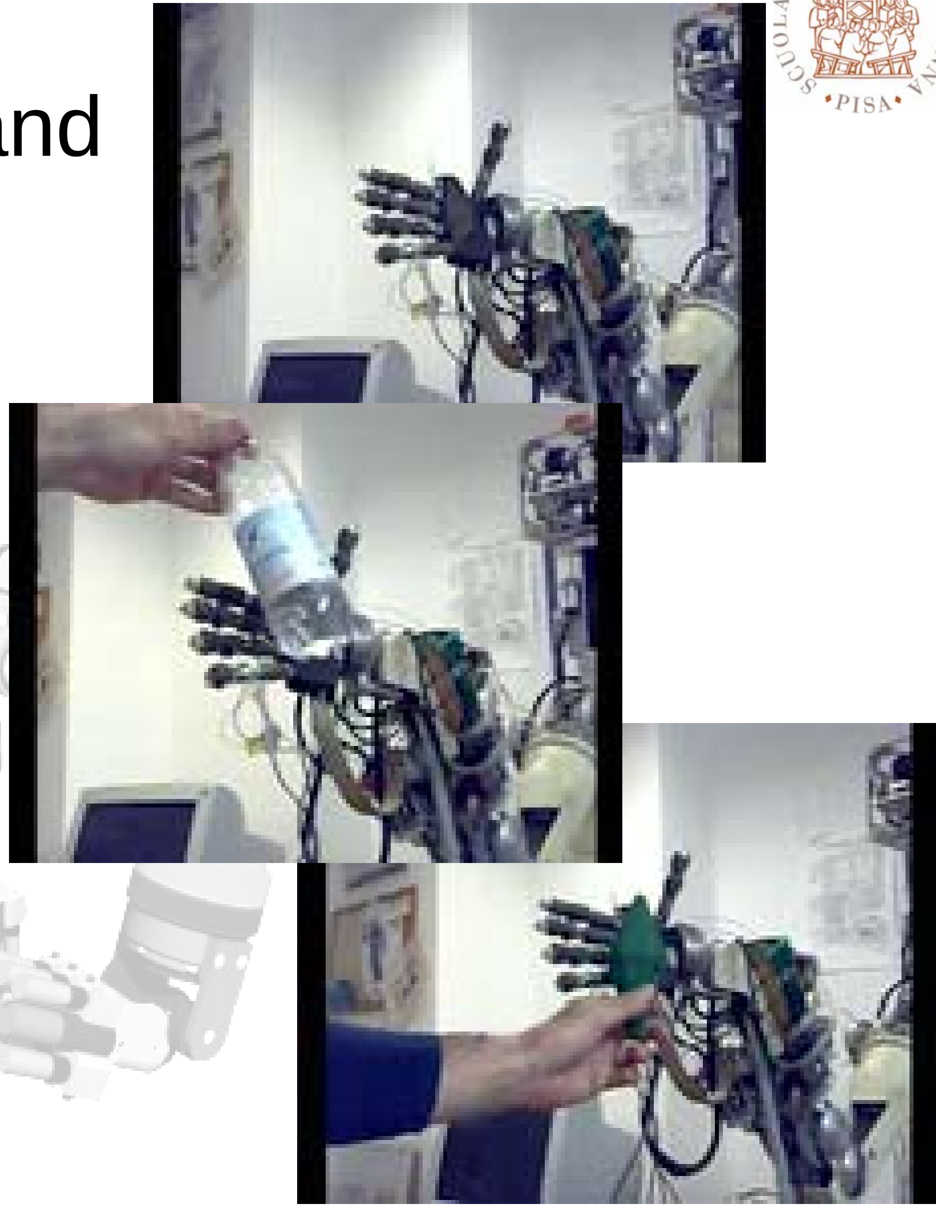
ExPer2
project

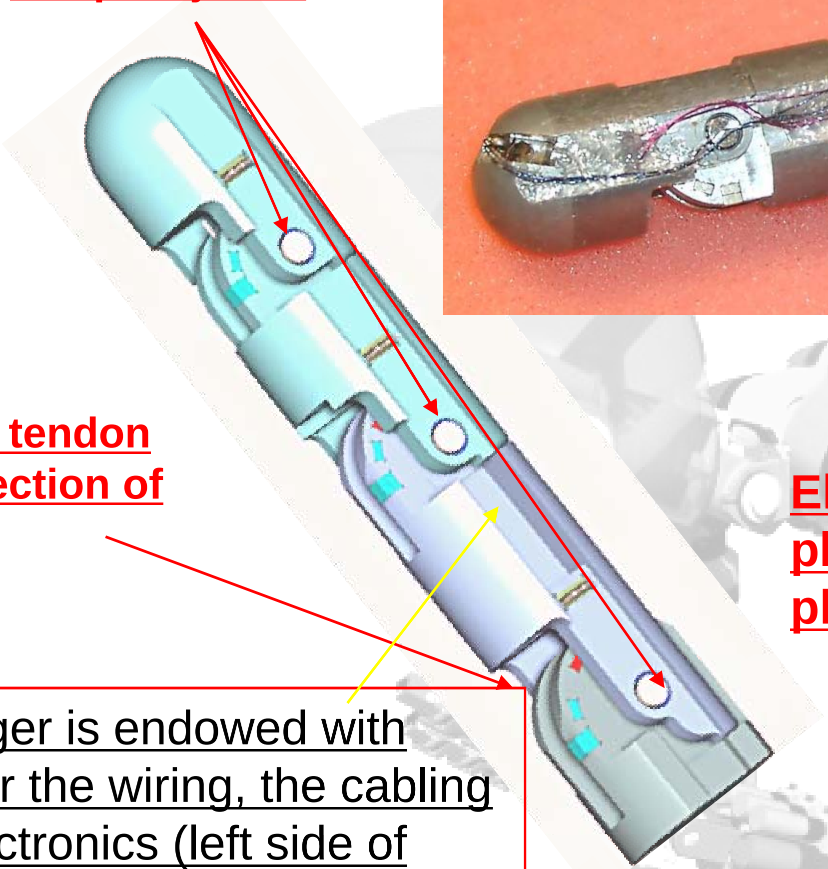
Background: Exper1

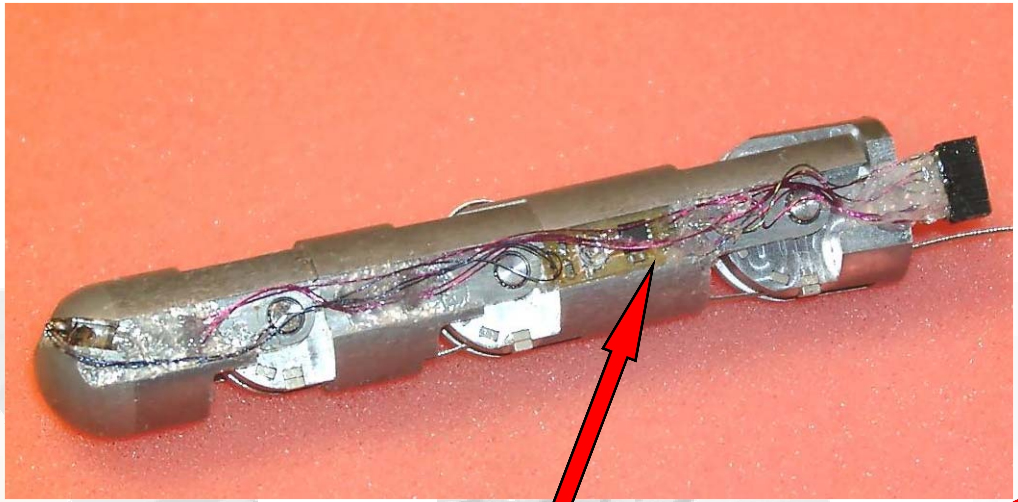
The Exper2 Hand

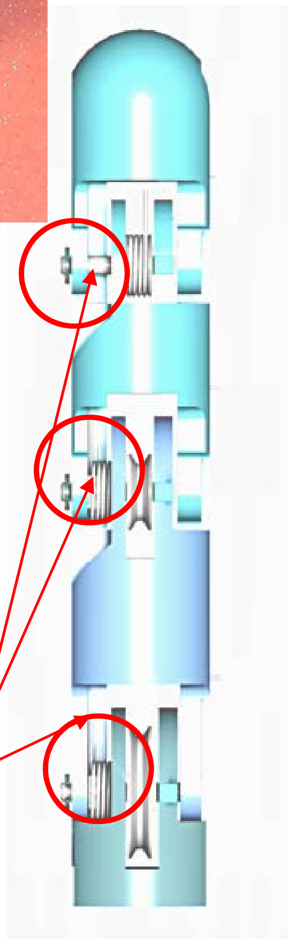
Hand mechanical specifications

- 16 d.o.f. total – 6 d.o.m. total
- Underactuated fingers, each driven by a single cable actuated by a motor
- 6 d.o.m. : one for each finger (flexion/extension) + one for thumb positioning (adduction/abduction) 6 DC 6V motors
- trapezo-metacarpal thumb joint abduction/adduction range: 0° -120°
- finger joints flexion range: 0-90°
- Weight: Palm+fingers about 400 gr., Socket interface (actuation and transmission system) about 1400 gr.
- Grasping force: 55 N (estimated).
- Tip to tip force: 22 N (estimated).
- Closing time: 0.8 sec
- Anthropomorphic size, and kinematics.









The finger is endowed with room for the wiring, the cabling and electronics (left side of each phalanx)

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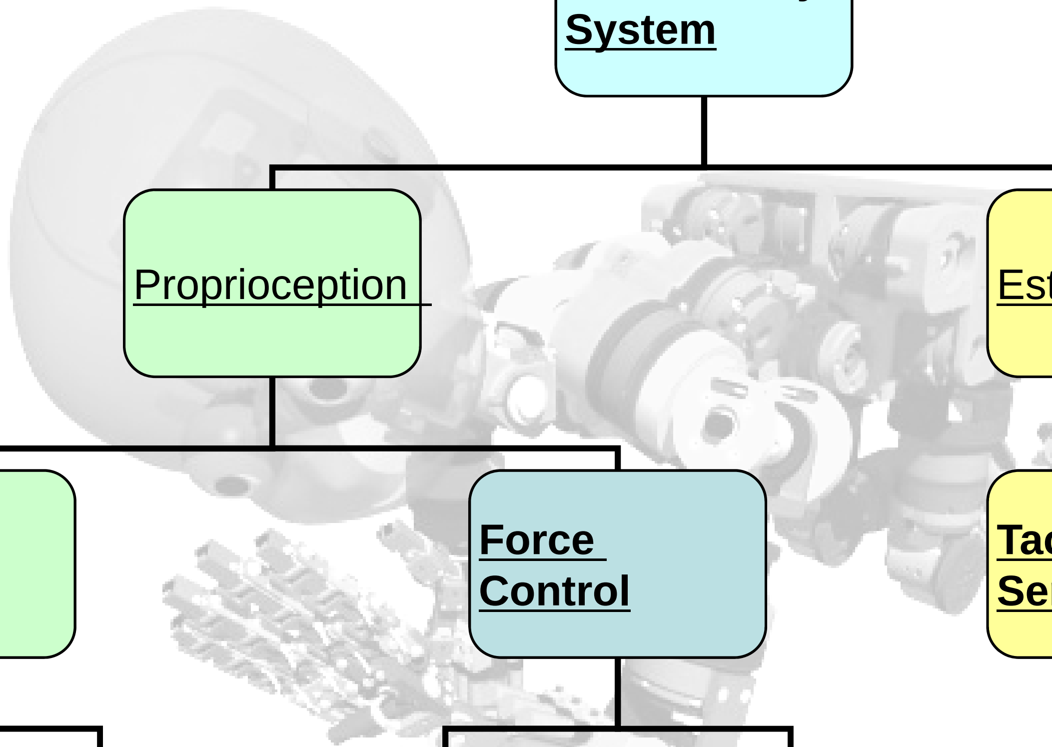
The Sensory System



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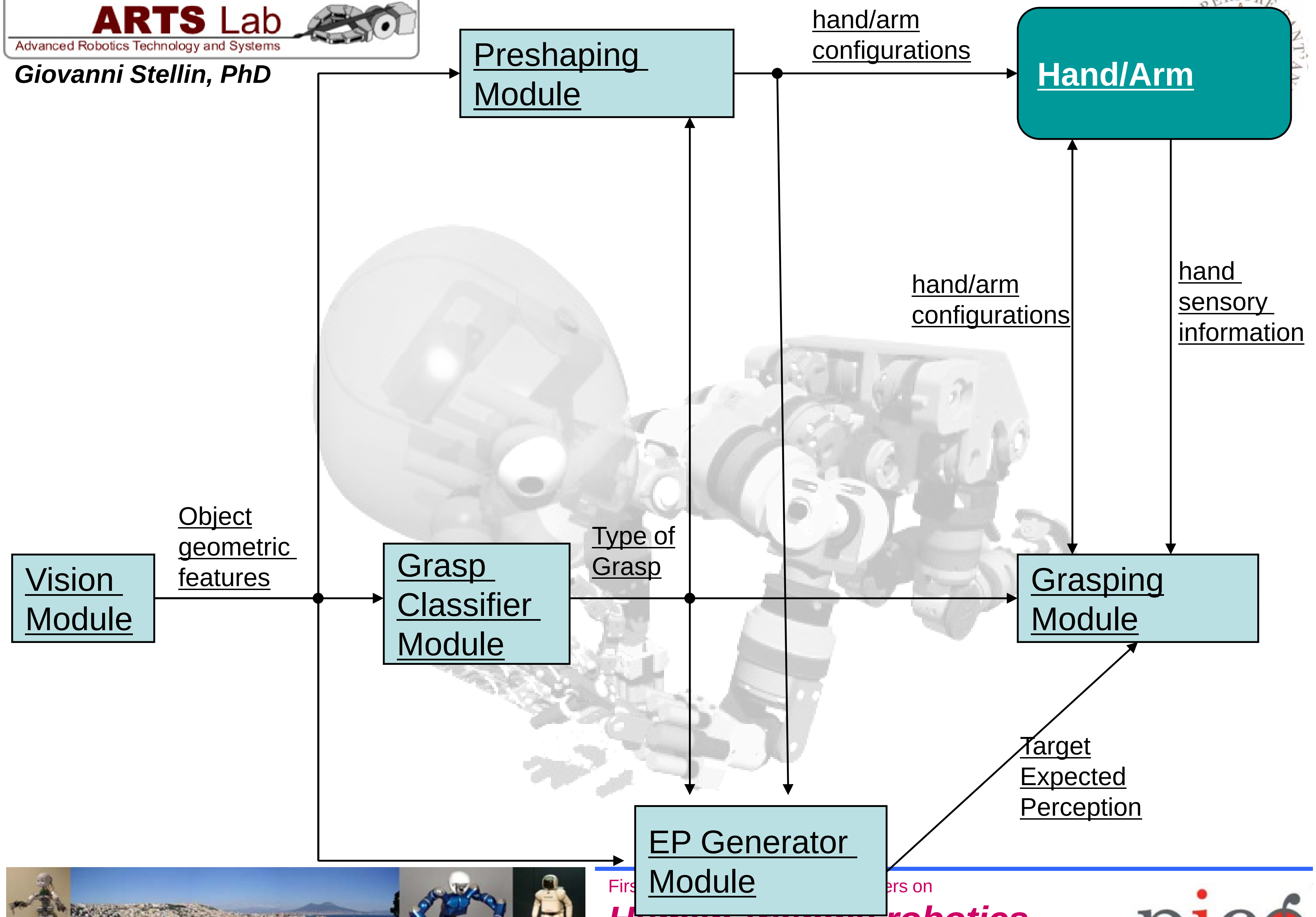
      - Current Detection
  - Esteroception
    - **Tactile Sensing**
      - FingerTPS (off-the-shelf)

Re-design of the System

- **Objectives**:
  - Design of the different modules composing the system:
    - Vision module,
    - Preshaping module,
    - EP Generator module,
    - Grasping module,
    - Grasp Classifier module


Preshaping Module
hand/arm configurations
Hand/Arm
hand/arm configurations
hand sensory information
Vision Module
Object geometric features
Grasp Classifier Module
Type of Grasp
Grasping Module
Target Expected Perception
EP Generator Module

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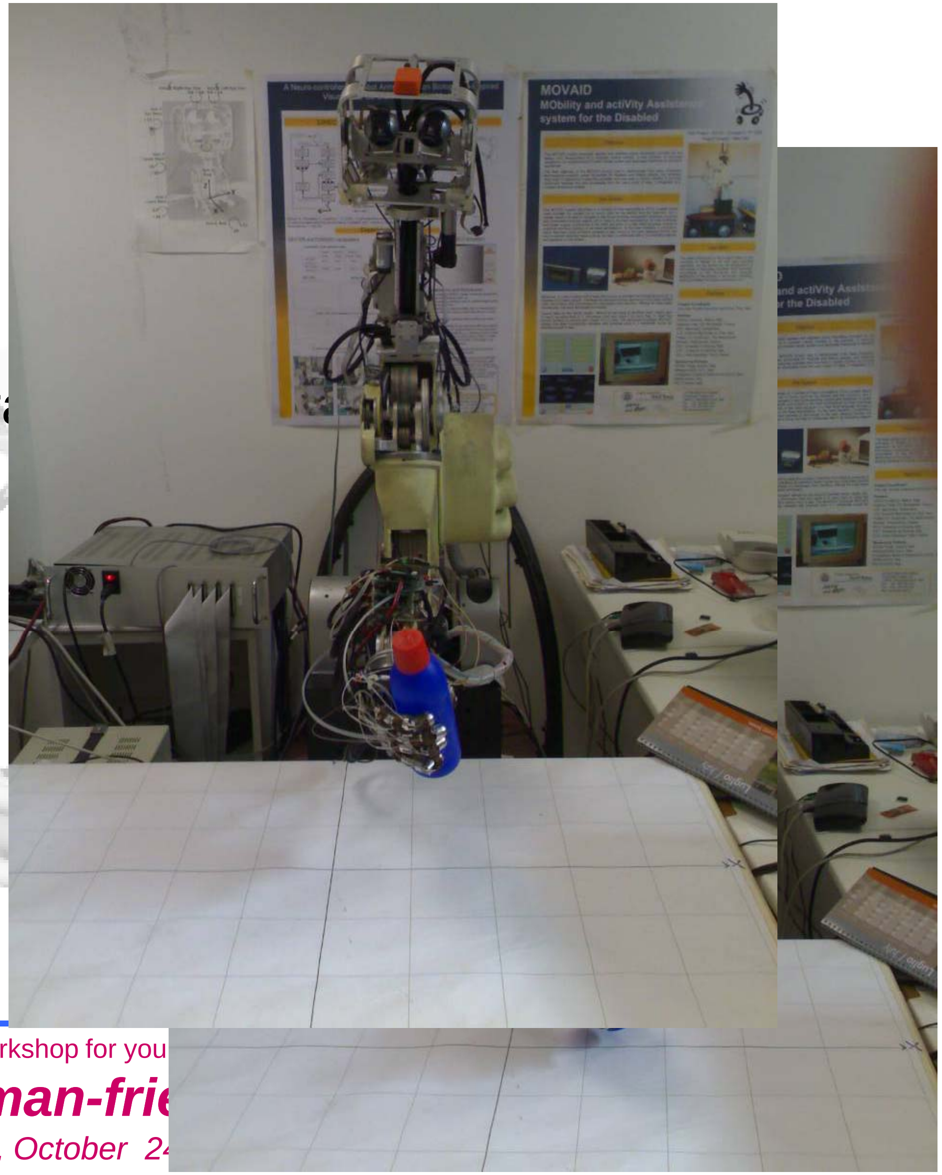
“Training of the system ”

Collection of the Data:

1. put the target object in the operative space;
2. give the operative space position and teach the type of gr
3. teach a good preshaping;
4. teach a good grasping;
5. lift the object.
6. repeat from point 1 for each object and for each position and orientation in the operative space.



Experimental trials:

- The data has been splitting in three parts:
- training set (70%), validation set (20%), and testing set (10%).
- The training set has been used to teach the network and the validation set is used for defining a stop criteria.
- The testing set has been used to measure the obtained results.

The object considered for the experimental trials:

- cube (side dimension: 60 mm);
- sphere (radius: 40 mm);
- box (35 x 50 x 70 mm).

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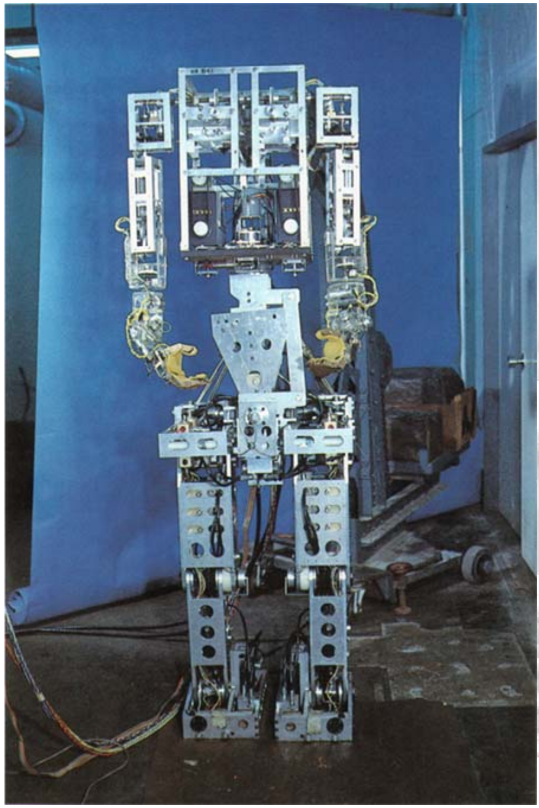
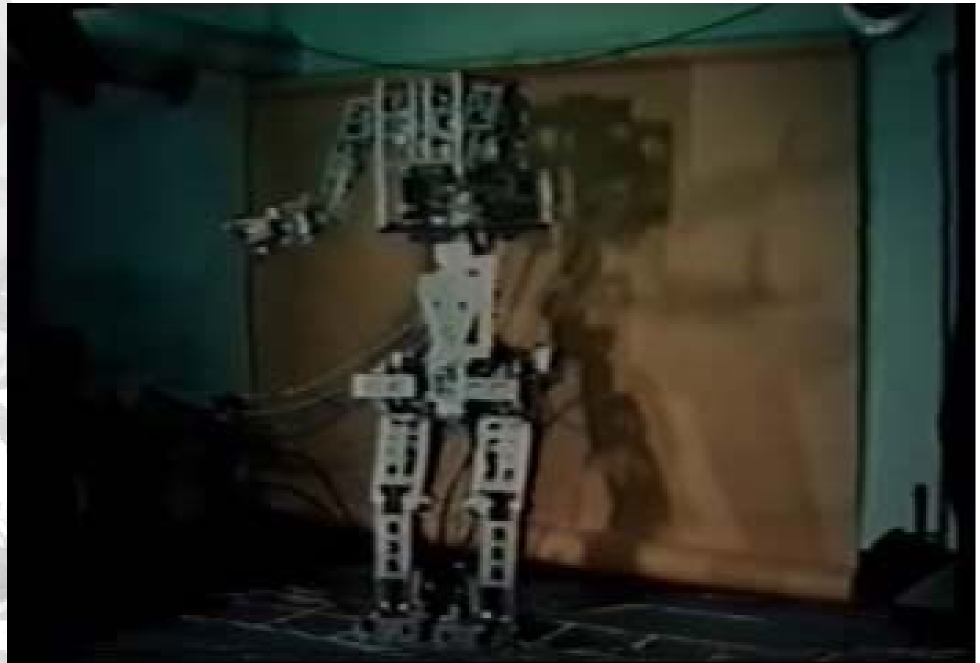
The First Humanoid in the world





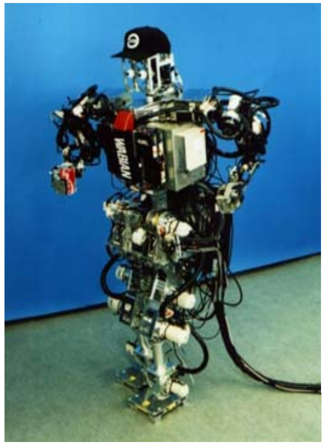
WABOT-1 (WAseda roBOT-1, 1972)

WABIAN Series

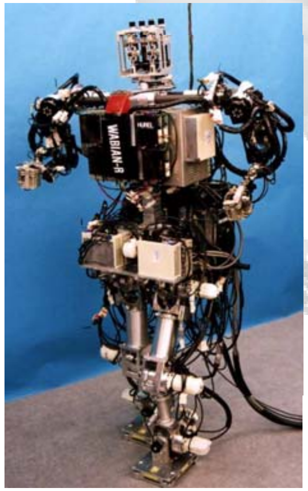
WABIAN; WAseda BIpedal humANoid

with two legs, a trunk, two arms, hands, a head, etc.

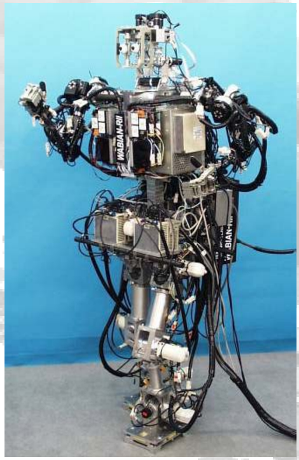
1996 1997 1998 1999 2000 2001



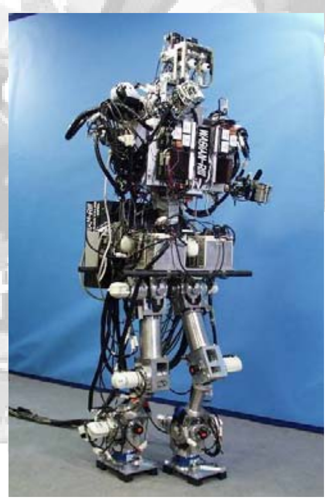
WABIAN



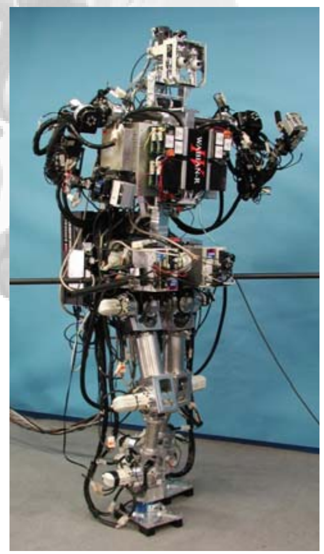
WABIAN-R



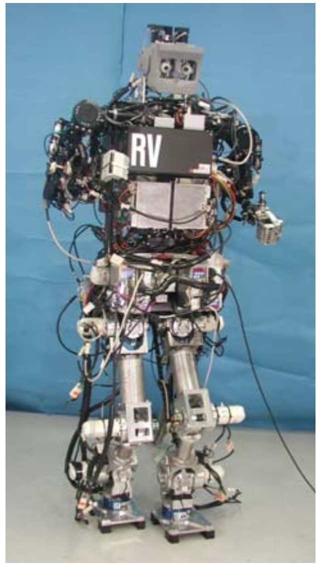
WABIAN-RII



WABIAN-RIII



WABIAN-RIV

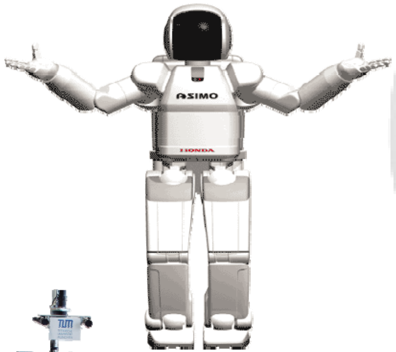


WABIAN-RV

Previous Humanoid Robot with Legs

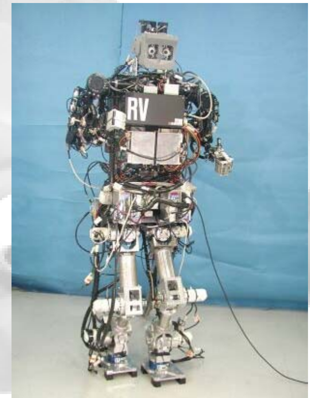
Are 6DOF legs enough for a *human-like* robot?

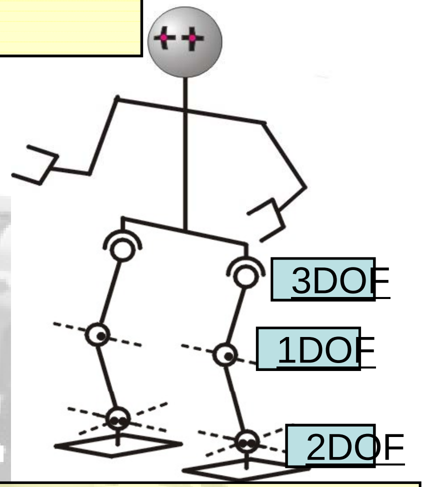
ASIMO



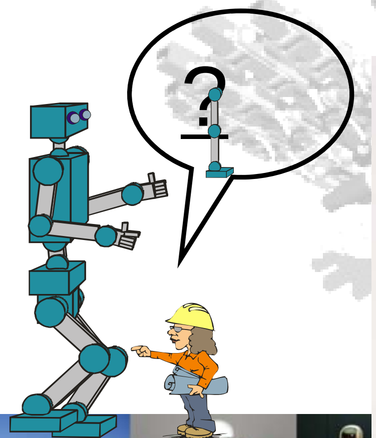
QRIO

WABIAN-RV





Legs **6DOF x 2**

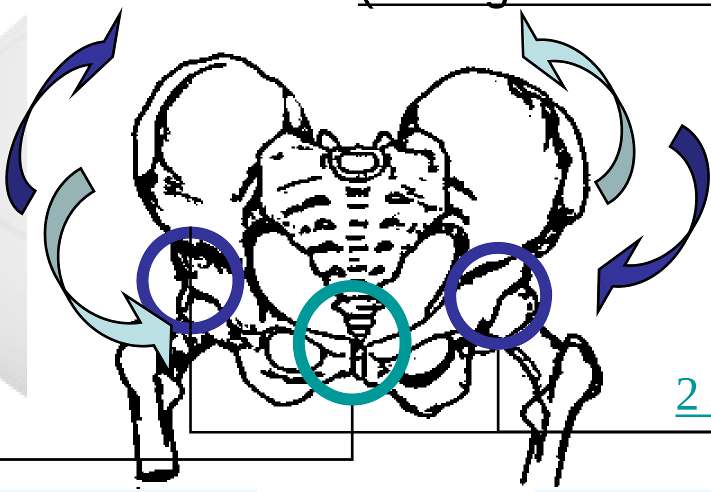


≠ Human walking

New Leg Mechanism

Modeling of Pelvis Motion

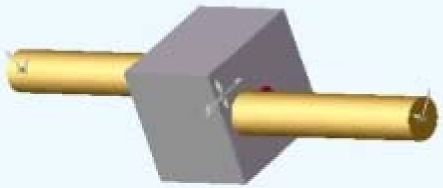
The relative motion of two hipbones (sliding on each other)

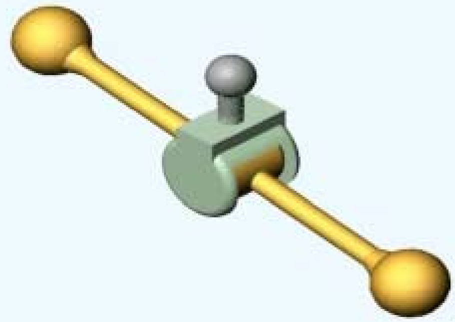


2 DOF hips

Pubic symphysis

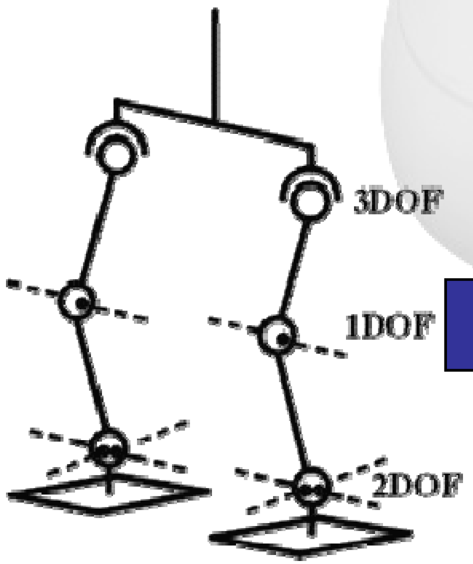
(like a crank mechanism)





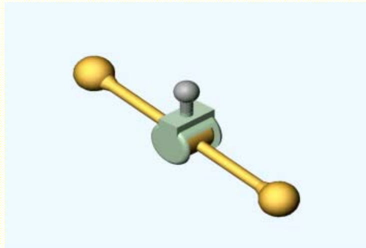
DOF of New Leg System

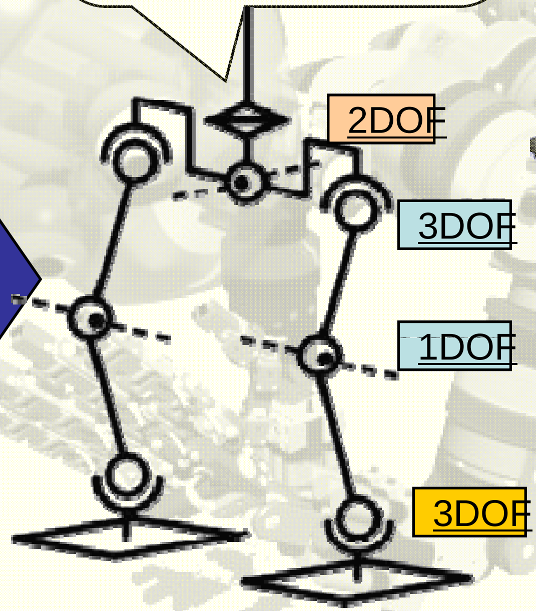
Conventional biped robot

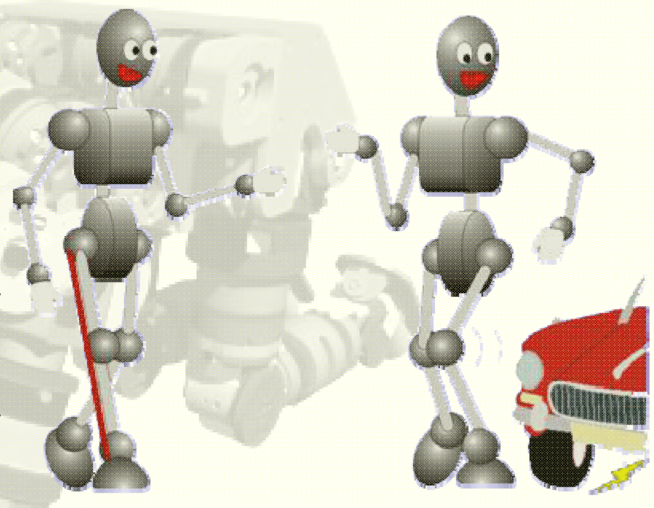


Legs 6DOF×2

New biped robot

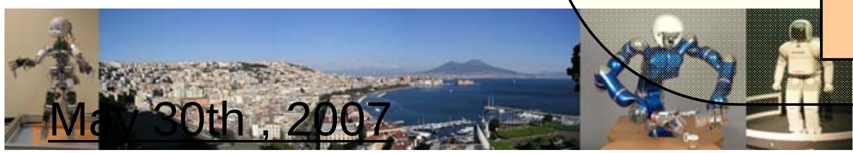






- Stretch walking
- Obstacle avoidance

Legs 7DOF×2, Waist 2DOF



Specifications of Wabian-2

- **Design and processing by students**
- **All commercial parts**
- Simulator for the handicapped
- Knee-stretching walk like a human
- Proper link length and weight
- Large movable range
- Effective DOF configuration

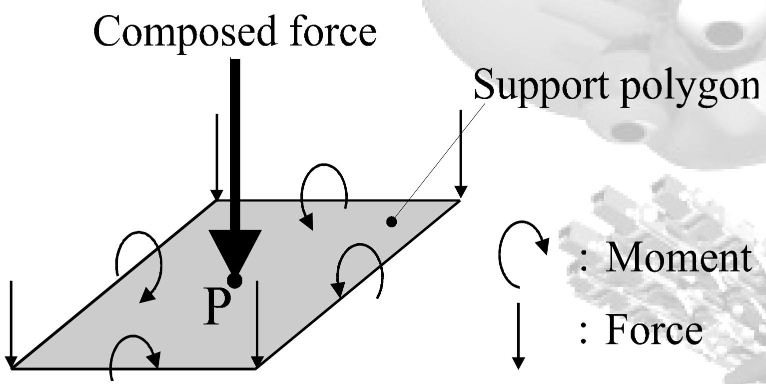
Height : 1.53 [m]
Weight (with Batt.) : 64.5 [kg]

Active DOF : 41
Legs : 7×2, Waist: 2 (roll,yaw)
Trunk: 2 (pitch, roll), Arms: 7×2
Neck : 3, Hands: 3×2

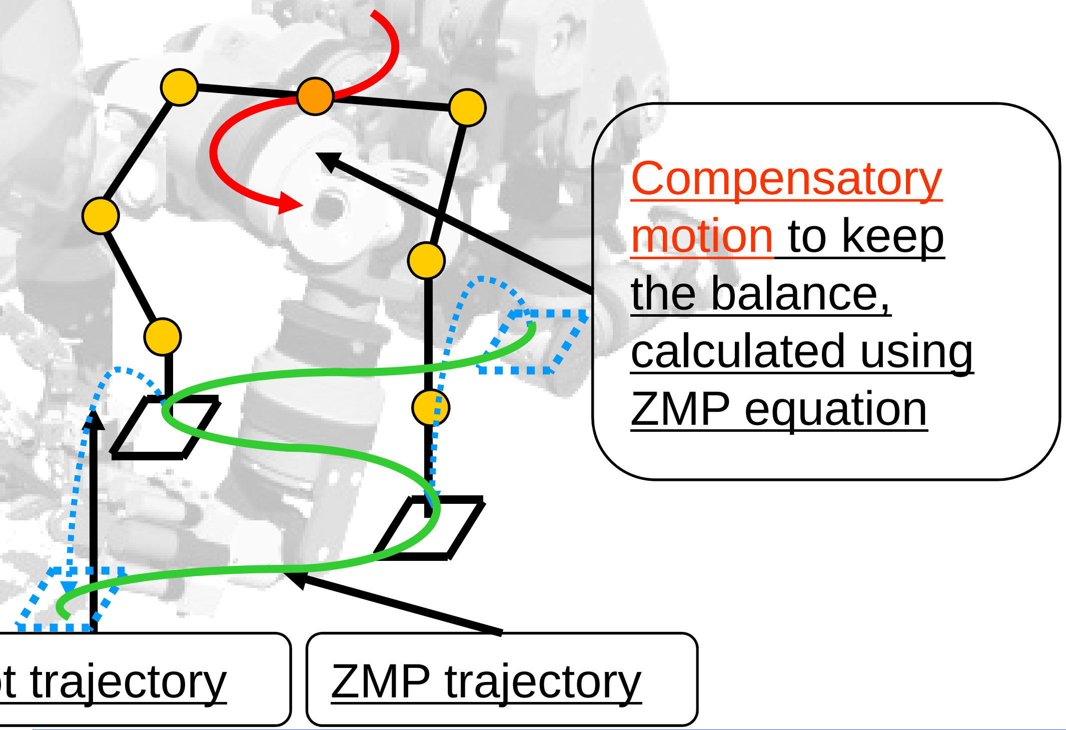
How to walk with balance

Stability criterion for biped robot based on ZMP (Zero Moment Point)

- ZMP: a point where the total forces and moments acting on the robot are zero
- ZMP trajectory: set arbitrarily within the support polygon



Stable region



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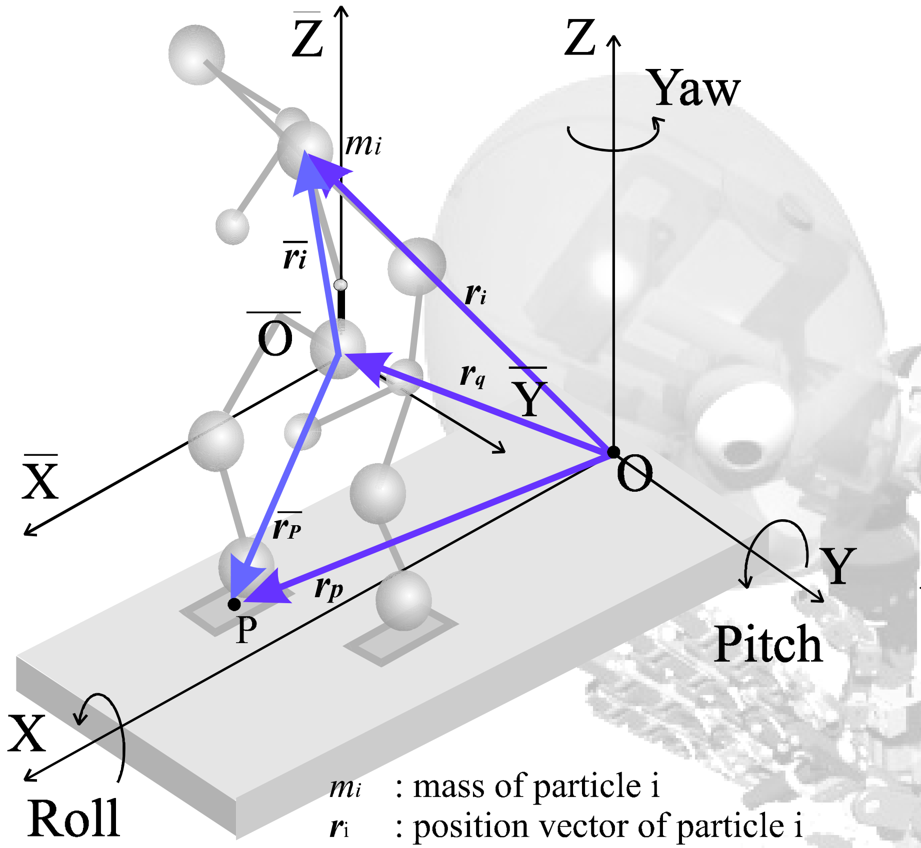
ZMP Equation

$\mathrm{O-XYZ}$

$$\sum_{i}^{All\ Particles} m_i(\boldsymbol{r}_i - \boldsymbol{r}_P) \times (\ddot{\boldsymbol{r}}_i - \boldsymbol{G})$$

$$-\sum_{k}^{All\ Points} \{(\boldsymbol{r}_{Fk} - \boldsymbol{r}_P) \times \boldsymbol{F}_k + \boldsymbol{M}_k\} + \boldsymbol{T} = \boldsymbol{0}$$



m_i : mass of particle i
$\boldsymbol{r}_i$: position vector of particle i
$\boldsymbol{r}_p$: position vector of P
$\boldsymbol{T}$: total torque acting on P
$\boldsymbol{G}$: gravity acceleration vector
O-XYZ : absolute coordinate system
$\overline{\mathrm{O}}$-$\overline{\mathrm{X}}\overline{\mathrm{Y}}\overline{\mathrm{Z}}$: moving coordinate system

ZMP Equation

$$\sum_{i}^{All\ Particles} m_i(\boldsymbol{r}_i - \boldsymbol{r}_{ZMP}) \times (\ddot{\boldsymbol{r}}_i - \boldsymbol{G})$$

$$-\sum_{k}^{All\ Points} \{(\boldsymbol{r}_{Fk} - \boldsymbol{r}_{ZMP}) \times \boldsymbol{F}_k + \boldsymbol{M}_k\} = \boldsymbol{0}$$

$\overline{\mathrm{O}} - \overline{\mathrm{XYZ}}$

$$\sum_{i}^{All\ Particles} m_i(\overline{\boldsymbol{r}}_i - \overline{\boldsymbol{r}}_{ZMP}) \times \{\ddot{\overline{\boldsymbol{r}}}_i + \ddot{\overline{\boldsymbol{Q}}} - \overline{\boldsymbol{G}}$$

$$+ \dot{\overline{\boldsymbol{\omega}}} \times \overline{\boldsymbol{r}}_i + 2\overline{\boldsymbol{\omega}} \times \dot{\overline{\boldsymbol{r}}}_i + \overline{\boldsymbol{\omega}} \times (\overline{\boldsymbol{\omega}} \times \overline{\boldsymbol{r}}_i)\}$$

$$-\sum_{k}^{All\ Points} \{(\overline{\boldsymbol{r}}_{Fk} - \overline{\boldsymbol{r}}_{ZMP}) \times \overline{\boldsymbol{F}}_k + \overline{\boldsymbol{M}}_k\} = \boldsymbol{0}$$

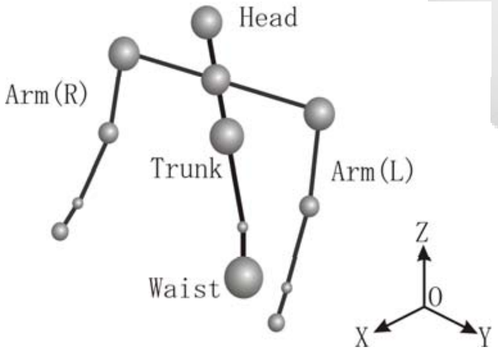
To Solve ZMP equation (1)

Assumption 1: ignore external forces

$$\sum_{i}^{\text{All Particles}} \mathrm{m_i}(\bar{\boldsymbol{r}}_\mathrm{i} - \bar{\boldsymbol{r}}_\mathrm{ZMP}) \times \{\ddot{\bar{\boldsymbol{r}}}_\mathrm{i} + \ddot{\boldsymbol{Q}} - \overline{\boldsymbol{G}}$$
$$+ \dot{\bar{\varpi}} \times \bar{\boldsymbol{r}}_\mathrm{i} + 2\bar{\varpi} \times \dot{\bar{\boldsymbol{r}}}_\mathrm{i} + \bar{\varpi} \times (\bar{\varpi} \times \bar{\boldsymbol{r}}_\mathrm{i})\} = 0$$

$$\mathrm{m_U}\bar{\boldsymbol{r}}'_\mathrm{T} \times \{\ddot{\bar{\boldsymbol{r}}}'_\mathrm{T} + \dot{\bar{\varpi}} \times \bar{\boldsymbol{r}}'_\mathrm{T} + 2\bar{\varpi} \times \dot{\bar{\mathbf{r}}}'_\mathrm{T} + \bar{\varpi} \times (\bar{\varpi} \times \bar{\boldsymbol{r}}'_\mathrm{T})\}$$
$$+ \mathrm{m_T}(\bar{\boldsymbol{r}}_\mathrm{T} - \bar{\boldsymbol{r}}_\mathrm{ZMP}) \times \{\ddot{\bar{\boldsymbol{r}}}_\mathrm{T} + \ddot{\boldsymbol{Q}} - \overline{\boldsymbol{G}}$$
$$+ \dot{\bar{\varpi}} \times \bar{\boldsymbol{r}}_\mathrm{T} + 2\bar{\varpi} \times \dot{\bar{\boldsymbol{r}}}_\mathrm{T} + \bar{\varpi} \times (\bar{\varpi} \times \bar{\boldsymbol{r}}_\mathrm{T})\}$$
$$+ \mathrm{m_W}(\bar{\boldsymbol{r}}_\mathrm{W} - \bar{\boldsymbol{r}}_\mathrm{ZMP}) \times \{\ddot{\bar{\boldsymbol{r}}}_\mathrm{W} + \ddot{\boldsymbol{Q}} - \overline{\boldsymbol{G}}$$
$$+ \dot{\bar{\varpi}} \times \bar{\boldsymbol{r}}_\mathrm{W} + 2\bar{\varpi} \times \dot{\bar{\boldsymbol{r}}}_\mathrm{W} + \bar{\varpi} \times (\bar{\varpi} \times \bar{\boldsymbol{r}}_\mathrm{W})\}$$
$$= -\mathbf{M}_{LL}$$

Assumption 2: approximate the mass distribution



Strict model

M : Moment generated by lower limb

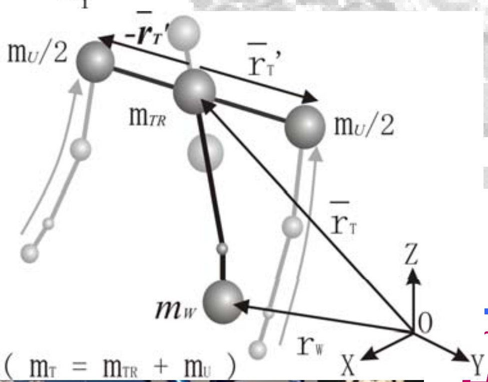
Roll axis

$$m_U(7\ \bar{y}'_T\ddot{\bar{z}}'_T - \bar{z}'_T\ddot{\bar{y}}'_T)$$
$$+ m_T(\bar{y}_T - \bar{y}_{ZMP})(\ddot{\bar{z}}_T + \ddot{\bar{z}}_q - \bar{g}_z) - m_T(\bar{z}_T - \bar{z}_{ZMP})(\ddot{\bar{y}}_T + \ddot{\bar{y}}_q - \bar{g}_y)$$
$$+ m_W(\bar{y}_W - \bar{y}_{ZMP})(\ddot{\bar{z}}_W + \ddot{\bar{z}}_q - \bar{g}_z) - m_W(\bar{z}_W - \bar{z}_{ZMP})(\ddot{\bar{y}}_W + \ddot{\bar{y}}_q - \bar{g}_y)$$
$$= -M_x$$

Pitch axis

$$m_U(\bar{z}'_T\ddot{\bar{x}}'_T - \bar{x}'_T\ddot{\bar{z}}'_T)$$
$$+ m_T(\bar{z}_T - \bar{z}_{ZMP})(\ddot{\bar{x}}_T + \ddot{\bar{x}}_q - \bar{g}_x) - m_T(\bar{x}_T - \bar{x}_{ZMP})(\ddot{\bar{z}}_T + \ddot{\bar{z}}_q - \bar{g}_z)$$
$$+ m_W(\bar{z}_W - \bar{z}_{ZMP})(\ddot{\bar{x}}_W + \ddot{\bar{x}}_q - \bar{g}_x) - m_W(\bar{x}_W - \bar{x}_{ZMP})(\ddot{\bar{z}}_W + \ddot{\bar{z}}_q - \bar{g}_z)$$
$$= -M_y$$

4-particles mode
for upper body



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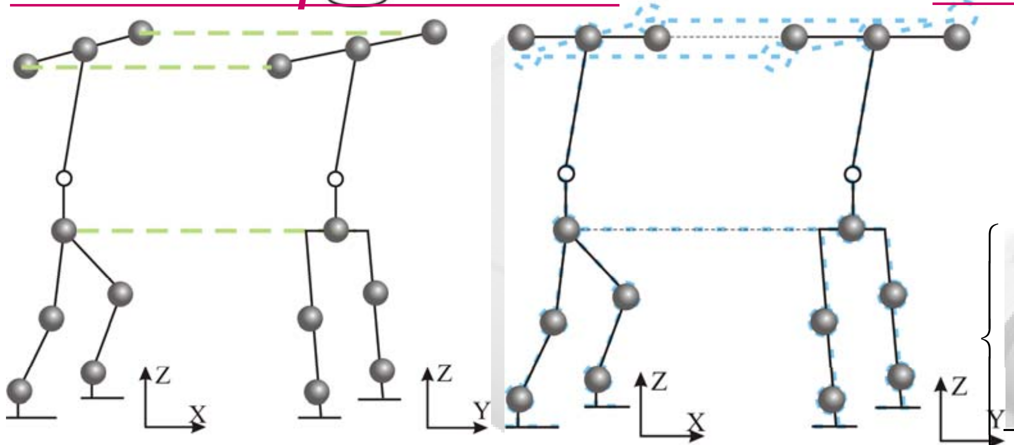
To Solve ZMP equation (2)

Assumption 3: ignore motion along Z axis for linearization



strict model   linearized model

Pitch axis

$$m_T(\bar{z}_T - \bar{z}_{ZMP})\ddot{\bar{x}}_T - m_T(-\bar{g}_z)\bar{x}_T$$
$$+ m_W(\bar{z}_W - \bar{z}_{ZMP})\ddot{\bar{x}}_W - m_W(-\bar{g}_z)\bar{x}_W = -M^*_y$$

Roll axis

$$-m_T(\bar{z}_T - \bar{z}_{ZMP})\ddot{\bar{y}}_T + m_T(-\bar{g}_z)\bar{y}_T$$
$$-m_W(\bar{z}_W - \bar{z}_{ZMP})\ddot{\bar{y}}_W + m_W(-\bar{g}_z)\bar{y}_W = -M^*_x$$

Assumption 4: divide compensated moment into trunk and waist motion

$$M^*_y = M^*_{trunk\_y} + M^*_{waist\_y}$$

$$M^*_x = M^*_{trunk\_x} + M^*_{waist\_x}$$

$$\begin{cases} m_T(\bar{z}_T - \bar{z}_{ZMP})\ddot{\bar{x}}_T - m_T(-\bar{g}_z)\bar{x}_T = -M^*_{trunk\_y} \\ m_W(\bar{z}_W - \bar{z}_{ZMP})\ddot{\bar{x}}_W - m_W(-\bar{g}_z)\bar{x}_T = -M^*_{waist\_y} \\ -m_T(\bar{z}_T - \bar{z}_{ZMP})\ddot{\bar{y}}_T + m_T(-\bar{g}_z)\bar{y}_T = -M^*_{trunk\_x} \\ -m_W(\bar{z}_W - \bar{z}_{ZMP})\ddot{\bar{y}}_W + m_W(-\bar{g}_z)\bar{y}_W = -M^*_{waist\_x} \end{cases}$$

FFT&IFFT

Derive $\bar{x}_T, \bar{y}_T, \bar{x}_W, \bar{y}_W$
(Trunk and waist motion)

Flow of Pattern Generation

Initial parameters;
Foot trajectory,
Initial trunk and waist trajectories,
ZMP trajectory, and
εM (a tolerance level moment error)

Compute walking pattern using initial waist motion

Compute moments **M** generated by lower-limbs

Compute compensatory trunk and waist motion

$$\bar{x}_T, \bar{y}_T, \bar{x}_W, \bar{y}_W$$

using linear model (FFT&IFFT)

Compute walking pattern using compensatory waist motion

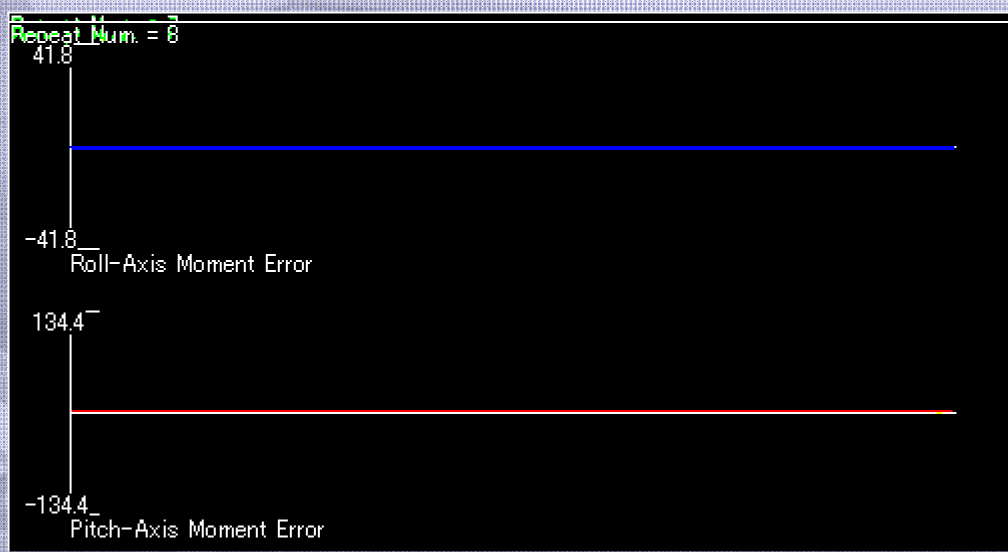
Compute moment errors (**eM**) between calculated ZMP and planned ZMP

Repeat calculation
to derive ***compensated moment:*** **M**

$$\mathbf{M} = \mathbf{M}_{LL} + \mathbf{E}_n$$

$$\mathbf{E}_n = \mathbf{E}_{n-1} + Gain \cdot \mathbf{eM}_{(n-1)}$$

moment errors (**eM**)



eM < *εM* ?

No

Yes

Complete walking pattern

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Online Continuous Walking

Generate 1st ~ 5th Steps just before the 1st Step

Select 1st ~ 3rd Steps

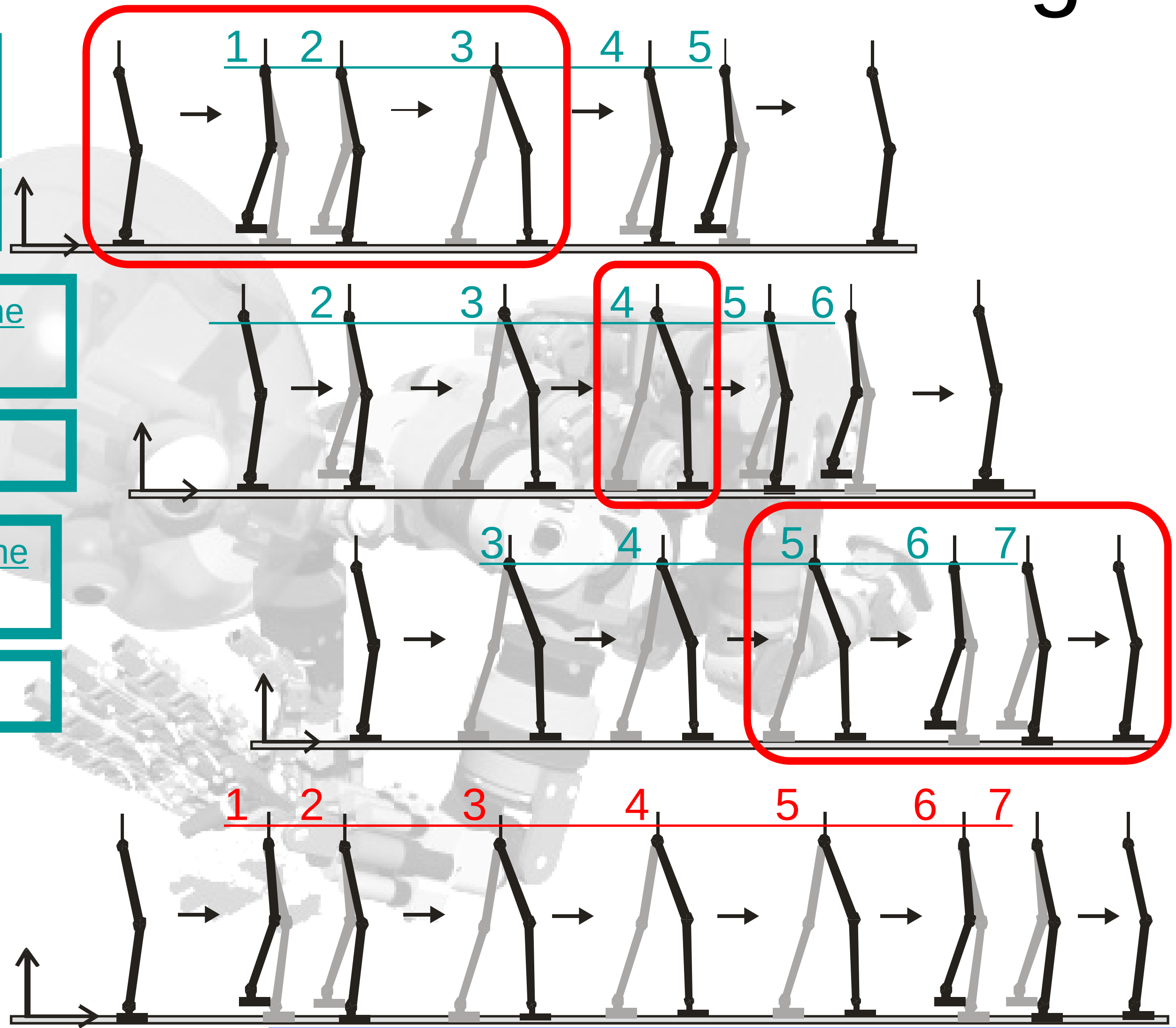
Generate 2nd ~ 6th Steps at the 3rd Step

Select 4th Step

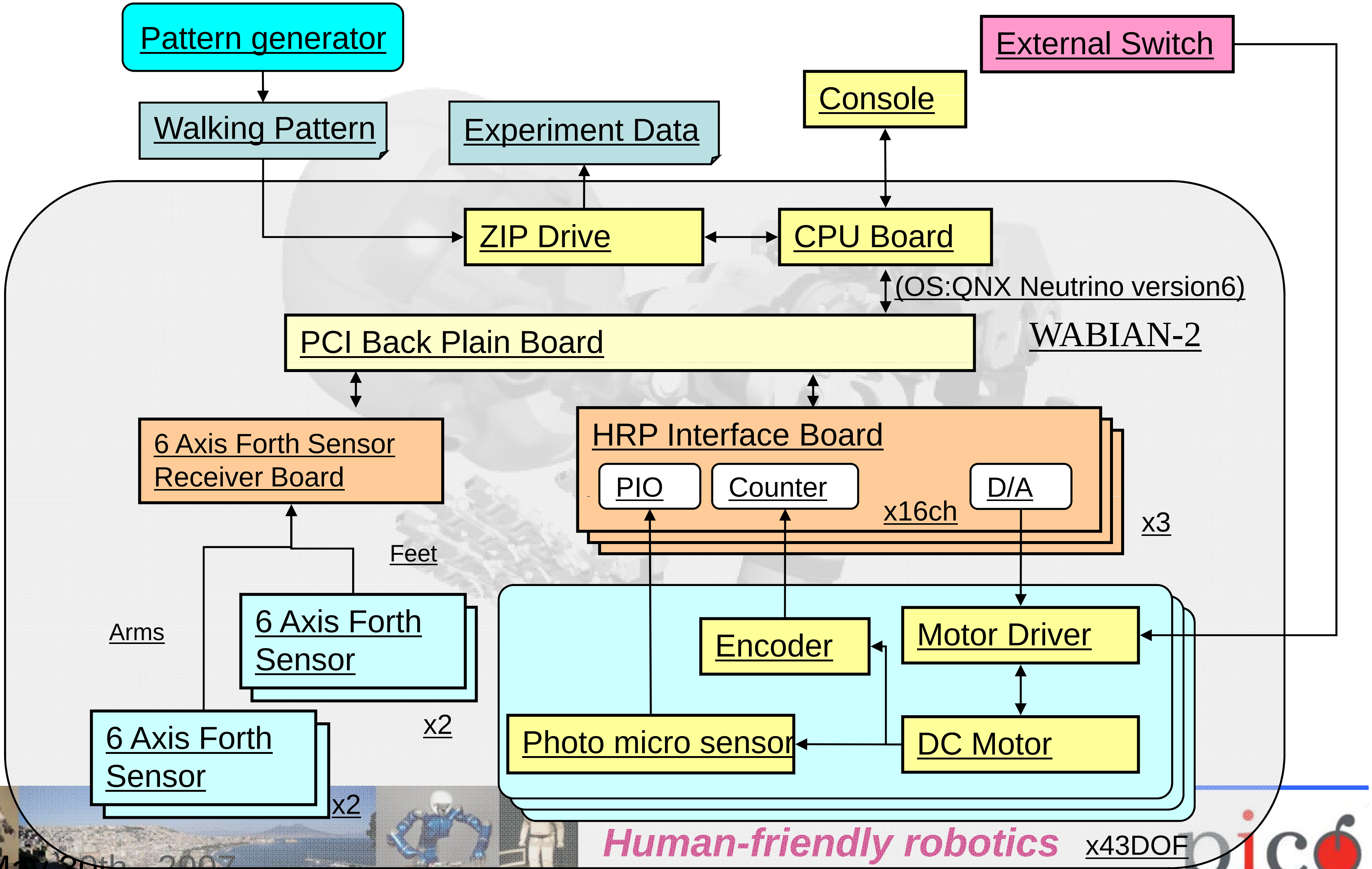
Generate 3rd ~ 7th Steps at the 4th Step

Select 5th ~ 7th Step

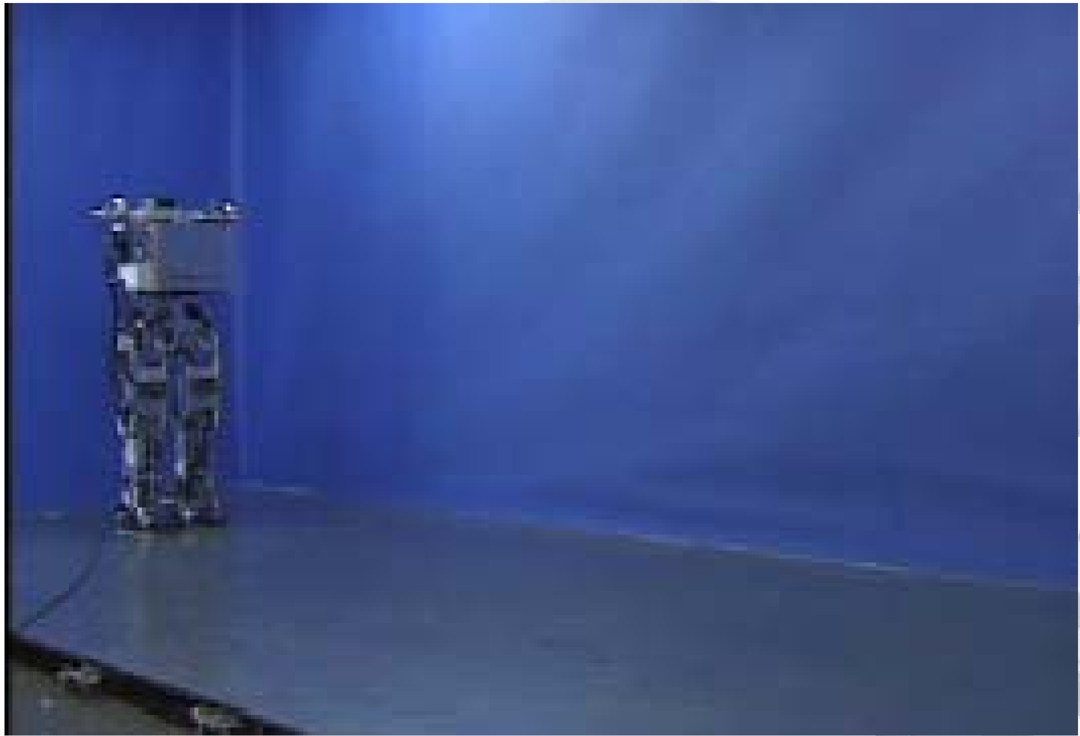
Continuous Walking

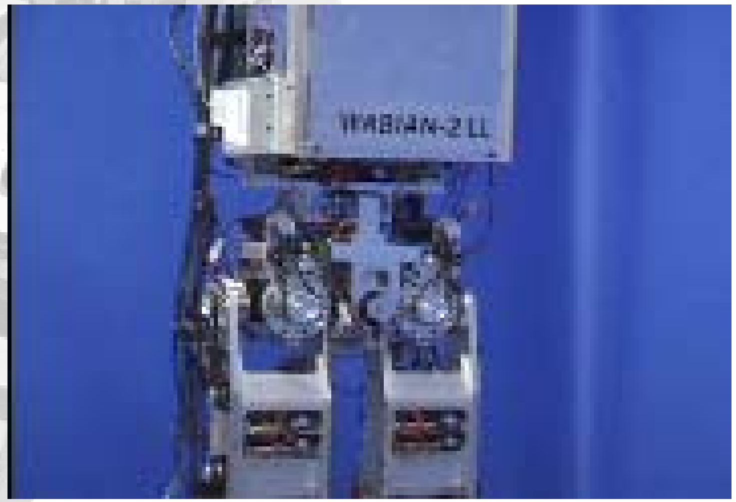


Control System of WABIAN-2



Wabian 2 LL





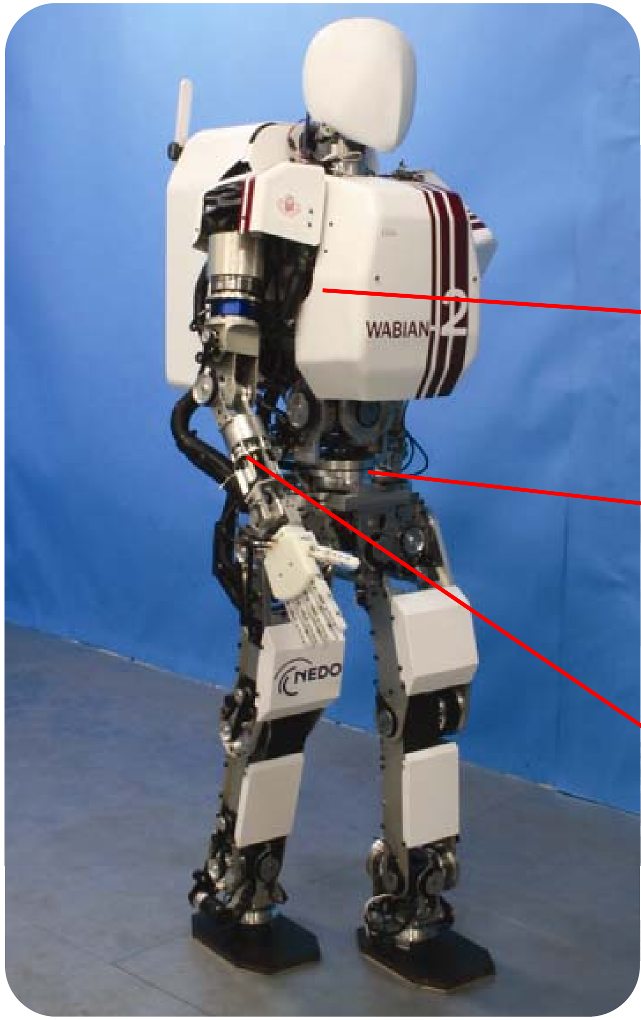
For the latest videos of WABIAN 2R go to

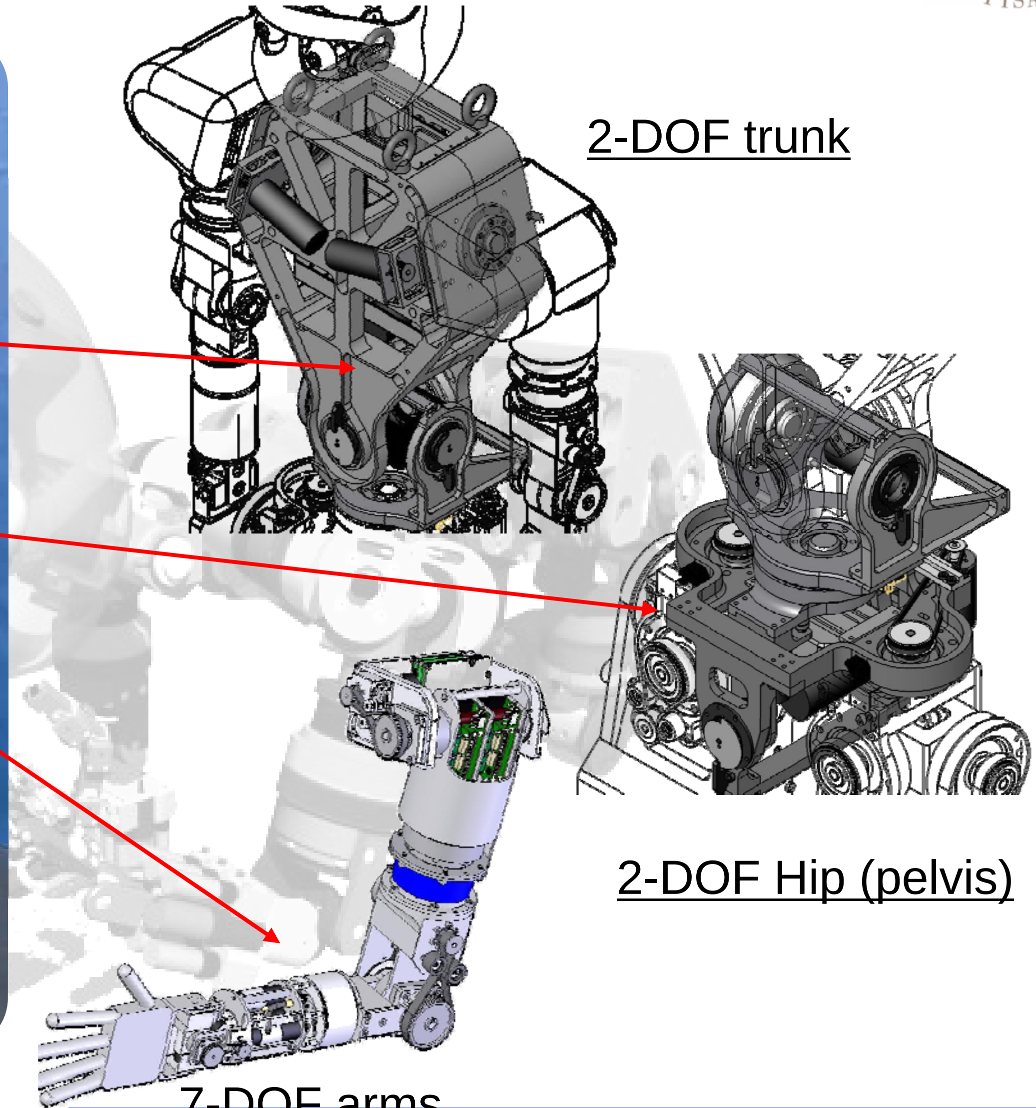
http://www.takanishi.mech.waseda.ac.jp/research/index.htm

Outline

- The Robot-An Lab
- The iCub
- The ARTS Humanoid
- The SABIAN: Technology Transfer Phase
- The SABIAN: Original Development Phase

Mechanisms of WABIAN-2





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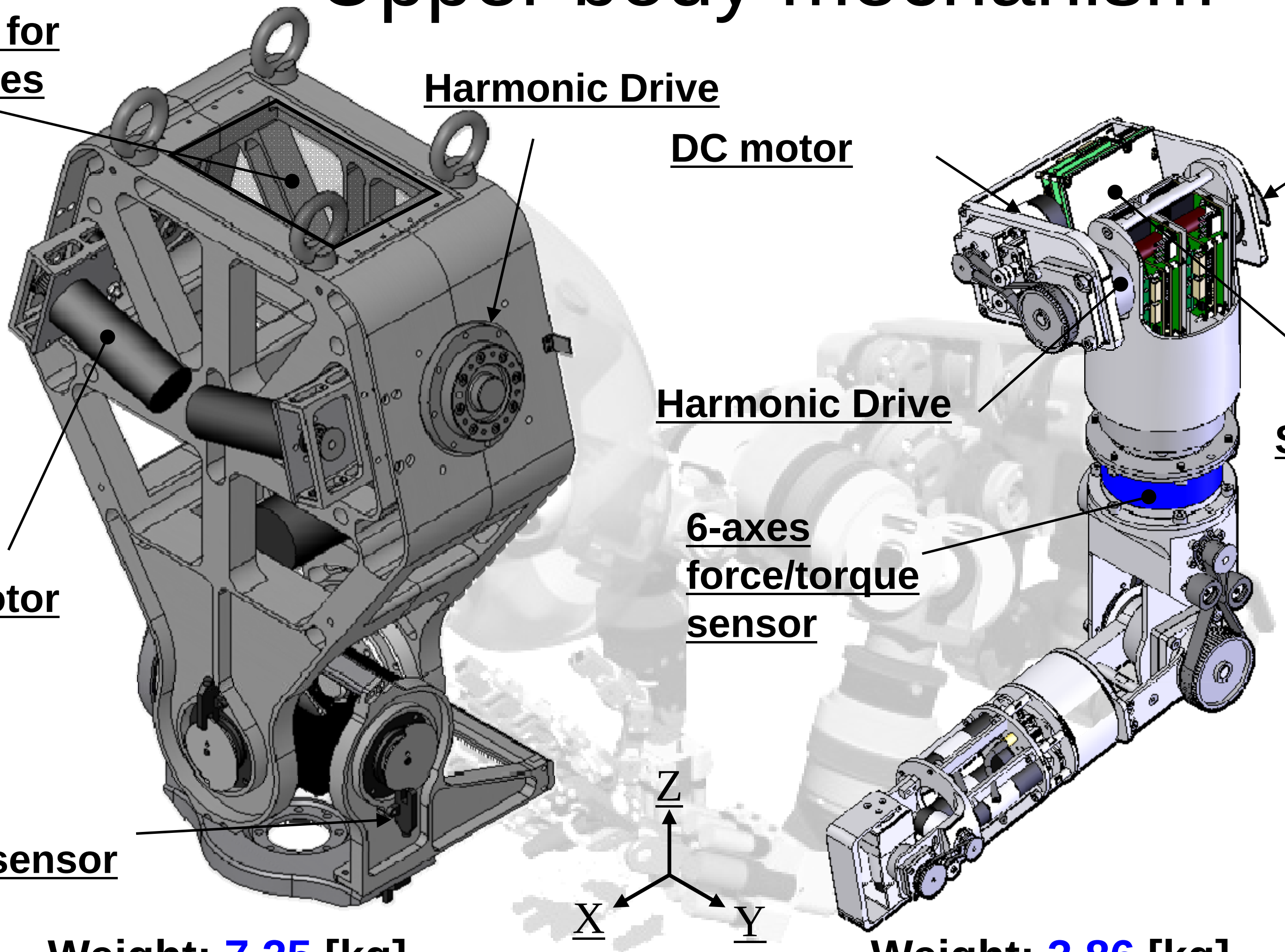
Upper body mechanism

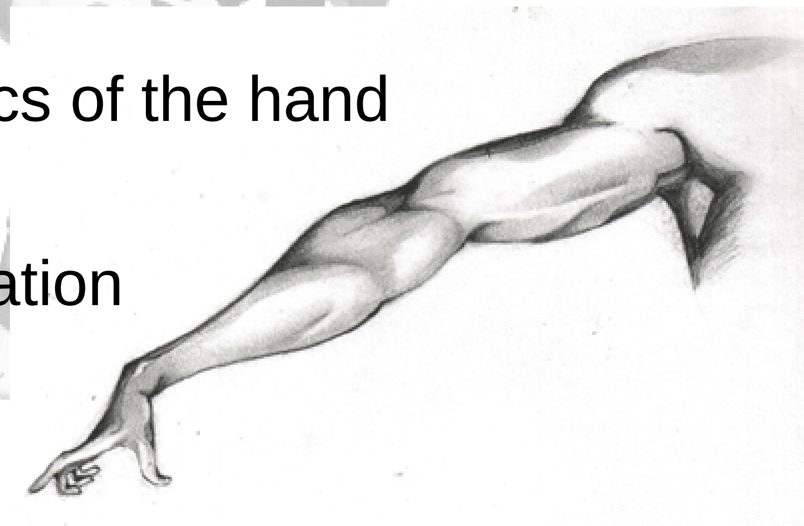


Weight: 7.25 [kg]

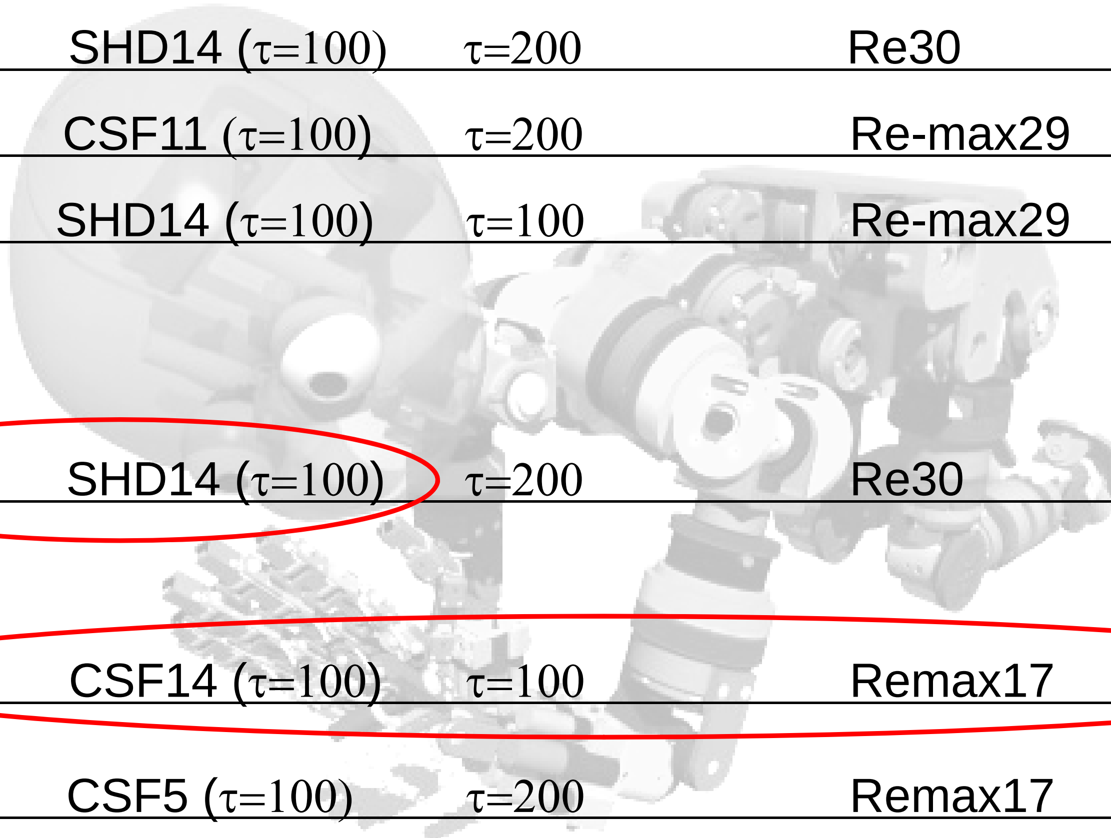
Weight: 3.86 [kg]

Sabian's arm-hand purposes

- Simulating human arm movement connected with walking
- Simulating human arm and hand movement in grasping objects and interacting with the environment
- Evolute emotional characteristics of the hand
- Possibility of bi-manual cooperation

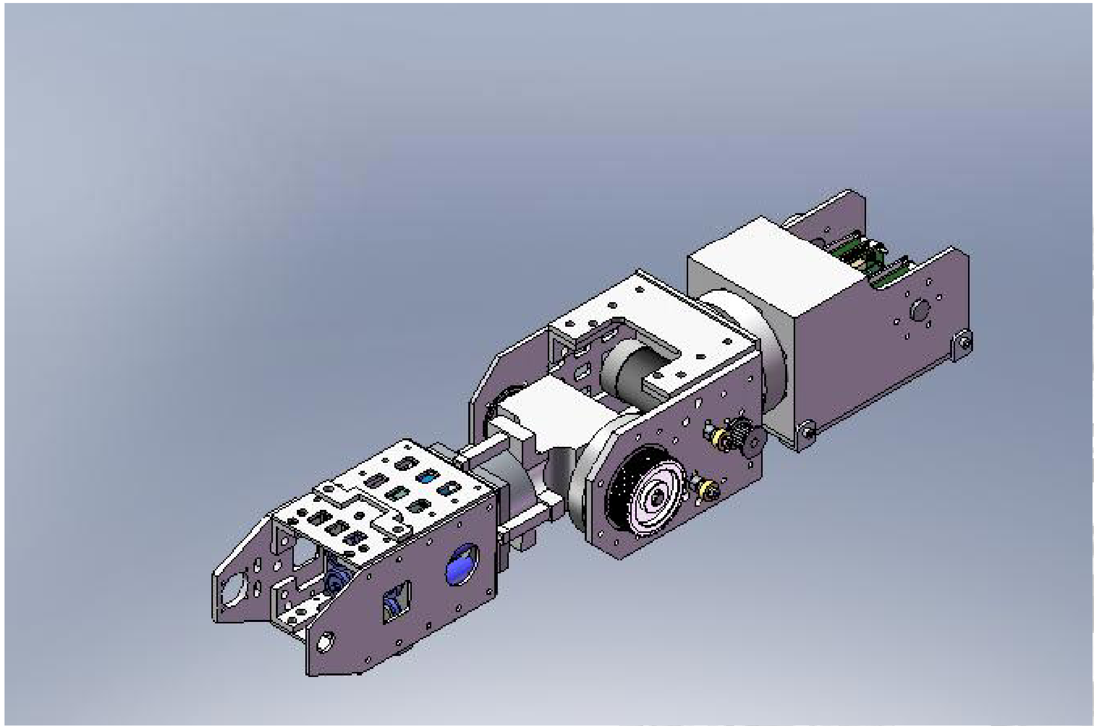


Sabian's arm joint properties



		Harmonic Drive	Joint ratio	Motors	Power
•Shoulder:					
	•Pitch	SHD14 (τ=100)	τ=200	Re30	60W
	•Yaw	CSF11 (τ=100)	τ=200	Re-max29	22W
	•Roll	SHD14 (τ=100)	τ=100	Re-max29	22W
•Elbow					
	•Pitch	SHD14 (τ=100)	τ=200	Re30	60W
•Wrist:					
	•Roll	CSF14 (τ=100)	τ=100	Remax17	4,5W
	•Pitch	CSF5 (τ=100)	τ=200	Remax17	4,5W
	•Yaw	CSF5 (τ=100)	τ=200	Remax17	4,5W

Preliminar Design



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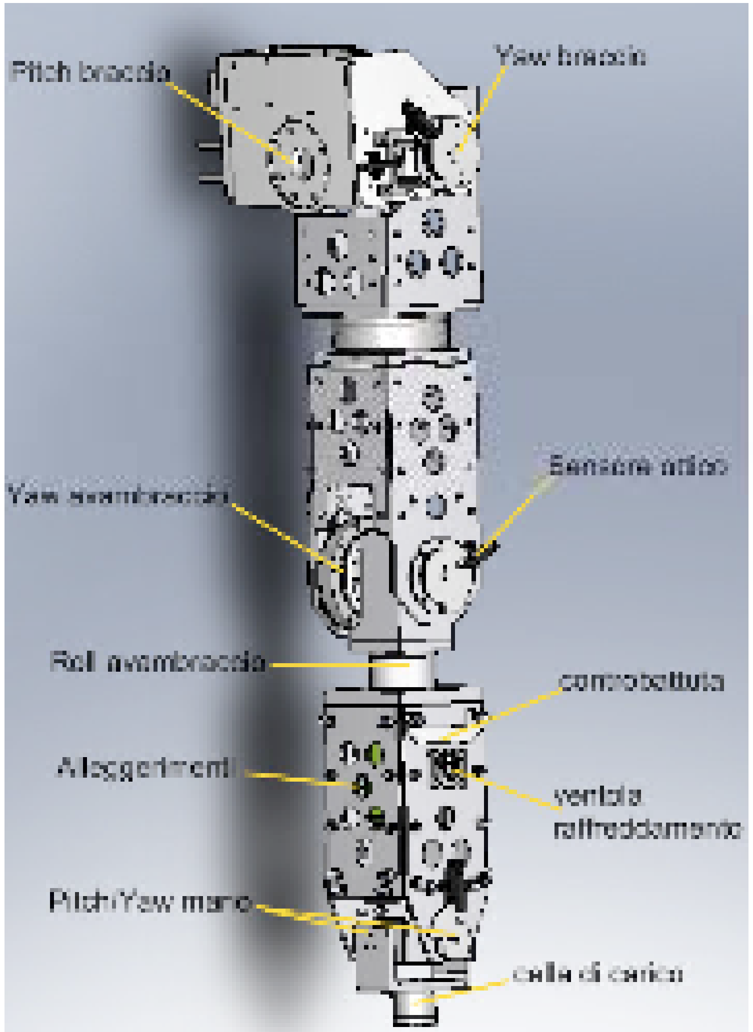
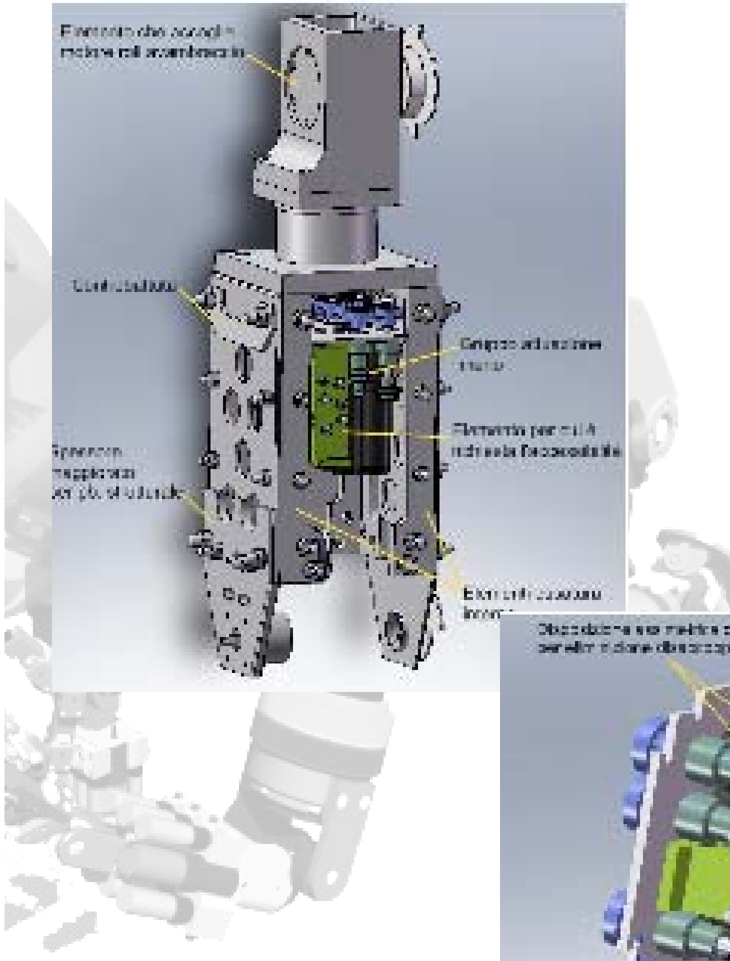
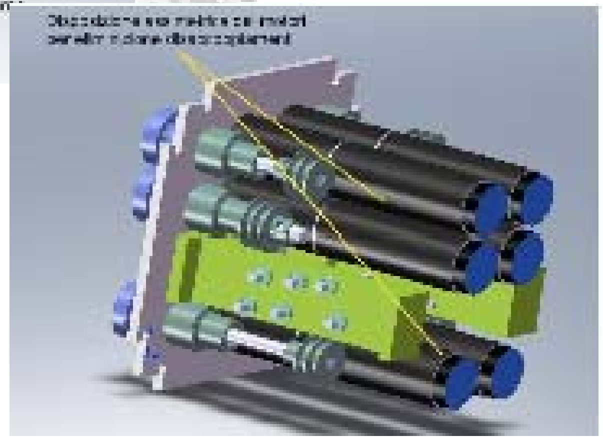
Preliminar Arm Design







Hand Concepts Requirements

	DOFs/DoMs	DOF1	DOF2	DOF3	DOF4
Thumb	4/3	palmar abduct-adduct (contact, 45°)	radial abduct-adduct (contact, 60°)	MCP flex-extend (0°, 90°)	IP flex-extend (0°, 90°)
Index	4/1+(1)	abduct-adduct (0°, 20°)	MCP flex-extend (0°, 90°)	PIP flex-extend (0°, 90°)	DIP flex-extend (0°, 90°)
Middle	3/1	MCP flex-extend (0°, 90°)	PIP flex-extend (0°, 90°)	DIP flex-extend (0°, 90°)	
Ring	4/1+(1)	abduct-adduct (0°, 20°)	MCP flex-extend (0°, 90°)	PIP flex-extend (0°, 90°)	DIP flex-extend (0°, 90°)
Little	4/1+(1)	abduct-adduct (0°, 20°)	MCP flex-extend (0°, 90°)	PIP flex-extend (0°, 90°)	DIP flex-extend (0°, 90°)

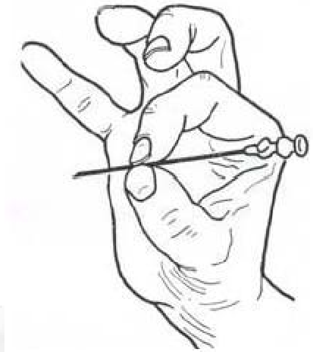
19 DoFs Total Vs 8 DoMs

1 DoMs

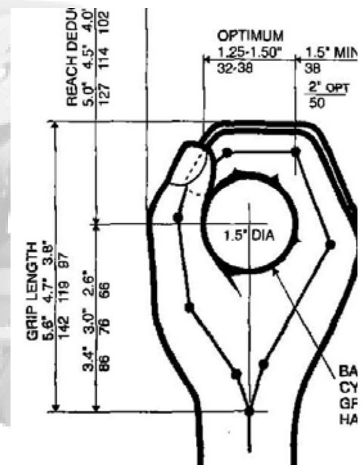
Common ab/abd: 1 DoMs

Grasp force and velocity specs

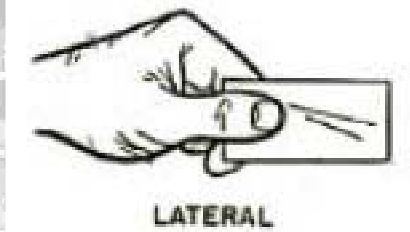
- Tip Pinch Grasp: *about 40N*



- Cylindrical Grasp: *about 250N*



- Lateral Pinch: *about 40N*



<u>*Closing time about 1 sec*</u>

Optimization

- Improve under-actuated efficiency

Kinetostatic Analysis via Screw Theory

Lionel Birglen, Clément M. Gosselin *Kinetostatic Analysis of Underactuated Fingers* IEEE TRANSACTIONS ON ROBOTICS AND AUTOMATION, VOL. 20, NO. 2, APRIL 2004

- Dinamic optimization

Mimic human's finger dinamics

B. Massa, S. Roccella, M. C. Carrozza, and P. Dario, "Design and development of an underactuated prosthetic hand," in *Proc. IEEE Int. Conf. Robotics and Automation*, Washington, DC, May 2002, pp. 3374–3379.

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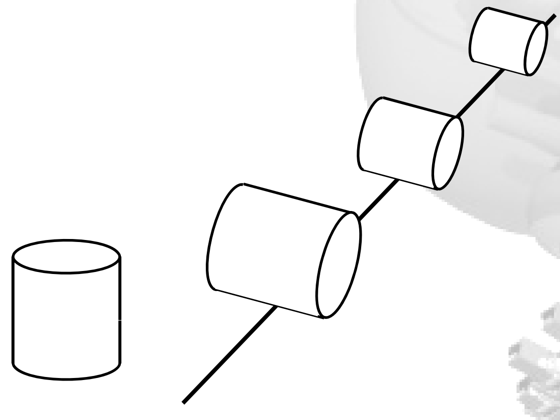
Cable Routing (1): Sensors integrate



1

Fully Underactuated (3 DoFs – 1 motor) MCP/PIP/DIP coupled, spring return on joint - Hall sensor on joint - separate actuation of all ab/ads

Pros: Only one actuated tendon. Auto-adaptive grasping to the object. Low control burden.

Cons: Can't flex MCP and PIP/DIP independently. Hence it is not possible to control the finger configuration. Needs separate mechanism in the hand to do ab/ad.

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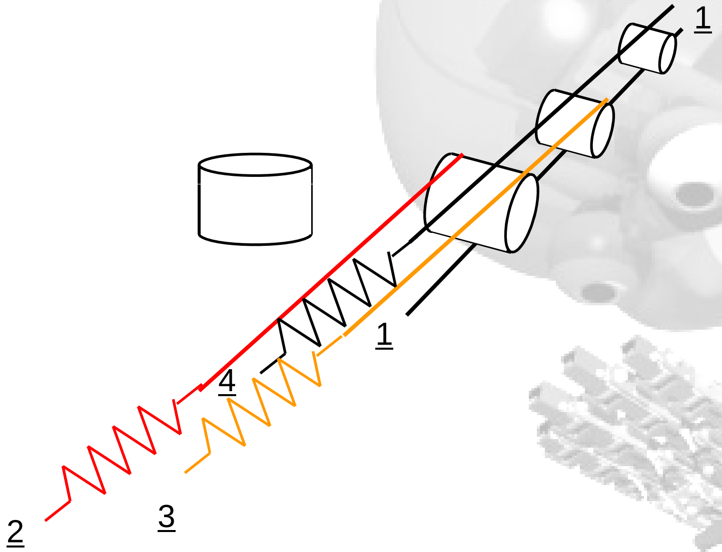
Cable Routing (2): Low inertia and adjustable joint preload



Fully Underactuated (3 DoFs – 1 motor)
MCP/PIP/DIP coupled, spring return on palm drive by tendon – Joint sensor on palm - separate actuation of all ab/ads

Pros: Only one actuated tendon. Three extensor tendons. Auto-adaptive grasping to the object. Low control burden. Low inertia. Adjustable joint preload.
Both PASSIVE and ACTIVE compliance (if the antagonist tendon system is actuated)

Cons: Can't flex MCP and PIP/DIP independently. Hence it is not possible to control the finger configuration. Needs separate mechanism in the hand to do ab/ad.

Wireless solutions for Advanced Robotics

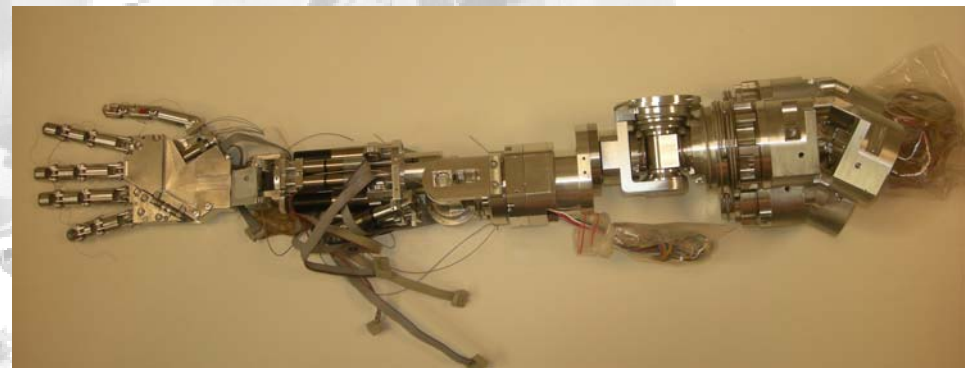
- Various kind of sensors (inertial, tactile, magnetic, etc…).
- Low cost and consumption.
- Small, miniature.
- Easy to use.

One problem to be solved:

Many wires

Specific case: SABIAN Hand @ SSSA

- <u>Hall effect sensors (15)</u>
- <u>Stress/tension (5)</u>
- <u>Tactile (10)</u>
- <u>Encoder (3)</u>



<u>This means too many wires and problems in designing the hand and in increasing the device reliability.</u>

ZigBee solution (1)

- Questions: Can ZigBee solve the problem of reducing wires?

- Problems: ZigBee bandwidth is narrow (250kbps) Is it enough for the control of robot?.

- Developments: Find the right compromise in terms of bandwidth and wires to be cut. Each devices need a custom solution.

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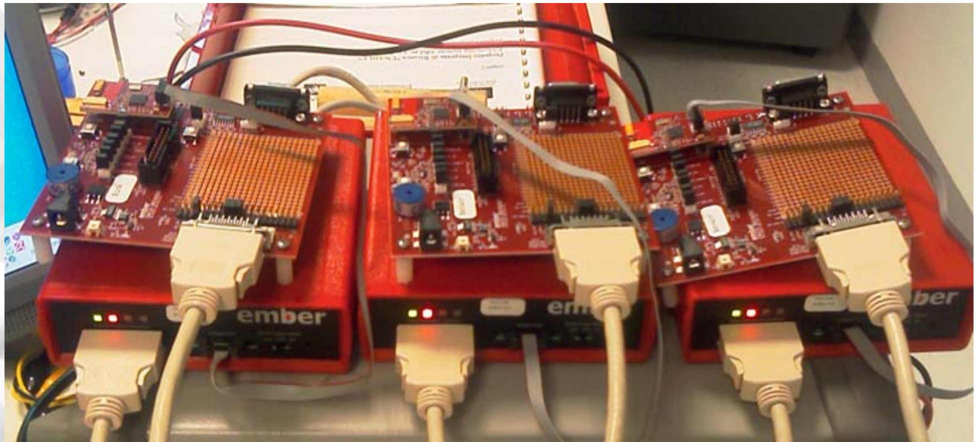
ZigBee solution

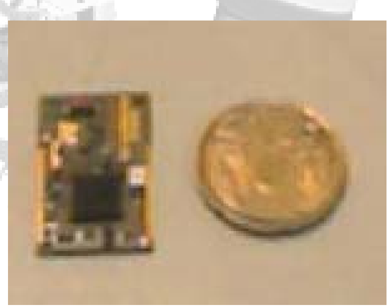
- Solutions:

- Study performance of the network wireless sensor with network debugger.



ST microelectronics
SNDEV250

- Use small ZigBee board



ST microelectronics
SN250/SN260

Now working on at SSSA

ZigBee solution

- We have to define the number of sensors which can be made wireless, keeping save the control.

Case of SSSA (load including all sensors)

-Hall Sensors:	15 bytes	(120bits)
-Stress (tension):	5 bytes	(40bits)
-Tactile:	10 bytes	(80bits)
-Encoder:	3 bytes	(24bits)
		Total: 264 bits

-ZigBee bandwidth (theoretical): 250kbps

-Dimensions: 16,4 x 26,5 mm

-Cost: 20-25 € (VAT included)

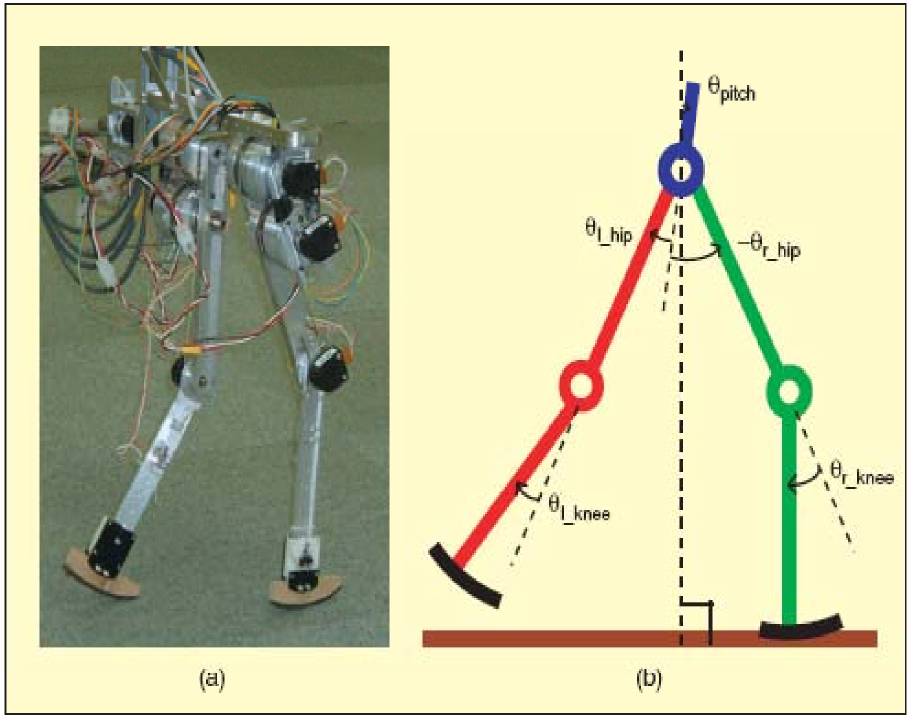
- In Japan 25$ (please contact davide.bruno@st.com)

-Max frequency: ~900Hz

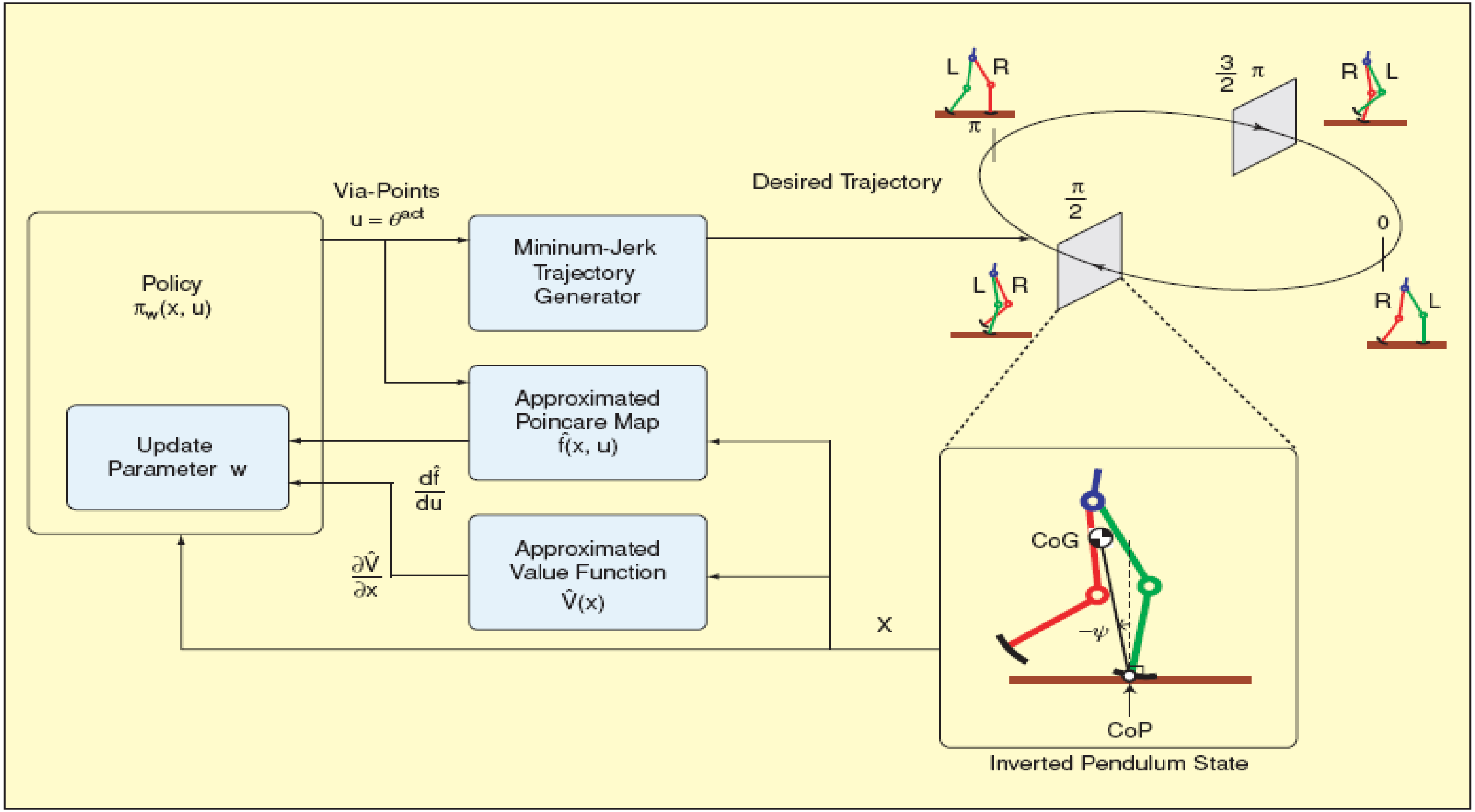
Please be careful:
Theoretically

Learning BIPED LOCOMOTION

- The robot learns to modulate an observed walking pattern.
- The model maps from a state in the single support phase to a state in the next single support phase.
- The approach is to learn to walk as humans do.



Learning a policy for biped locomotion (based on Poincare Map RL)



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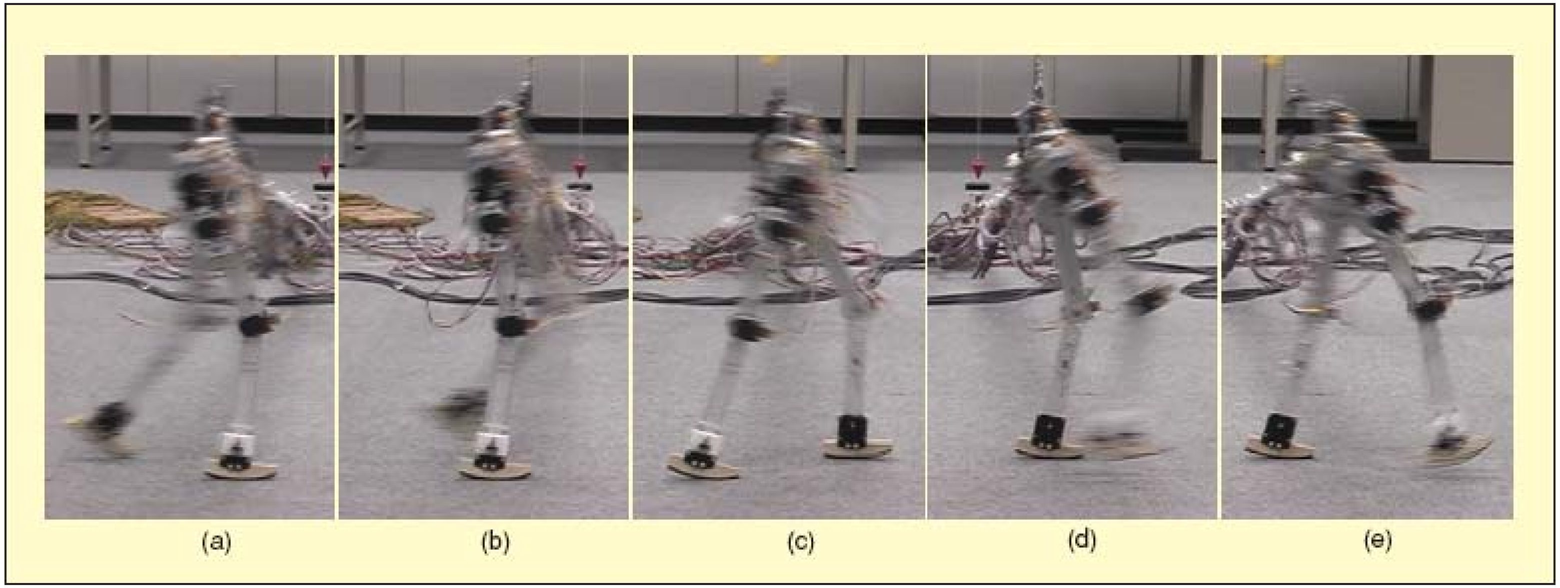
Implementation on a physical robot



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Thank you for your attention!!!