Advances in the Design of the iCub Humanoid Robot: Force Control and Tactile Sensing

Bled, Slovenia

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iit ISTITUTO ITALIANO DI TECNOLOGIA

Cogsys Cognitive Systems

RobotCub

what are we looking for?

- the focus of our research is in the implementation of biologically sound models of cognition in robots of humanoid shape

- this has the two-fold aim of:
  - furthering our understanding of brain functions
  - realizing robot controllers that can learn and adapt from their mistakes

we set up to reach our goals by…

- ✓ designing a humanoid robot platform, namely the iCub
- ✓ making it the platform of choice for researchers in artificial cognitive systems
- ✓ studying cognition from a developmental perspective (neuroscience)

iCub is an **open source** international endeavour initially funded by the EU project **RobotCub**

- a full humanoid robot
- is 104cm, weighs 22 kg
- has 53 degrees of freedom
- can crawl, sit and manipulate
- open design as LGPL/GPL

why is the iCub so special (for us)?

- hands: we started the design from the hands
  - 5 fingers, 9 degrees of freedom, 19 joints

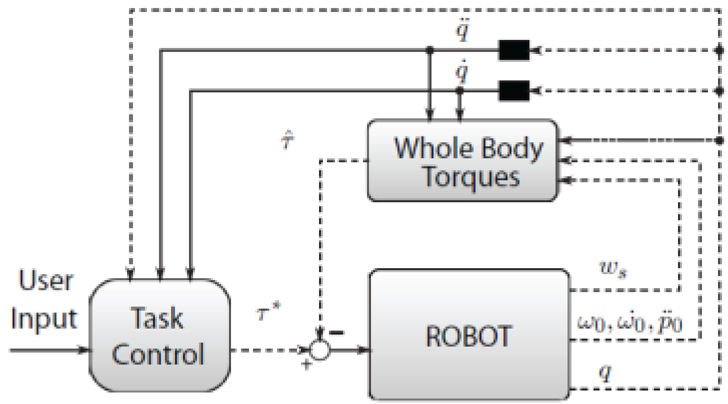
- sensors: human-like, e.g. no lasers
  - cameras, microphones, gyros, encoders, force, tactile…

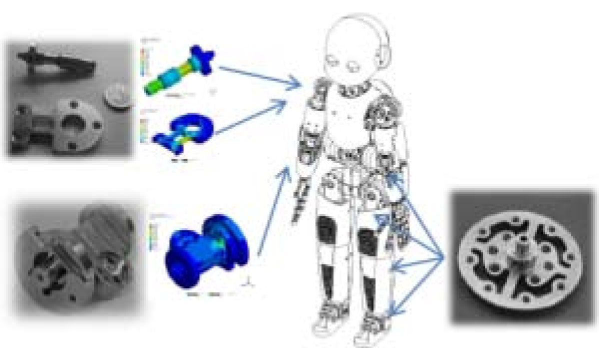
- electronics: flexibility for research
  - custom electronics, small, programmable (DSP)

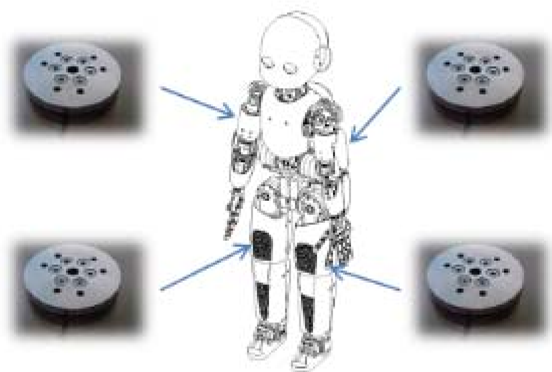
- reproducible platform: community designed
  - reproducible & maintainable yet evolvable platform


R:What Should i do?

force/torque control on the iCub







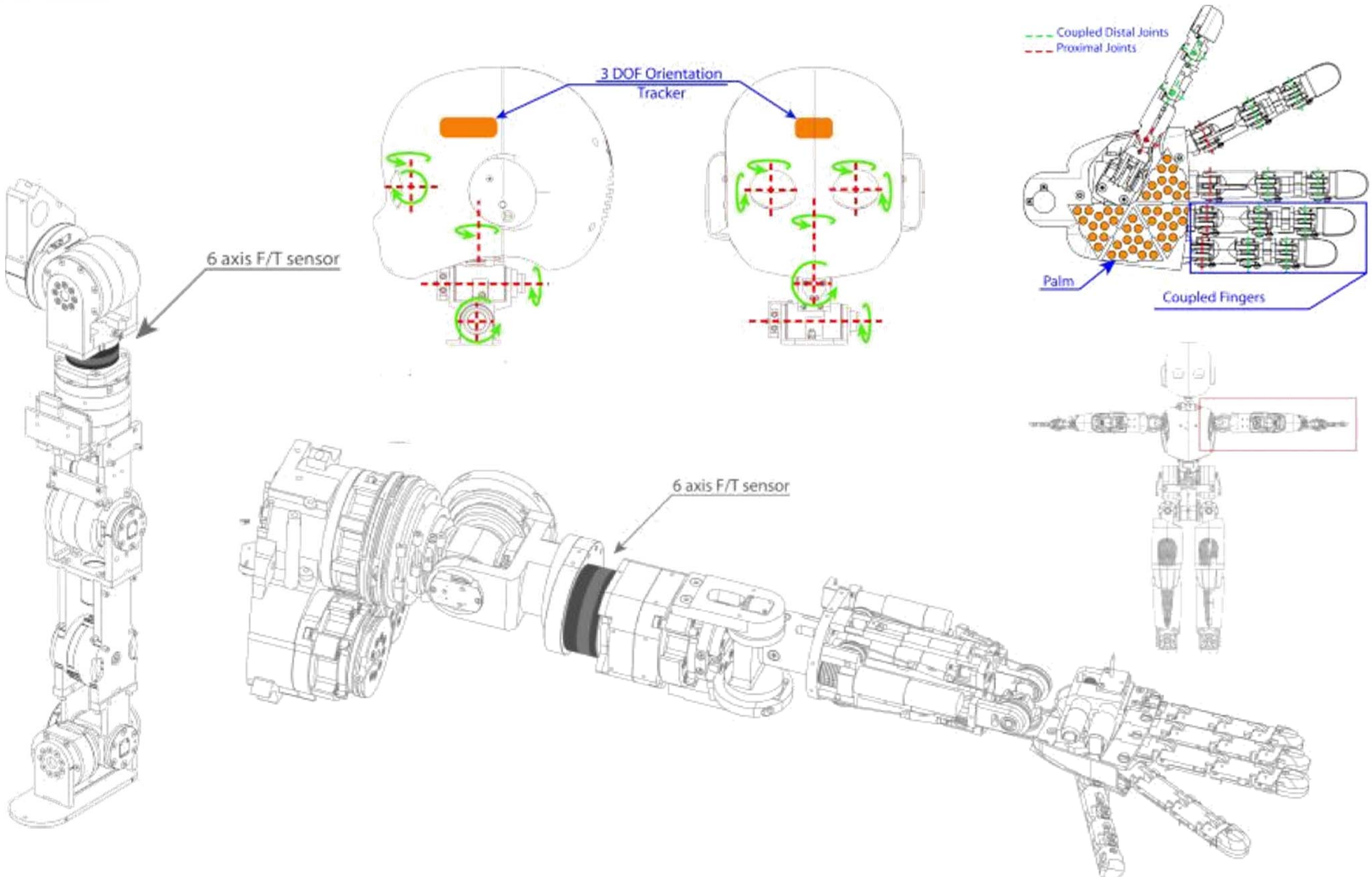
joint torque sensors

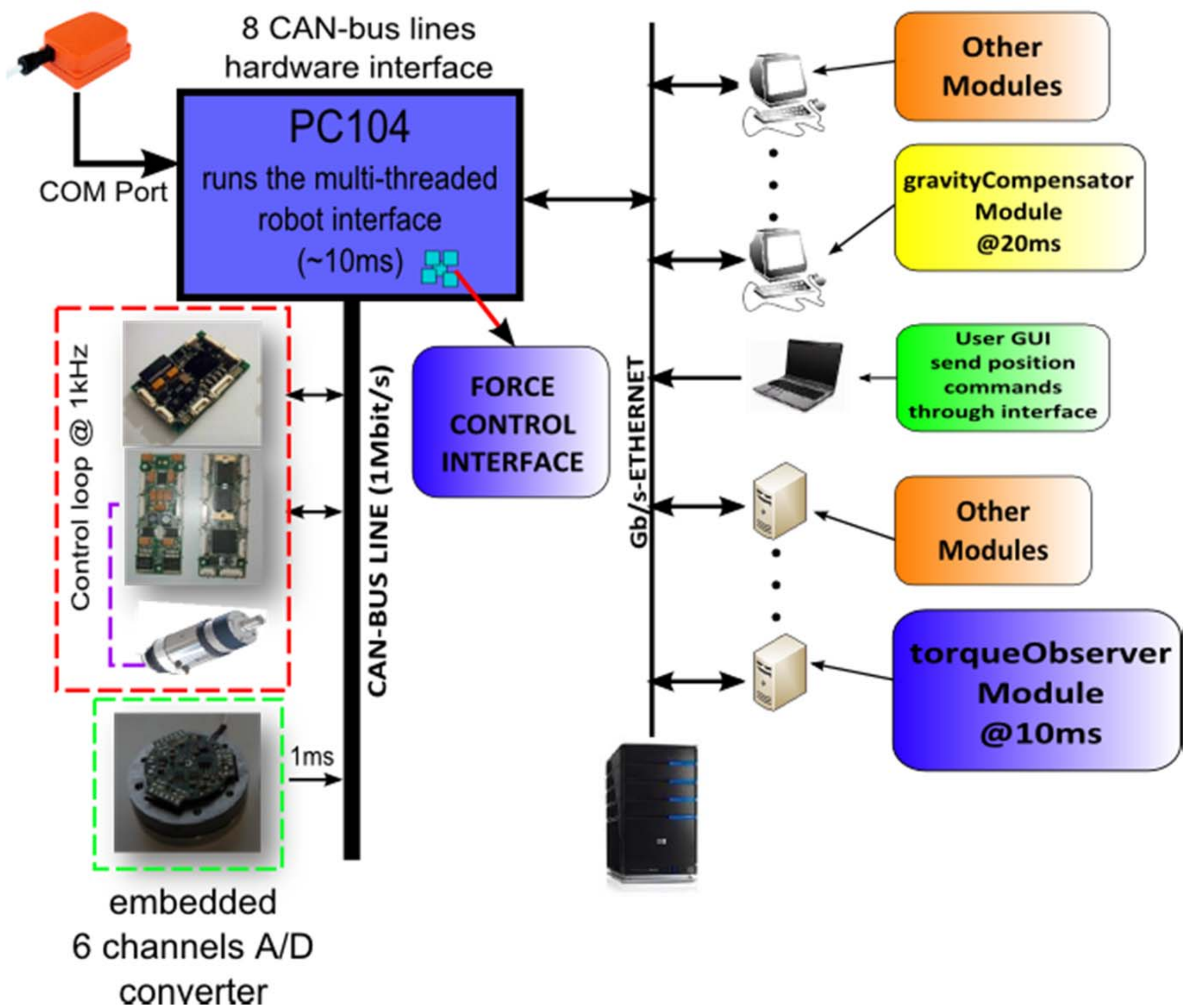
pros: direct feedback loop
cons: requires mechanical re-design

six-axis F/T sensors

pros: scalability, full perception
cons: computational delays

iCub sensorization





$$e = \tau - \tau_d$$

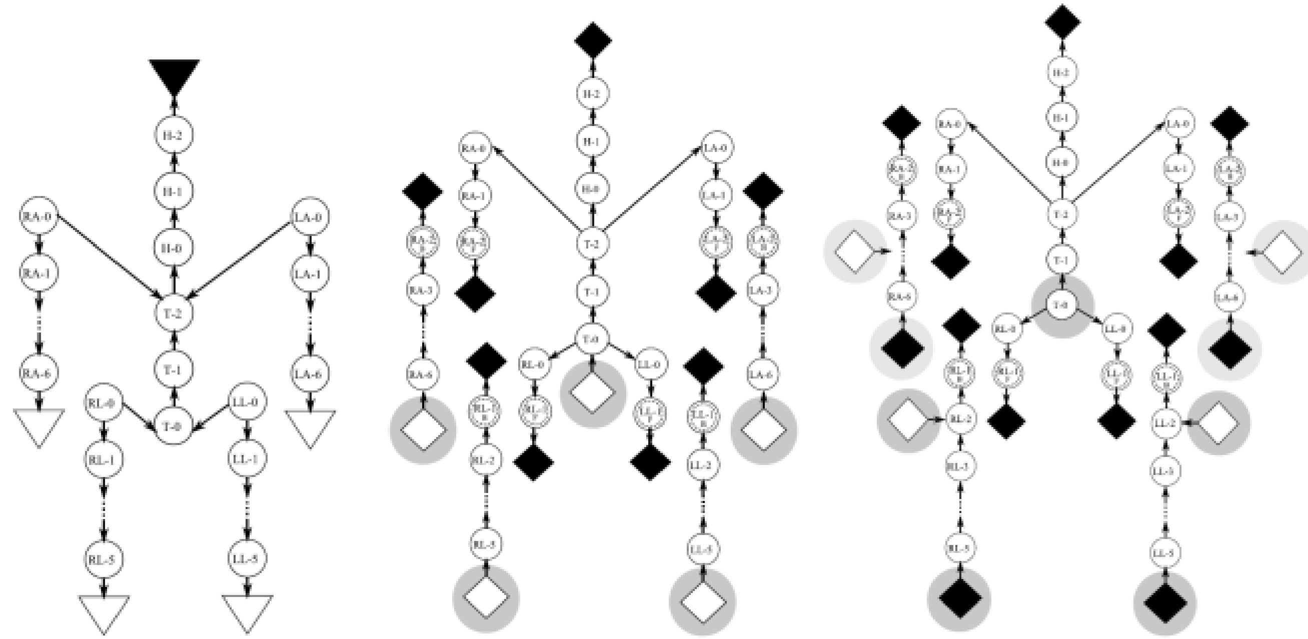
$$\hat{w}_e = \begin{bmatrix} I & 0 \\ -[r_{se}]_\times & I \end{bmatrix} \cdot (w_s - w_i)$$

$$\hat{\tau}_e = J^T(q) \cdot \hat{w}_e$$

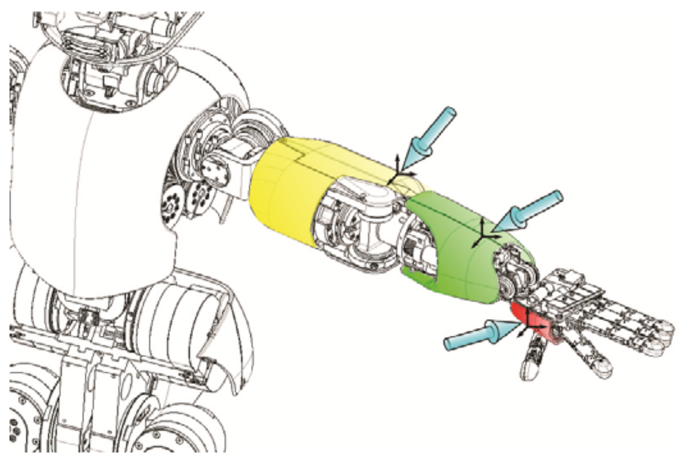
$$e = \hat{\tau}_e - \tau_d$$

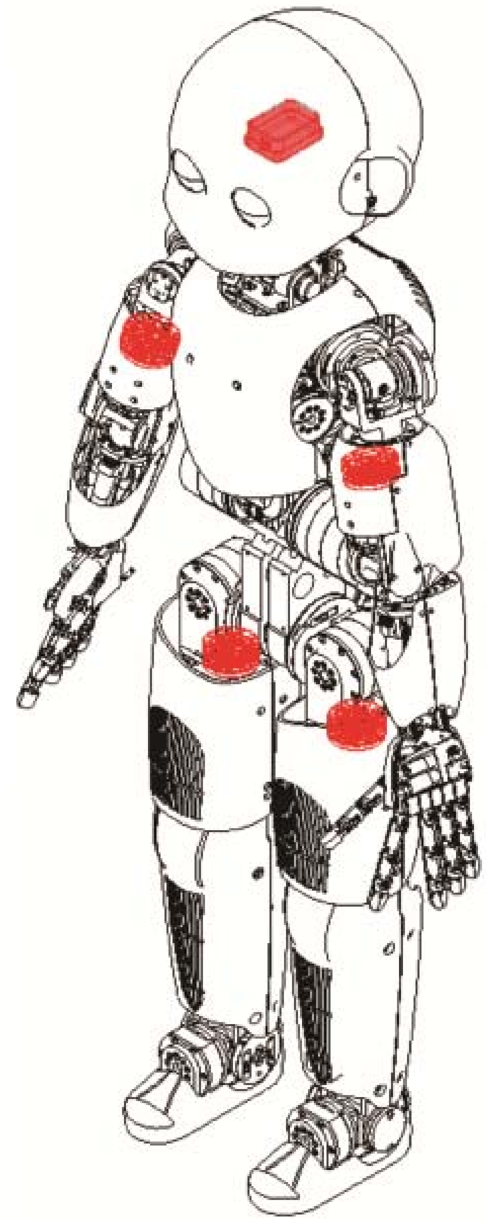
$$u = k_p \cdot e + k_d \cdot \dot{e} + k_i \cdot \int e$$

$$\tau_d = K \cdot (q - q_d) + D \cdot (\dot{q} - \dot{q}_d)$$

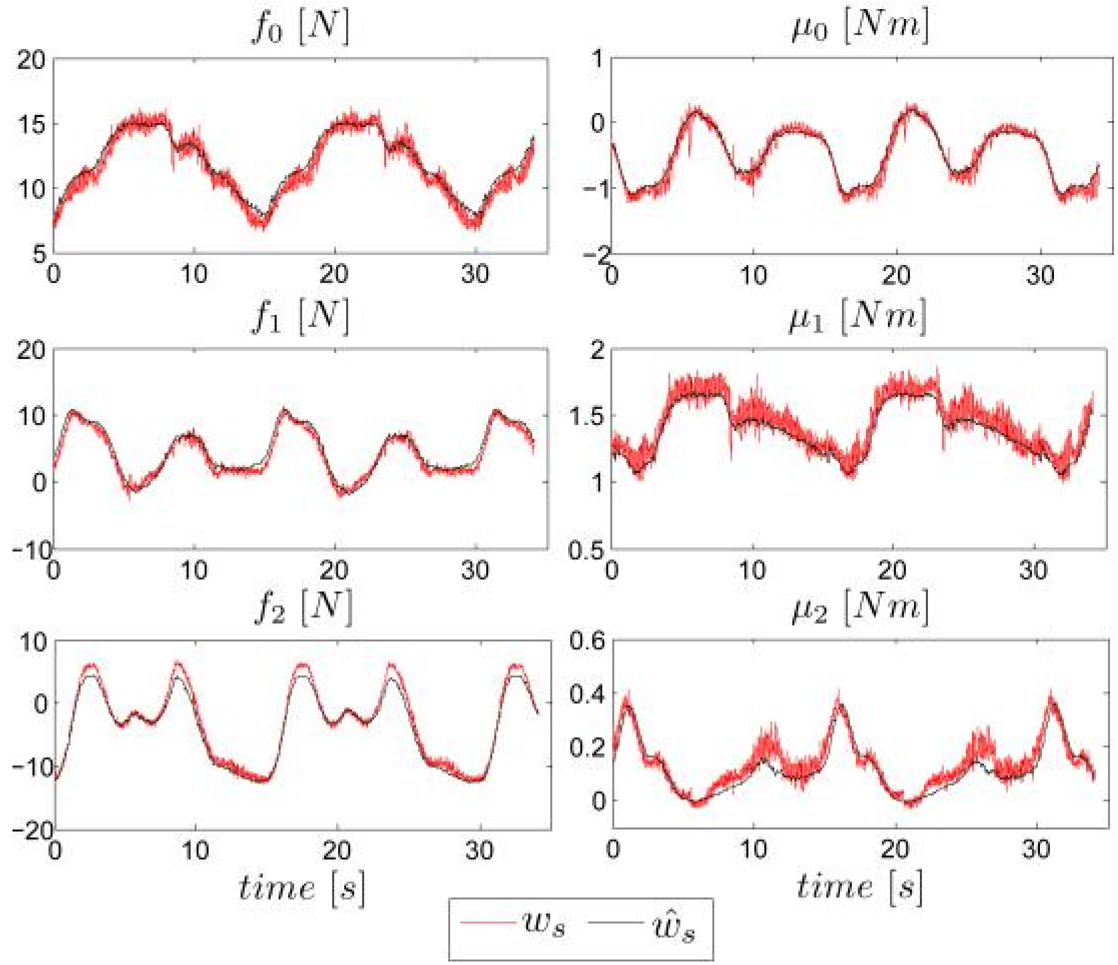


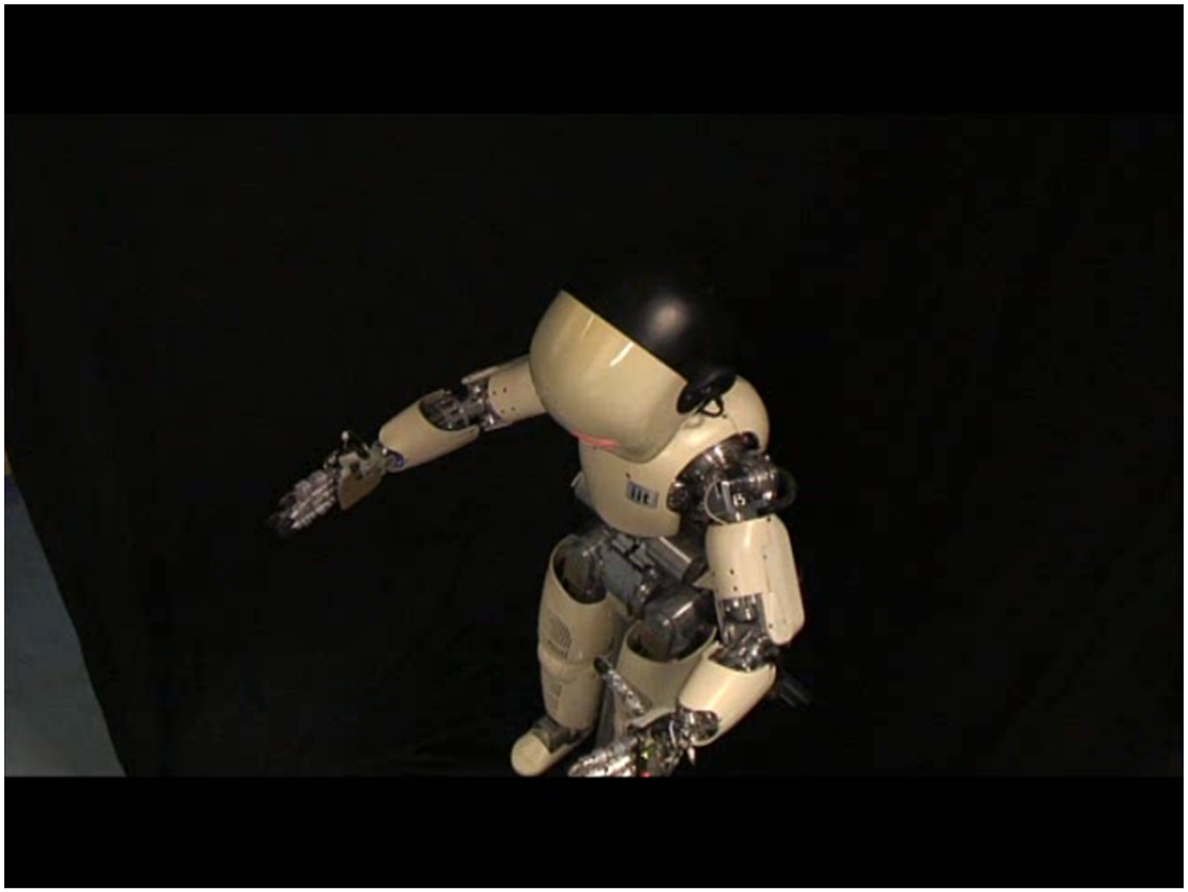
(a) (b) (c)



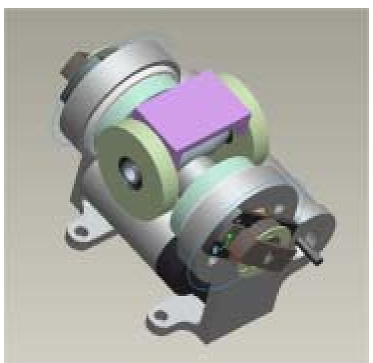


Test of the dynamical model



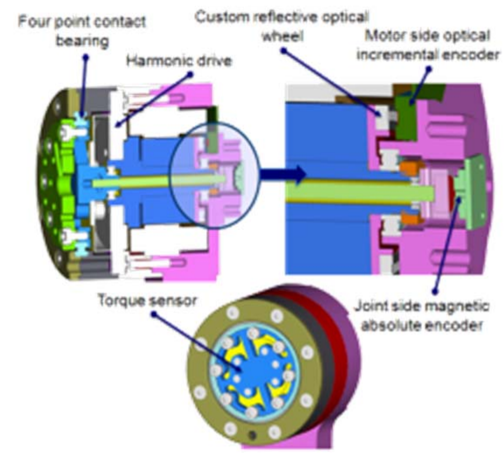


iCub 2.0



new mechanics

compliant actuators

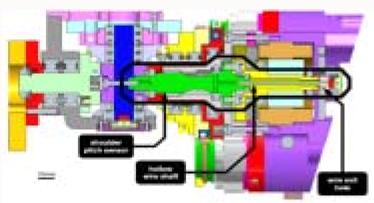


force/torque measurements

iCub sensorization

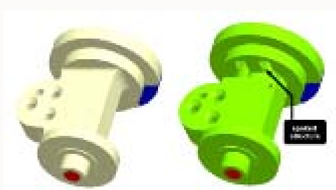
new iCub arm:

- integrated joint torque sensor on majors joints: shouder (3 DoF) + elbow (1 DoF)

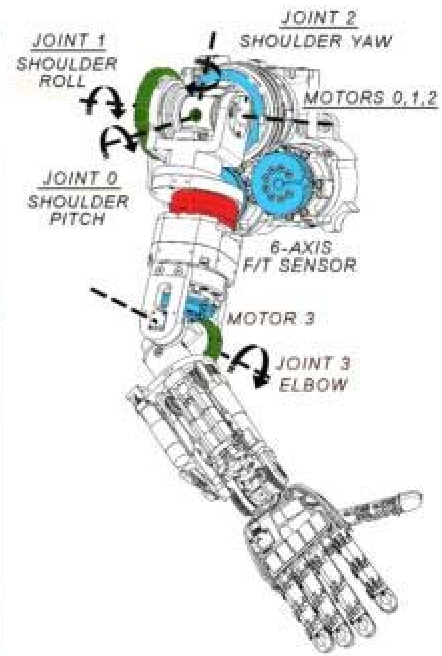


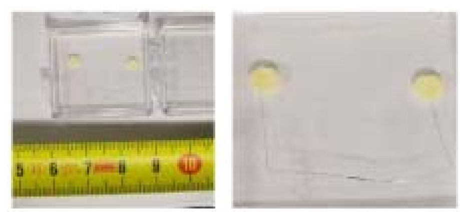
Shoulder roll

Shoulder pitch



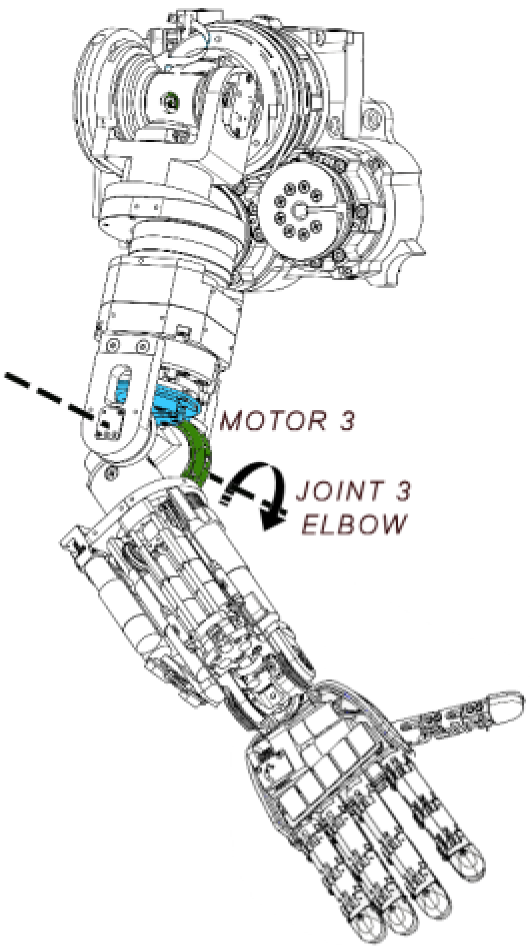
Elbow





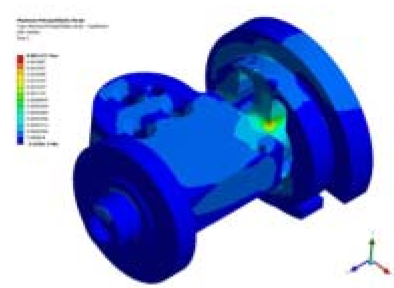
semiconductor strain gauges (SSGs)

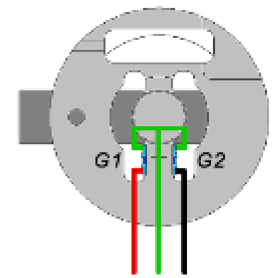
iCub Hardware: elbow joint



Elbow (1DOF):

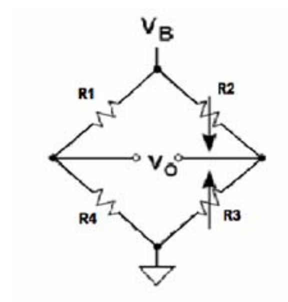
- 2 SSGs configured as an half Wheatstone bridge.



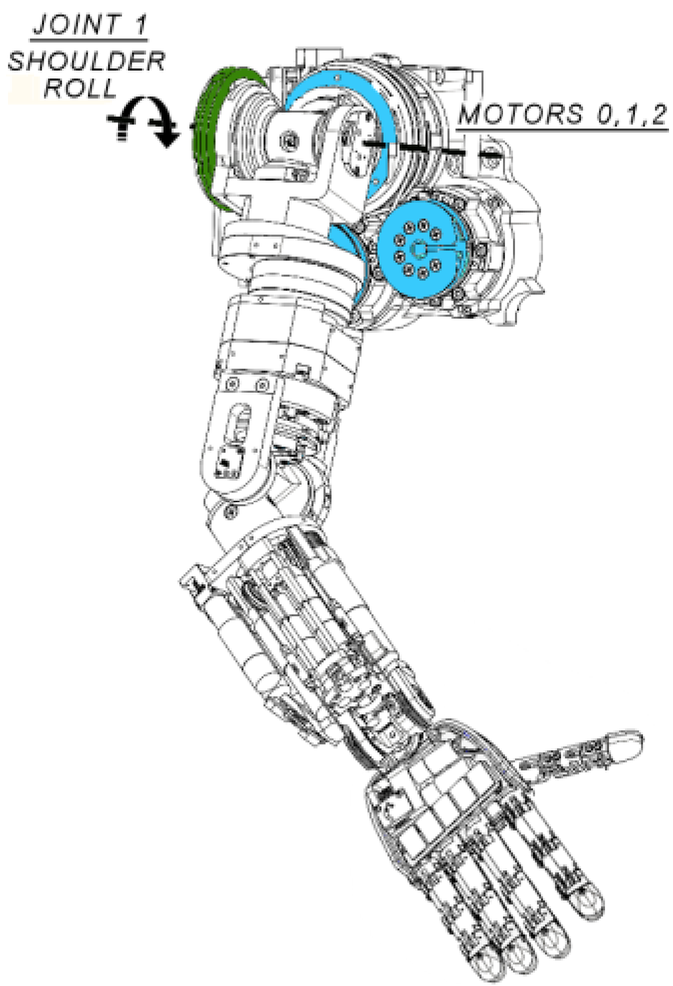


- Calibration:

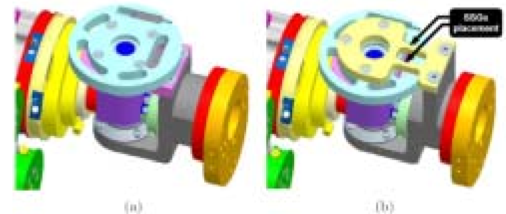
$$\tau_{elbow} = c_1 \cdot (s_1 + o_1)$$



iCub Hardware: shoulder roll

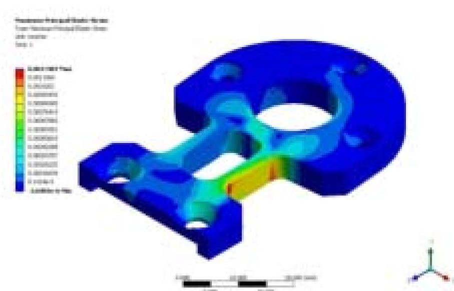


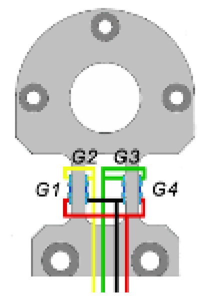
Shoulder (3 DOF):



Shoulder Roll:

- 4 SSGs configured as two half Wheatstone bridges.

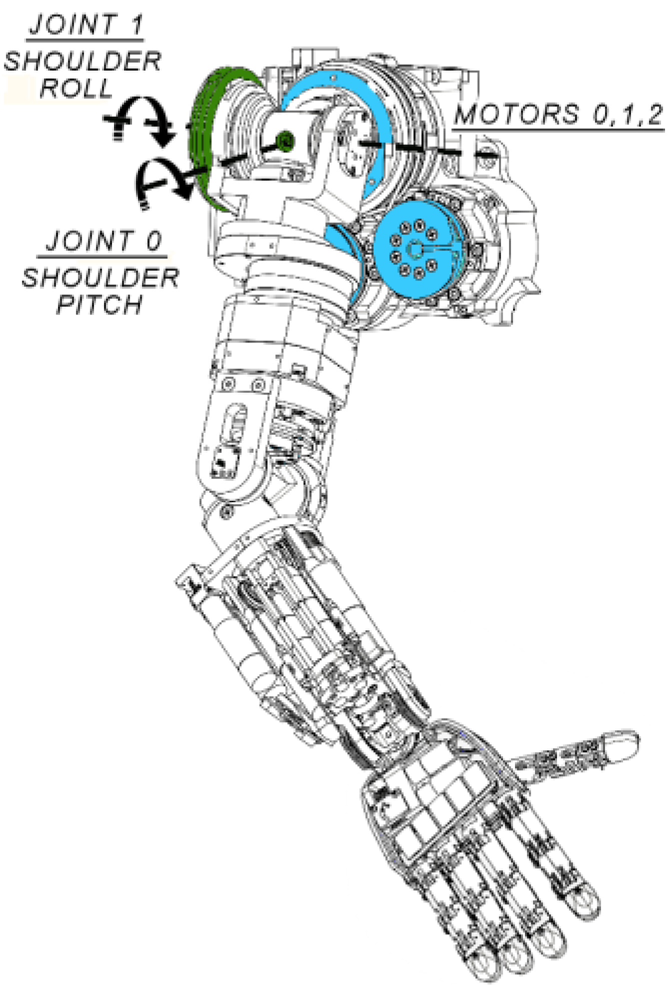




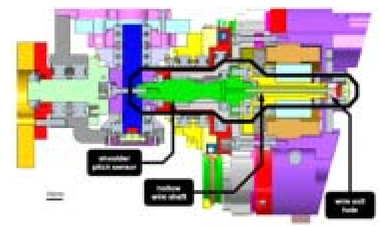
- Calibration:

$$\tau_{roll} = c_2 \cdot (s_2 + o_2) + c_3 \cdot (s_3 + o_3)$$

iCub Hardware: shoulder pitch

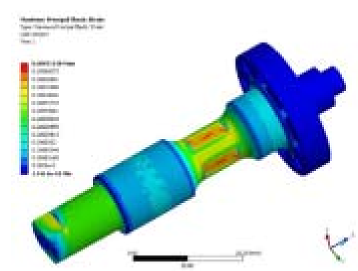


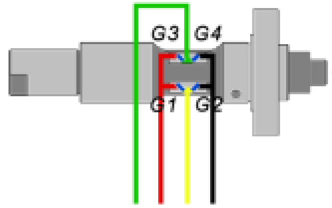
Shoulder (3 DOF):



Shoulder Pitch:

- 4 SSGs mounted directly on an hollow motor shaft.





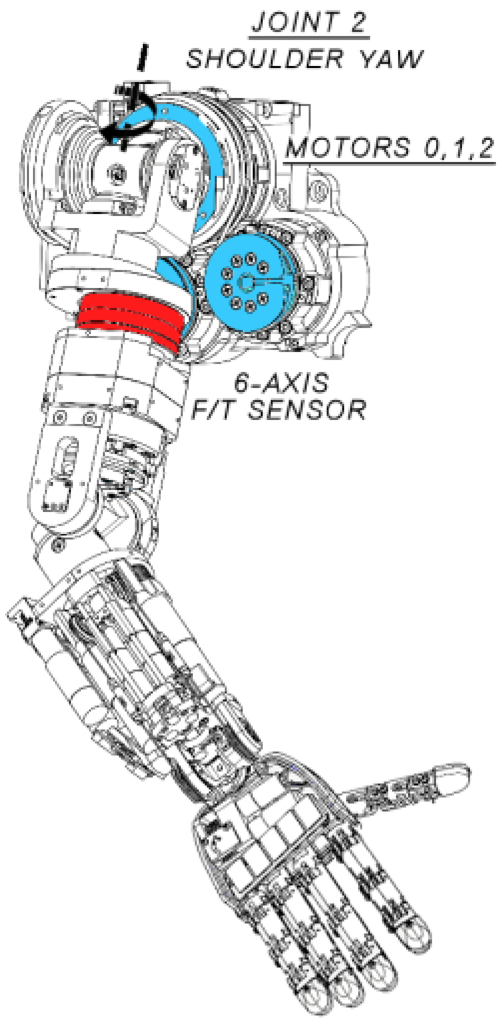
.Coupling with the shoulder roll:

$$\tau_m = T^{-T}\tau_j \qquad T^{-T} = \begin{bmatrix} 1 & 1 & 0 \\ 0 & 1/r & -1/r \\ 0 & 0 & 1/r \end{bmatrix}$$

- Calibration:

$$\tau_{pitch} = c_4 \cdot (s_4 + o_4) + c_5 \cdot (s_5 + o_5) - \tau_{roll}$$

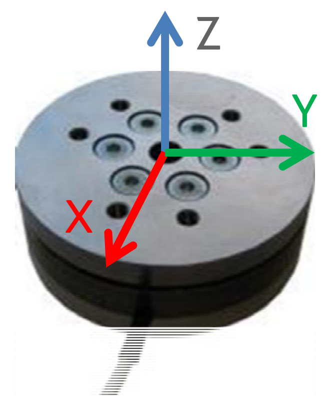
iCub Hardware: shoulder yaw



Shoulder (3 DOF):

Shoulder Yaw:

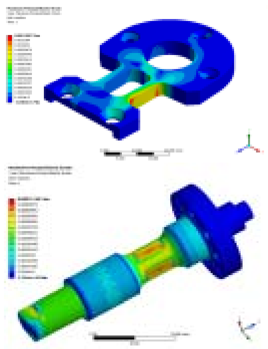
- No additional joint torque sensors required.
- The joint torque is obtained through the direct measurements of the six axis F/T sensor.

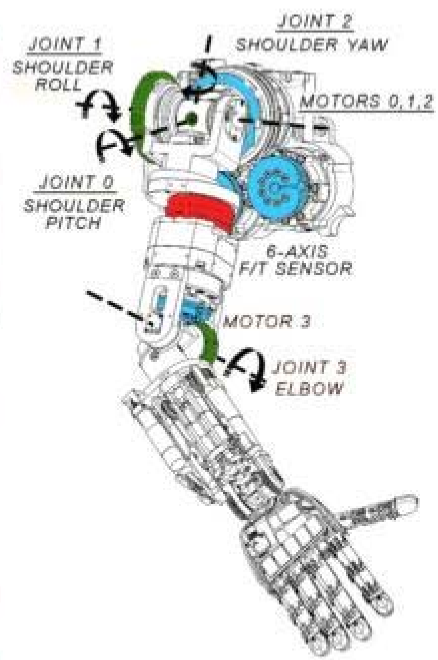


- No calibration is required (the F/T sensor is already calibrated):

$$\tau_{yaw} = F_y \cdot d + T_z$$

joint torque sensors





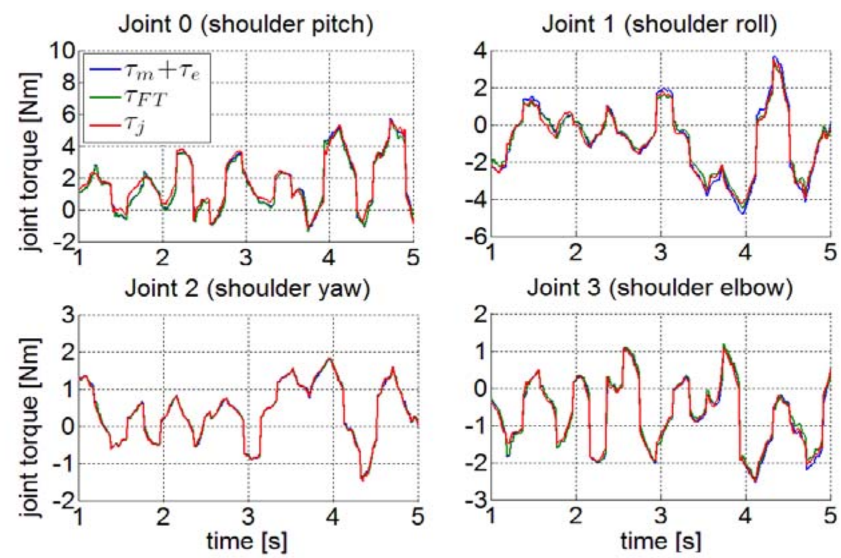
experiments and model validation

static configuration:

an additional six axis F/T sensor is placed at the end effector to measures the external wrenches w_e

in this experiment we consider the following quantities:

- joint torques measured by the joint torque sensors: t_j
- joint torques computed from the arm F/T sensor: t_{FT}
- joint torques estimated thought the additional F/T sensor located at the end effector: $t_e = J^T w_e$
- joint torques predicted by the arm model (no external forces): t_m



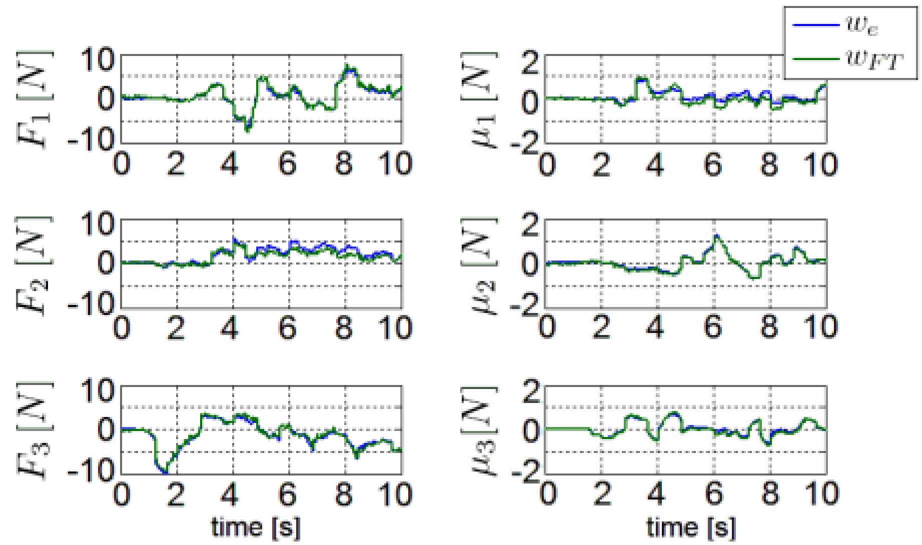
	Joint 0	Joint 1	Joint 2	Joint 3
$E(\tau_j - \tau_{ft})$	0.127 Nm	-0.049 Nm	-0.002 Nm	-0.032 Nm
$\sigma(\tau_j - \tau_{ft})$	0.186 Nm	0.131 Nm	0.013 Nm	0.042 Nm
$E(\tau_j - (\tau_m + \tau_e))$	0.075 Nm	-0.098 Nm	-0.006 Nm	0.006 Nm
$\sigma(\tau_j - (\tau_m + \tau_e))$	0.191 Nm	0.173 Nm	0.020 Nm	0.032 Nm

experiments and model validation

representation of the external wrenches:

the arm FT sensor allows to retrieve also the external wrench at the end effector.

- w_e: the external wrenches measured by the additional F/T sensor at the end-effector
- w_{FT}: the external wrenches computed using the arm F/T sensor

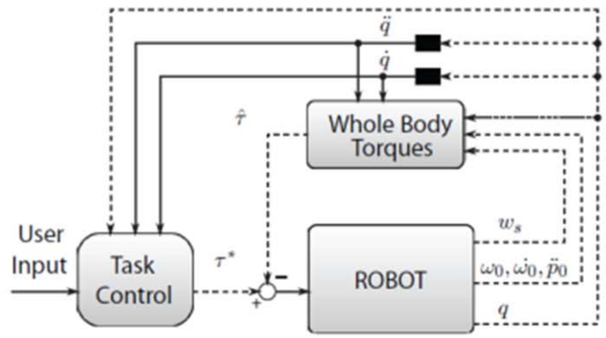


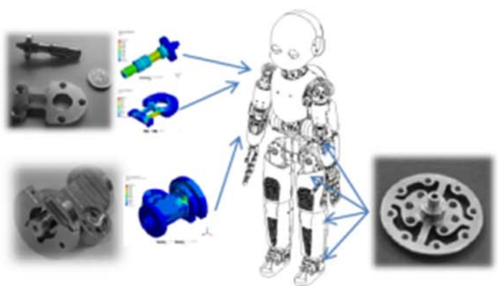
	F_1 (N)	F_2 (N)	F_3 (N)	μ_1(Nm)	μ_2(Nm)	μ_3(Nm)
$E(w_e-w_{FT})$	0.181	-0.465	-0.154	-0.079	-0.024	-0.024
$\sigma\ (w_e-w_{FT})$	0.384	0.426	0.469	0.149	0.048	0.059

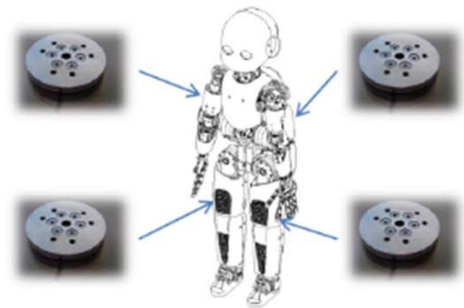
remarks:

- it is not possible to estimate the externally applied wrenches $w_e \in R^6$ using the only measurements of joint torques $t_j \in R^4$
- joint torques are effected by the null space of the Jacobian

force/torque control on the iCub







joint torque sensors

pros: direct feedback loop
cons: requires mechanical re-design

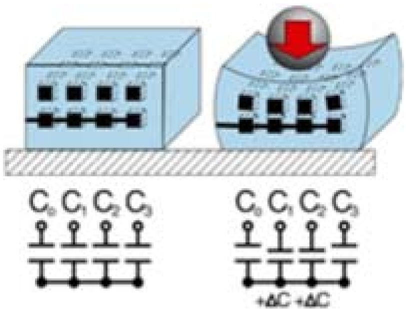
six-axis F/T sensors

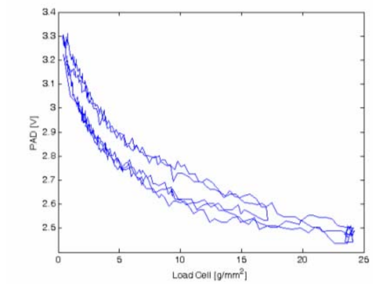
pros: scalability, full perception
cons: computational delays

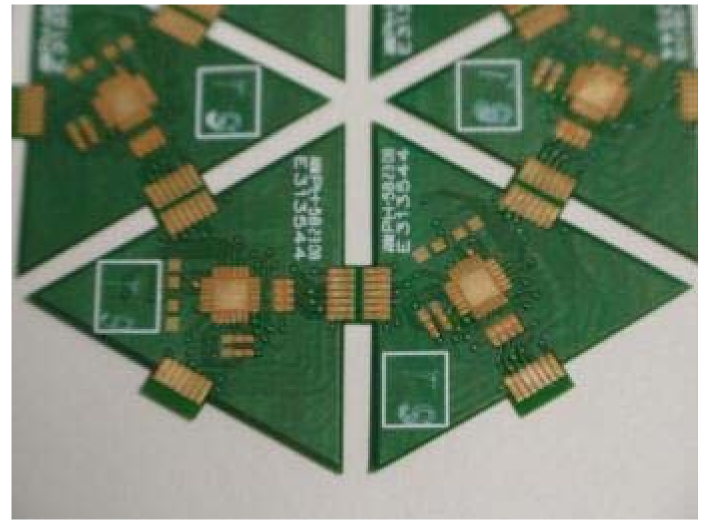
iCub 2.0

skin

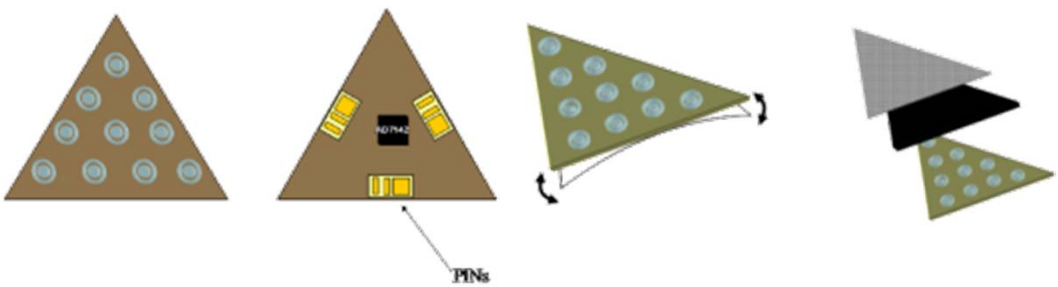
principle

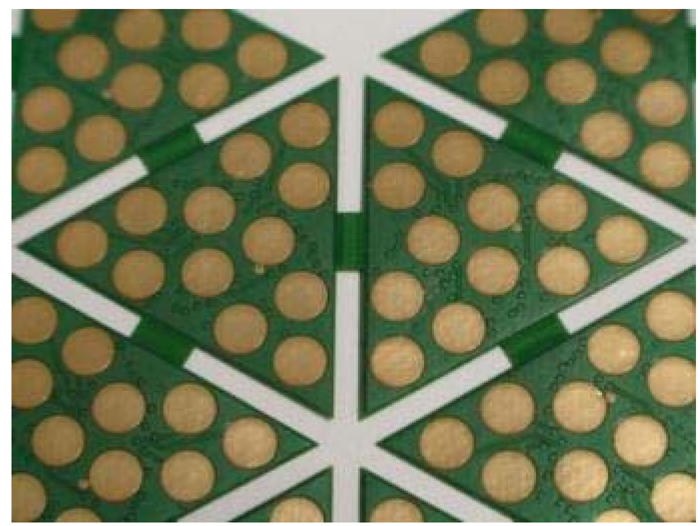




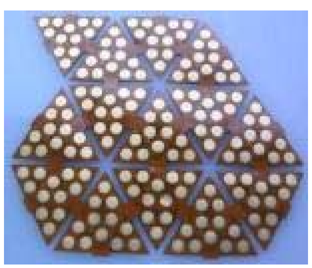


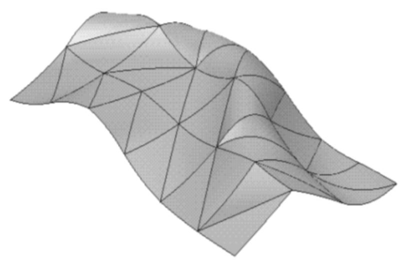
lots of sensing points



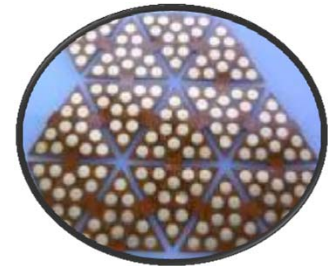


structure of the skin

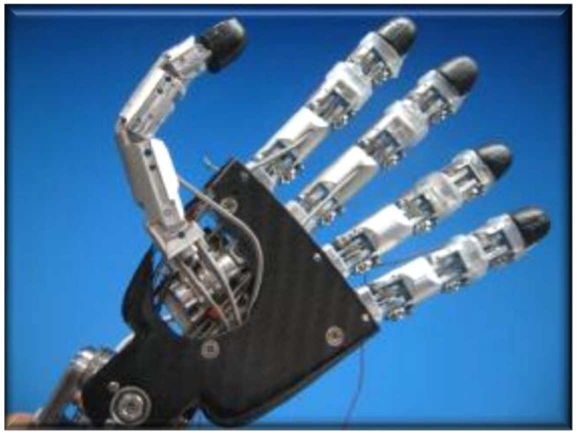


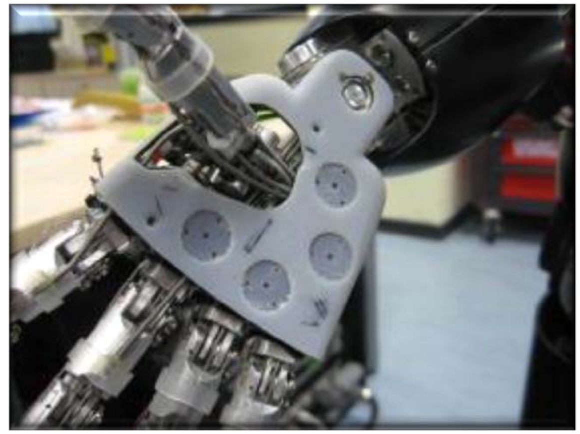
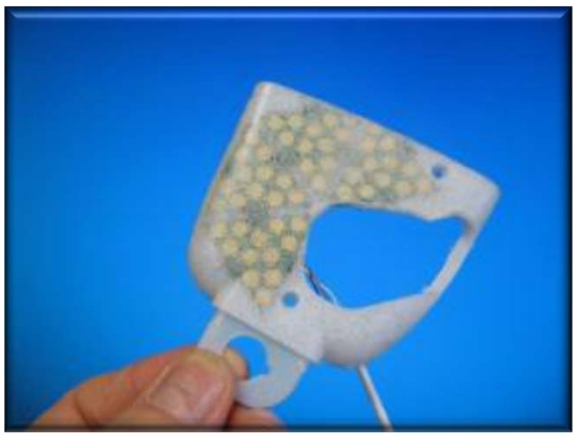


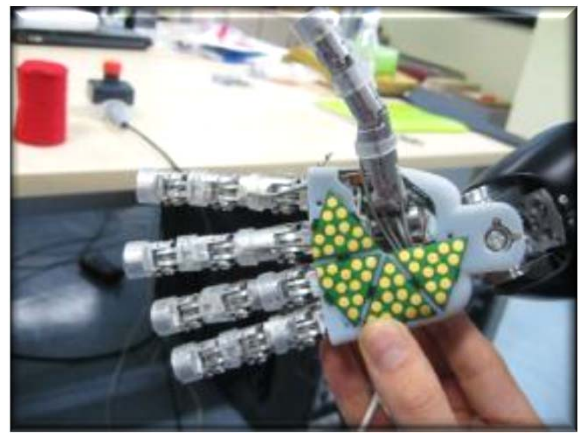
fingertips

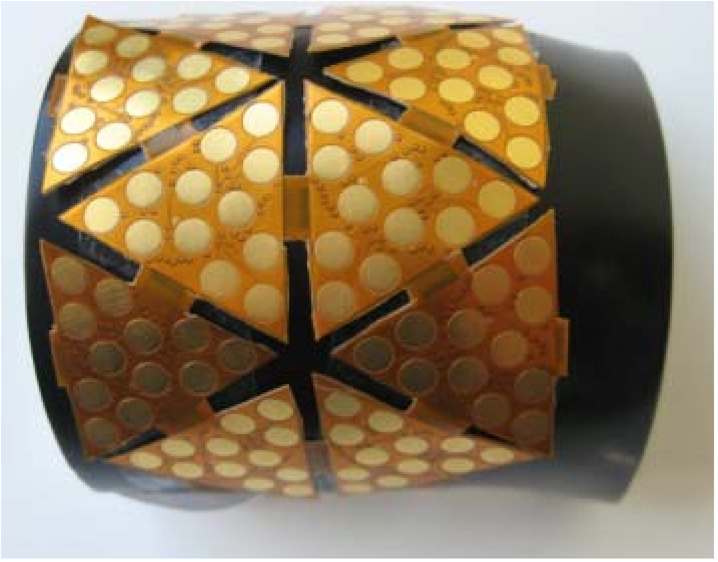


- capacitive pressure sensor with 12 sensitive zones
- 14.5 mm long and 13 mm wide, sized for iCub
- embedded electronics: twelve 16 bit measurements of capacitance
  - either all 12 taxels independently at 50 Hz or an average of the 12 taxels at about 500 Hz

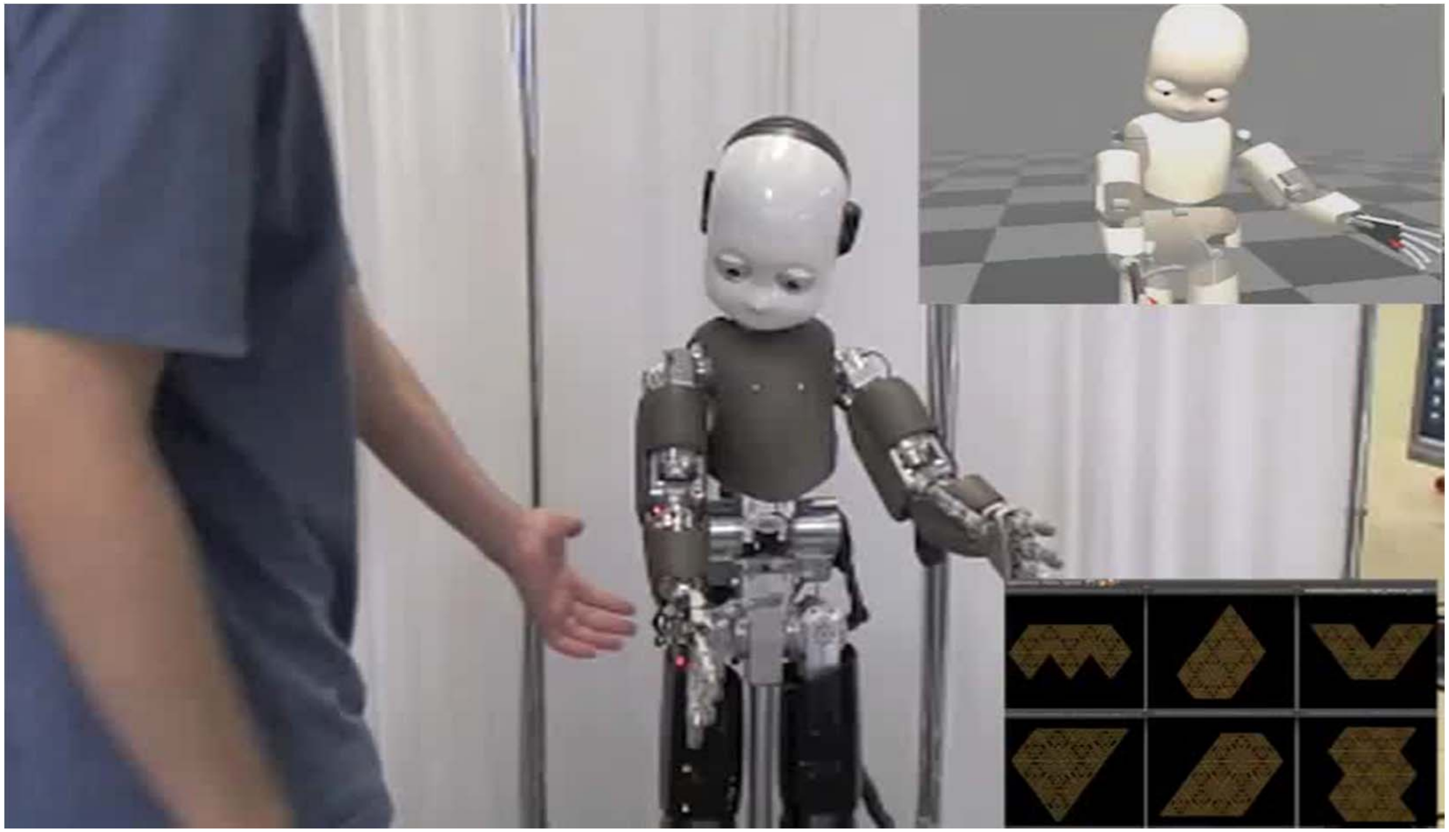






touch



learning new actions

some philosophy to conclude

why open (source) platforms?

- repeatable experiments

- benchmarking

- quality

this also resonates with industry-grade R&D in robotics

open source™

sponsors

- EU Commission projects:
  - RobotCub, grant FP6-004370, http://www.robotcub.org
  - CHRIS, grant FP7-215805, http://www.chrisfp7.eu
  - ITALK, grant FP7-214668, http://italkproject.org
  - Poeticon, grant FP7-215843 http://www.poeticon.eu
  - Robotdoc, grant FP7-ITN-235065 http://www.robotdoc.org
  - Roboskin, grant FP7-231500 http://www.roboskin.eu
  - Xperience, grant FP7-270273 http://www.xperience.org
  - EFAA, grant FP7-270490 http://efaa.upf.edu/

- More information: http://www.iCub.org

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