AUTOMATIC KINEMATIC CHAIN CALIBRATION USING ARTIFICIAL SKIN: SELF-TOUCH IN THE ICUB HUMANOID ROBOT

ISTITUTO ITALIANO DI TECNOLOGIA

Alessandro Roncone

Matej Hoffmann, Ugo Pattacini, Giorgio Metta

INDUSTRIAL ROBOT CALIBRATION.

TARGET: Robot kinematics in Denavit Hartenberg notation

METHODS: OPEN LOOP → external metrology system

CLOSED LOOP → physical constraints that act as ground truth

CONTEXT: (usually) well defined and very constrained

THE ICUB IS DIFFERENT !

AND HUMANOID ROBOTS AS WELL

1 COMPLEXITY

2 RELIABILITY

3 MEASUREMENTS

THE ICUB IS DIFFERENT !

AND HUMANOID ROBOTS AS WELL

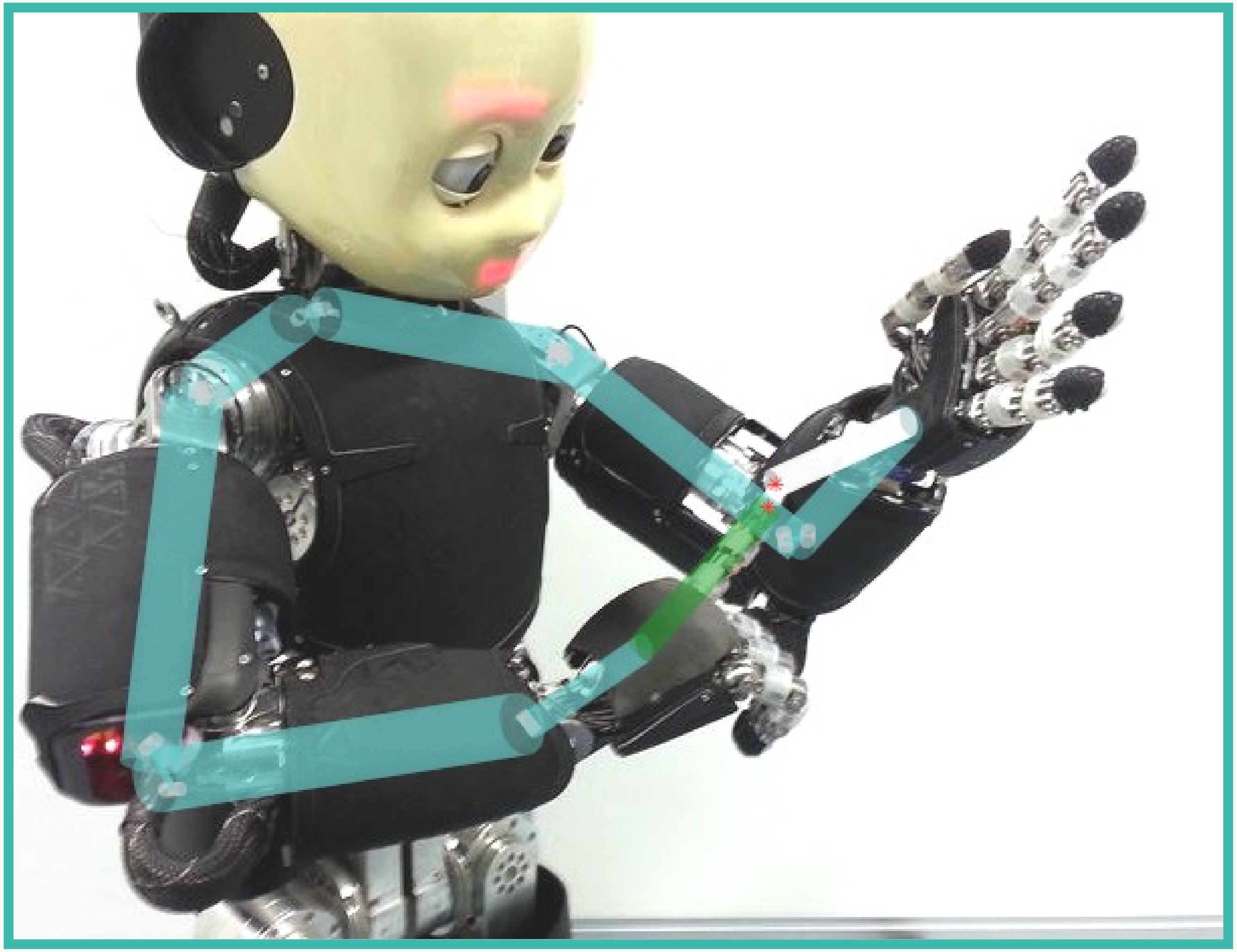
COMPLEXITY — need for FREQUENT calibrations — 1

RELIABILITY — need for AUTOMATIC methods — 2

MEASUREMENTS — new SENSORS to play with — 3

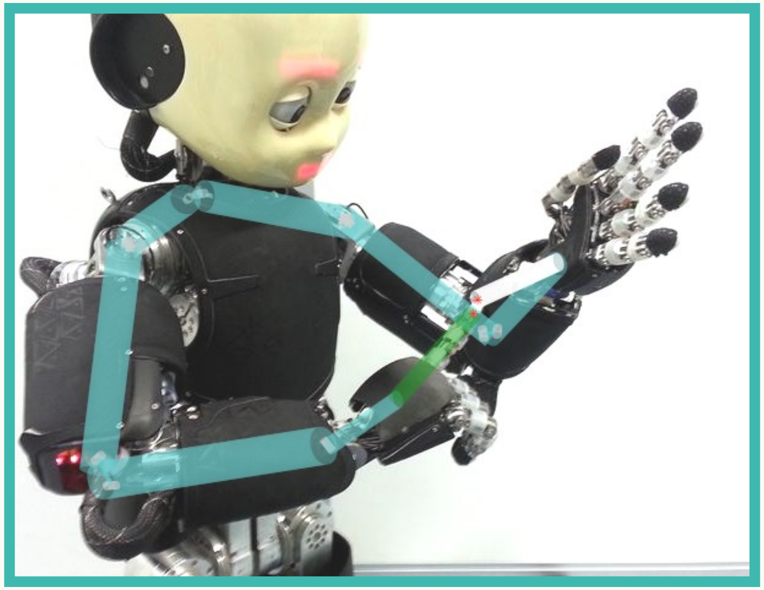
DOUBLE TOUCH .

AS A SELF-CONTAINED CLOSED LOOP CALIBRATION METHOD



DOUBLE TOUCH .

AS A SELF-CONTAINED CLOSED LOOP CALIBRATION METHOD



it is a **CLOSED LOOP** method 1

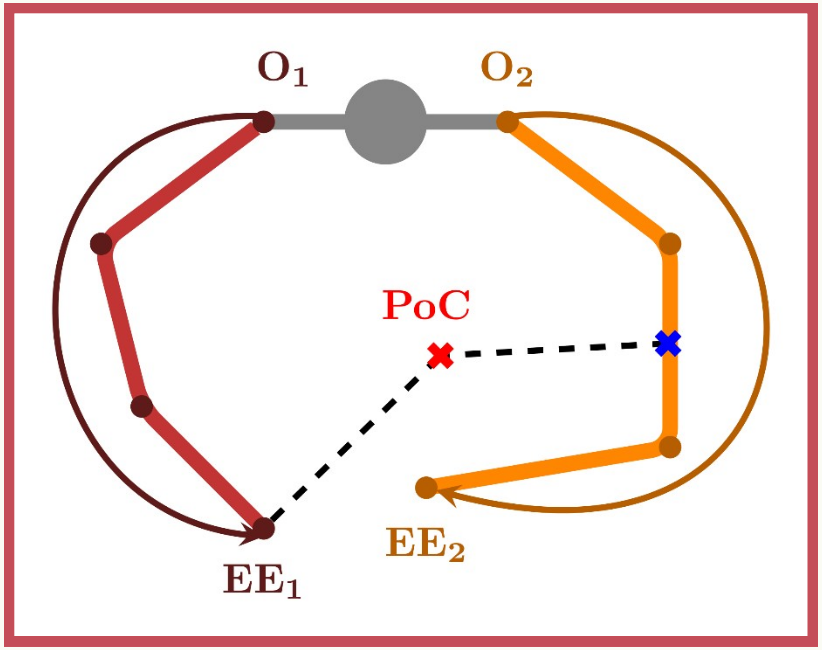
SKIN is the ground truth 2

no need for **EXTERNAL METROLOGY SYSTEMS** 3

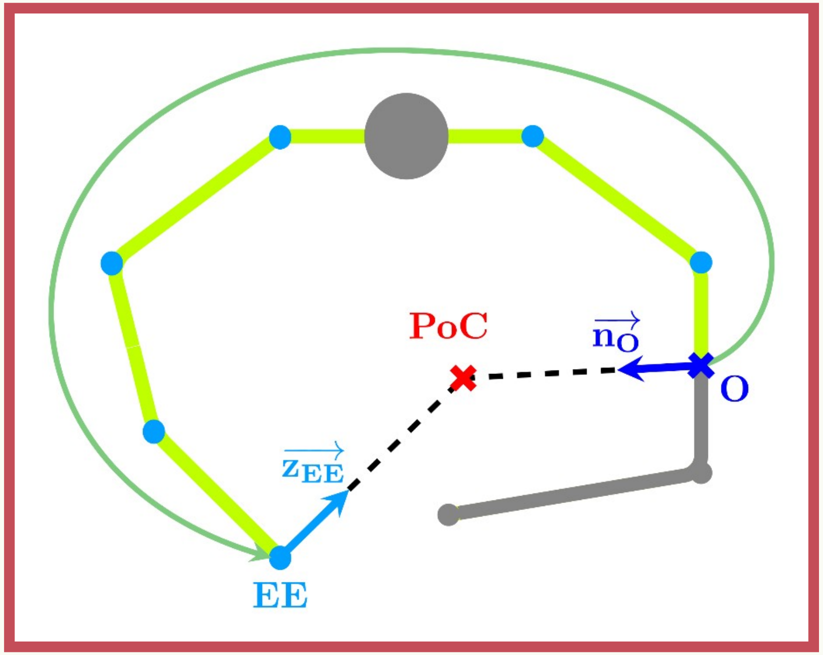
METHOD

KINEMATIC CHAIN REFORMULATION.

FROM TWO FIXED-BASE PARALLEL ARMS TO A SINGLE FLOATING-BASE SERIAL CHAIN



CLASSIC APPROACH



PROPOSED APPROACH

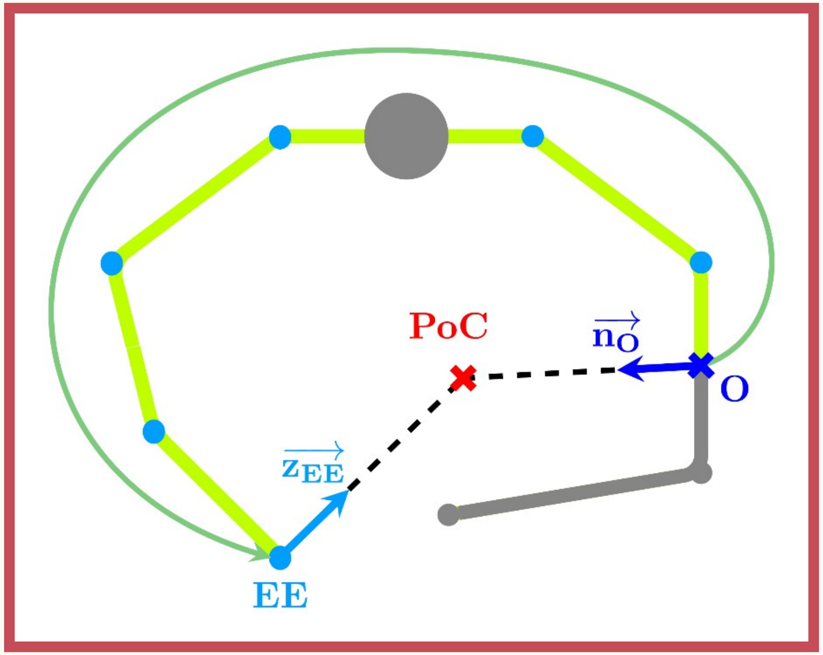
KINEMATIC CHAIN REFORMULATION .

FROM TWO FIXED-BASE PARALLEL ARMS TO A SINGLE FLOATING-BASE SERIAL CHAIN

1 FLOATING BASE

2 MORE DOFs

3 STANDARD IK TECHNIQUES

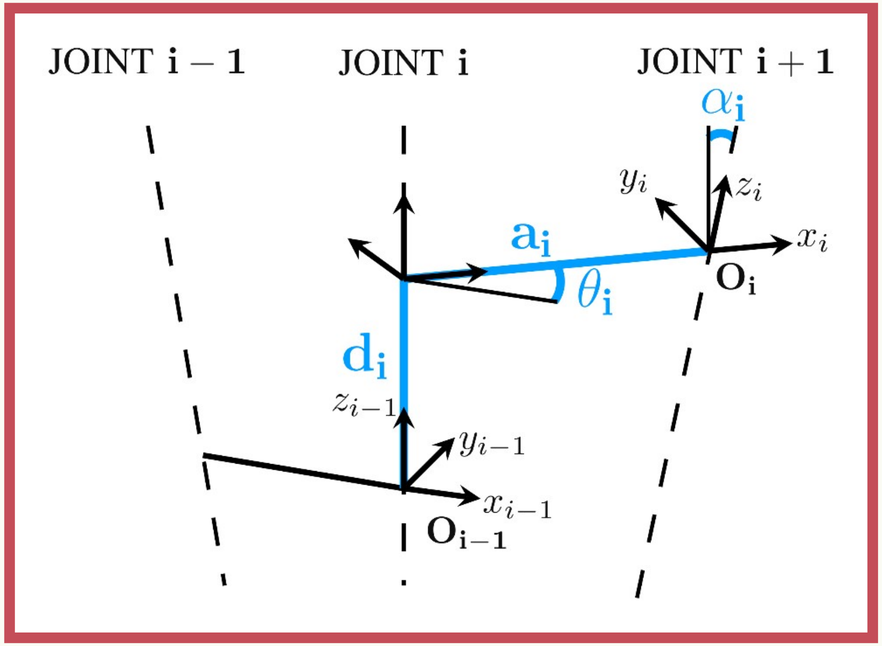


DENAVIT-HARTENBERG "REVERSION".

IT'S NOT AN INVERSION.

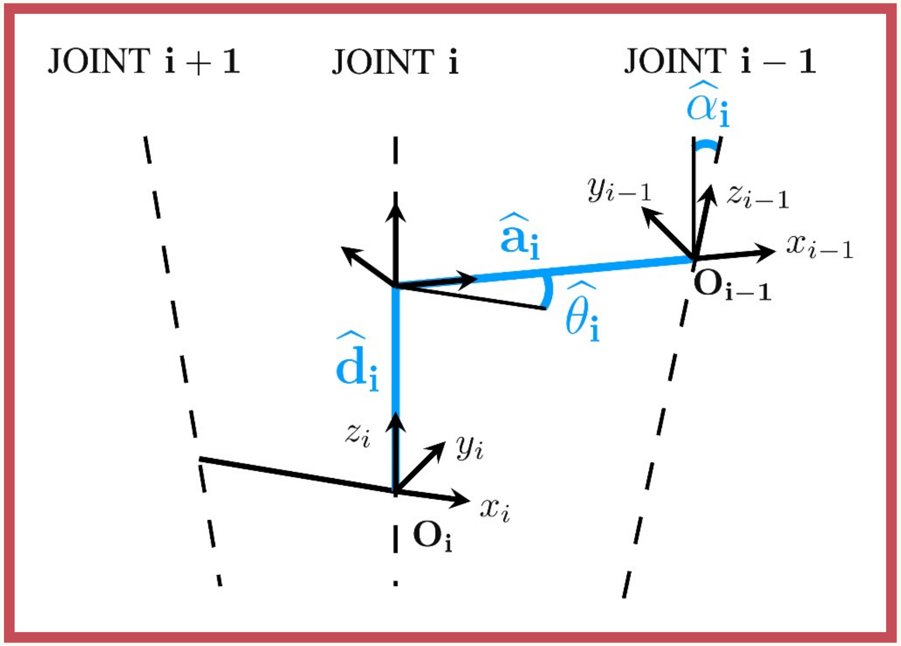
$$\boldsymbol{\Phi}_i = \{a_i,\ d_i,\ \alpha_i,\ \theta_i\}$$

$$\widehat{\boldsymbol{\Phi}}_i = \{\widehat{a}_i,\ \widehat{d}_i,\ \widehat{\alpha}_i,\ \widehat{\theta}_i\}$$



ORIGINAL (DIRECT) D-H

[from right to left]



"REVERSED" D-H

[from left to right]

DENAVIT-HARTENBERG "REVERSION".

IT'S NOT AN INVERSION.

$$dDH = \begin{bmatrix} c_\theta & -s_\theta c_\alpha & s_\theta s_\alpha & a c_\theta \\ s_\theta & c_\theta c_\alpha & -c_\theta s_\alpha & a s_\theta \\ 0 & s_\alpha & c_\alpha & d \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$rDH = \begin{bmatrix} c_{\widehat{\theta}} & -s_{\widehat{\theta}} & 0 & \widehat{a} \\ s_{\widehat{\theta}} c_{\widehat{\alpha}} & c_{\widehat{\theta}} c_{\widehat{\alpha}} & -s_{\widehat{\alpha}} & -\widehat{d} s_{\widehat{\alpha}} \\ s_{\widehat{\theta}} s_{\widehat{\alpha}} & c_{\widehat{\theta}} s_{\widehat{\alpha}} & c_{\widehat{\alpha}} & \widehat{d} c_{\widehat{\alpha}} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

ORIGINAL (DIRECT) D-H

"REVERSED" D-H

$$\begin{aligned} \langle \widehat{\mathbf{a_0}}, \widehat{\mathbf{a_1}}, \ldots, \widehat{\mathbf{a_n}} \rangle &= \langle -\mathbf{a_n}, -\mathbf{a_{n-1}}, \ldots, -\mathbf{a_0} \rangle \\ \left\langle \widehat{\mathbf{d_0}}, \widehat{\mathbf{d_1}}, \ldots, \widehat{\mathbf{d_n}} \right\rangle &= \langle -\mathbf{d_n}, -\mathbf{d_{n-1}}, \ldots, -\mathbf{d_0} \rangle \\ \langle \widehat{\alpha_\mathbf{0}}, \widehat{\alpha_\mathbf{1}}, \ldots, \widehat{\alpha_\mathbf{n}} \rangle &= \langle -\alpha_\mathbf{n}, -\alpha_\mathbf{n-1}, \ldots, -\alpha_\mathbf{0} \rangle \\ \left\langle \widehat{\theta_\mathbf{0}}, \widehat{\theta_\mathbf{1}}, \ldots, \widehat{\theta_\mathbf{n}} \right\rangle &= \langle -\theta_\mathbf{n}, -\theta_\mathbf{n-1}, \ldots, -\theta_\mathbf{0} \rangle \end{aligned}$$

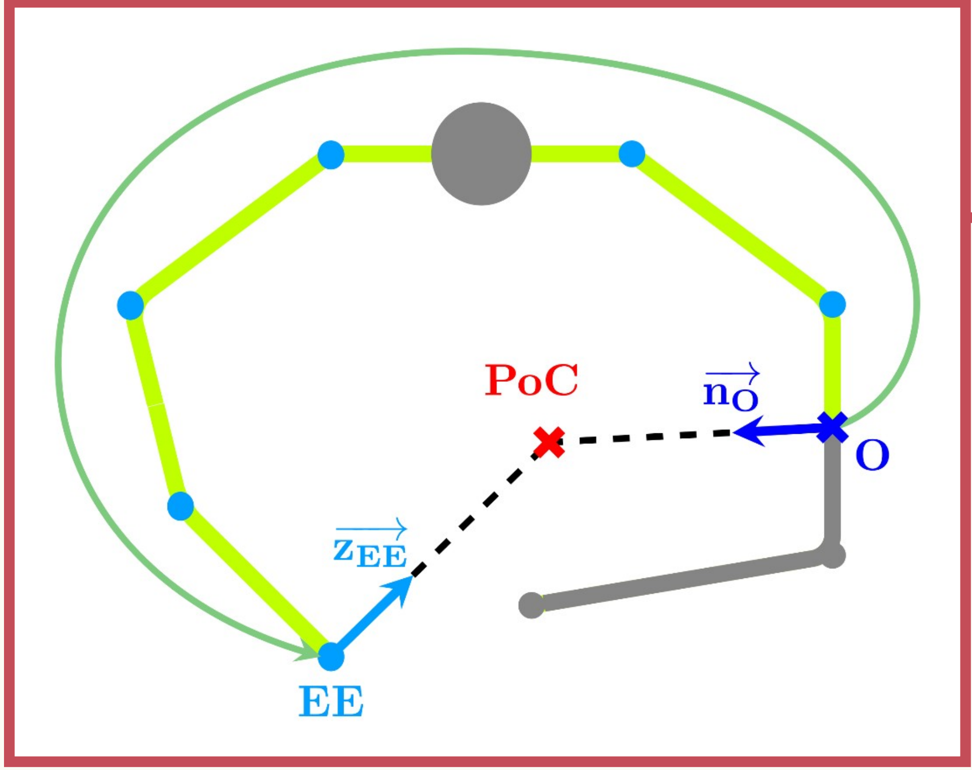
INVERSE KINEMATIC SOLVER .

5+7 = 12 DoFs

$$\mathbf{q}^* = arg \min_{\mathbf{q}\in\mathbb{R}^n} \langle \mathbf{n_O}, \mathbf{z_{EE}} \rangle =$$

$$= arg \min_{\mathbf{q}\in\mathbb{R}^n} \left\{ \|\mathbf{n_O}\| \cdot \|\mathbf{z_{EE}}\| \cdot cos(\alpha) \right\}$$

$$s.t. \begin{cases} \|K_x(\mathbf{q}) - \mathbf{O}\|^2 < \epsilon \\ \mathbf{q}_l < \mathbf{q} < \mathbf{q}_u \end{cases}$$



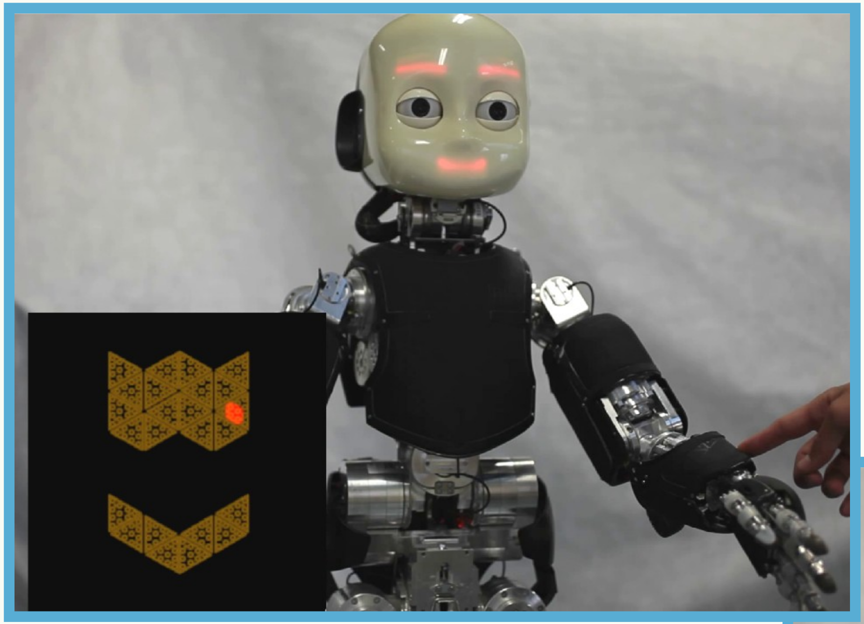
IPOPT

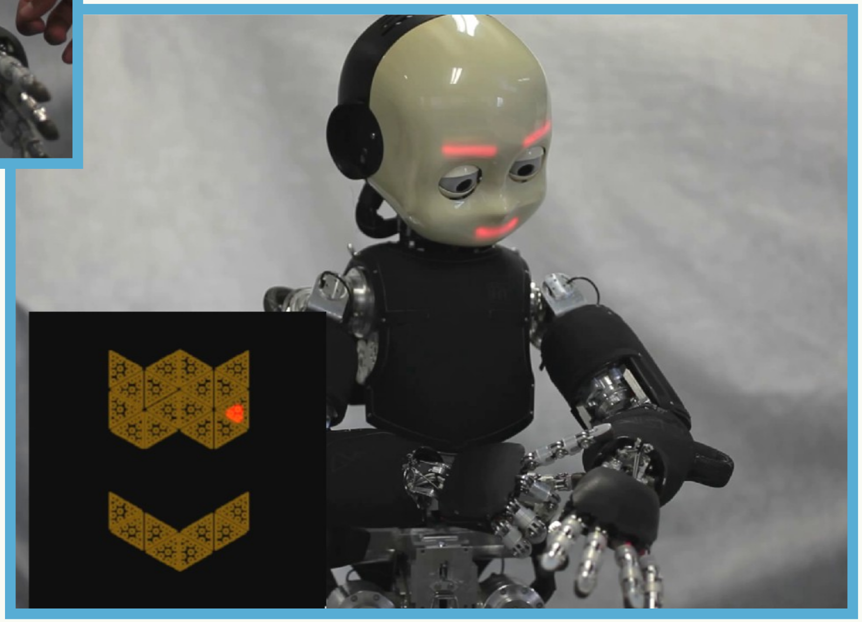
CALIBRATION.

$$\boldsymbol{\Phi}^* = arg \min_{\boldsymbol{\Phi}} \sum_{m=1}^{M} \|\mathbf{p}_s - \mathbf{p}_e(\boldsymbol{\Phi}, \theta_m)\|$$

RESULTS

EXPERIMENTS.





EXPERIMENTS.

$$\mathbf{\Phi}^* = arg \min_{\mathbf{\Phi}} \sum_{m=1}^{M} \|\mathbf{p}_s - \mathbf{p}_e(\mathbf{\Phi}, \theta_m)\|$$

M=300 samples

12x4=48 parameters

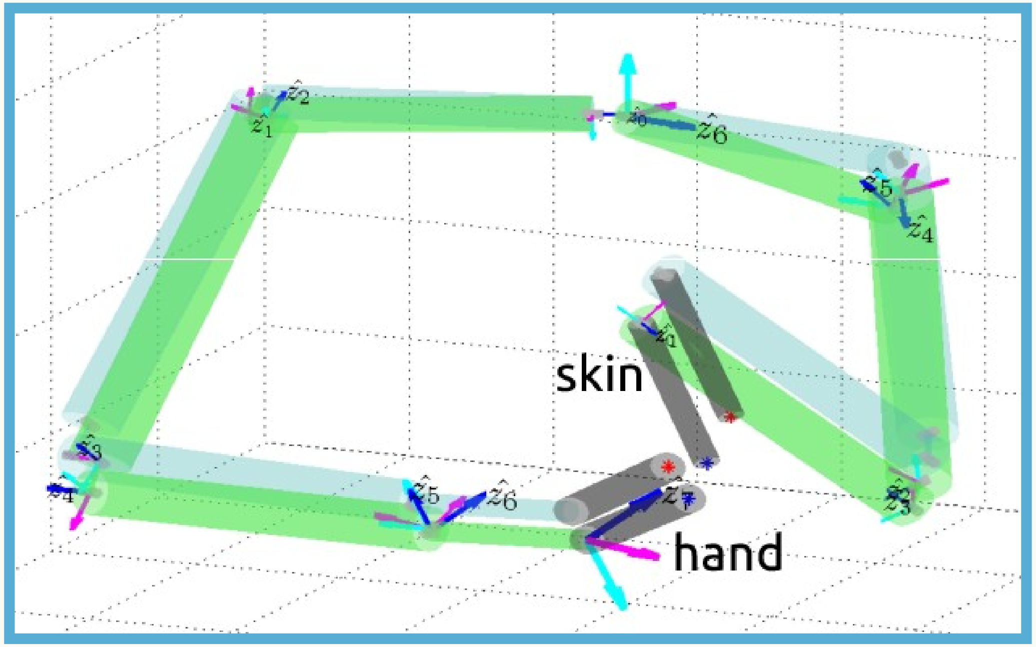
DH from CAD model

10% noise

30 % noise

3 EXP.

RESULTS.



	INITIAL ERROR [m]	OPTIMIZED ERROR [m]
EXP 1 (DH model)	0.0226	0.0208
EXP 2 (10% noise)	0.0819 ± 0.0299	0.0377 ± 0.0139
EXP 3 (30% noise)	0.1919 ± 0.0301	0.0664 ± 0.0175