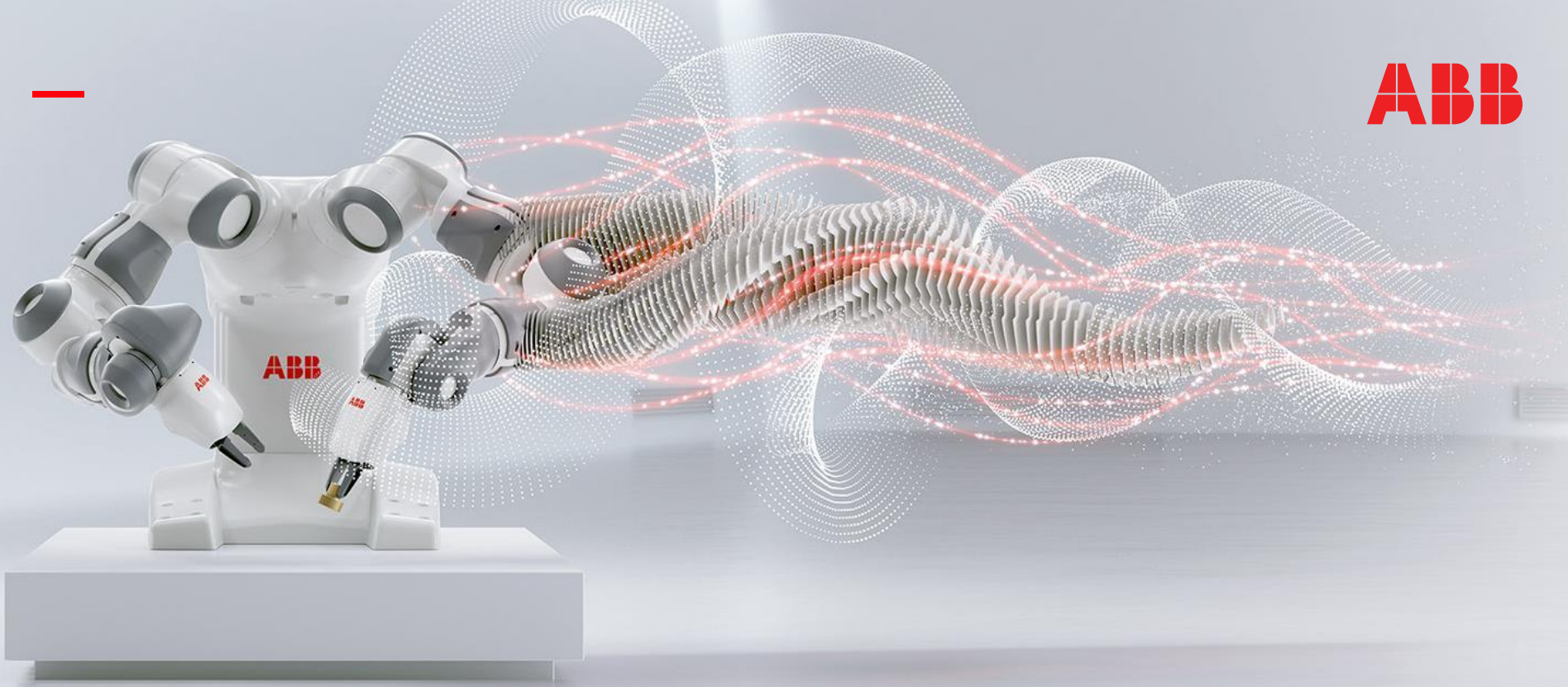


EUROPEAN ROBOTICS FORUM 2017, 2017-03-23

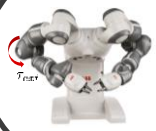
You cannot measure everything

On the importance of models for estimation in robotics

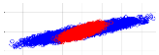
Arne Wahrburg, ABB Corporate Research Germany

You cannot measure everything – Overview

Increasing importance of models



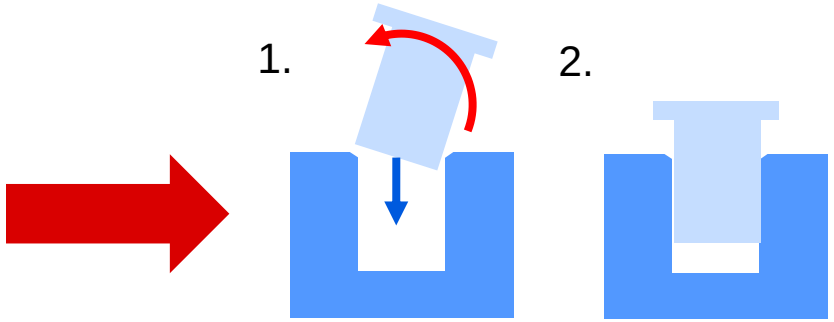
Models for joint load torque estimation



Models for Cartesian contact force estimation

Increasing importance of models in robotics

New applications



Pure motion control → Combined force/motion control

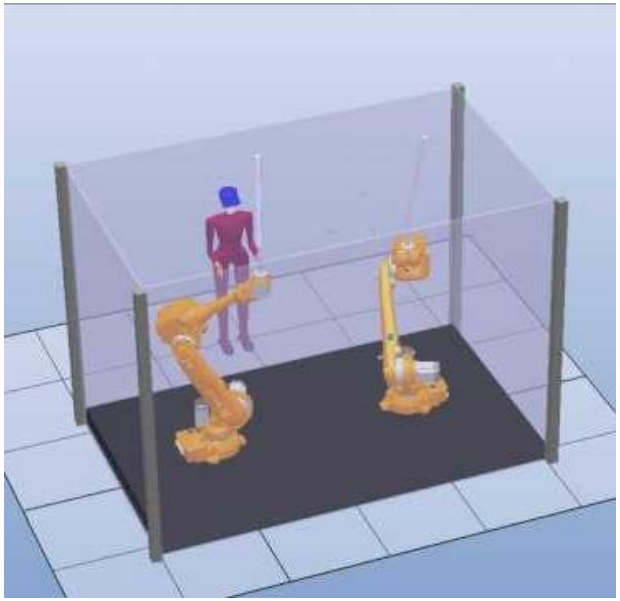
Increasing importance of models in robotics

New robot designs

Lightweight designs → Reduced stiffness

Increasing importance of models in robotics

Human-robot collaboration



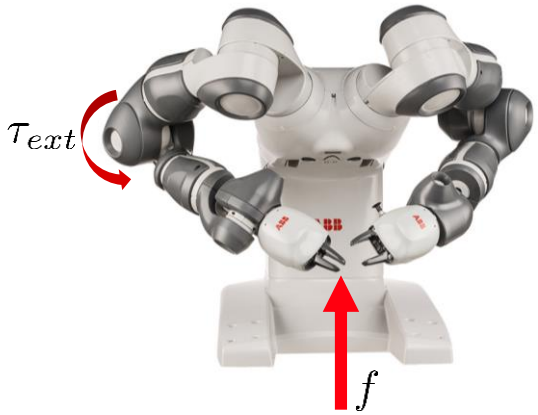
HRC → Additional robot & human models

Cartesian Contact Force Estimation

Estimating joint load torques

Rigid manipulator $M\ddot{q} + C\dot{q} + G + \tau_{fric} + \tau_{ext} = \tau_{mot}$

Assuming contact solely at TCP $\tau_{ext} = J^T f$



Simple load torque estimation

$$\hat{\tau}_{ext} = \tau_{mot} - \tau_{fric} - (M\ddot{q} + C\dot{q} + G)$$

Can be measured — Model needed

Assume $\hat{\tau}_{ext} = \tau_{ext} + e_j,\ e_j \sim \mathcal{N}(0, \Sigma_j)$

$$\hat{f} = W\hat{\tau}_{ext} = \left(J^T\right)^{-1}\hat{\tau}_{ext}$$

$$\Sigma_f(q) = W(q) \cdot \Sigma_j \cdot W(q)^T$$

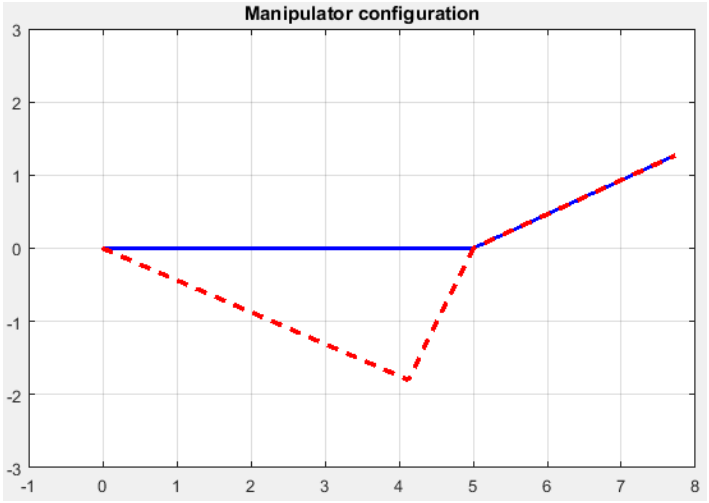
Uncertainty in Cartesian space

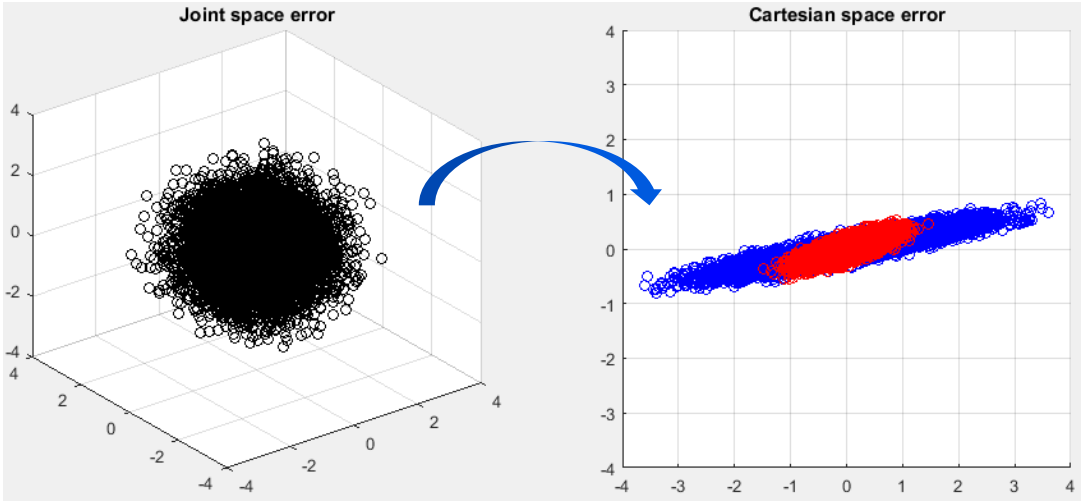
Cartesian Contact Force Estimation

Mapping joint load torques to Cartesian space

Mapping from joint space to Cartesian space – Redundant case

$$\hat{f} = \left(J^T\right)^+ \hat{\tau}_{ext}$$





Reduced variance in Cartesian space

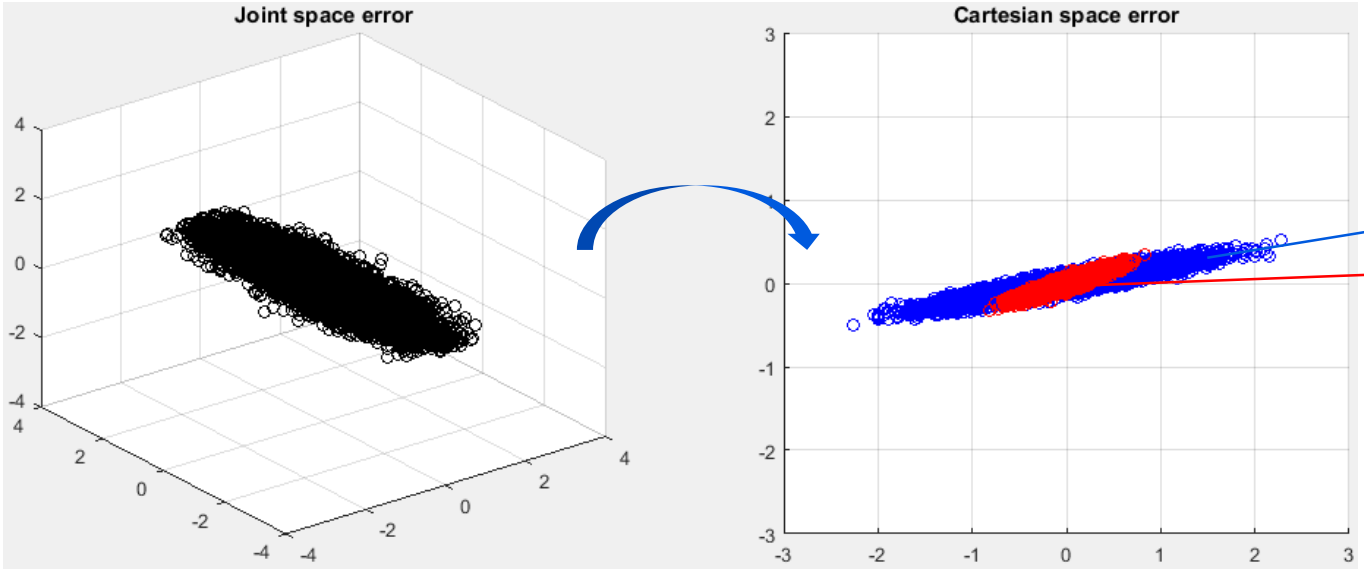
More information → Better results

Cartesian Contact Force Estimation

Mapping joint load torques to Cartesian space

Exploiting prior knowledge on joint level uncertainty $\Sigma_j \neq I$

Maximum likelihood estimator $\hat{f} = \underbrace{\left(J \cdot \Sigma_j^{-1} \cdot J^T\right)^{-1} \cdot J \cdot \Sigma_j^{-1}}_{W = \left(J^T\right)^{\#}_{\Sigma_j}} \cdot \hat{\tau}_{ext}$



Example:

$\Sigma_j = \mathrm{diag}\left(0.4; 1.6; 0.1\right)$

$\left(J^T\right)^{+}$

$\left(J^T\right)^{\#}_{\Sigma_j}$

Confidence information → Better results

Cartesian Contact Force Estimation

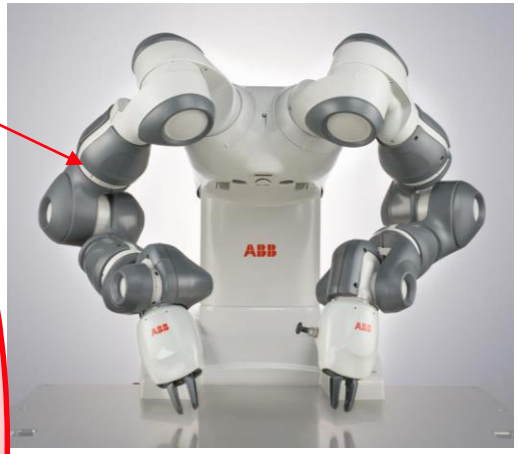
Mapping joint load torques to Cartesian space

(Artificial) YuMi example: $J(q) \in \mathbb{R}^{6\times 7}, \quad \Sigma_j = \mathrm{diag}\,(1;1;1;1;1;1;100)$

Joint load torque estimation much worse on J7

$$\left(J^T\right)^+ = \begin{bmatrix} 2.35 & 1.63 & -5.73 & 0.01 & 3.12 & 0.44 & 0.63 \\ 2.78 & -0.15 & -1.80 & -0.88 & -0.77 & -0.86 & -1.46 \\ 0.28 & 1.53 & 1.52 & 0.45 & -2.27 & 1.46 & 0.52 \\ 0.26 & -0.48 & -0.02 & 0.32 & 0.38 & -0.36 & 0.34 \\ -0.01 & -0.08 & 0.14 & 0.33 & -0.72 & 0.52 & -0.02 \\ -0.02 & 0.18 & -0.21 & 0.22 & 0.85 & 0.52 & -0.13 \end{bmatrix}$$

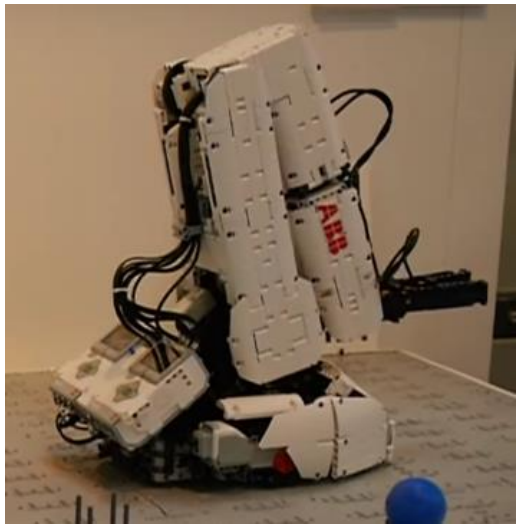
$$\left(J^T\right)^{\#}_{\Sigma_j} = \begin{bmatrix} 2.04 & 2.28 & -5.86 & 1.12 & 3.04 & -0.31 & 0.00 \\ 3.51 & -1.51 & -1.51 & -3.47 & -0.54 & 0.88 & -0.00 \\ 0.02 & 2.07 & 1.42 & 1.37 & -2.35 & 0.84 & 0.00 \\ 0.09 & -0.13 & -0.09 & 0.92 & 0.33 & -0.76 & 0.00 \\ -0.01 & -0.09 & 0.15 & 0.31 & -0.72 & 0.54 & -0.00 \\ 0.04 & 0.05 & -0.19 & -0.01 & 0.87 & 0.67 & -0.00 \end{bmatrix}$$



You cannot measure everything – Conclusion

Increasing importance of models

Drivers
- Performance demands
- Estimation and supervision
- Safety



More sensing
→ more models needed
(not less!)

Having models: good
Knowing how much to trust them: better

(One) open question: What type of model for which purpose?