Tools for Mobile Manipulation in Space and Service Applications

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Mobile Manipulation

- Synchronous, hard real-time control of a manipulator system and ist mobile base (wheeled or legged)

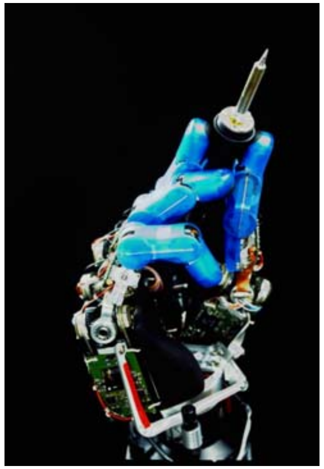
Mobile Manipulation

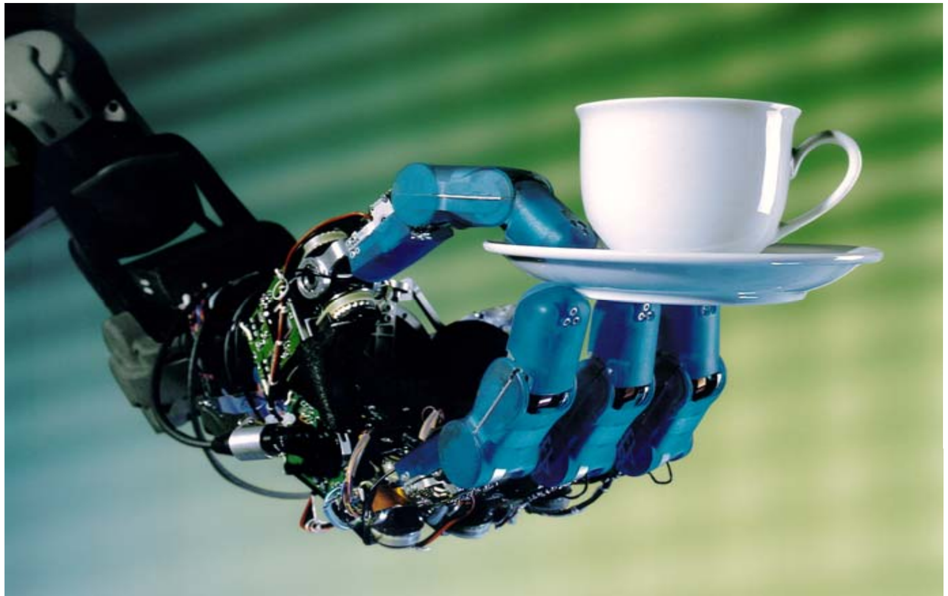
Mobile Manipulation
(Navigation, SLAM, Global planning)

Inverse Kinematics with Null-Space Motion

Long-Term Activity in Development of Hand-Arm Systems

Hand II: 13 Joints,
3kg finger tip force



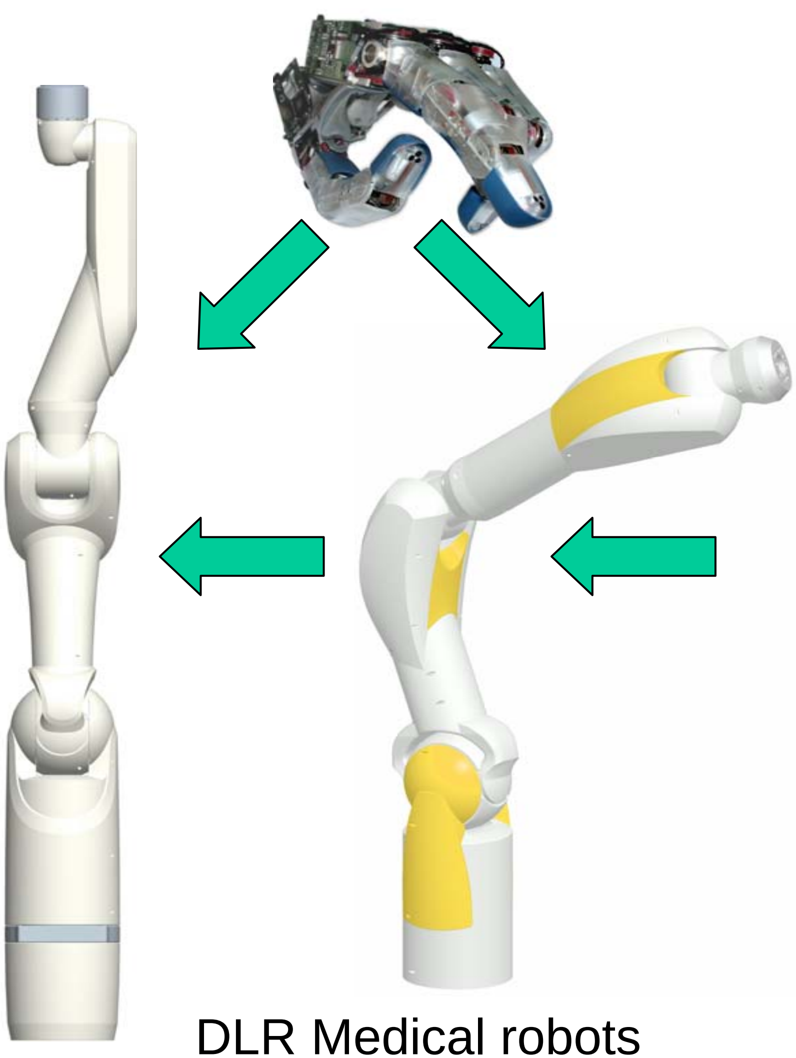


LBRIII

load/weight ~1/1 (14kg)
Consumed power~150 Watt,
Integrated Electronics

Mechatronic Developments

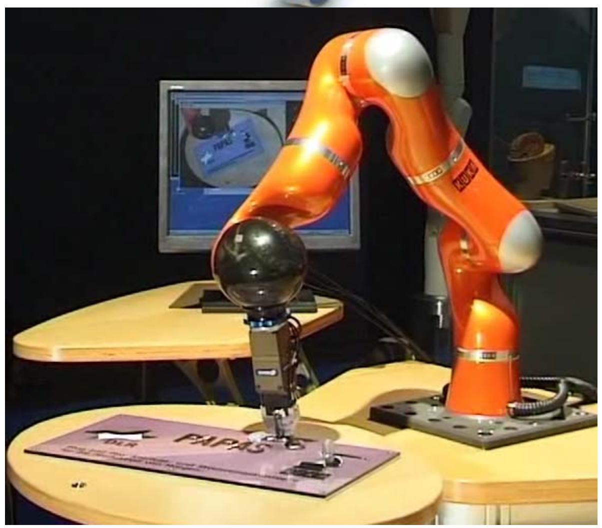
Torque sensing in each joint



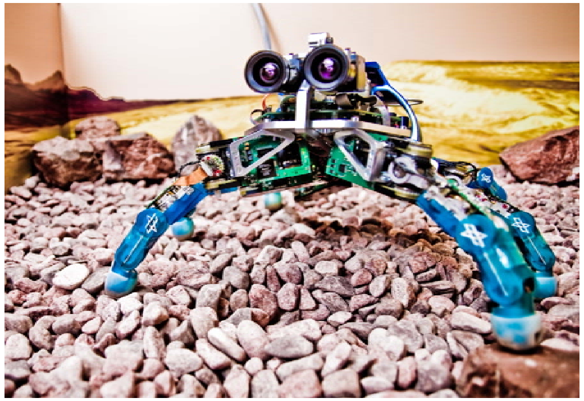
DLR Medical robots

Justin

Commercialized by KUKA



Mechatronic Developments



6 legged Crawler

DLR-Hand IIb

Justin

DEXHAND (ESA-Project)

Commercialized by Schunk

DLR-HIT Hand I, II

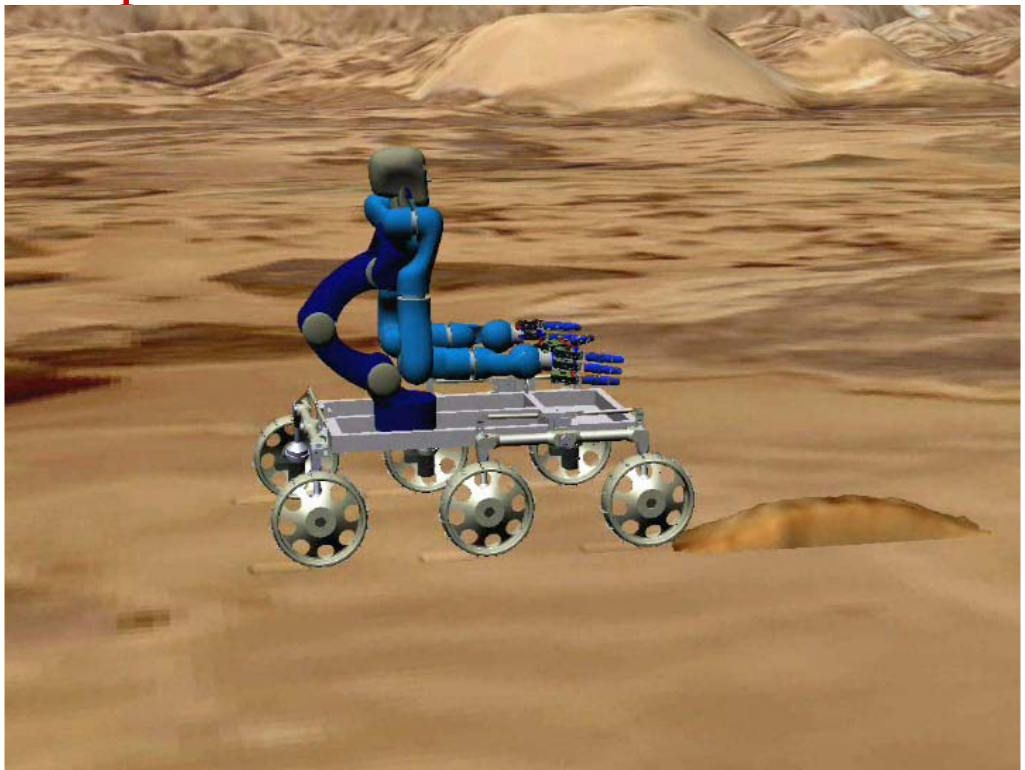
Space Robotics

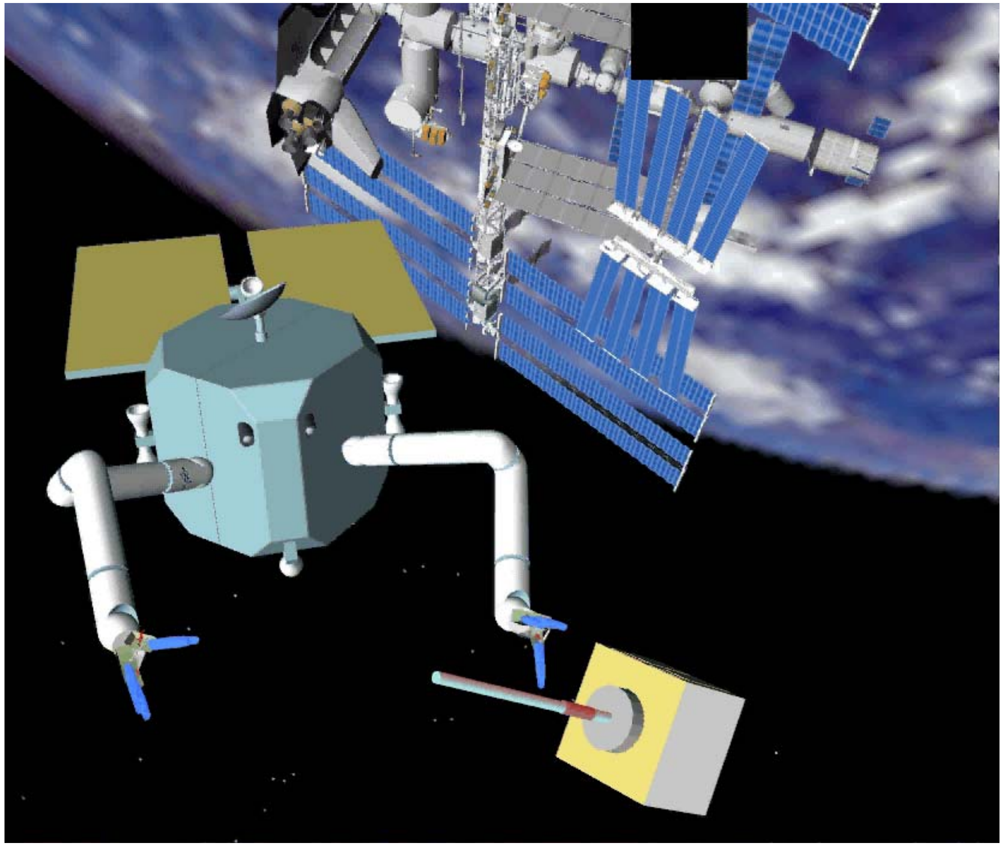
„Affordable“, operations in space with mobile/free-flying robonauts for

- Servicing

  and

- Exploration

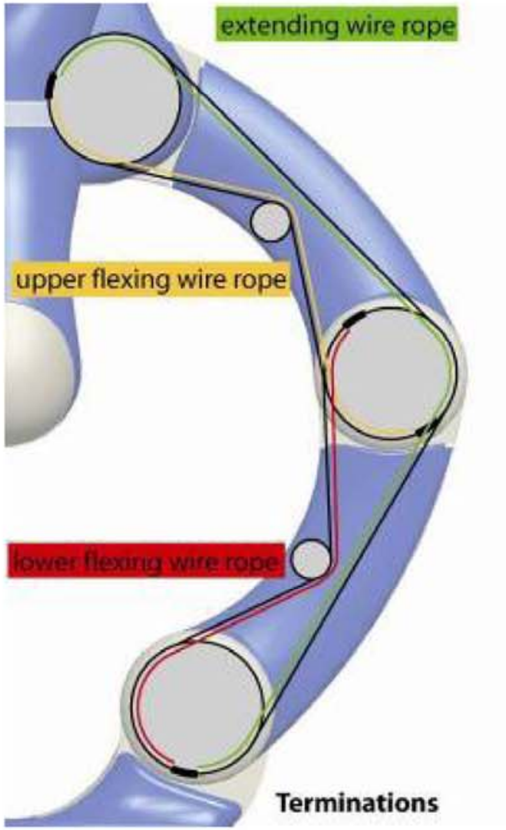


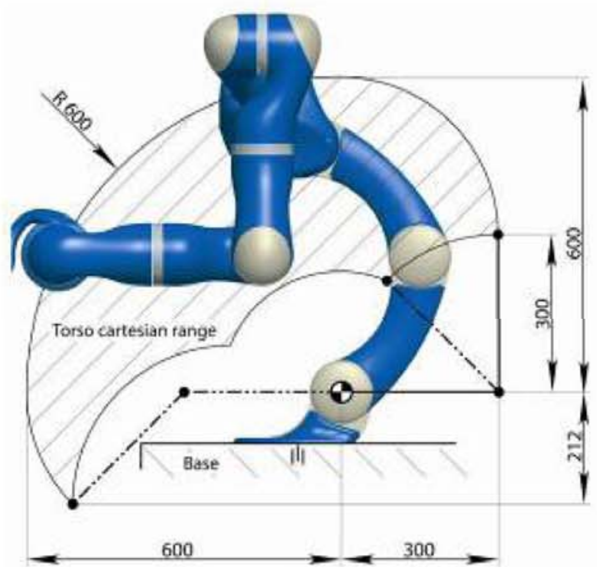


Production Assistant

Kinematics & Workspace

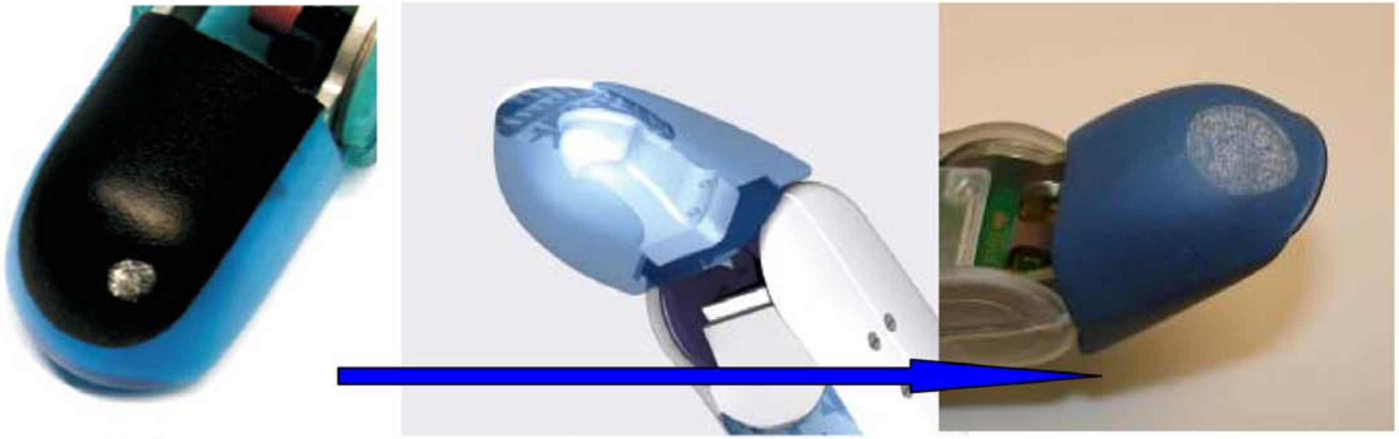
Passive joint is driven via tendons





Anthropomorphic Fingertip Design

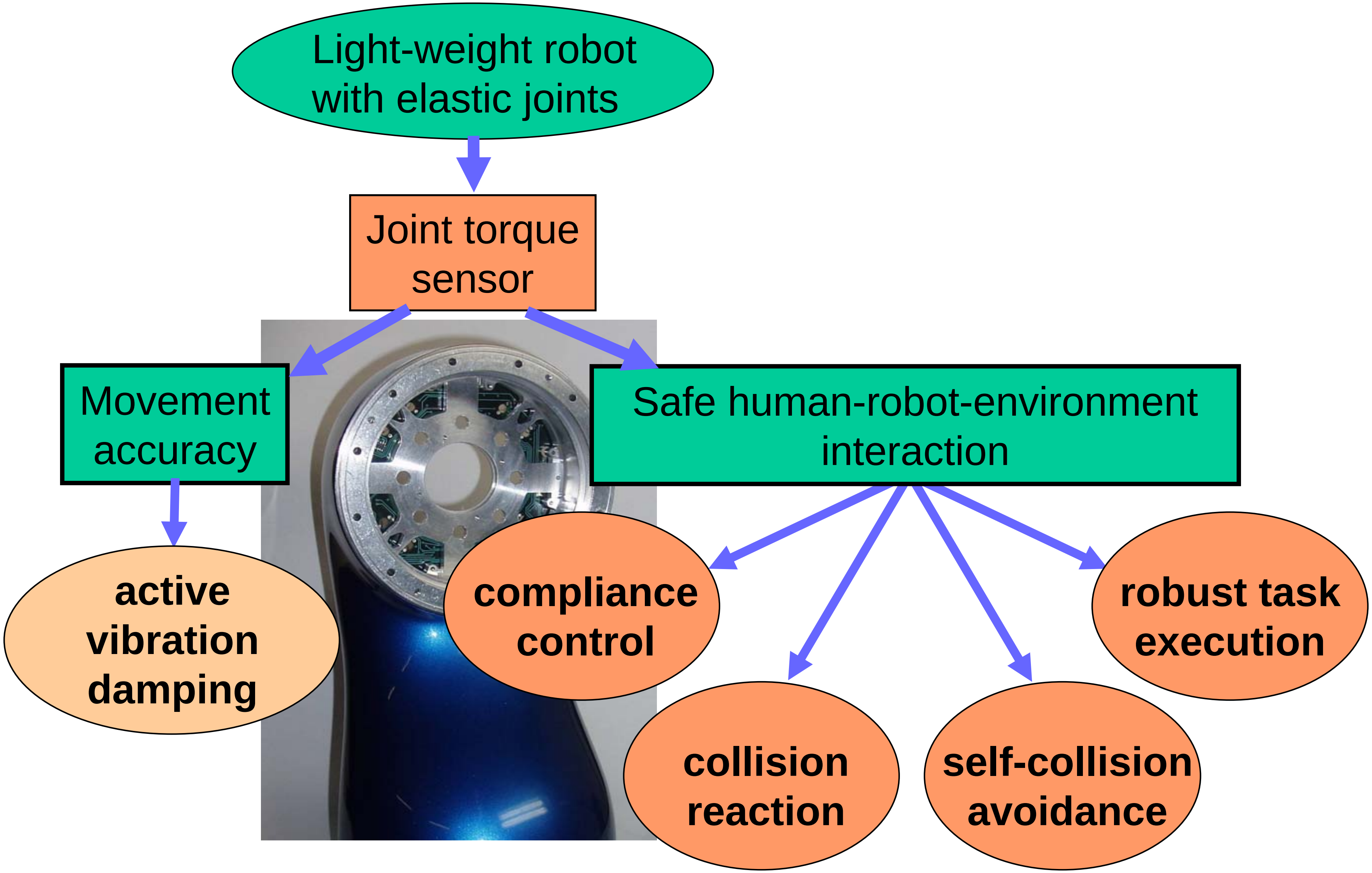
- Hard Fingertip
  - Small Area of Contact
  - Small Surface Torque
- Very soft (anthropomorphic) Fingertip
  - Large Area of Contact
  - Variable Stiffness



Hard Fingertip | Anthropomorphic Fingertip | Very soft Fingertip

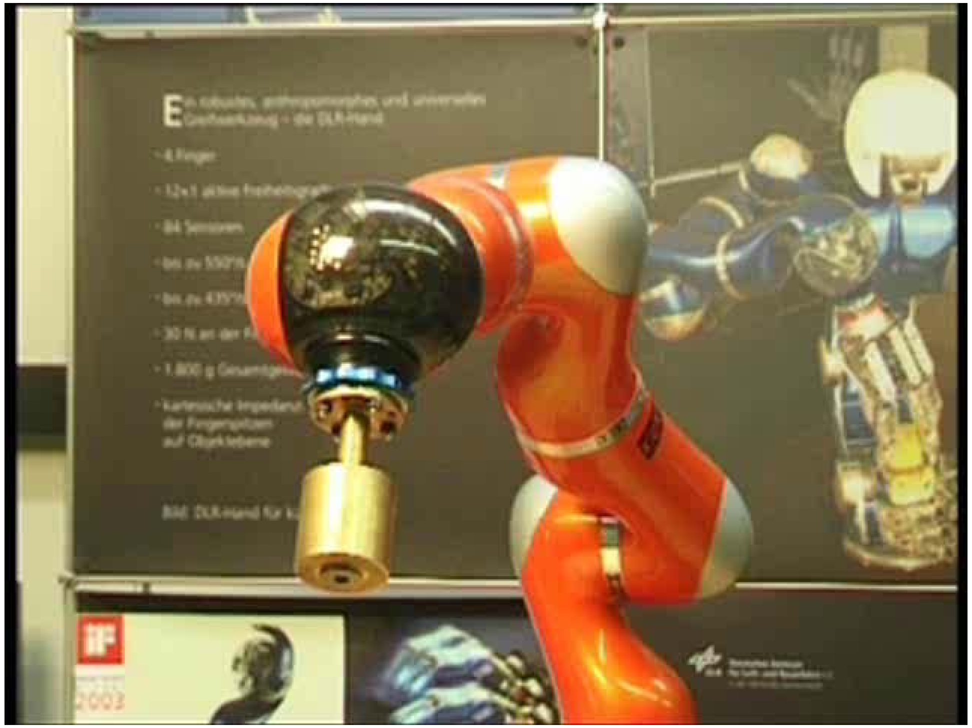
Robust Pinch Grasp of a wine glass

Control components



Vibration Damping

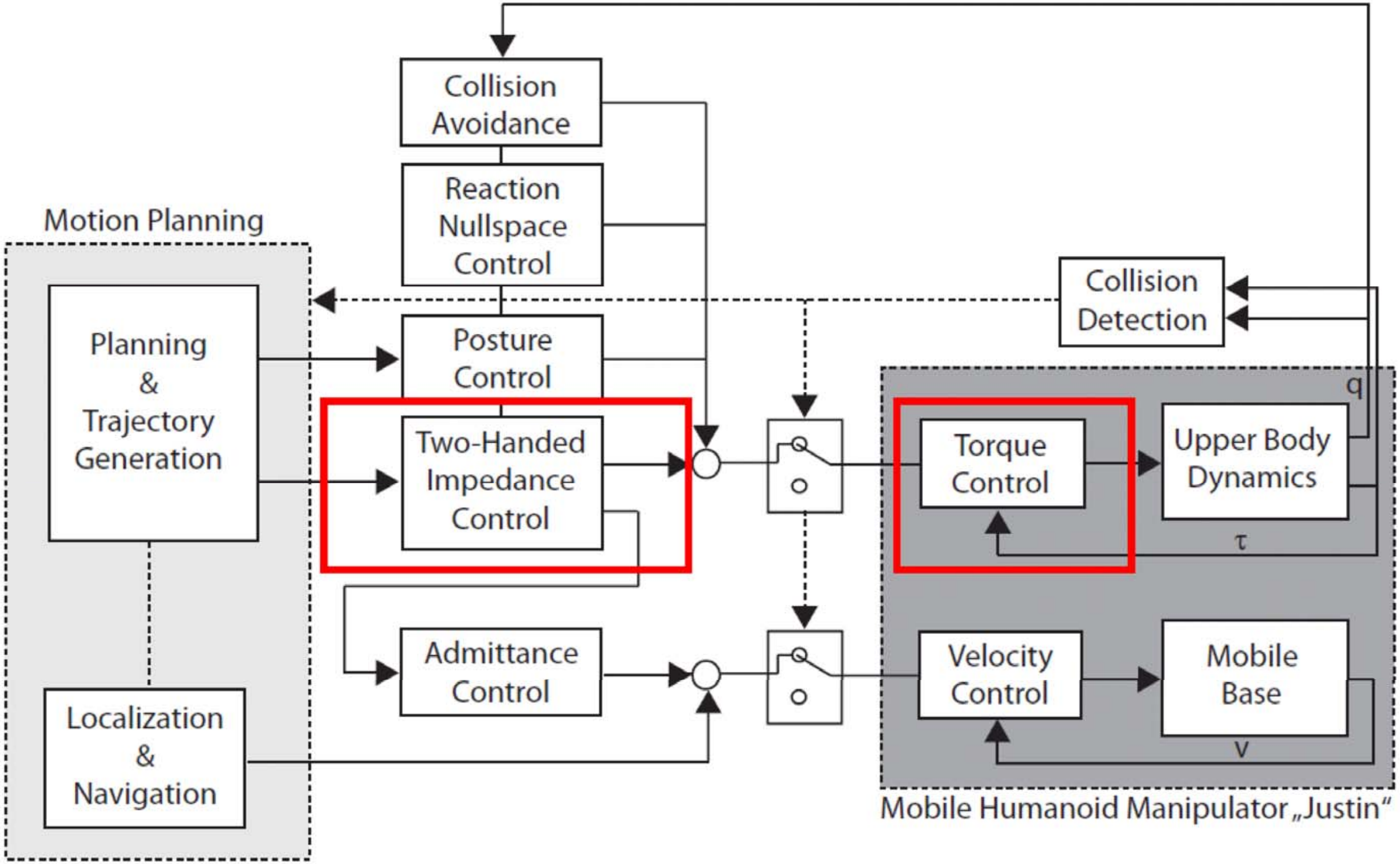
Vibration Damping OFF



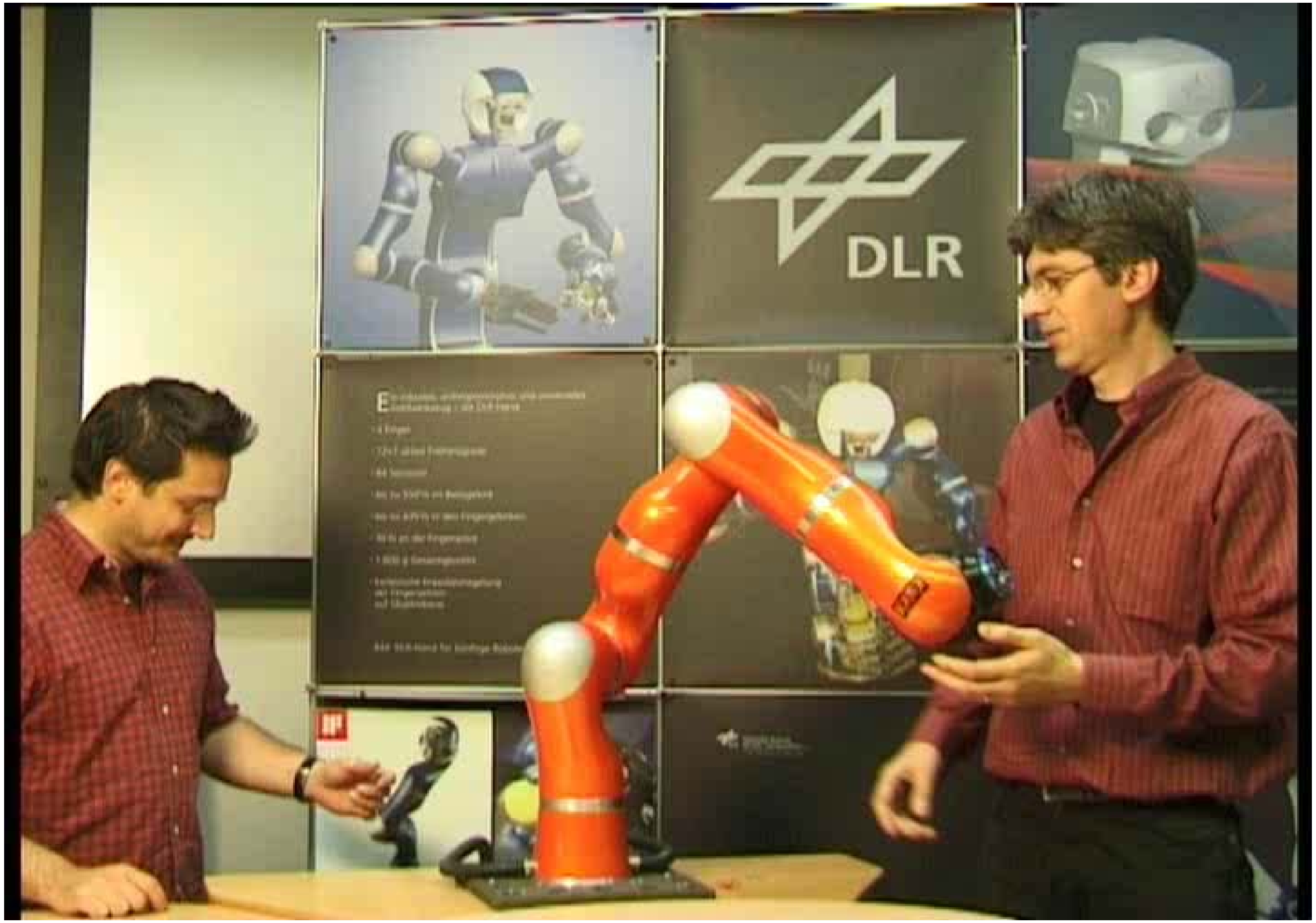
Vibration ON

Robot reaches the dynamics and accuracy of an industrial arm (according to KUKA ISO-Tests)

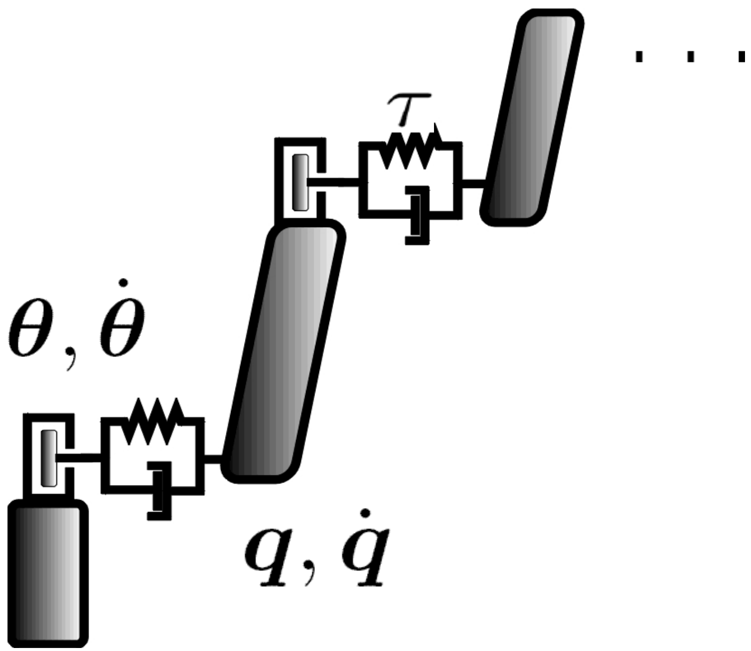
Control Architecture



Torque Control with Gravity Compensation



Model of the flexible joint robot



possible state vector:

$$x_1^T = \{\theta, \dot{\theta}, q, \dot{q}\}$$

used state vector:

$$x^T = \{\theta, \dot{\theta}, \tau, \dot{\tau}\}$$

$$\begin{aligned} M(q)\ddot{q} + C(q,\dot{q})\dot{q} + g(q) &= \tau + DK^{-1}\dot{\tau} + \tau_{ext} \\ B\ddot{\theta} + \tau + DK^{-1}\dot{\tau} &= \tau_m \\ \tau &= K(\theta - q) \end{aligned}$$

Cartesian Impedance Controller

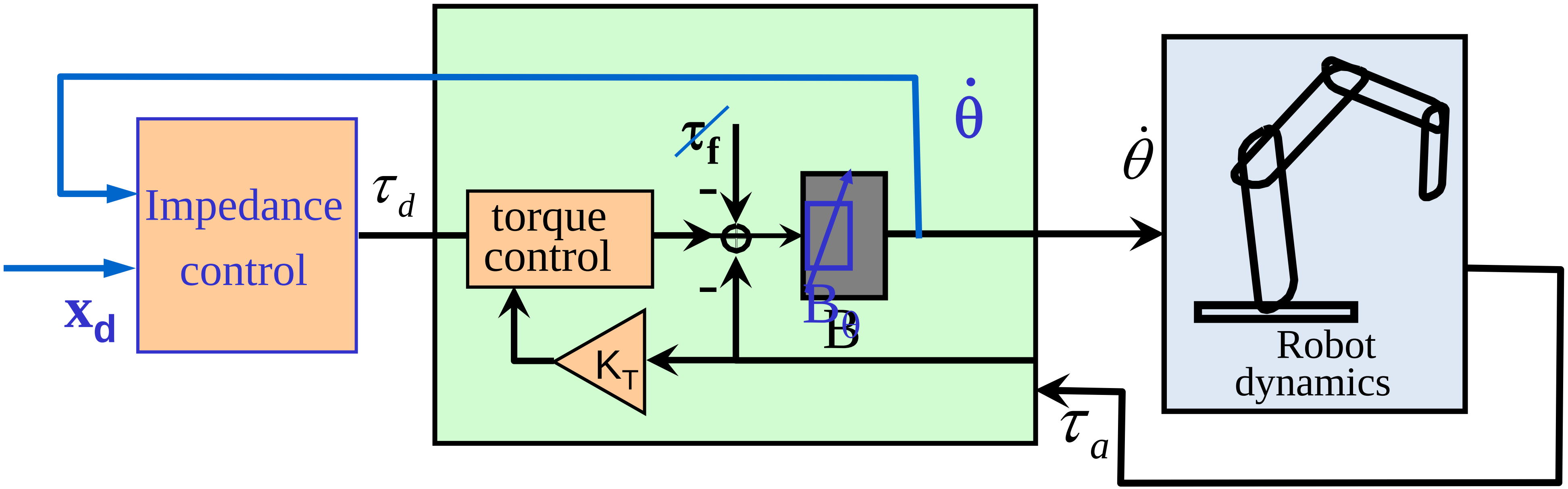
Generalization of approaches from rigid robots to the flexible case

- Shaping the potential energy - collocated feedback
  - Asymptotic stabilization around $\boldsymbol{x}_\mathbf{d}$ ($\boldsymbol{\tau}_{ext} = \mathbf{0}$)
  - Implementation of the desired compliance relationship ($\boldsymbol{\tau}_{ext} \neq \mathbf{0}$
  - Feedback of $\boldsymbol{\theta}$, $\dot{\boldsymbol{\theta}}$
- Shaping of the kinetic energy - noncollocated feedback
  - Damping of vibrations => increased performance
  - Feedback of $\boldsymbol{\tau}$, $\dot{\boldsymbol{\tau}}$ (torque controller)

=> Full state feedback

Cartesian Impedance Control

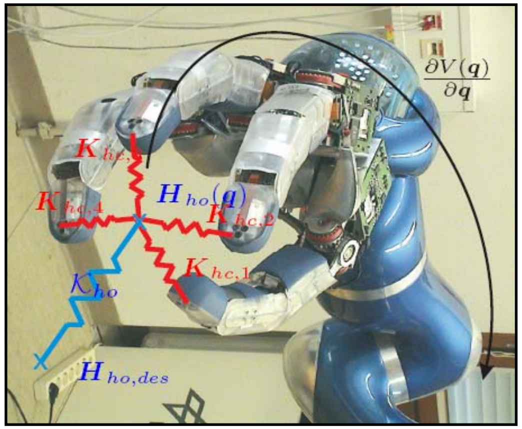
Unified approach for torque, position and impedance control on Cartesian and joint level

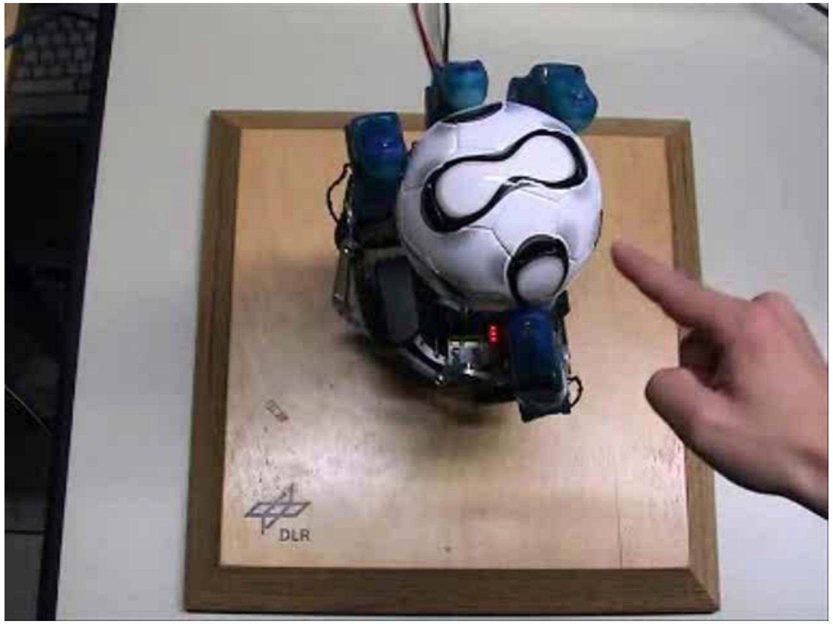


Passivity ⟶ Robustness in contact with the environment

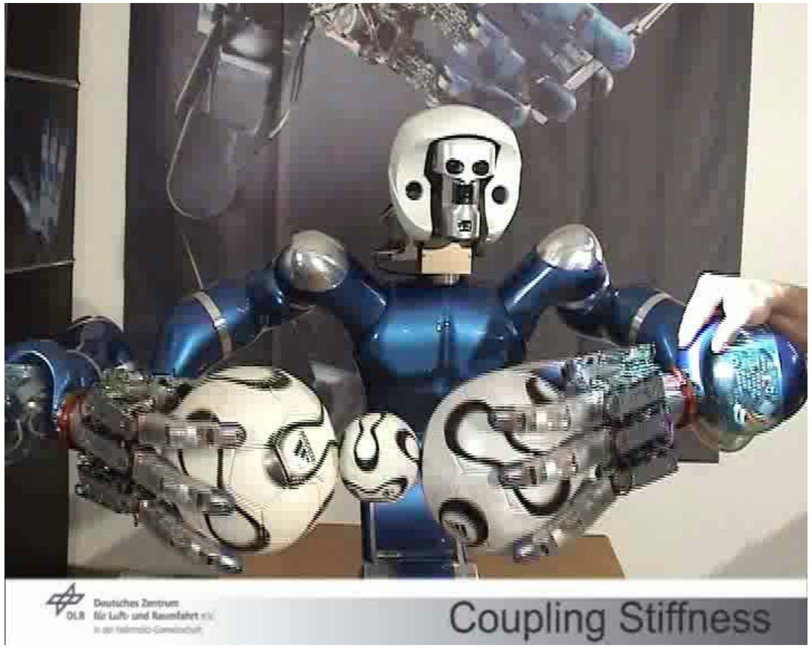
DLR Hand II – Impedance Control

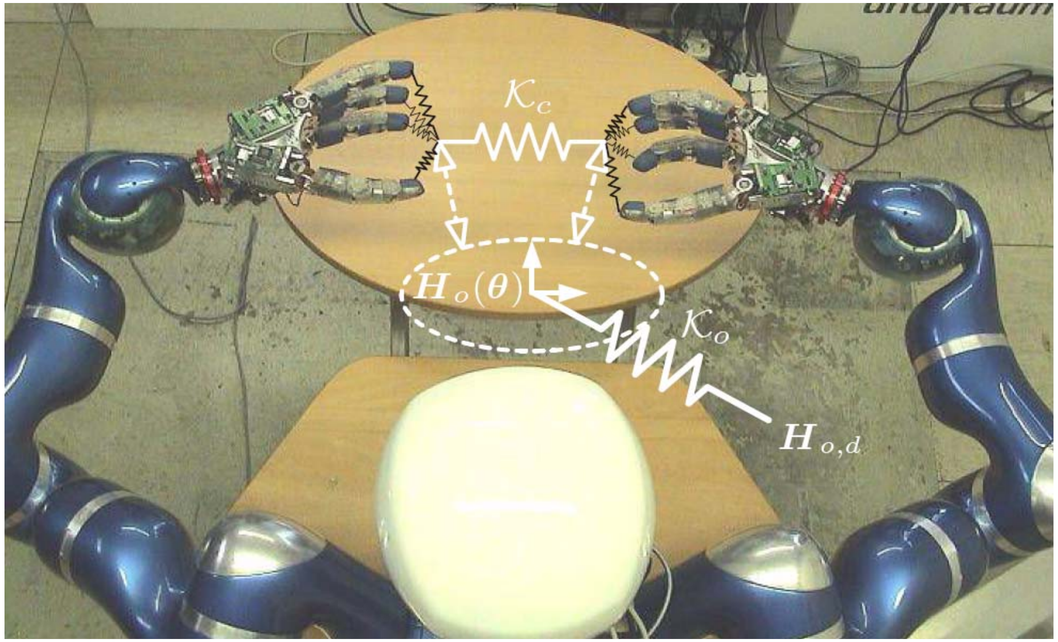
- Joint impedance Control
- Cartesian Impedance Control
- Object Impedance Control





Impedance Control for Two Handed Manipulation





$$\tau_d = \bar{g}(\theta) - \frac{\partial V(\theta)}{\partial \theta} - D(\theta)\dot{\theta}$$

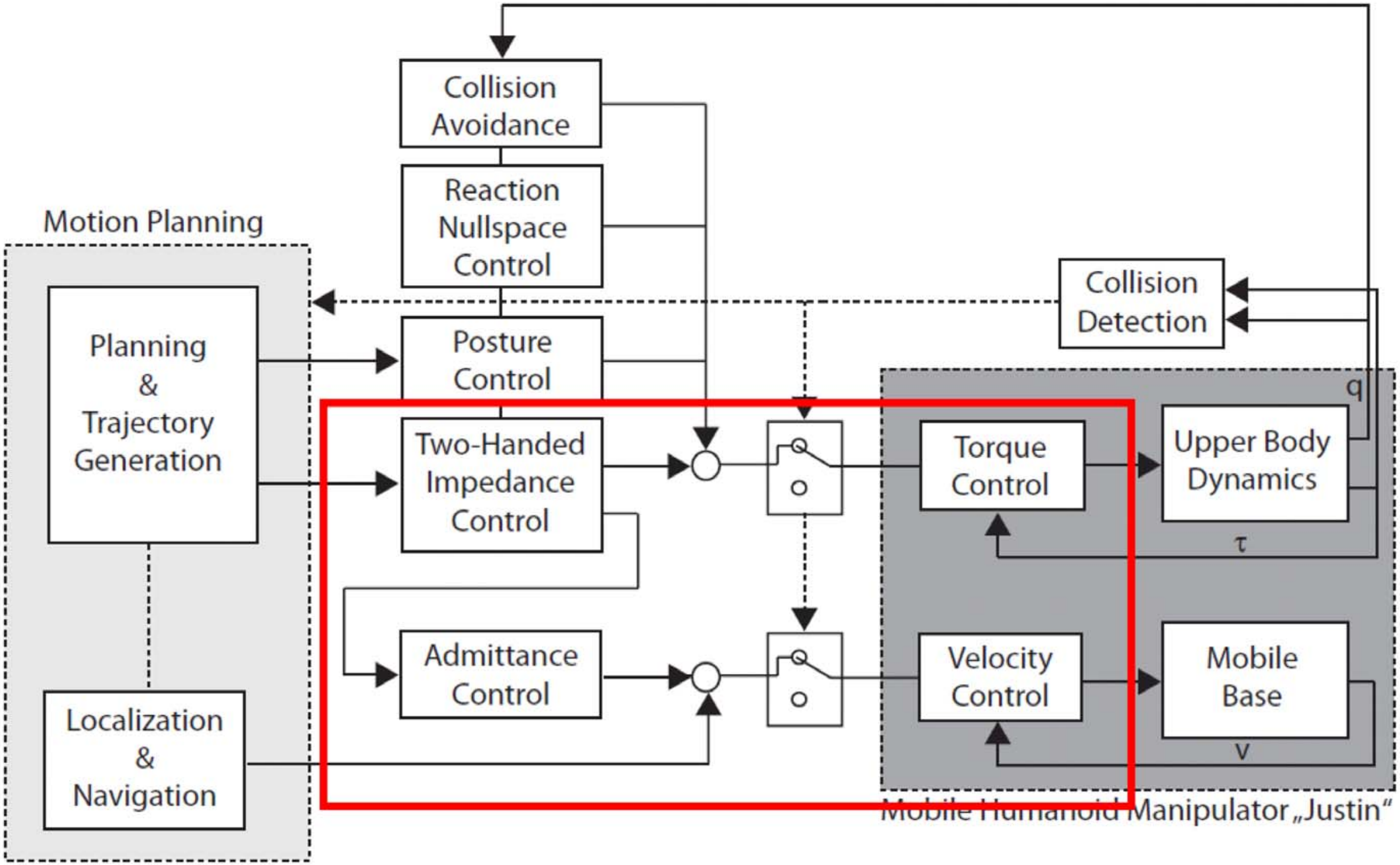
Gravity compensation

Stiffness term

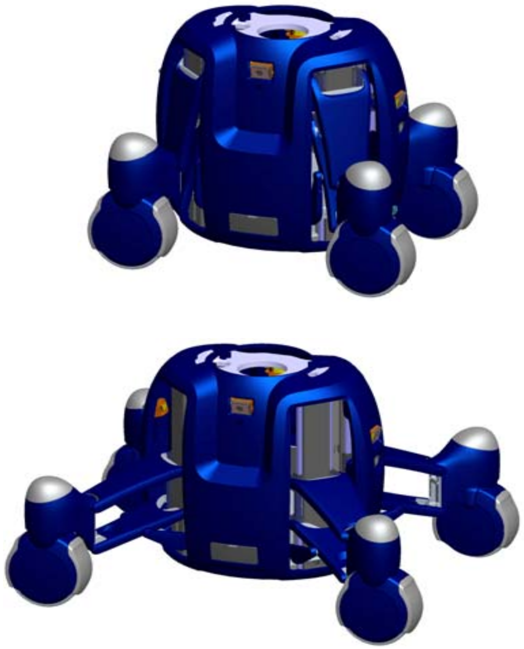
Damping term

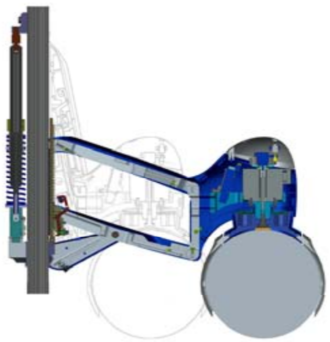
1ms control cycle for the whole system

Control Architecture



Development and Control of the Omni-Directional, Mobile Platform





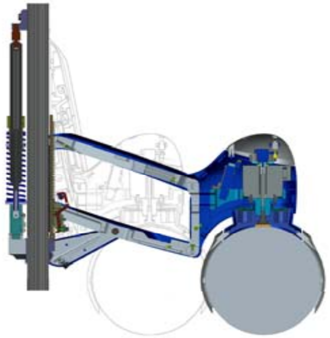
- Wheels can be independently retracted

  (variable support area)
- 8 actuators
  - 4 steering actuators
  - 4 wheel actuators
- Passive suspension - lockable

Fixed leg length: all joint axes intersect in the Instantaneous Center of Rotation (ICR)

For leg extension while moving no ICR exists – controller generalizations were needed

Development and Control of the Omni-Directional, Mobile Platform



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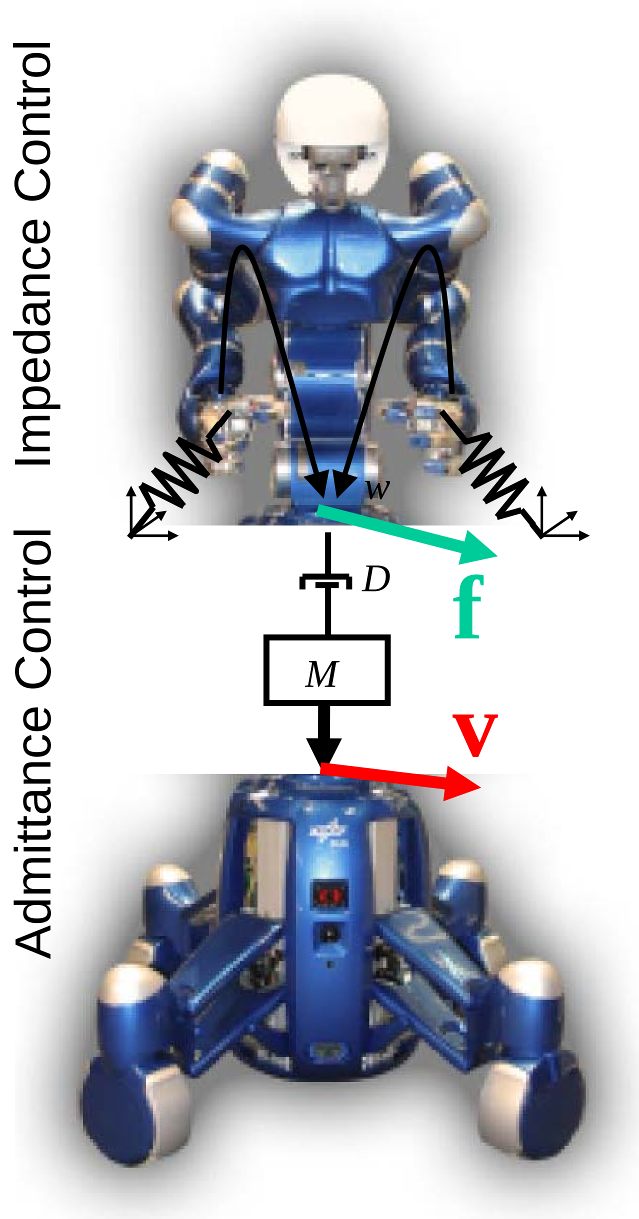
Human-Robot-Interaction

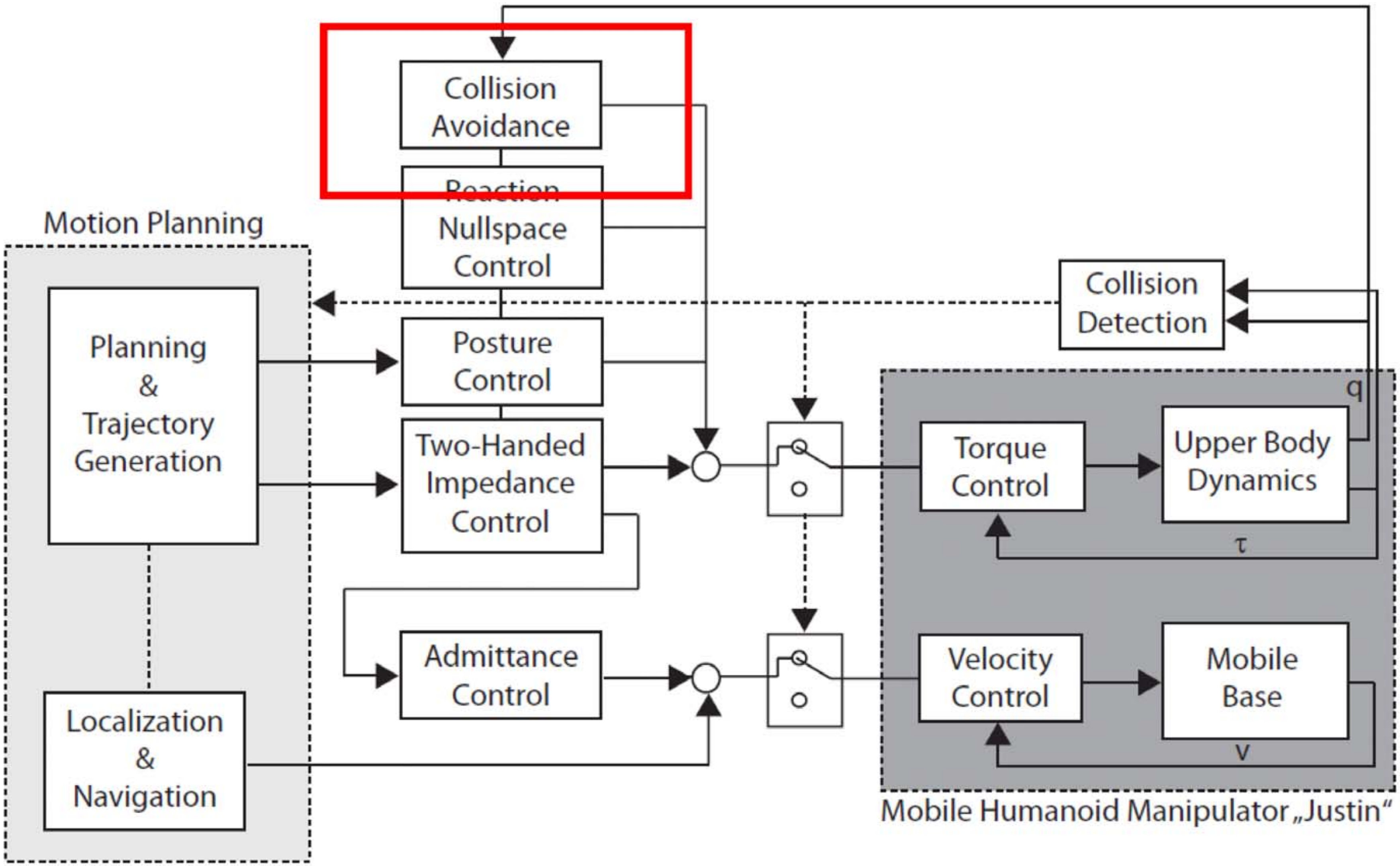
Compliant Control of the entire Robot

Rollin' Justin

- 53 active dof
- 150 kg



Control Architecture



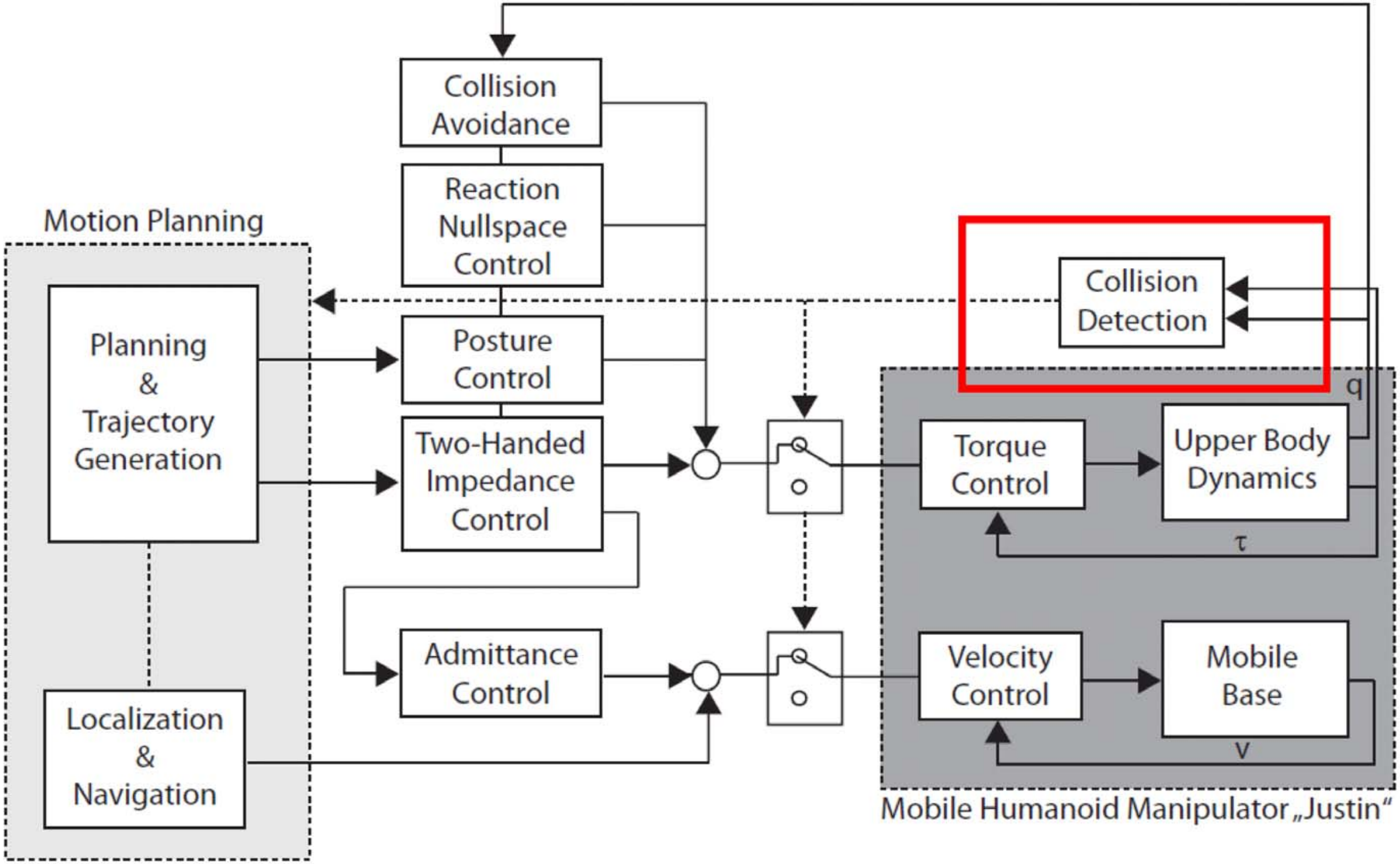
Collision Avoidance

Avoidance of collisions with repulsive potentials

Compatible with the passivity based approach

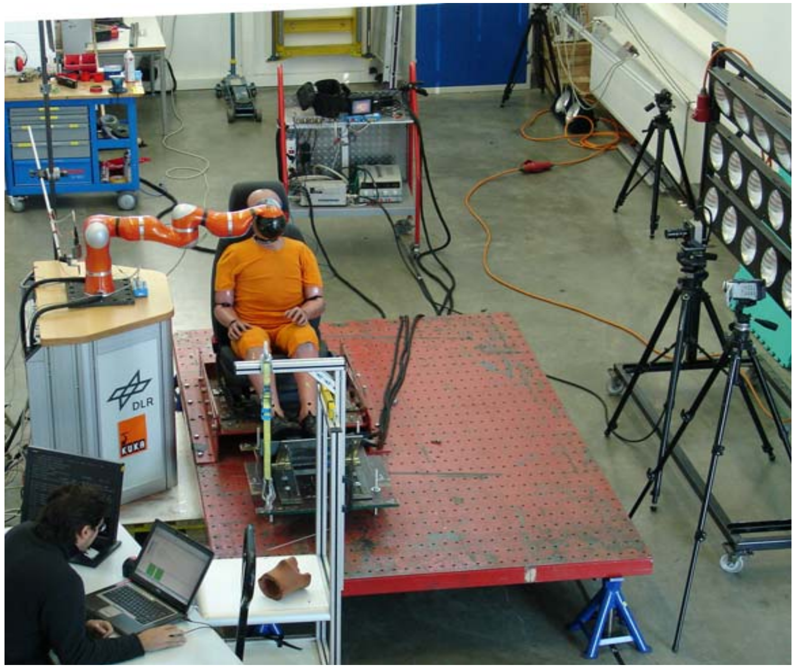
Cooperation with Univ. of Naples
(Lab of Bruno Siciliano)

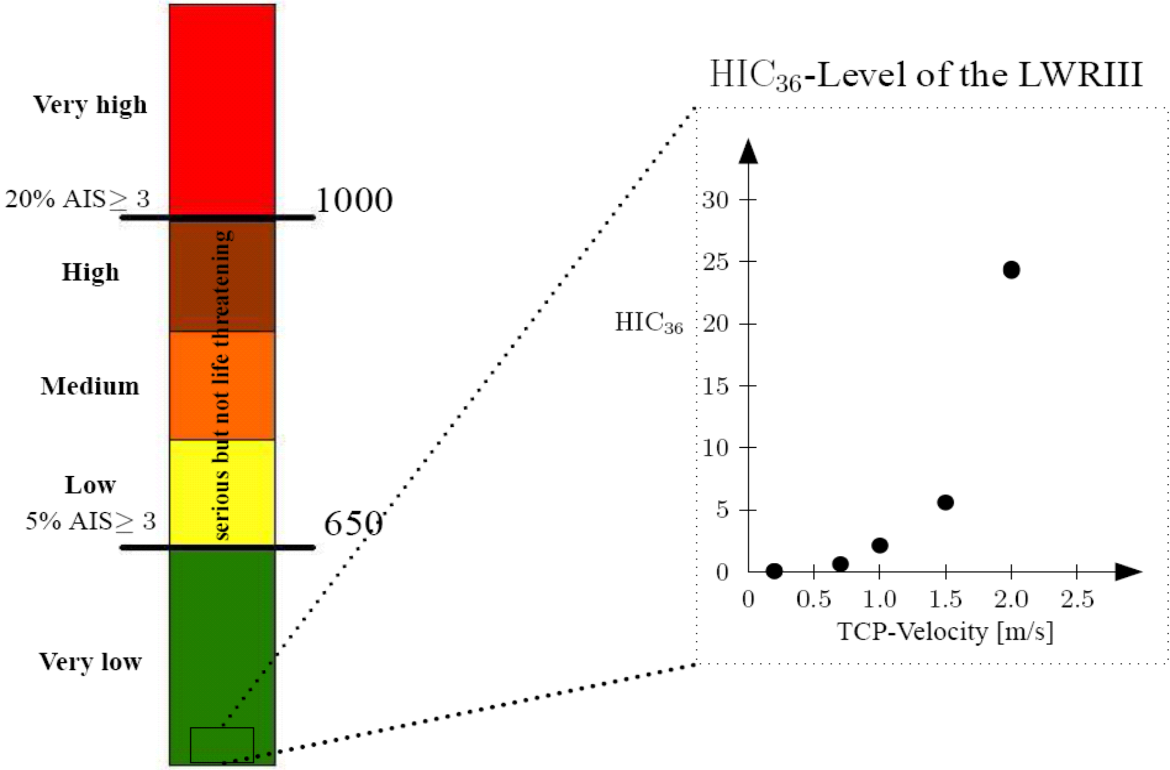
Control Architecture



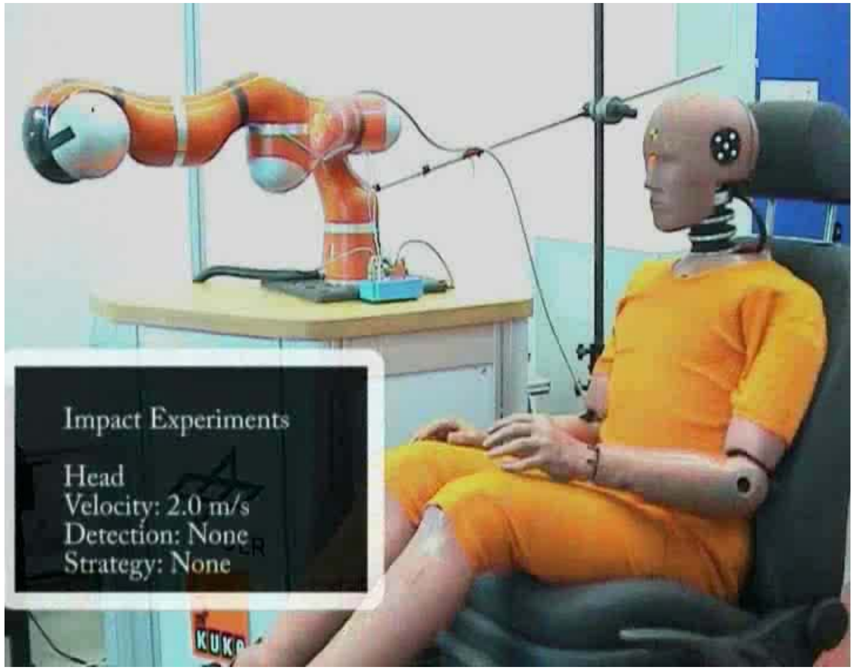
How Dangerous is the Robot Really?

First collision experiments with standardized methods for evaluation of injury potential and related safety measures in robotics



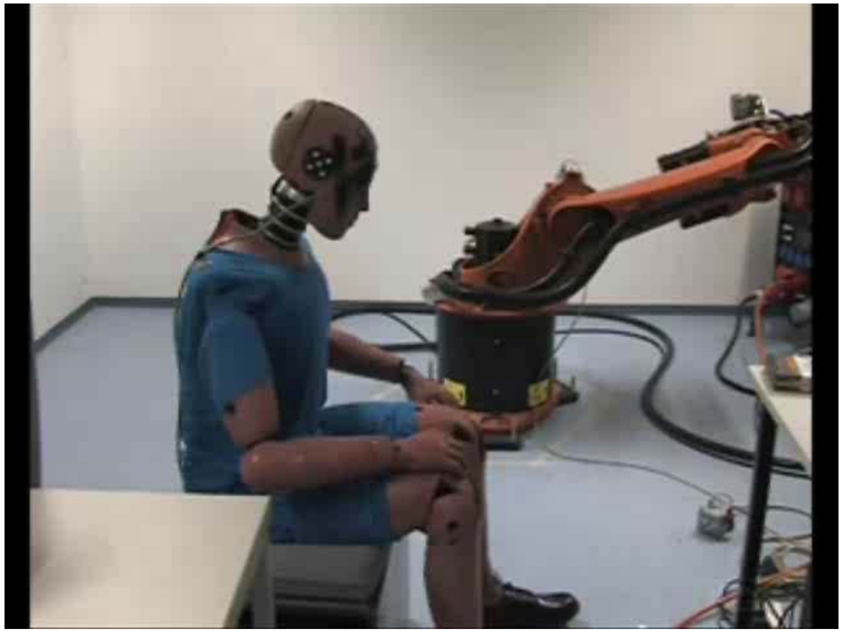


For all evaluated criteria, the LWR proved to be in the lower quarter of the green, uncritical area

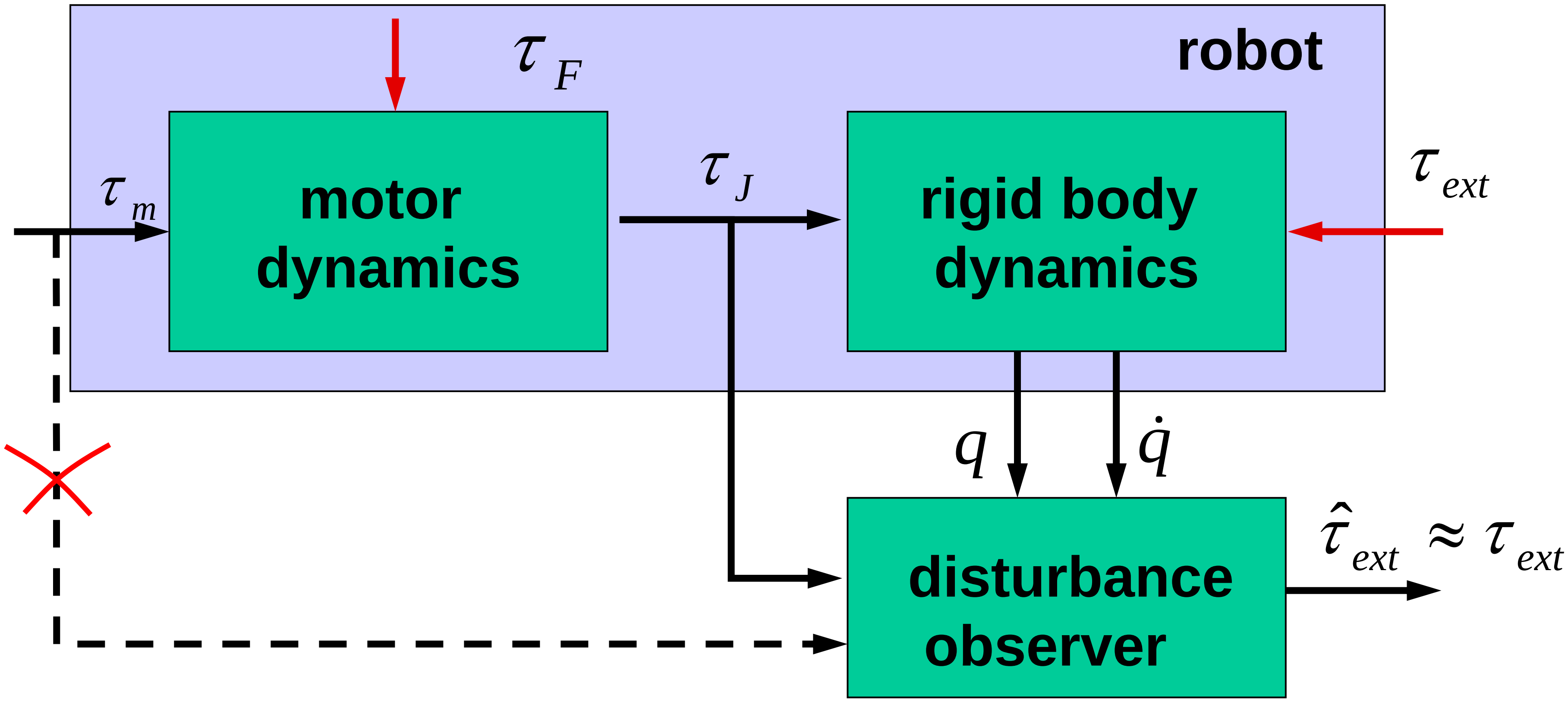

Impact Experiments
Head
Velocity: 2.0 m/s
Detection: None
Strategy: None


DLR
No Collision Detection
DLR


DLR
III. Impact Experiments LWRIII - Human

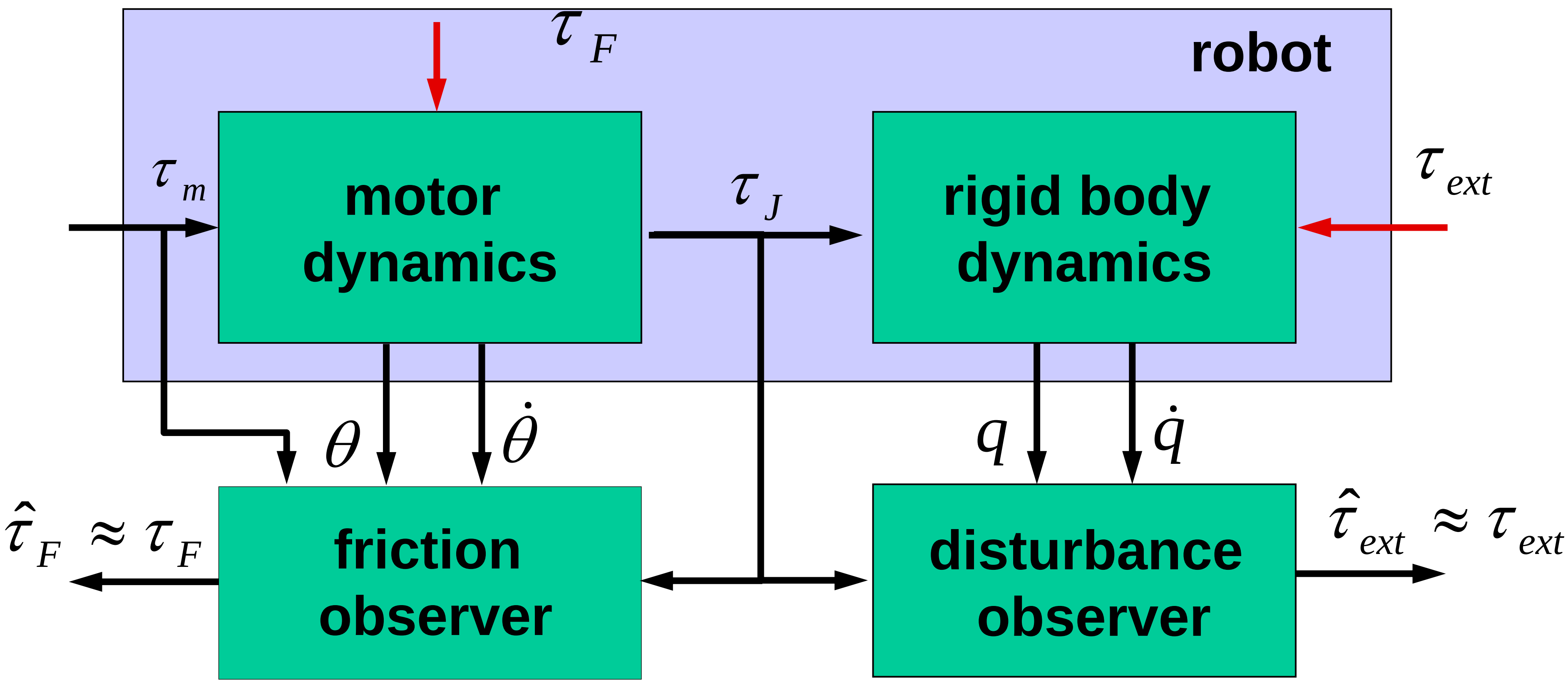


Disturbance Observer for Collision Detection



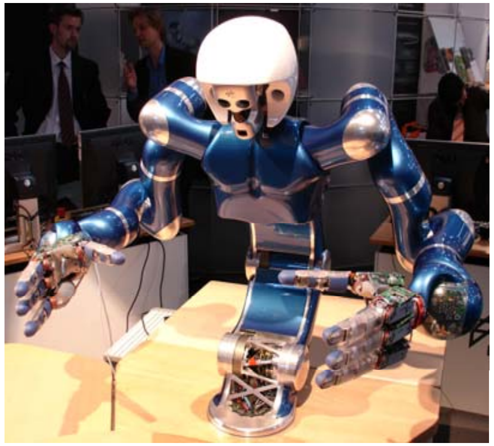
with Alessandro De Luca

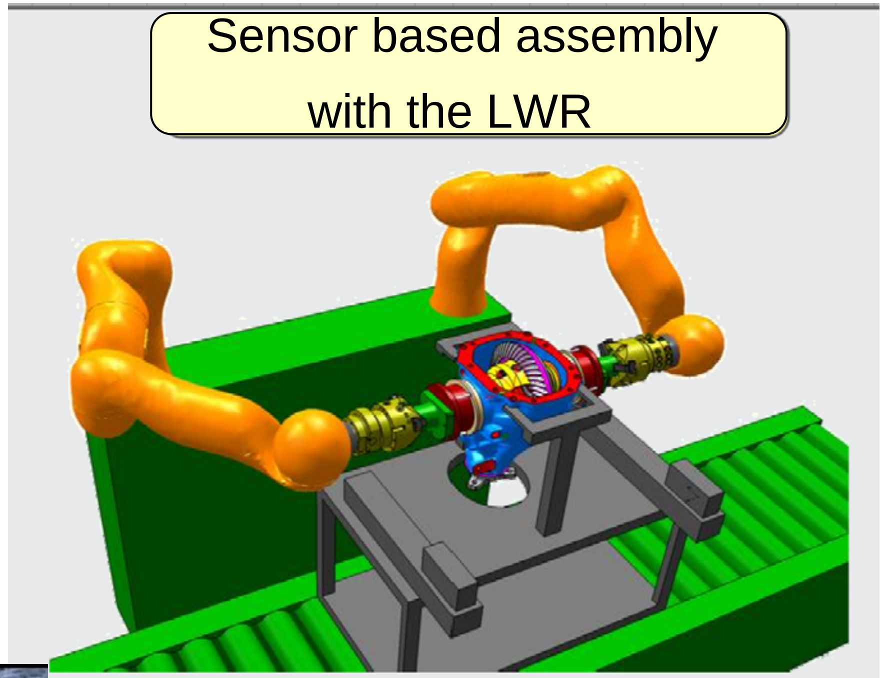
Disturbance Observer for Collision Detection and Friction Compensation

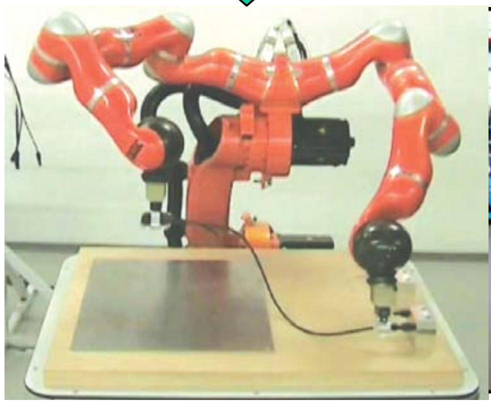


IROS'08
with Alessandro De Luca

First Application of the Technology in Automotive Industry





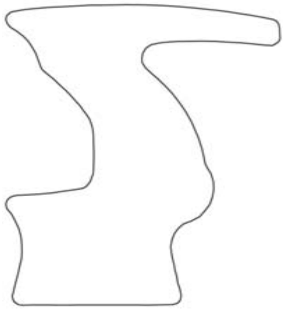


Mercedes-Benz

- Gearbox assembly tests since March 2009
- Production starting from September 2009

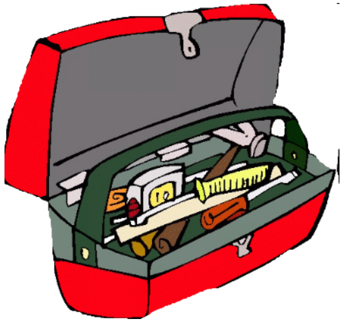
KUKA Demonstrator

Basic Idea

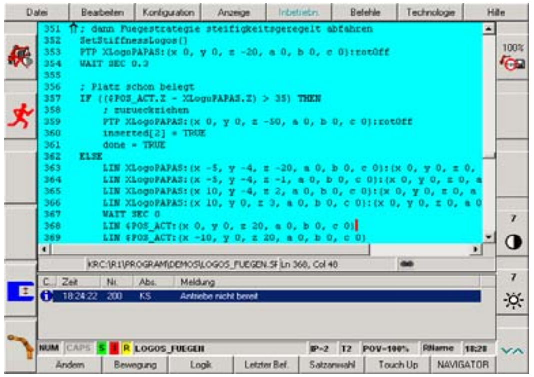


Geometrical Model
(from image processing / CAD)

Additional information:
- tolerance
- material properties
- Robot and camera accuracy
- additional constraints



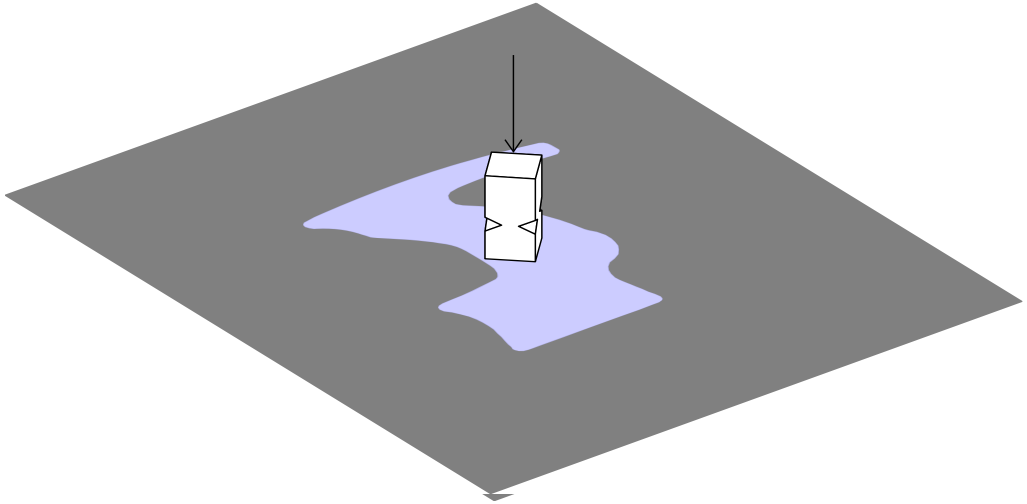
Assembly Planning Toolbox



KRL code

Online-Data:
- Position estimation
- Workspace limitations
- Robot configuration
- additional sensor data

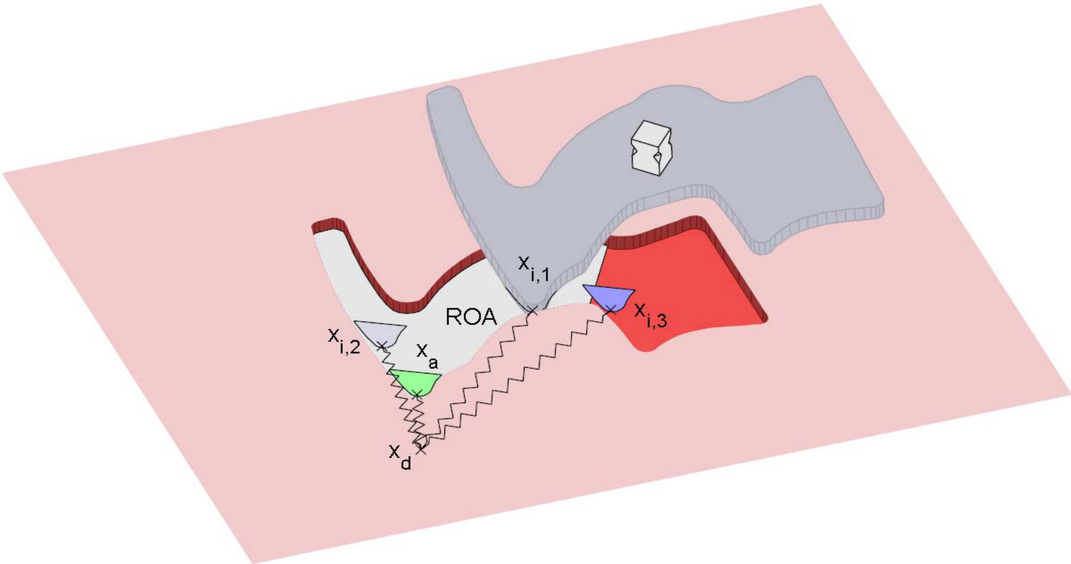
Vision and Impedance Based Assembly



$$\boldsymbol{F} = -\boldsymbol{K}(\boldsymbol{x} - \boldsymbol{x}_d) - \boldsymbol{D}\dot{\boldsymbol{x}}$$

- Problem statement : Automatically find and program the optimal strategy

Regions of Attraction (ROA)

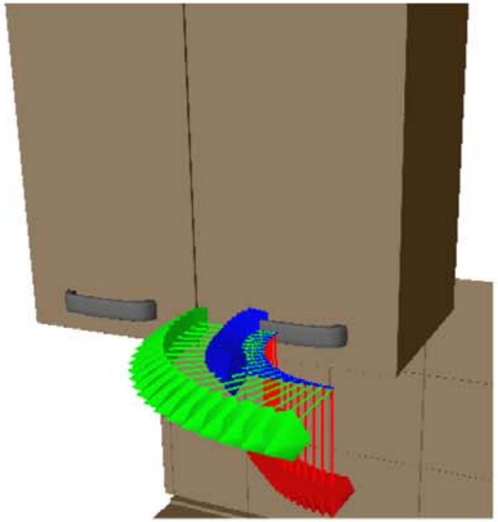


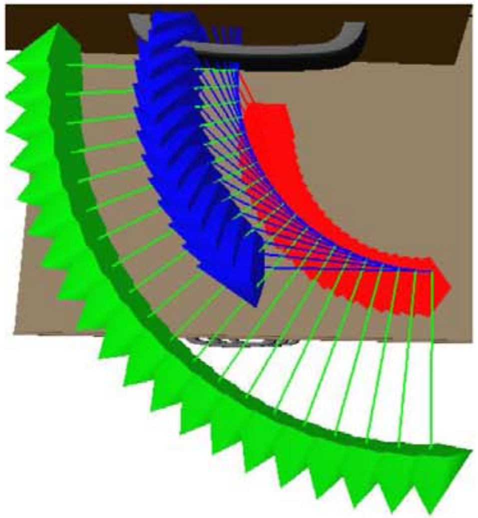
- The contact point with maximal ROA provides maximal robustness w.r.t. sensor and mode uncertainties
- A local Lyapunov Based convergence analysis is possible based on the impedance controlled robot and the contour geometry

Using a Model of the Reachable Workspace to Position Mobile Manipulators for 3-d Trajectories

Franziska Zacharias, Wolfgang Sepp, Christoph Borst and Gerd Hirzinger

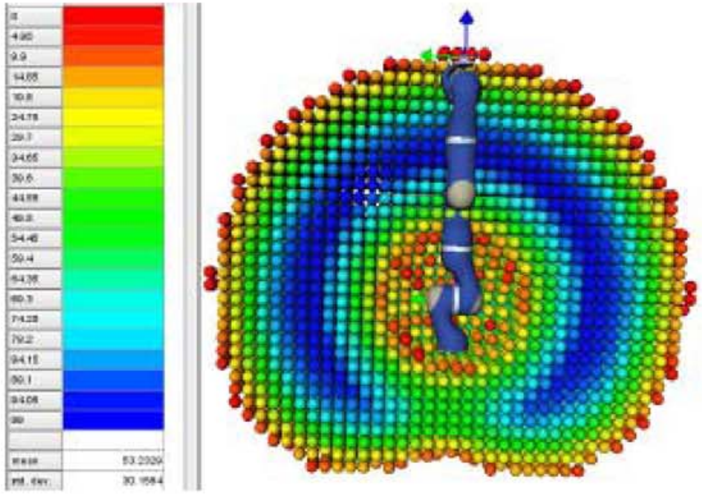
- In interaction with the environment (doors) specific 3d trajectories are followed
- The constrained trajectories are not executable in every part of the workspace
- Task planner has to:
  - Determine if and how a robot's upper body or its base can be moved to fulfill the task

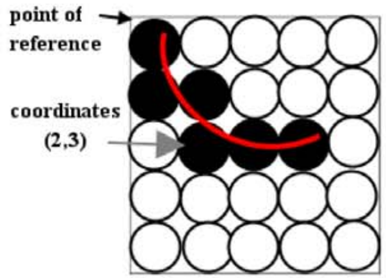


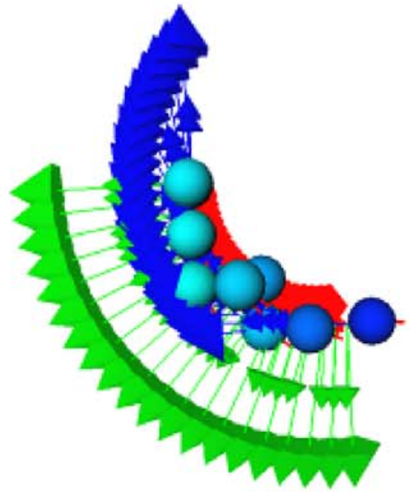


Placement for 3d trajectories

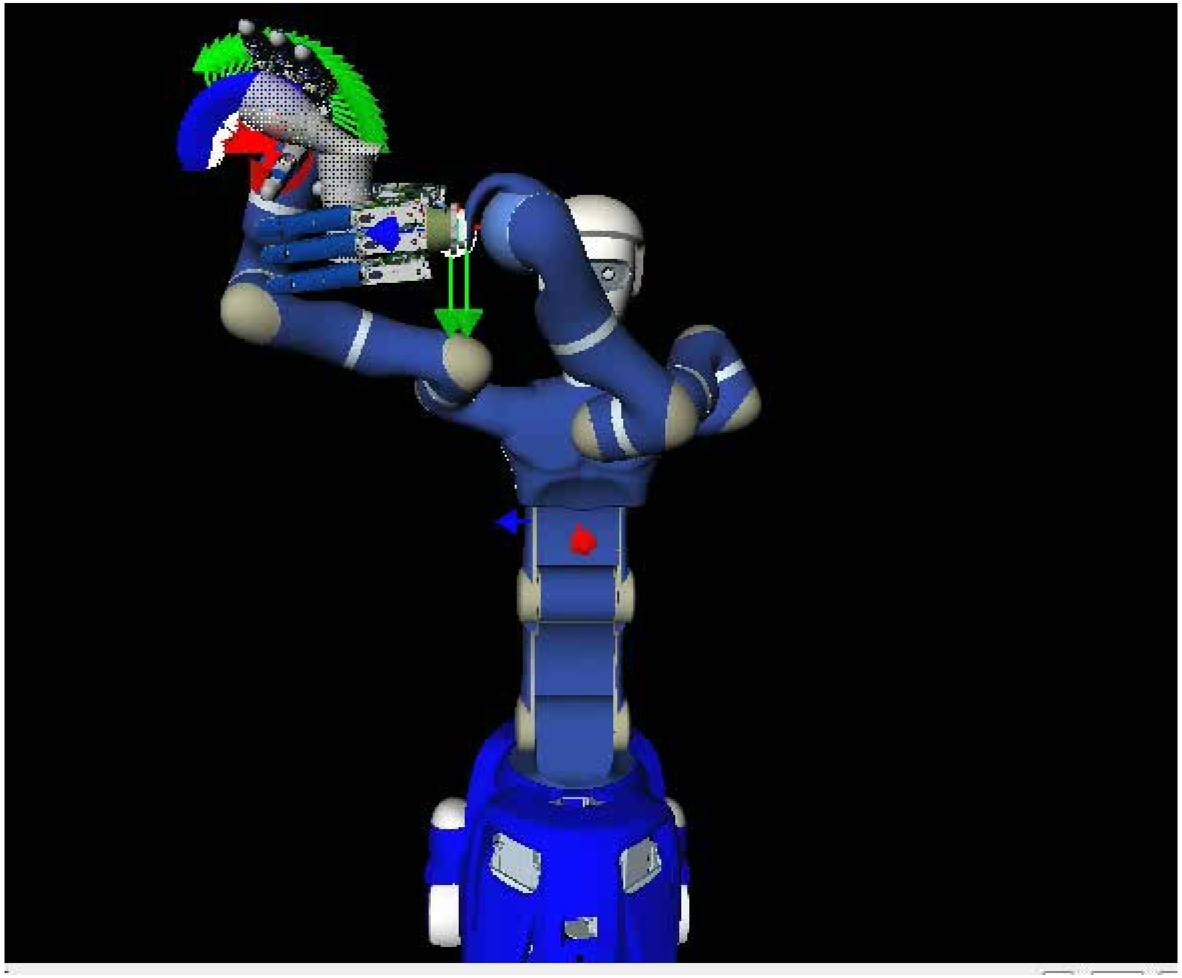
- Online computation of placements of manipulator for task-related 3-d trajectories
- Discrete representation of the robot arm workspace is used (Capability map)
- Trajectories are interpreted as patterns
- Search for the patterns using multi-dimensional correlation
- Evaluation in simulated positioning tasks





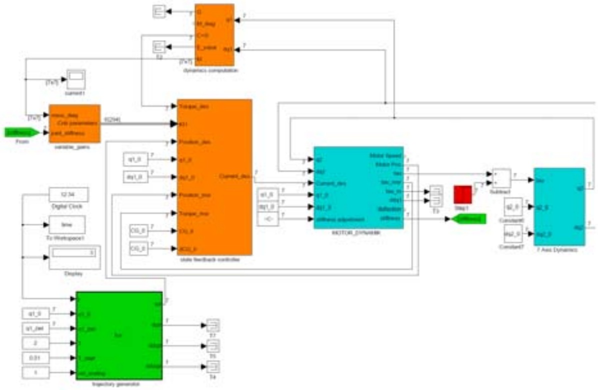


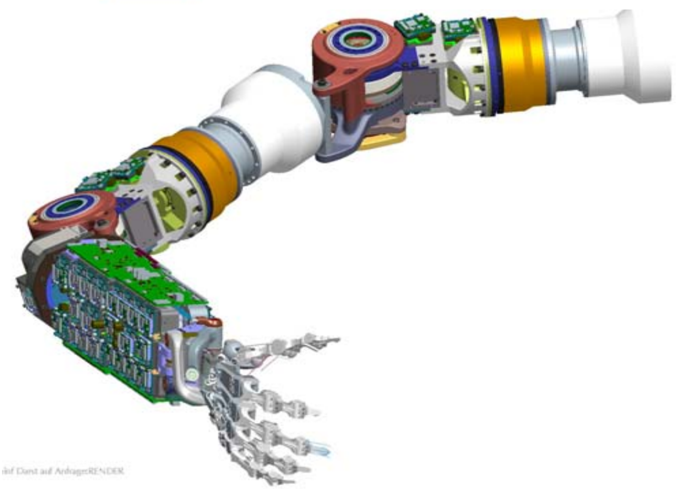
Application of the Planner



Service Robotics

A Hand-Arm System for Space Assistance





- Variable, nonlinear stiffness
- Strongly coupled joints

Extension of the passivity based control approaches to the VIA robots:

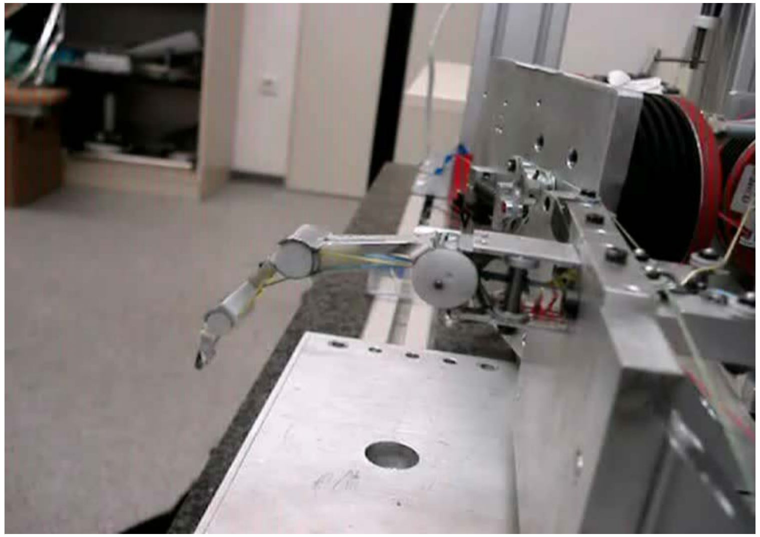
Performance Validation

Finger:

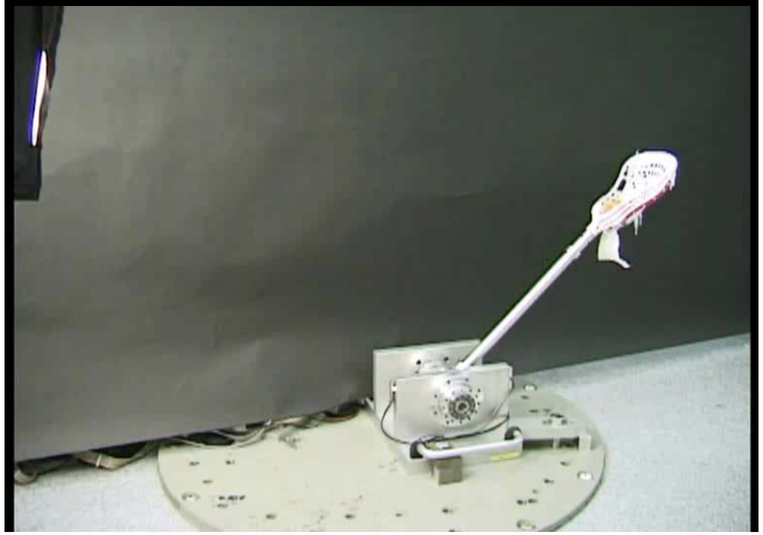
- Robust w.r.t. impacts

Arm Joints:

- Increase of performance due to energy storage

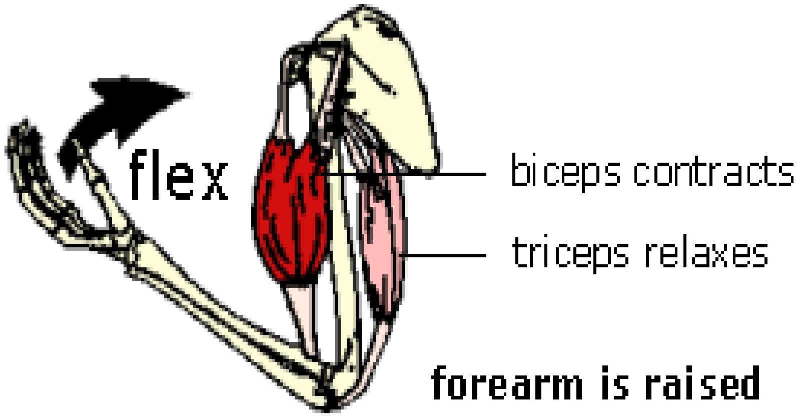


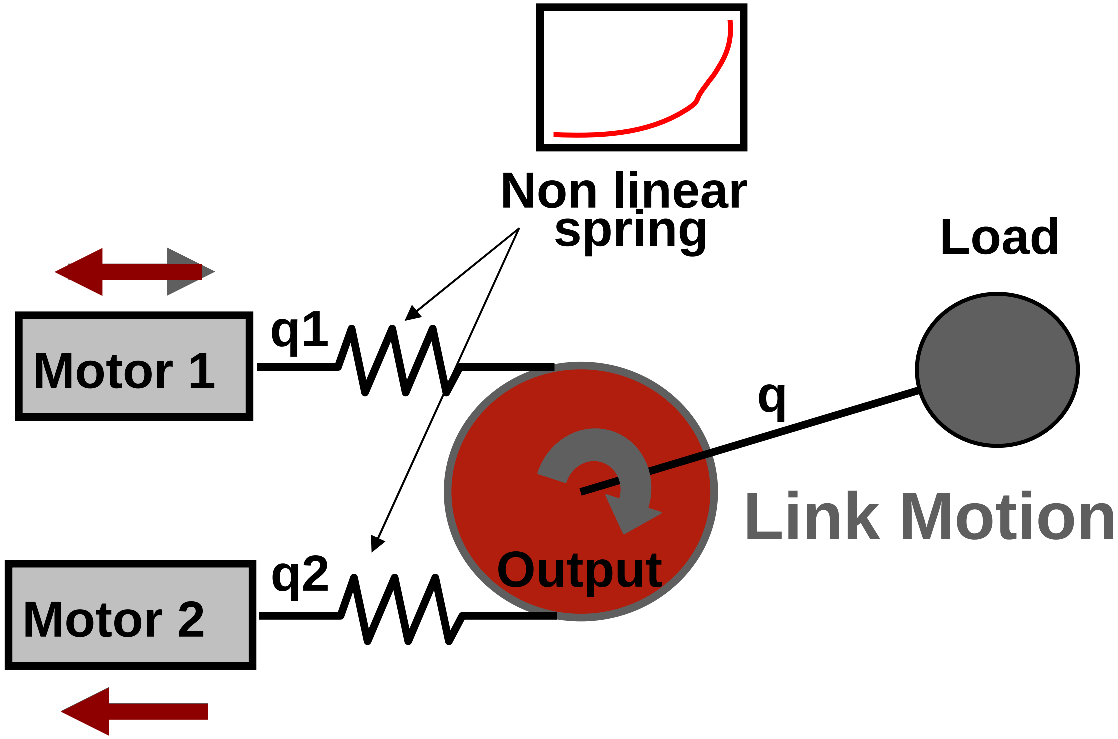
Rigid joint



VIA joint

New Actuation concepts: Variable Compliance Actuation (VIA)





The antagonistic concept

Stiffness adjustment

Several European Project following this idea: PHRIENDS

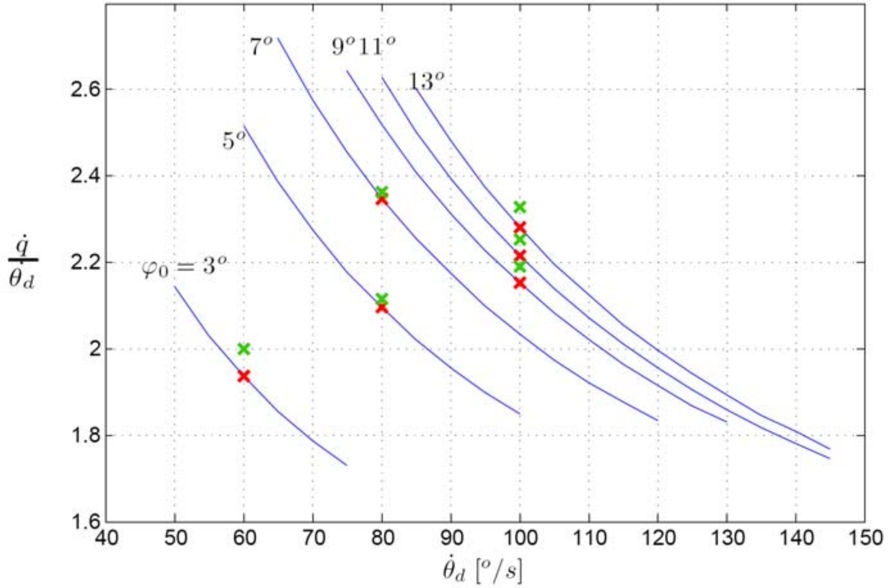
VIACTORS

LOCOMORPH

EMORPH

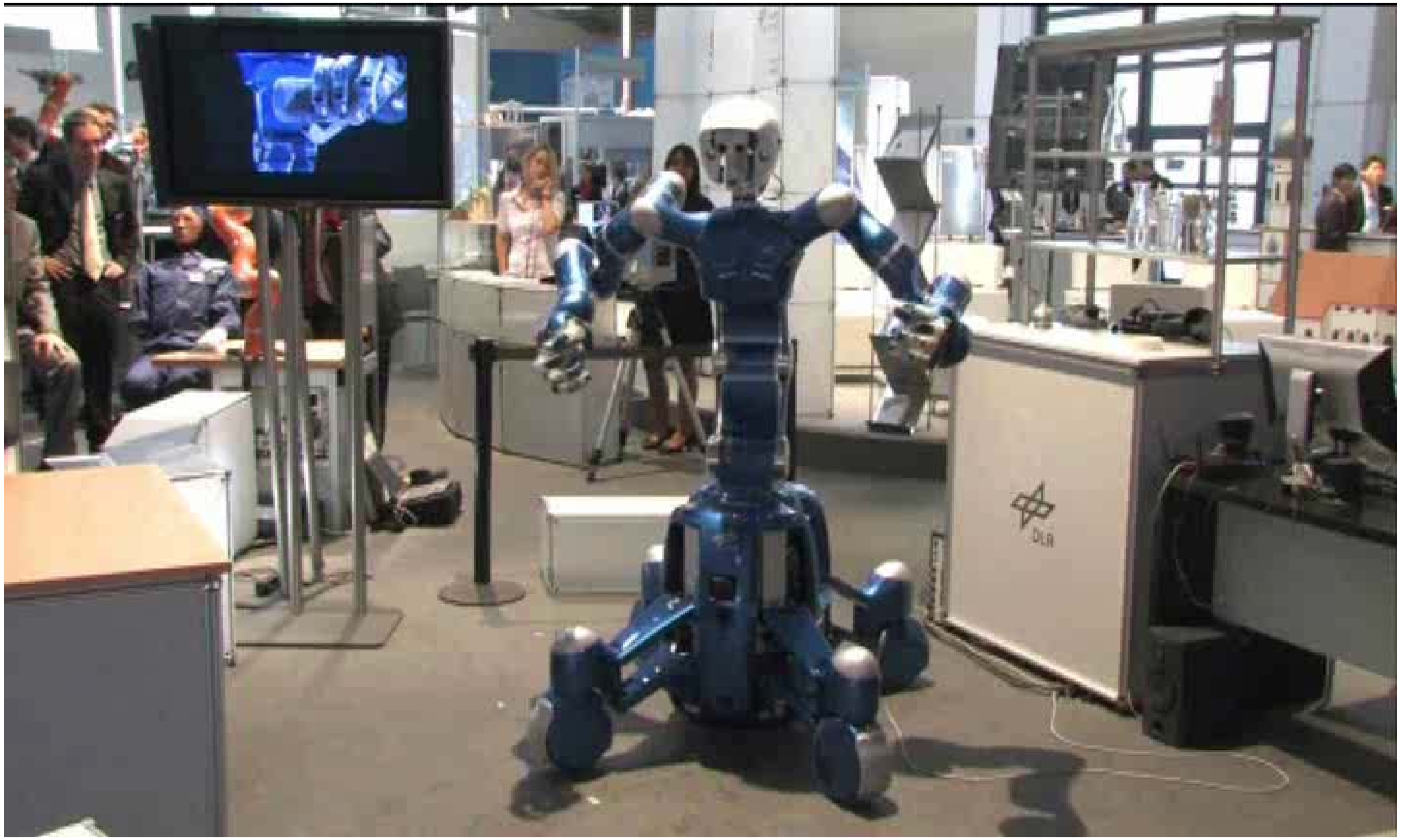
} FET Initiative Future and emerging Technologies

Optimal Control for Maximal Performance



Optimized
stiffness and motion trajectory

Justin at AUTOMATICA Fair



Task Programming

- Task Programming environment
- Open Software Architecture with real-time interface
- Speech recognition and synthesis
- Interactive guidance of the robot using its compliance
- Path planning