Safe Human-Robot Interaction

Sami Haddadin

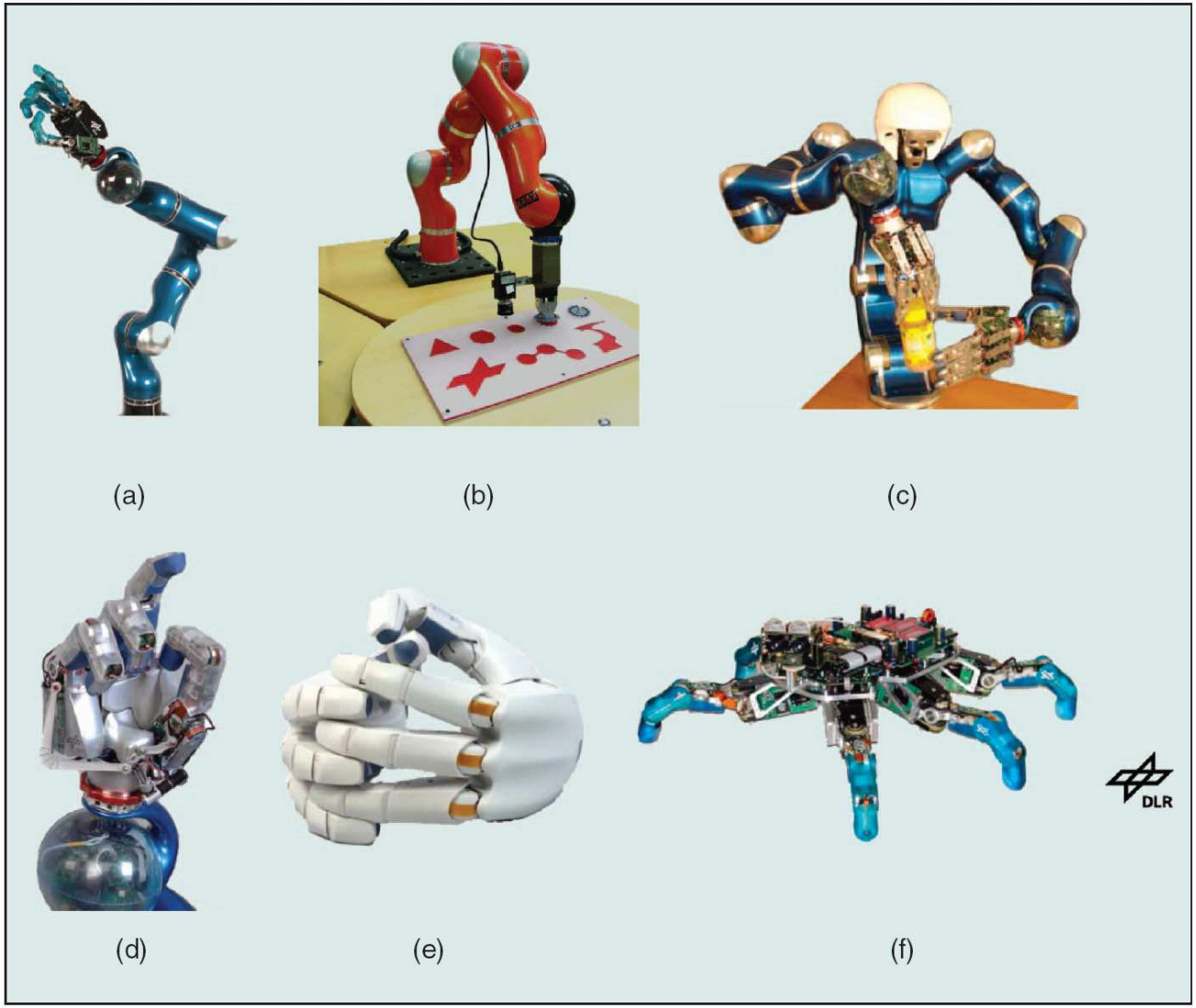
Institute of Robotics and Mechatronics
German Aerospace Center (DLR), Germany
www.robotic.dlr.de/Sami.Haddadin

30.09.2011

Outline

Industrial robots

The DLR Robots



Why safety evaluation?

Der Kanzler

Robotic Co-worker at fair

Possible applications

- Space robots and robonauts
- Industrial co-workers
- Service robots
- Rehabilitation robotics
- Surgical robotics
- **Assistive devices:** brain controlled LWR

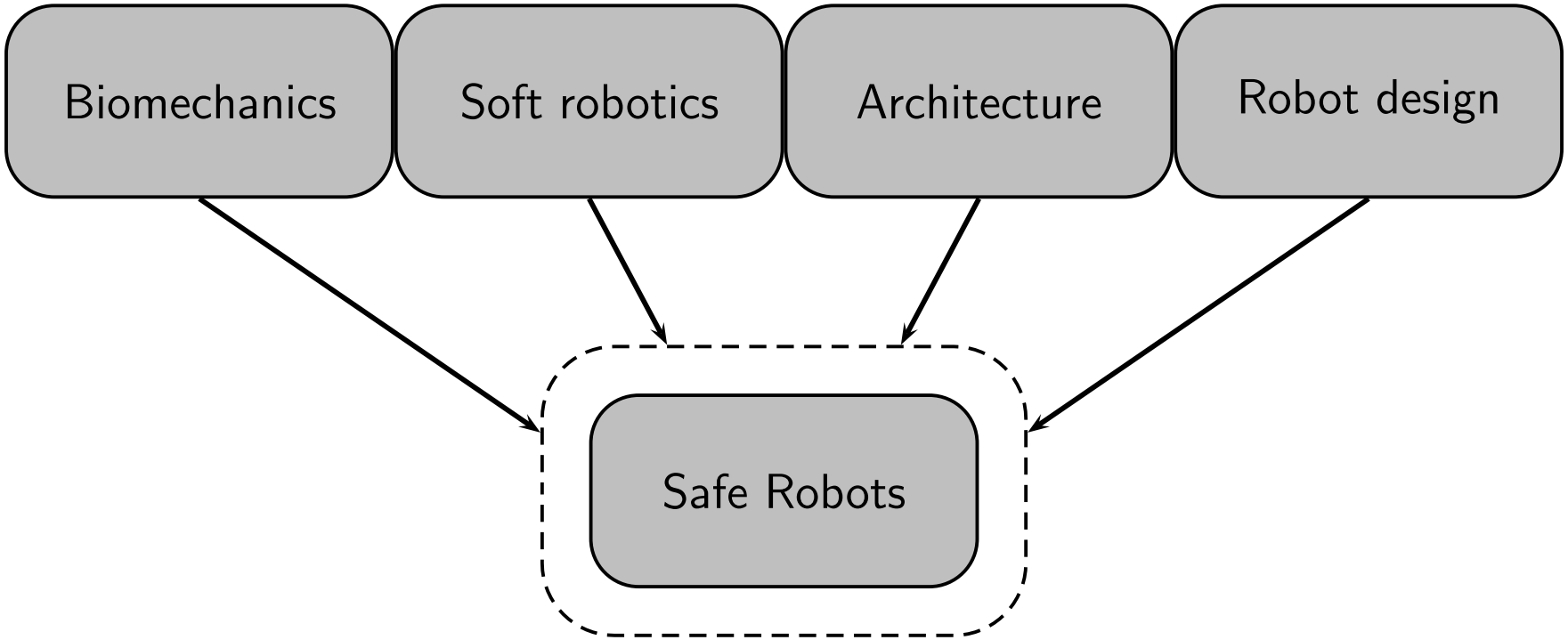
All applications aim at close physical human-robot interaction → **safety is of primary concern!**

safe physical Human-Robot Interaction

Problem statement

How do I prove that a robot is safe and cannot cause any harm?

Contributions



Approach

1. Select and/or define and classify the impact type
2. Select the appropriate biomechanical injury measure(s)
3. Evaluate the potential injury of the human
4. Quantify the influence of the relevant robot parameters
5. Evaluate the effectiveness of countermeasures for injury reduction and prevention

Severity Indices for the head

Annotation: The given **lower** boundaries represent a 5% probability of occurring $\mathrm{AIS} \geq 3$ injury (serious).

Head: Head Injury Criterion

$$\mathrm{HIC}_{36} = \max_{\Delta t} \left\{ \Delta t \left(\frac{1}{\Delta t} \int_{t_1}^{t_2} \ddot{\mathbf{x}}_H \mathrm{d}t \right)^{\left(\frac{5}{2}\right)} \right\} \leq 650$$

$$\Delta t_{\max} = \max \{ t_2 - t_1 \} \leq 36\mathrm{ms}$$

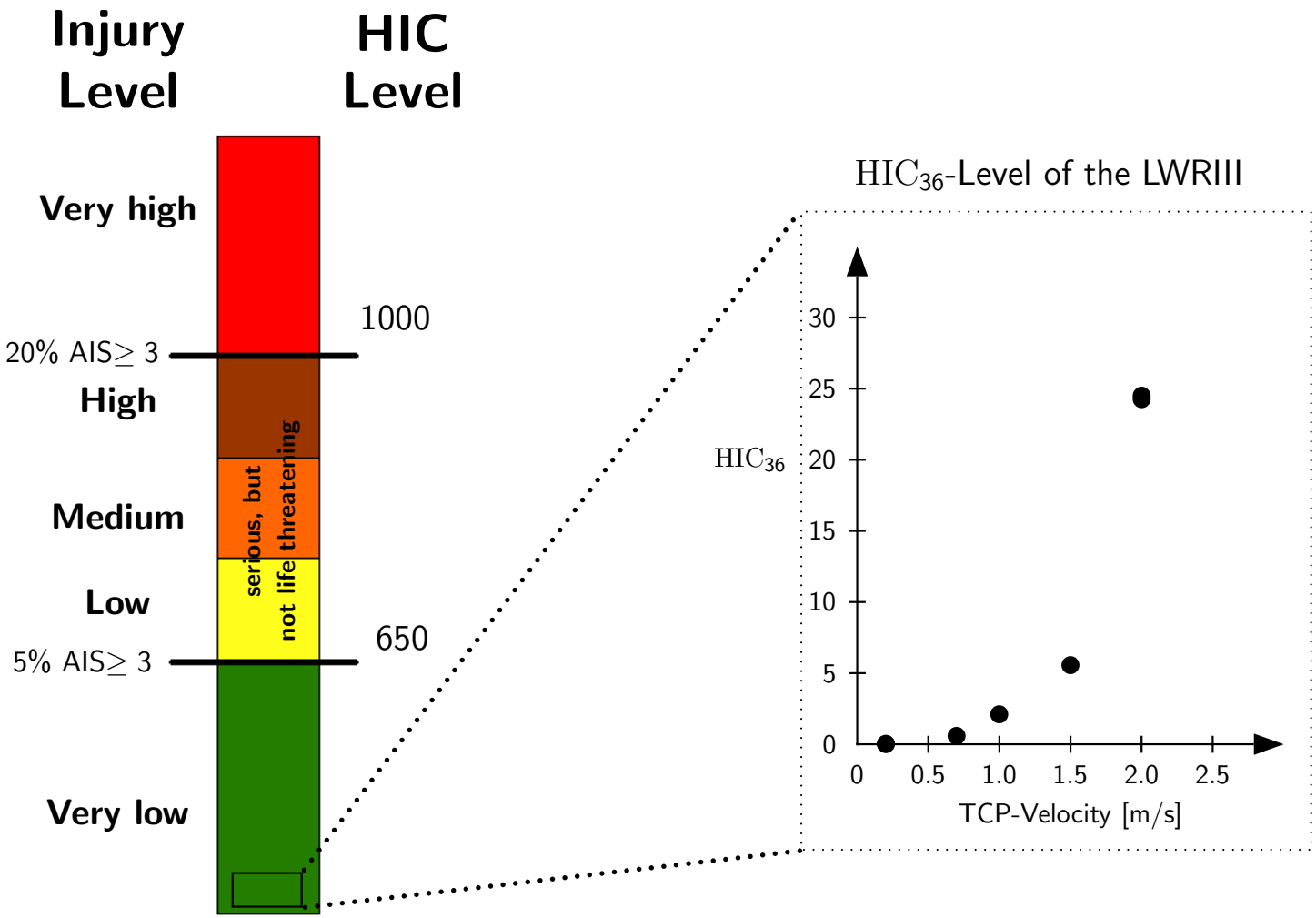
Head: 3ms-Criterion

$$\ddot{\mathbf{x}}_H^{\Delta t} \leq 72\mathrm{g}$$

$$\Delta t = 3\mathrm{ms}$$

Crash-tests at ADAC

Results of Head Injury Criterion



Impact tests with the human chest

Robot-Human impacts: chest

confidence

ADAC tests part II

Soft-tissue analysis

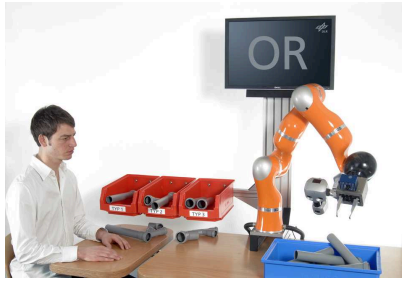
Towards the Robotic Co-Worker

Desired capabilities

Robotic co-workers have to be

- suitable for diverse applications,
- fast, precise, compliant, high load-to-weight ratio,
- highly sensorized,
- safe, reliable, and
- easy to program.

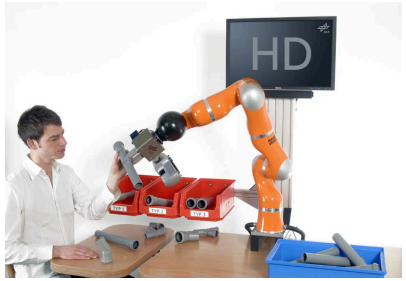
Robotic Co-worker: SMErobot



1

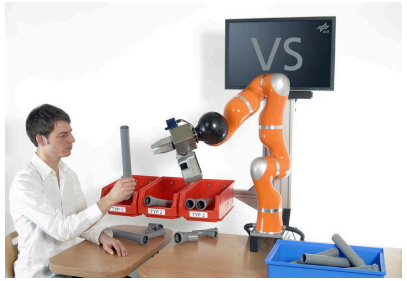
2

3

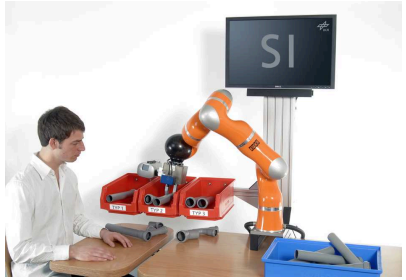


4

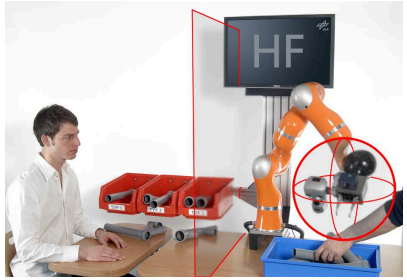
5



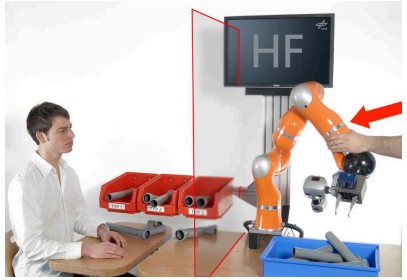
6



7



8



9

Robot control and trajectory generation

Desired capabilities

Control schemes for

- soft robotics control
- collision and contact detection, classification, and reaction

Reactive motion generation with

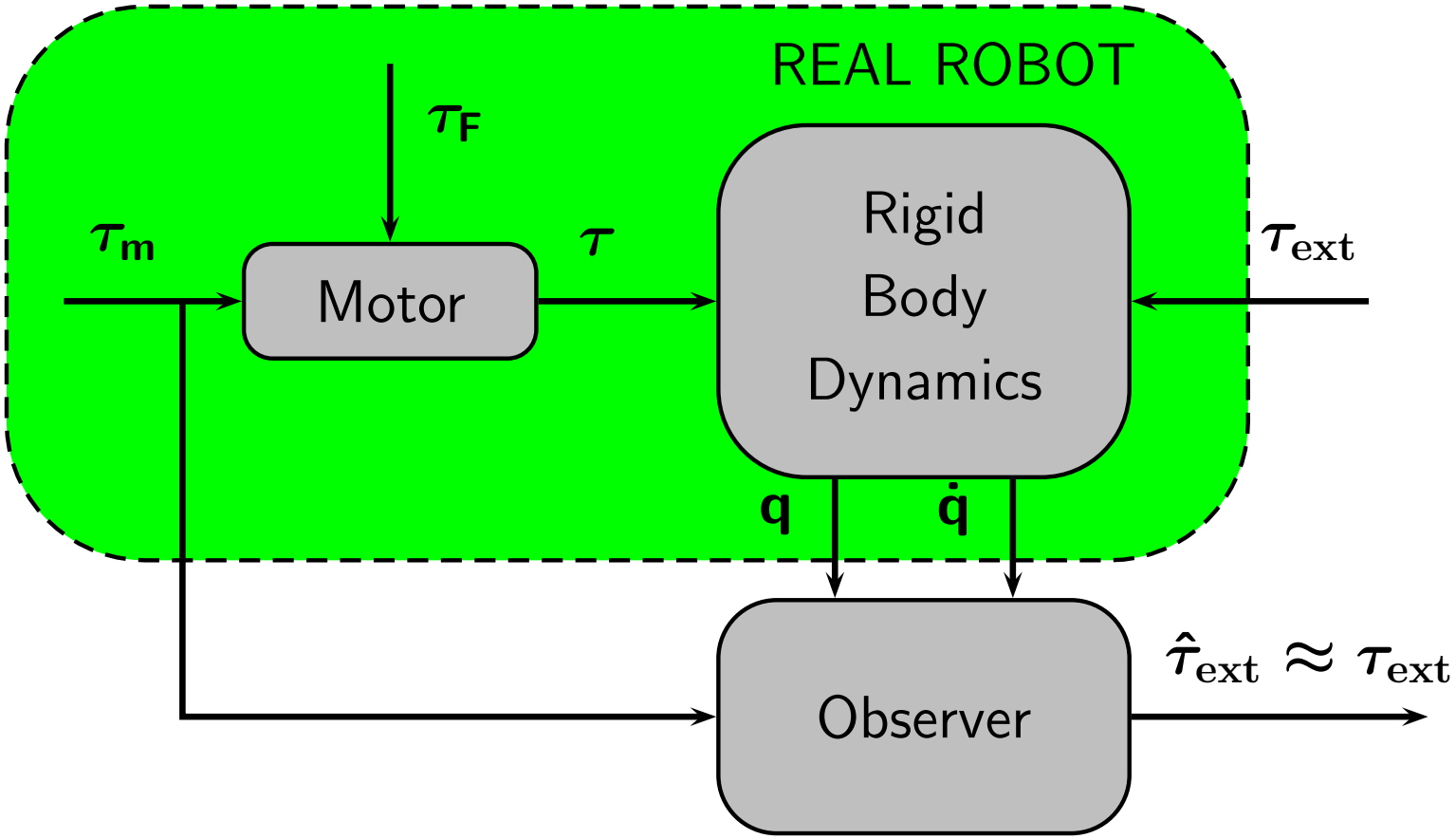
- task preservation
- task relaxation

based on both **force** and **vision** information.

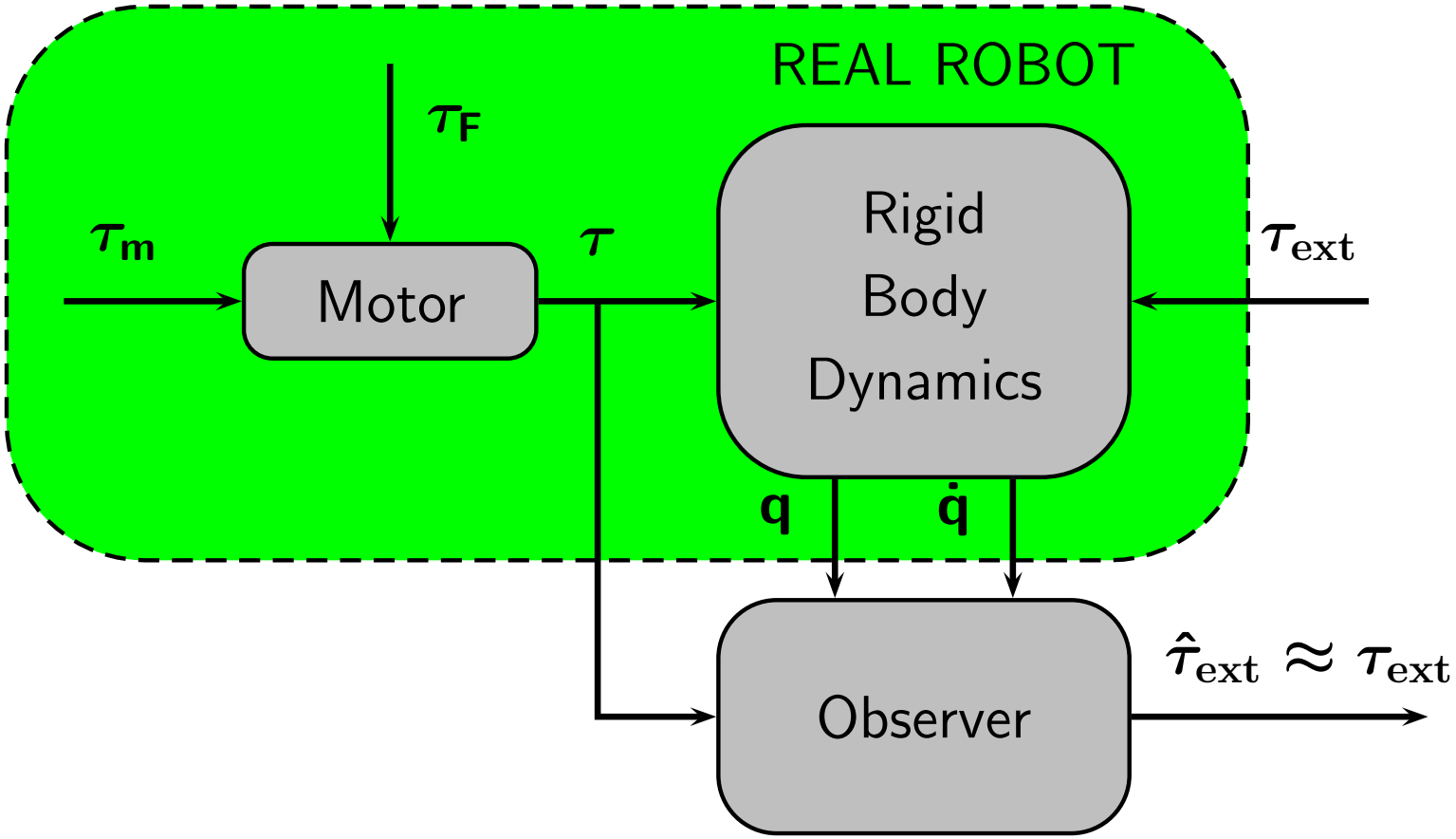
Soft robotics features

Collision Detection & Reaction

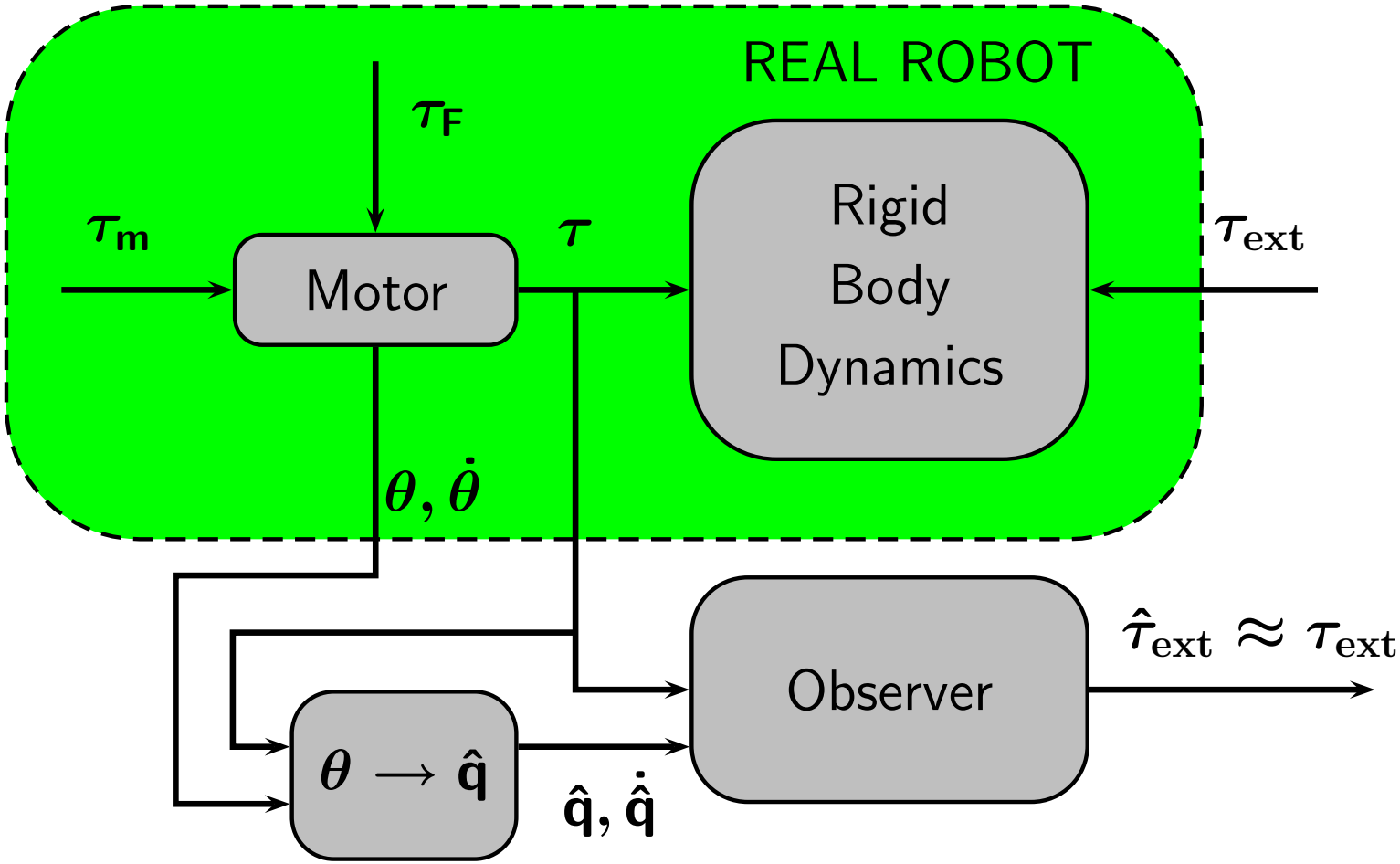
Collision detection: $\hat{\mathbf{r}}$-Observer



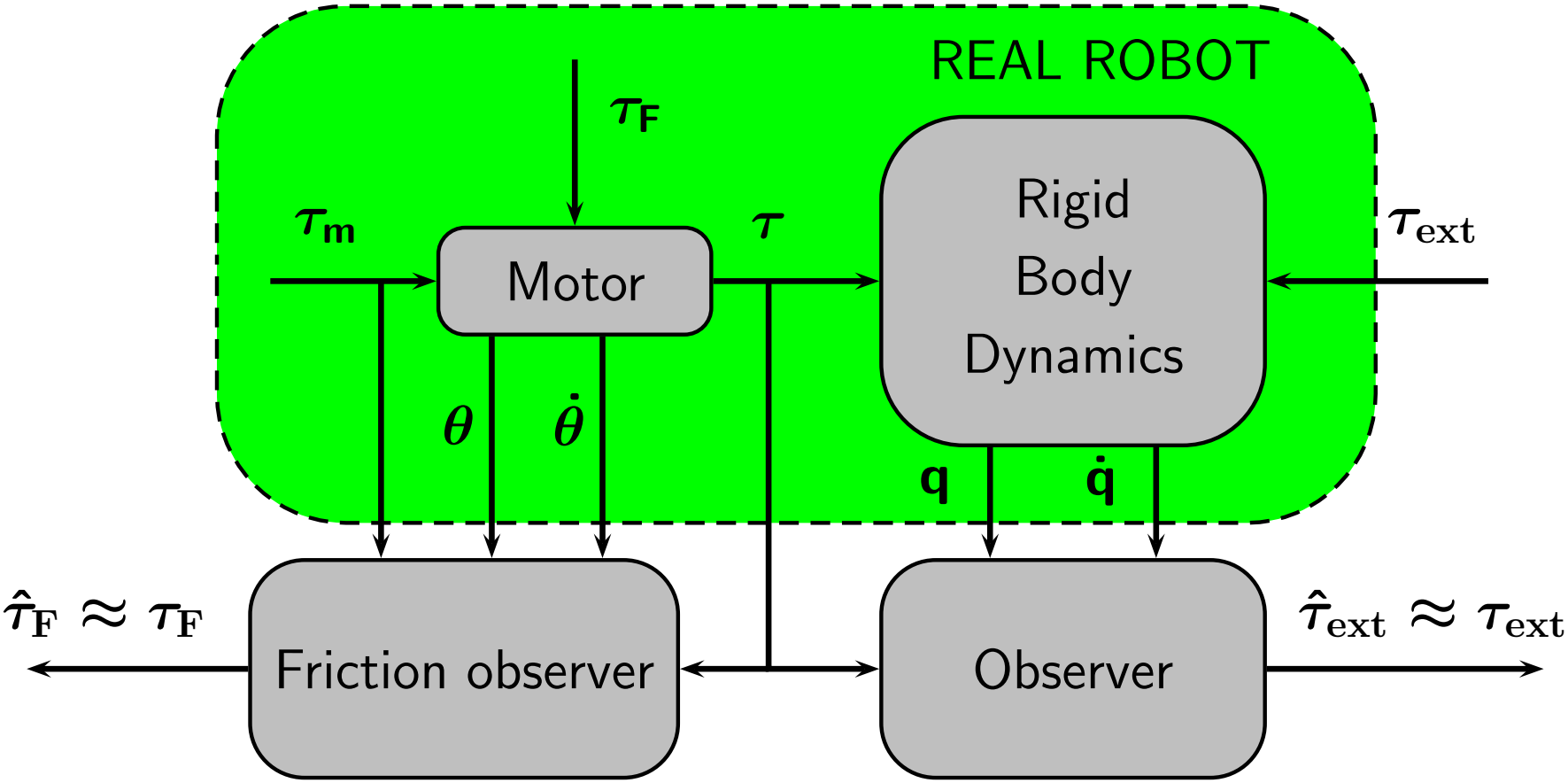
Collision detection: $\hat{\mathbf{r}}$-Observer



Collision detection: $\hat{\mathbf{r}}$-Observer



Collision detection: $\hat{\mathbf{r}}$-Observer



Collision detection and reaction

Miro: Pringles test

Task preservation

Task preserving motion schemes:

Stay on the desired trajectory but be compliant at the same time.

CCD with Justin

CCD Justin

Trajectory scaling: proximity

Task relaxation

Task relaxing motion schemes:

Keep the desired goal while being compliant during motion.

collision avoidance: experiments

Experiment with Kinect

Simulation Random 2D

2D random fields

6D Collision avoidance experiment

CFCA LWR-III

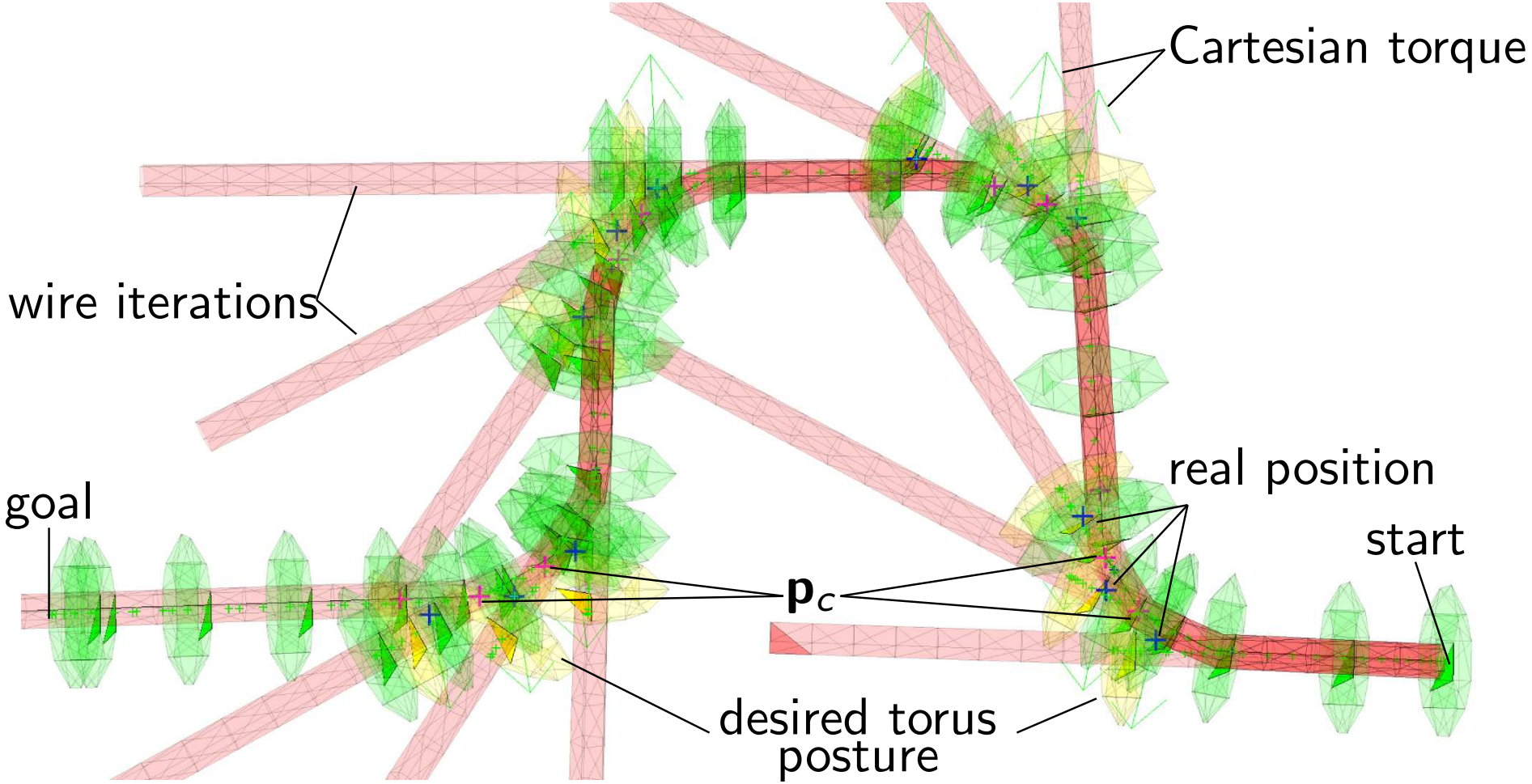
Box Experiment (without PF on rotation)

Tactile exploration

Hot-Wire experiment

Hot wire

Experiment: Hot Wire 1



Behavior based control: experiments

Contact/collision recovery for interaction

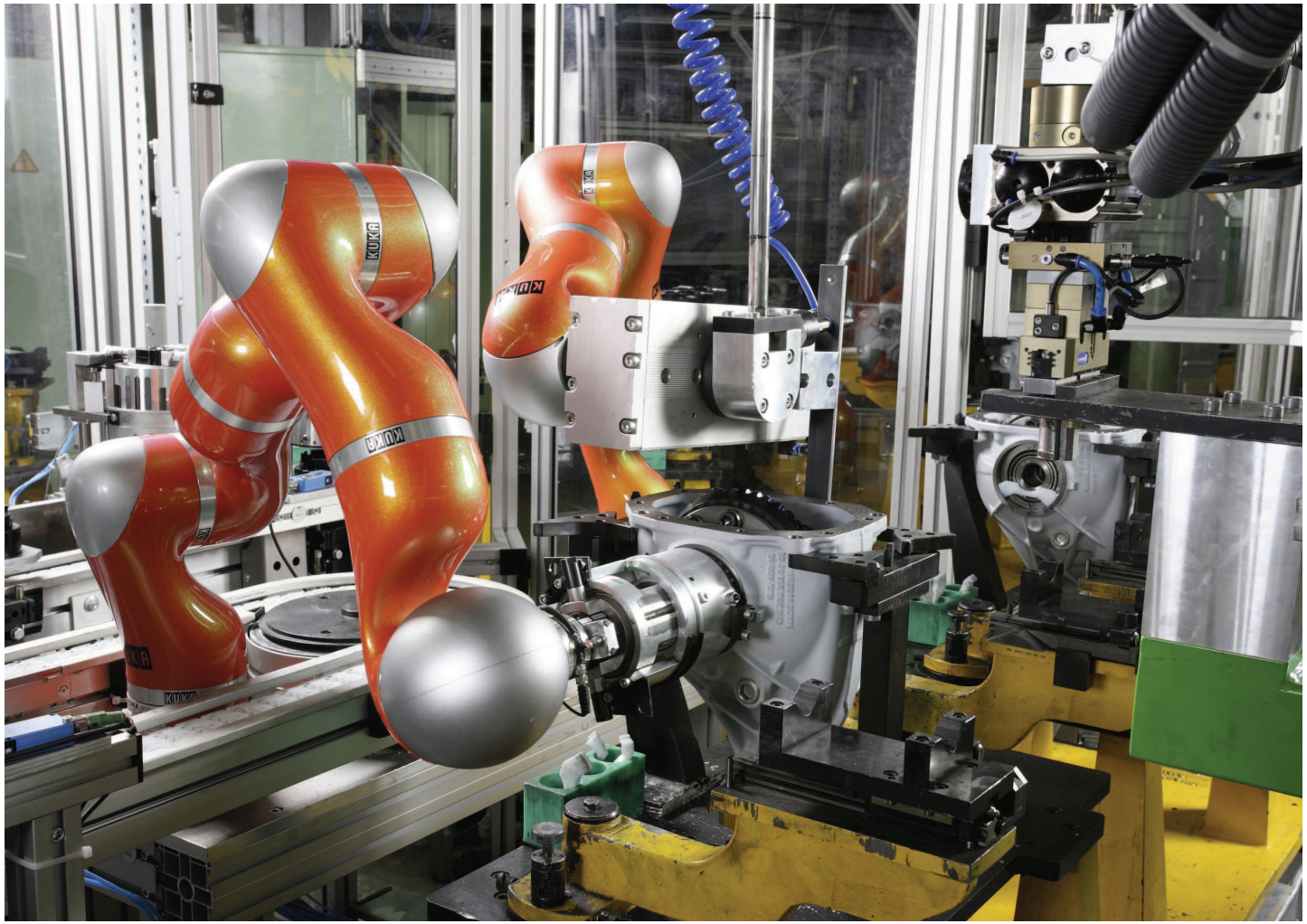
Behavior based control MIRO

Current state

The LWR-III

- has entered production
- no fences anymore in prototypical stadium
- ongoing work: large scale applications with physical human-robot interaction
- ongoing work: full qualification in everyday tasks

LWR-III at Daimler-Benz



Thank you very much!