Safe Human-Robot Interaction

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OUTLINE

1. Safe physical Human-Robot Interaction

2. Towards the Robotic Co-Worker
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

- Biomechanics
- Soft robotics
- Architecture
- Robot design

Safe Robots
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 AIS ≥ 3 injury (serious).

**Head: Head Injury Criterion**

\[
\text{HIC}_{36} = \max_{\Delta t} \left\{ \Delta t \left( \frac{1}{\Delta t} \int_{t_1}^{t_2} \dddot{x}_H \, dt \right)^{\frac{5}{2}} \right\} \leq 650
\]

\[
\Delta t_{\text{max}} = \max \{ t_2 - t_1 \} \leq 36 \text{ms}
\]

**Head: 3ms-Criterion**

\[
\dddot{x}_H^{\Delta t} \leq 72 \text{g}
\]

\[
\Delta t = 3 \text{ms}
\]
Crash-tests at ADAC
RESULTS OF HEAD INJURY CRITERION

Injury Level | HIC Level
---|---
Very high | 1000
High | 650
Medium | 5% AIS $\geq$ 3
Low | 20% AIS $\geq$ 3
Very low | 5% AIS $\geq$ 3

HIC$_{36}$-Level of the LWRIII

HIC$_{36}$ vs TCP-Velocity [m/s]
Impact tests with the human chest

Robot-Human impacts: chest
safe physical Human-Robot Interaction

confidence
safe physical Human-Robot Interaction

Towards the Robotic Co-Worker

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
safe physical Human-Robot Interaction

Towards the Robotic Co-Worker

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: \( \hat{r} - \text{Observer} \)

\[ \hat{\tau}_{\text{ext}} \approx \tau_{\text{ext}} \]

\[ \hat{\tau}_{\text{ext}} \]

[Diagram of real robot with motor, dynamics, observer, and external torque]
Collision detection: $\hat{\tau}$-Observer

\[
\tau_m \rightarrow \tau_F \rightarrow \tau \rightarrow \tau_{ext} \\
\tau_m \rightarrow \tau_{ext} \approx \tau_{ext}
\]

Motor \hspace{2cm} REAL ROBOT

Rigid Body Dynamics

Observer

$q \rightarrow \hat{q}$
Collision detection:  $\hat{r}$-Observer

$\tau_m$  $\Rightarrow$ Motor  $\tau$  $\Rightarrow$ Rigid Body Dynamics  $\Rightarrow$ Observer

$\theta, \dot{\theta}$  $\Rightarrow$ $\hat{\theta}, \dot{\hat{\theta}}$

$\tau_F$  $\Rightarrow$ $\tau$

$\hat{\tau}_{ext} \approx \tau_{ext}$

$\theta \rightarrow \hat{\theta}$  $\Rightarrow$ $\hat{\theta}, \dot{\hat{\theta}}$
**Collision detection: \( \hat{r} \)-Observer**

![Collision Detection Diagram](image)

\[
\tau_{ext} \approx \tau_{ext}
\]

\[
\hat{\tau}_F \approx \tau_F
\]

\[
\hat{\tau}_F \approx \tau_F
\]

\[
\tau \rightleftharpoons \tau
\]

\[
\theta \rightleftharpoons \theta
\]

\[
\dot{\theta} \rightleftharpoons \dot{\theta}
\]

\[
\hat{\tau}_F \approx \tau_F
\]

\[
\hat{\tau}_F \approx \tau_F
\]

\[
\tau \rightleftharpoons \tau
\]

\[
\theta \rightleftharpoons \theta
\]

\[
\dot{\theta} \rightleftharpoons \dot{\theta}
\]
Collision detection and reaction
Miro: Pringles test
Task preservation motion schemes:
Stay on the desired trajectory but be compliant at the same time.
CCD with 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**

- **Cartesian torque**
- **wire iterations**
- **real position**
- **start**
- **goal**
- **pc**
- **desired torus posture**

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!