# Human-Robot Collaboration in an industrial environment

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# Outline

# Motivation of presentation



Is it possible that humans and robots work together in an industrial environment like humans with humans?

Fig. 1 - https://images.app.goo.gl/4Kup5vSPPUZxG7eR9

# Human-Robot Interaction

- Human acts as the supervisor
- Human acts as the robot operator
- Human acts as the Team partner working with the robot
- Non-participant in the work process
- Robots perform tasks autonomously but are seperated from humans by protective fences

## Definition

`Human-Robot Interaction` is the Interaction between humans and robots.

# Human-Robot Collaboration

- Shared human and robot work / workspace: No separation by protective fences
- Integration of a sensorial system of a robot: Information, patterns
- High productivity and greater efficiency
- Safety-related considerations are regulated by ISO standards

## Definition

Human-Robot Collaboration is the shared working environment of humans and robots, in which they can work and carry out tasks together in order to achieve goals.

# The characteristics of HRC

- System requirements due to high risk potential:
  - Lightweight: Few kilograms of collision mass
  - Soft corners and edges
  - Slower than humans
  - Sensors to detect and avoid collision
- Protection mechanisms
  - Switching the robot off an on during physical contact

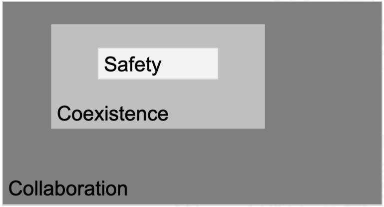


Fig. 1 - General control architecture
cf. [1]

# Working in an industrial environment



Before Industry 4.0

- Industry 1.0: First Mechanical Loom
- Industry 2.0: First Assembly Line
- Industry 3.0 First Programmable Logic Controller

Since Industry 4.0: Cyber-Physical Systems

- Motto: Smart Manufacturing
- Motivation: Mass Production
- Involved Technologies:
  - Internet of Things (IoT)
  - Cloud Computing
  - Big Data
  - Robotics and Artificial Intelligence (AI)

**Definition**

Industry 4.0 is the process of change in the industry through the striving of more flexible and more efficient manufacturing.

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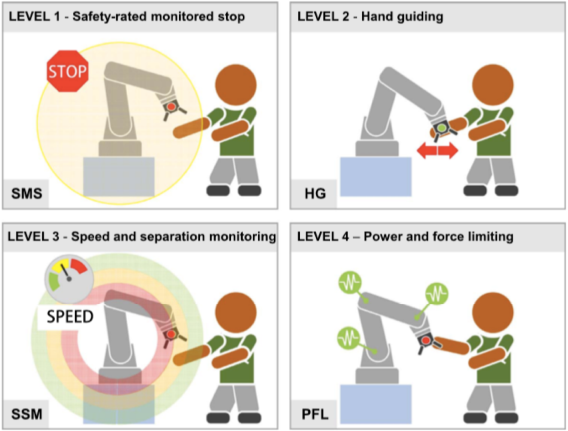
# Collaborative operative modes of HRC






The Four Collaborative and Operative modes of HRC [2]

# Speed between robot and human operator

- General calculation for minimum protective distance :

$$S(t_0) = S_h[v_h(t_0)] + S_r[v_r(t_0)] + S_s[v_s(t_0)] + C + Z_d + Z_r$$

$$S_h = \int_{t_0}^{t_0+T_r+T_s} v_h(t)dt$$

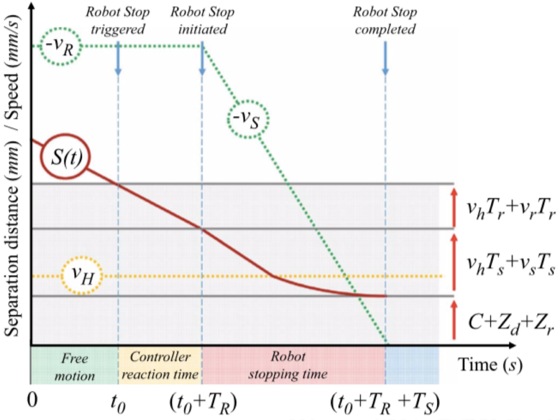
$$S_r = \int_{t_0}^{t_0+T_r} v_r(t)dt$$

$$S_s = \int_{t_0+T_r}^{t_0+T_r+T_s} v_s(t)dt$$

Speed
[2]

# Speed between robot and human operator

- Trend of separation distance




Trend of separation distance
[2]

# Robot programming approaches

Programming approaches

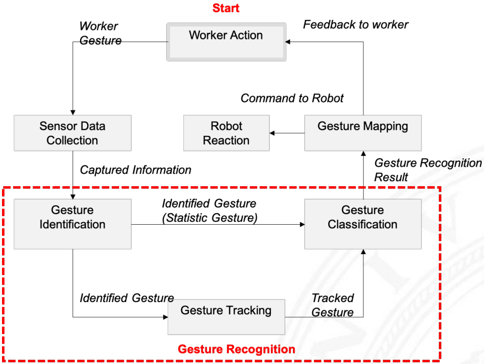
- Lead through programming
- Off-line programming
- Walk-through programming
- Learning by demonstration

Input modes

- Gestures

# Gesture Recognition - Overview






Gesture Recognition
cf. [3]

# Gesture Recognition

## Sensors

- Image based: Marker, Depth Sensor, Stereo Camera
- Non-image based: Glove, Band, Non-wearable

## Gesture Identification

- Visual Features
- Learning Algorithms
- Human Model

## Gesture Tracking

- Single Hypothesis Tracking
- Advanced Tracking Method (Extended Model Tracking)
- Tracking by detection

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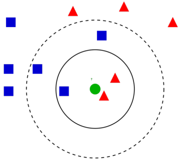
# Gesture Recognition - Gesture Classification

- K-Nearest Neighbours (A)
- Hidden Markov Model (B)
- Ensemble Method (C)
- Deep Learning (D)

A



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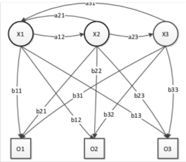
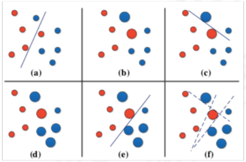
B




C




D

https://images.app.goo.gl/KPKwaRPCT5qSQwmh7

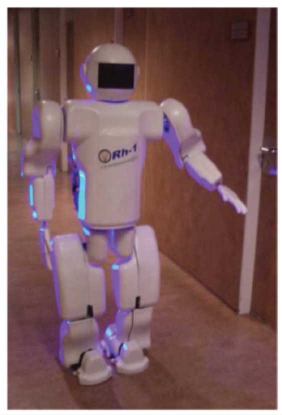
cf. [3]

# Paper

- Author: C.A. Monje, P. Pierro, C.Balaguer
- Title: A New Approach on Human-Robot Collaboration with Humanoid Robot RH-2. Goal: Joint Transportation of an Object between Human and a Robot
- Publisher: Robotica
- Year: 2011
- Pages: 949 - 957

# Model of humanoid robot RH-1 and RH-2





Humanoid robot RH-1

Humanoid robot RH-2

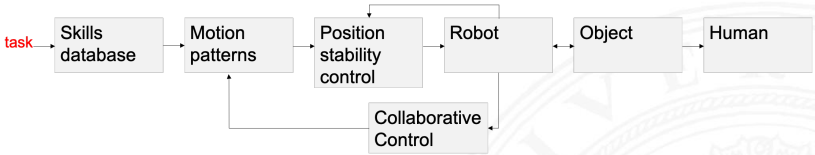
cf. [6]

# Implementation of HRC

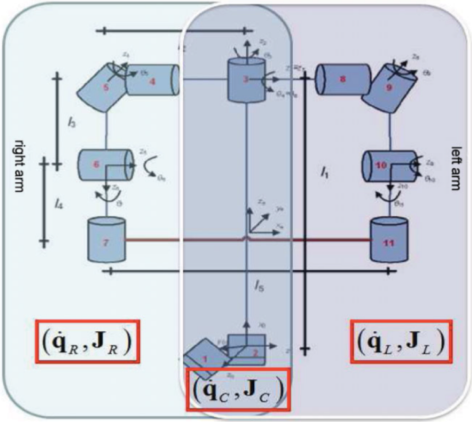


2 control Loops:

- Collaborative control loop
- Posture stability control loop




General control architecture
cf. [6]




General control architecture

cf. [6]

# Implementation of HRC - Collaborative control loop



- Task 1: The end-effector of right and left arms should coincide in position and orientation
- Task 2: The end-effector must follow the desired trajectory angels

$$\dot{\mathbf{x}}_r = \dot{\mathbf{x}}_l \Rightarrow \mathbf{J}_r\dot{\mathbf{q}}_r = \mathbf{J}_l\dot{\mathbf{q}}_l, \qquad (1)$$

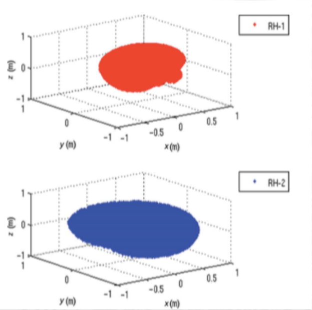
$$\begin{aligned}\dot{\mathbf{x}}_r &= \mathbf{J}_r\dot{\mathbf{q}}_r = \mathbf{J}_C\dot{\mathbf{q}}_C + \mathbf{J}_R\dot{\mathbf{q}}_R,\\ \dot{\mathbf{x}}_l &= \mathbf{J}_l\dot{\mathbf{q}}_l = \mathbf{J}_C\dot{\mathbf{q}}_C + \mathbf{J}_L\dot{\mathbf{q}}_L,\end{aligned} \qquad (2)$$

Task 1: $\dot{\mathbf{e}}_1 = \mathbf{0} = \mathbf{J}_R\dot{\mathbf{q}}_R - \mathbf{J}_L\dot{\mathbf{q}}_L.$
Task 2: $\dot{\mathbf{e}}_2 = \dot{\mathbf{x}}_r = \mathbf{J}_C\dot{\mathbf{q}}_C + \mathbf{J}_R\dot{\mathbf{q}}_R.$

$$\dot{\mathbf{e}} = \mathbf{J}\dot{\mathbf{q}}, \qquad (3)$$

$$\begin{bmatrix}\dot{\mathbf{e}}_1\\ \dot{\mathbf{e}}_2\end{bmatrix} = \begin{bmatrix}\mathbf{0} & \mathbf{J}_R - \mathbf{J}_L\\ \mathbf{J}_C\mathbf{J}_R & \mathbf{0}\end{bmatrix}\begin{bmatrix}\dot{\mathbf{q}}_C\\ \dot{\mathbf{q}}_R\\ \dot{\mathbf{q}}_L\end{bmatrix}. \qquad (4)$$

**A**

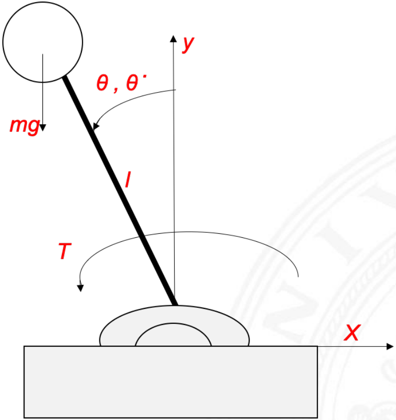



**B**

Single inverted pendulum
cf. [6]

# Implementation of HRC - Posture stability loop

## Model of single inverted pendulum

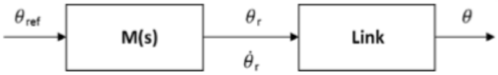



Single inverted pendulum
cf. [6]

# Implementation of HRC - Posture stability loop

The center of mass (COM) control problem and strategy

- Purpose: control the COM position
  - Innovative ankle actuator for the new prototype RH-2
  - Experimental transfer function of ankle actuator




Posture Control System
cf. [6]

- Control problem in an open loop must be solved
- Model matching technique is used

# KUKA Robot "LBR IIWA"




https://www.youtube.com/watch?$time_{c}ontinue = 83v = sJBgEk96igk$

# Implementation of the KUKA Robot "LBR IIWA"

- Configuration by programming
- Intuitive control enabled through Torque sensor
- Safe working environment
- 7 axes enable flexibility
- Technology: Java

# Conclusion

Limitations and Challenges of HRC

- Whole-body control problem
- Intuitive user interface needs to be designed
- Need to distinct between safe coexistence and collaboration
- Acceptance of Robots in the Workplace
- Redesign of Workplaces for Robots

# Conclusion

## Potential of HRC

- Precision
- Flexibility
- Globally used programming language
- New environment, same performance
- High level of Customization

# Conclusion

Is HRC still part of the Industry 4.0 or already part of the Industry 5.0?

- Motto: Human-Robot Co-working
- Motivation: Smart Society
- Involved Technologies:
  - Human-Robot Collaboration

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[9] Demir, K. A., Döven, G., Sezen, B. (2019). Industry 5.0 and Human-Robot Co-working. Procedia Computer Science, 158, 688-695.

# MABI Speedy - Collaborative Robot (Welding)


https://www.youtube.com/watch?time$_c$*ontinue* = 50*v* =
*mbVUdKTiQ8feature* = *emb$_l$ogo*

# MABI Speedy - Collaborative Robot (Welding)

- Relief during unpleasant movements (e.g overhead movements)
- Improving performance and quality of life
- Technical Information
  - Load capacity: 6kg
  - Range in A5
  - Number of axes: 6