Institute of Aircraft Production Technology

Robotics

12. Human-Robot-Collaboration in industrial production

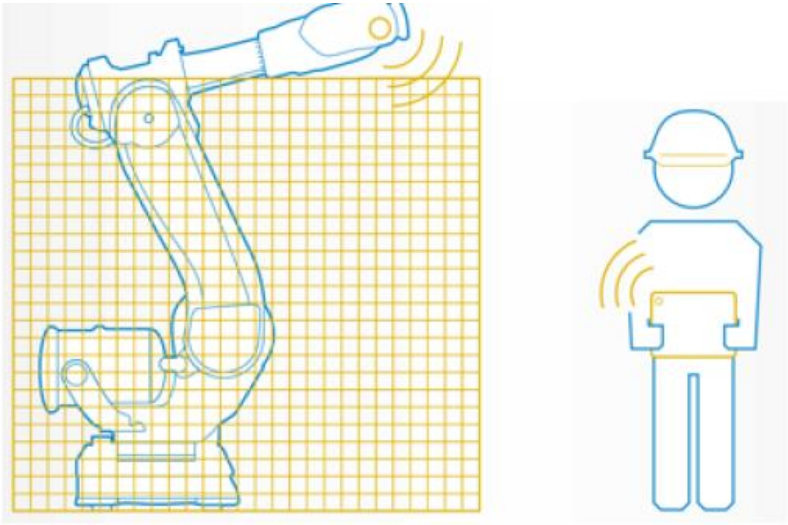
Lukas Büsch, M.Sc.

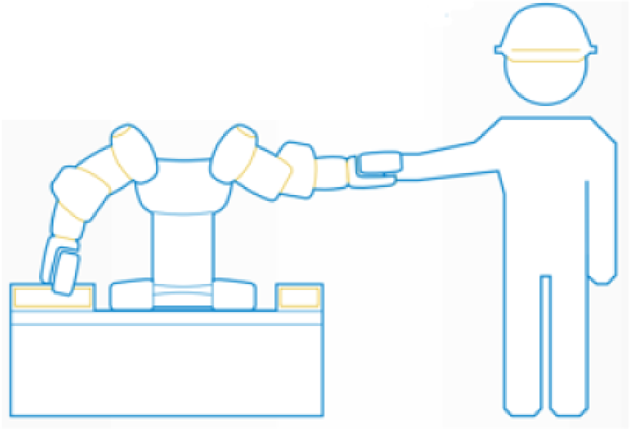
TUHH Technische Universität Hamburg

Source: Faude

Agenda

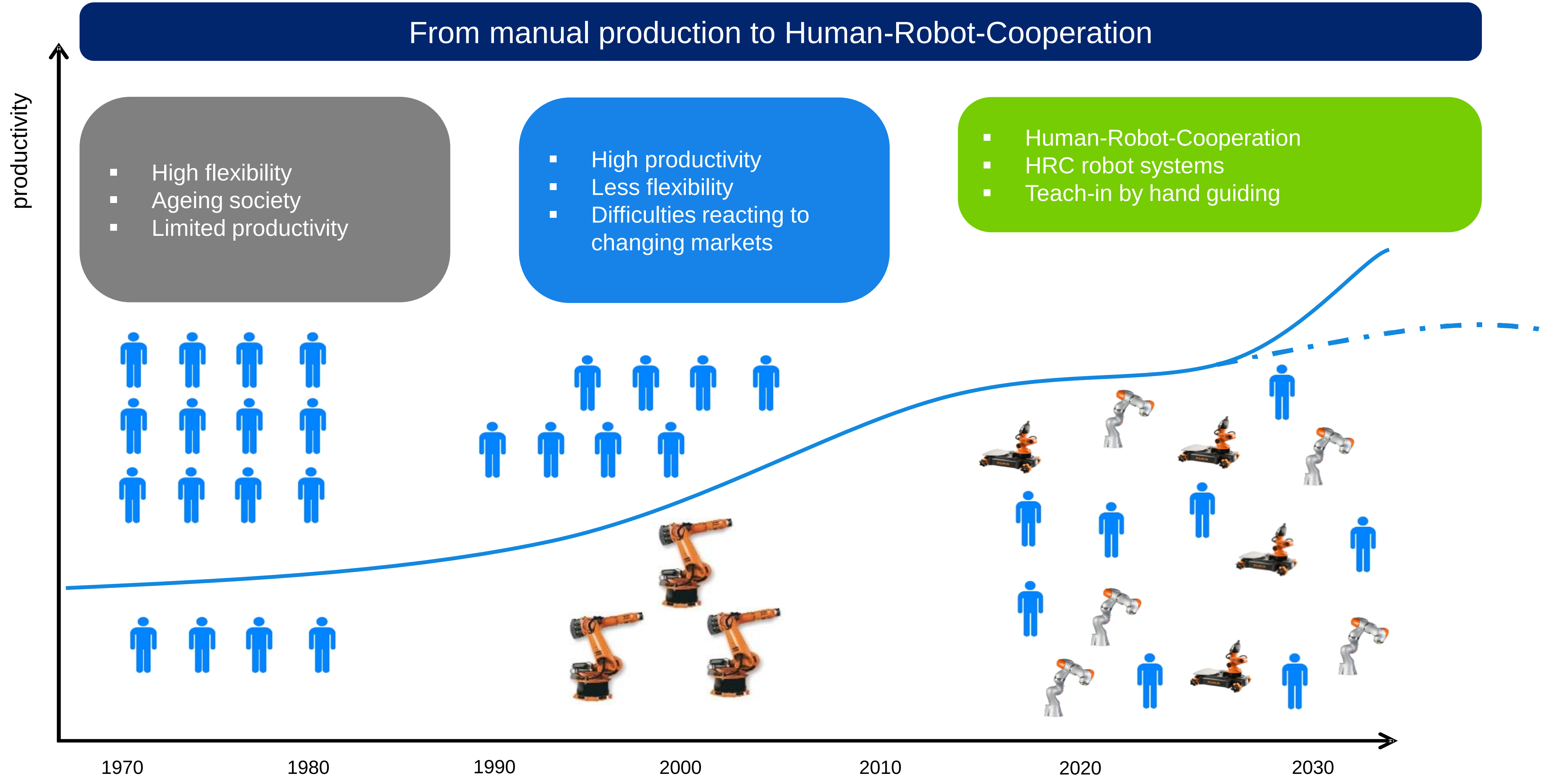
Traditional automation	Human-Robot-Collaboration
▪ Separated work spaces (e.g. by safety fences) ▪ Fixed production flow ▪ High quantities and repeatability	▪ Shared work space ▪ Flexible work allocation between human and robot ▪ Combination of the skills of robot and human ▪ Supervised workspace and detection of the human ensure a safe collaboration





[1]

The degree of automation aligned to changing market conditions

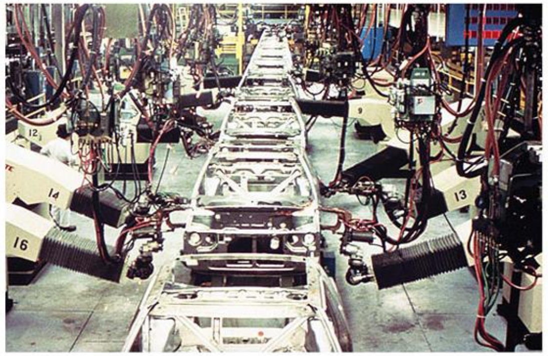


[2]

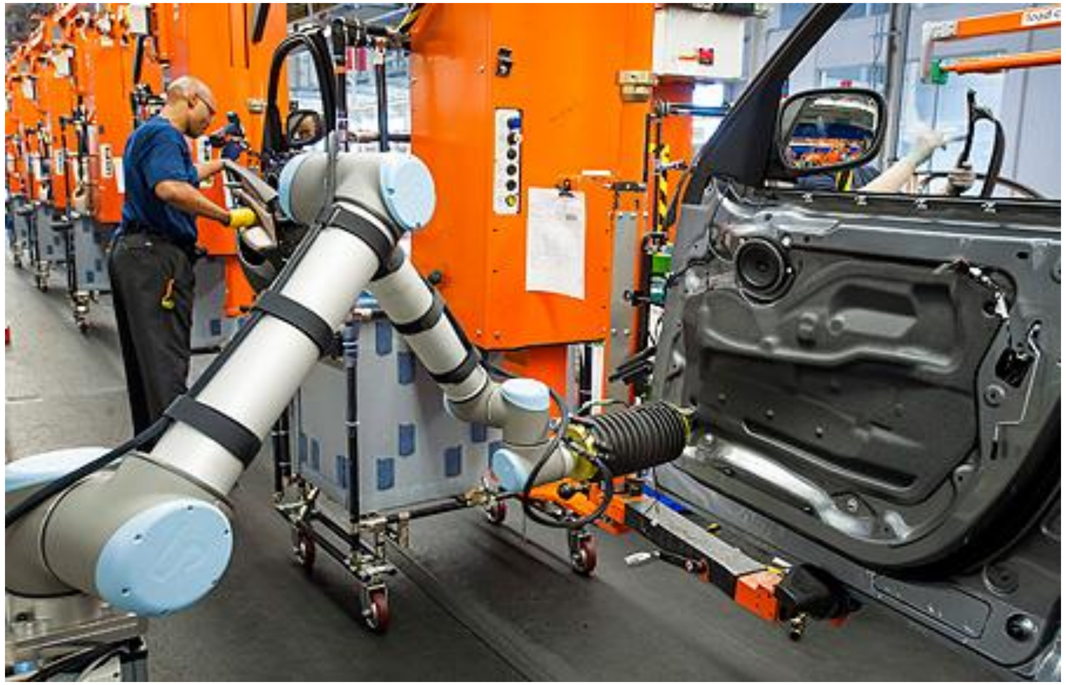
Fixed assembly line

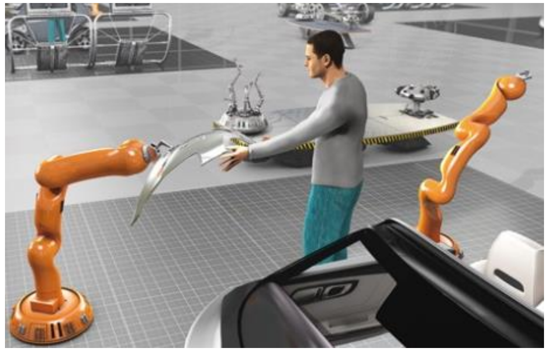
HRC robot systems and assistance systems, Industry 4.0

Flexible Production



Car body manufacturing: 1960s / 1970s



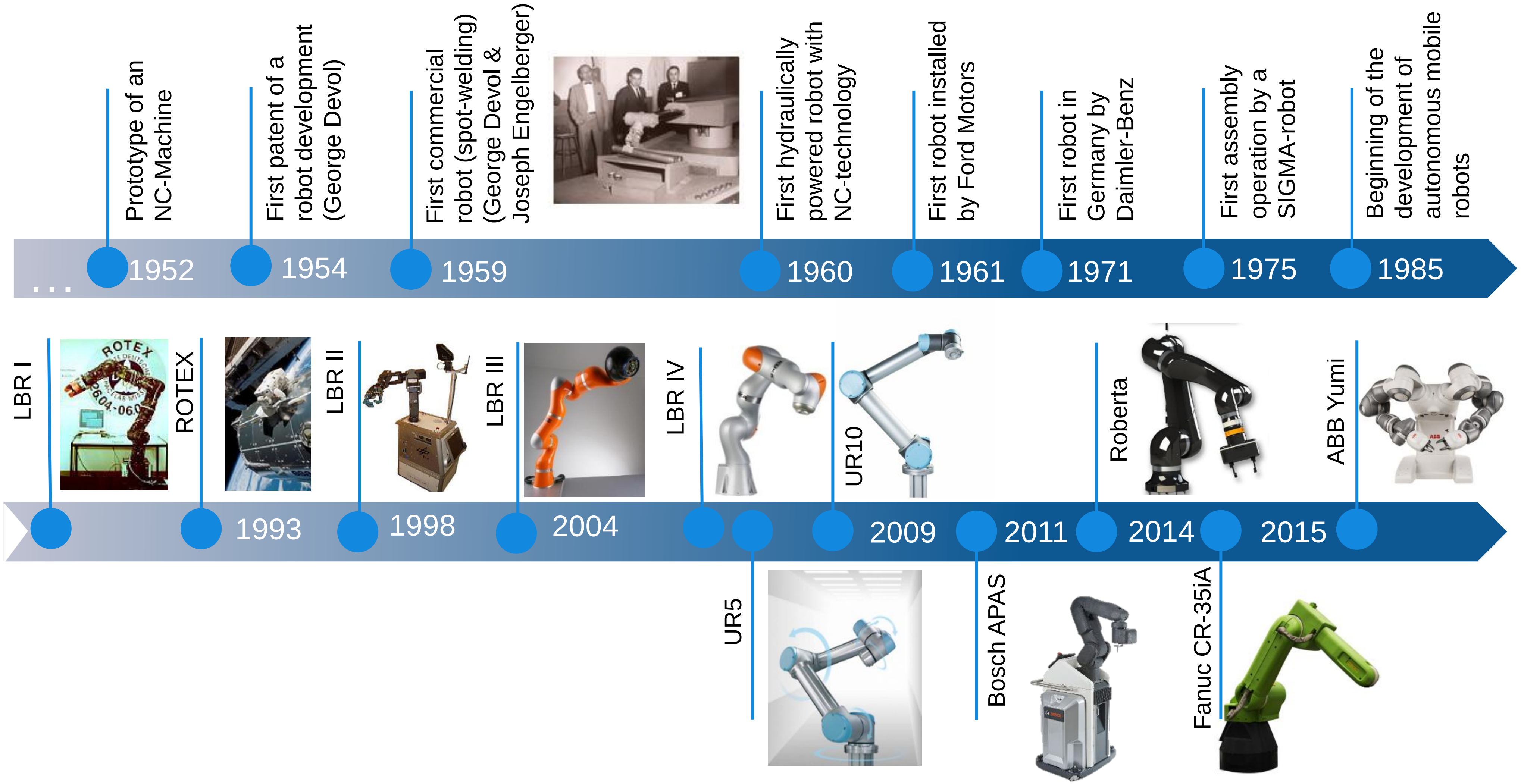


Flexible automation of the assembly process: tomorrow

The cost-effective use of sensor technology and the development of assistance systems are the basis of flexible automation through HRC robot systems.

[3]

From the development of industrial robots to HRC robot systems – A part of the new era of automation

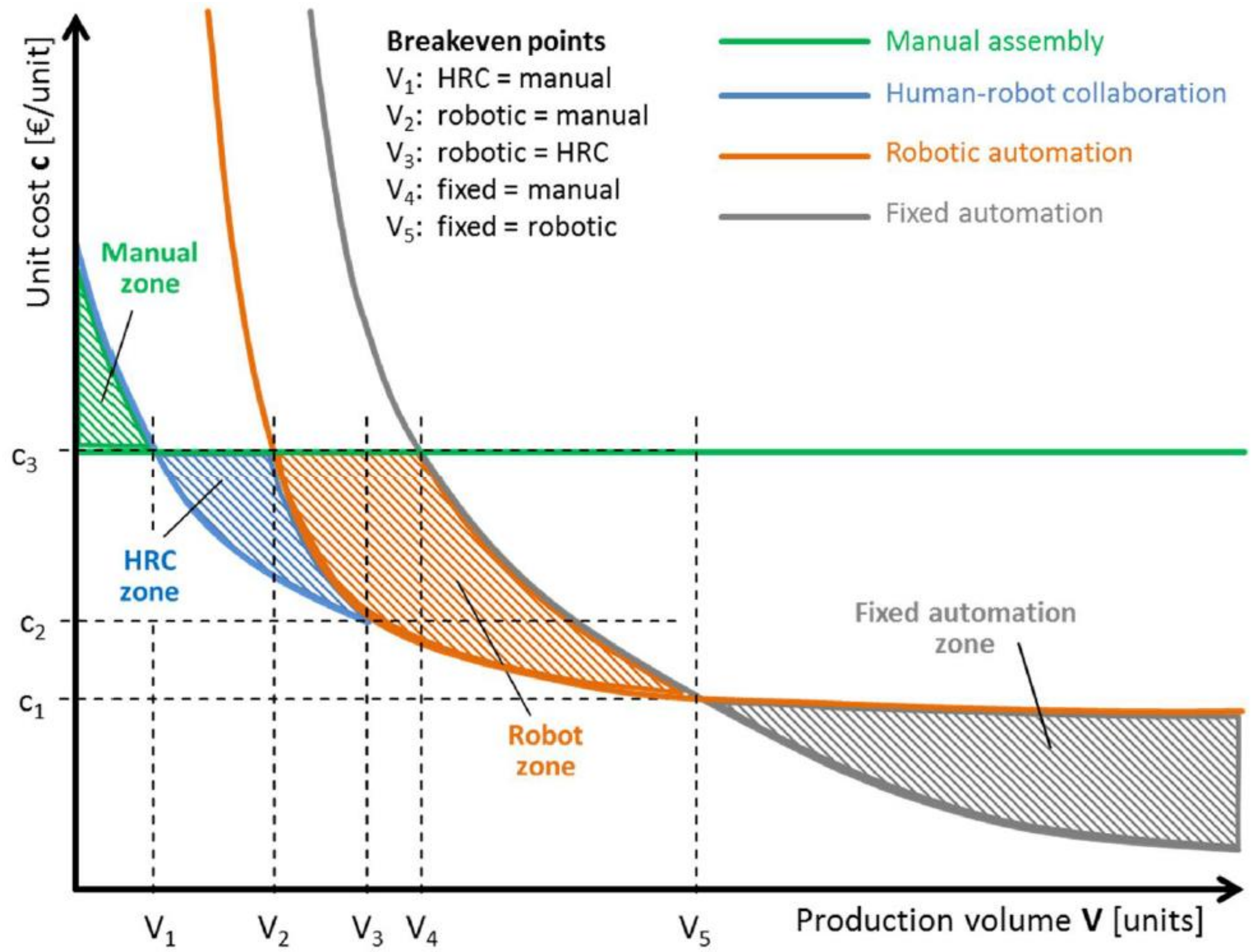


[4]

Assembly of a crumple zone structure for automotive vehicles

[5]

Economic motivation for Human-Robot-Collaboration



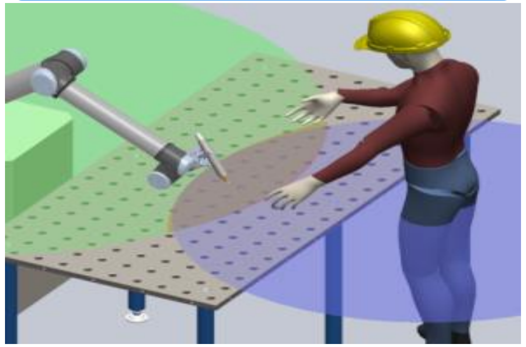
[6]

Motivation

Ergonomics

Combination of skills

Time and space



[7, 46]

Spectrum and definition of cooperation

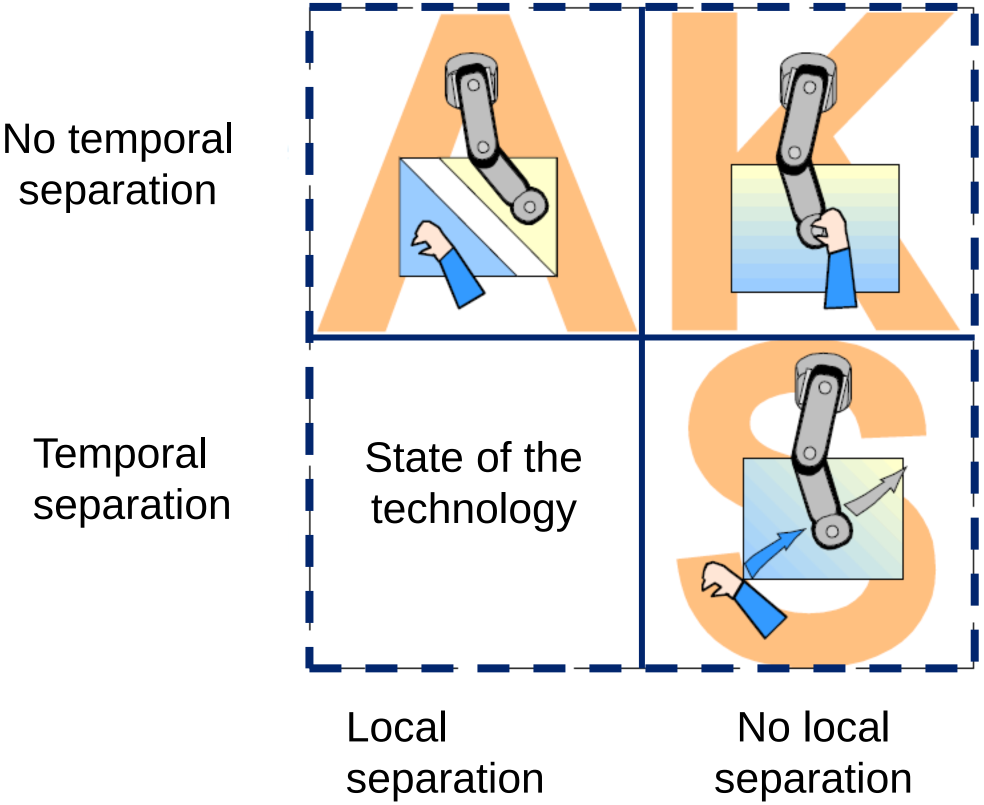
Conventional	Autarkic[1] / Coexistent[2]	Synchronized[1,2]	Cooperation[1,2]	Collaboration [1,2]

Spectrum	Description
Conventional	Strict separation of work space e.g. fences
Autarkic/ Coexistent	Human and robot are working without any fences, but have a separated work space
Synchronized	Only one is inside of the shared work space at a given time
Cooperation	Shared work space is used by both at the same time but the tasks are different
Collaboration	Shared work space and shared tasks

[1] Thiemann, Diss. Universität Tübingen, 2004
[2] Fraunhofer IAO, IAT University of Stuttgart

[8]

- Bridging the gap between fully automated processes and manual work
- Design parameters for the cooperation depend on the overlap of the workspace (temporal/regional)
- Classification of the cooperation between human and robot
  - **(A)** autarkic
  - **(K)** cooperating
  - **(S)** synchronized



Goal of the interaction concepts: Combine the skills of a human and HRC robot systems

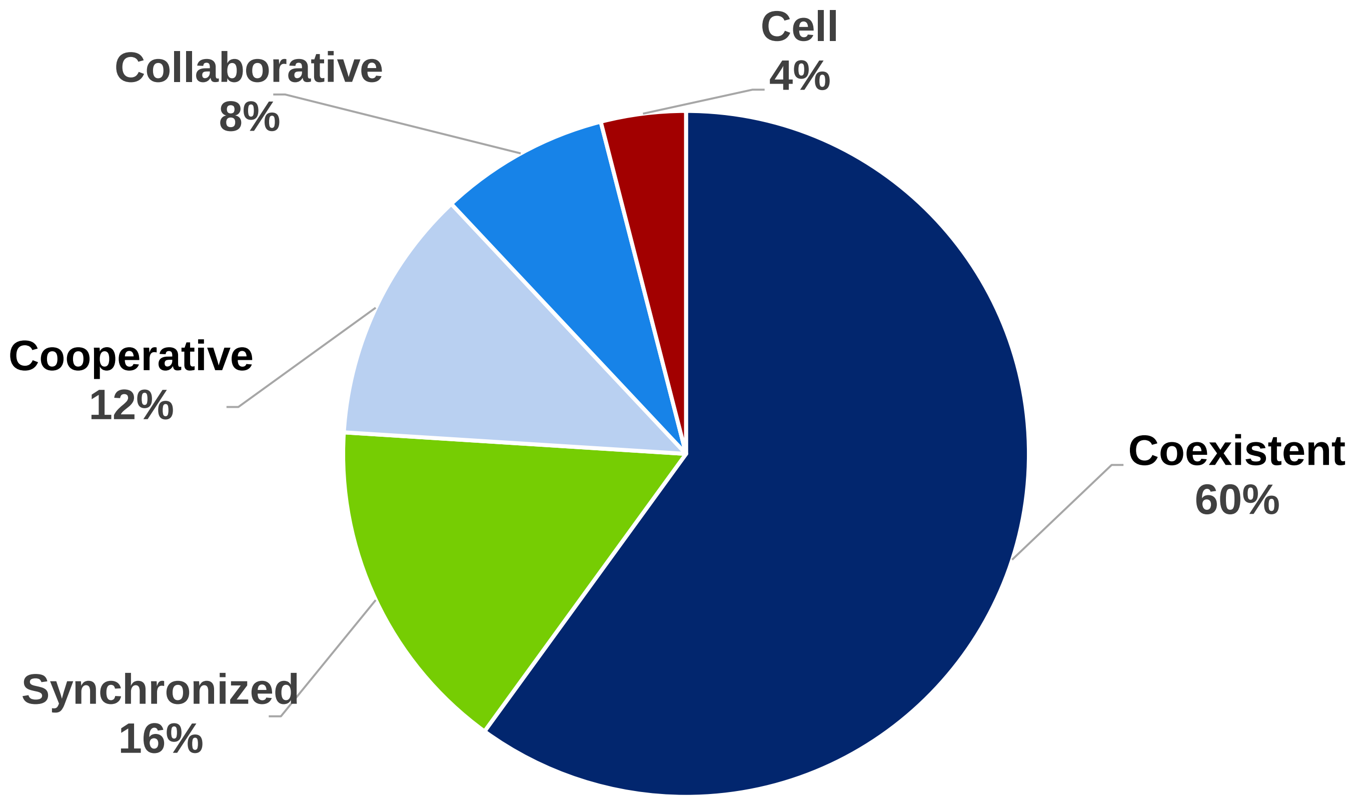
[9]

Survey from the Year 2016 conducted by the „Fraunhofer IAO“ about the usage of Human-Robot-Cooperation

Fraunhofer IAO

Universität Stuttgart

Confirmation of approx. 25 companies



Study: „Leichtbauroboter in der manuellen Montage – einfach EINFACH anfangen“

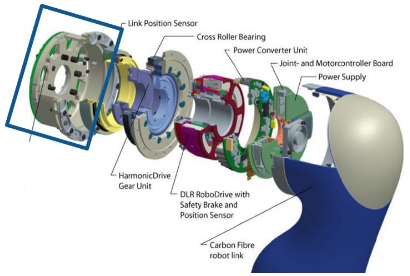
[10]

Agenda

The HRC robots available on the market distinguish themselves mainly by their safety strategies

HRC Robots System – Safety Features

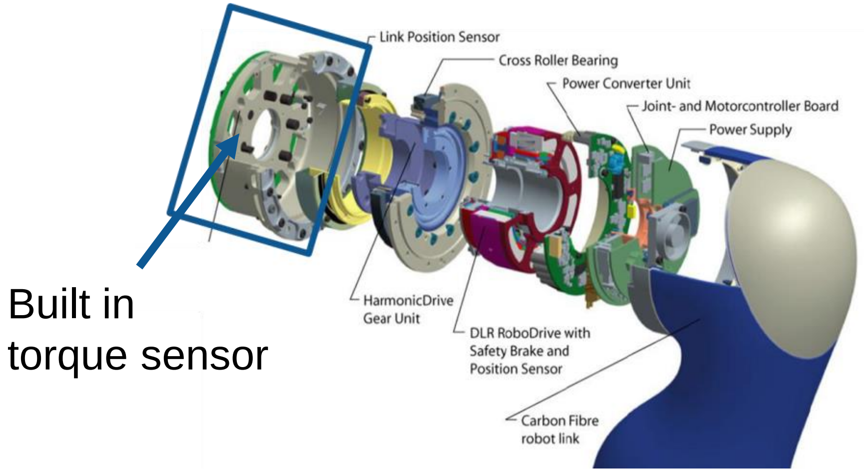
- **Internal Sensors**
- **External Sensors**
- **Robot Design**
- **Process Design**

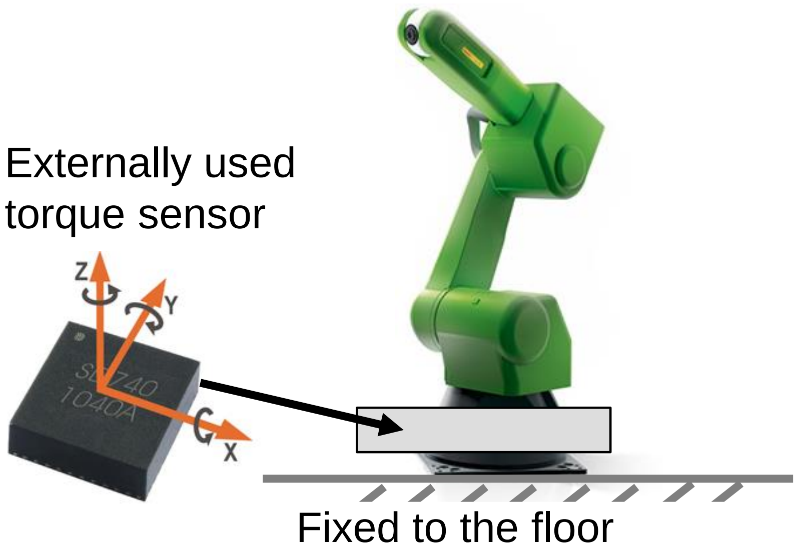


[12]

Internal and external sensors:
Force and torque sensors provide the robot system with sensitivity and safety

- By using sensors, the robot is able to measure forces and torques and is able to control them.
- Tracking of forces is enabled.
- Force and torque sensors can be internally and externally used in robot systems.

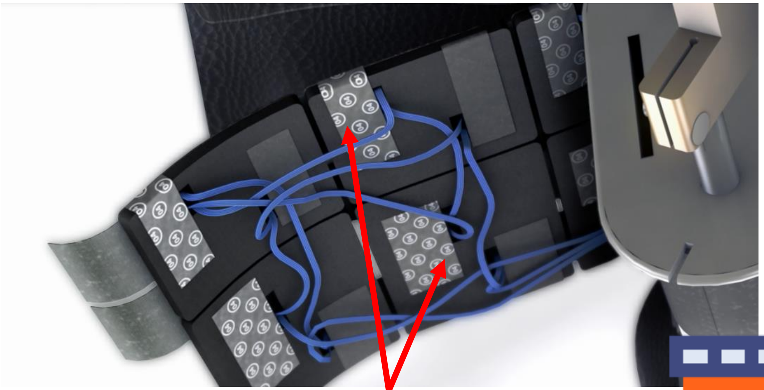




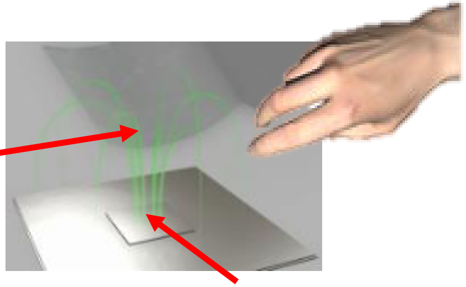
[13]

Sensor „skin“ for touchless safety

- Capacitive proximity sensors detect an approximation of a conductive or non-conductive subject before contact occurs.
- If the approximation of a body part is detected the robot system stops the movement to avoid a collision.
- The detection range, for example with the robot system APAS, if a body part or an object approaches
- Measured: changing of the capacity



capacitive proximity sensor



capacitive field

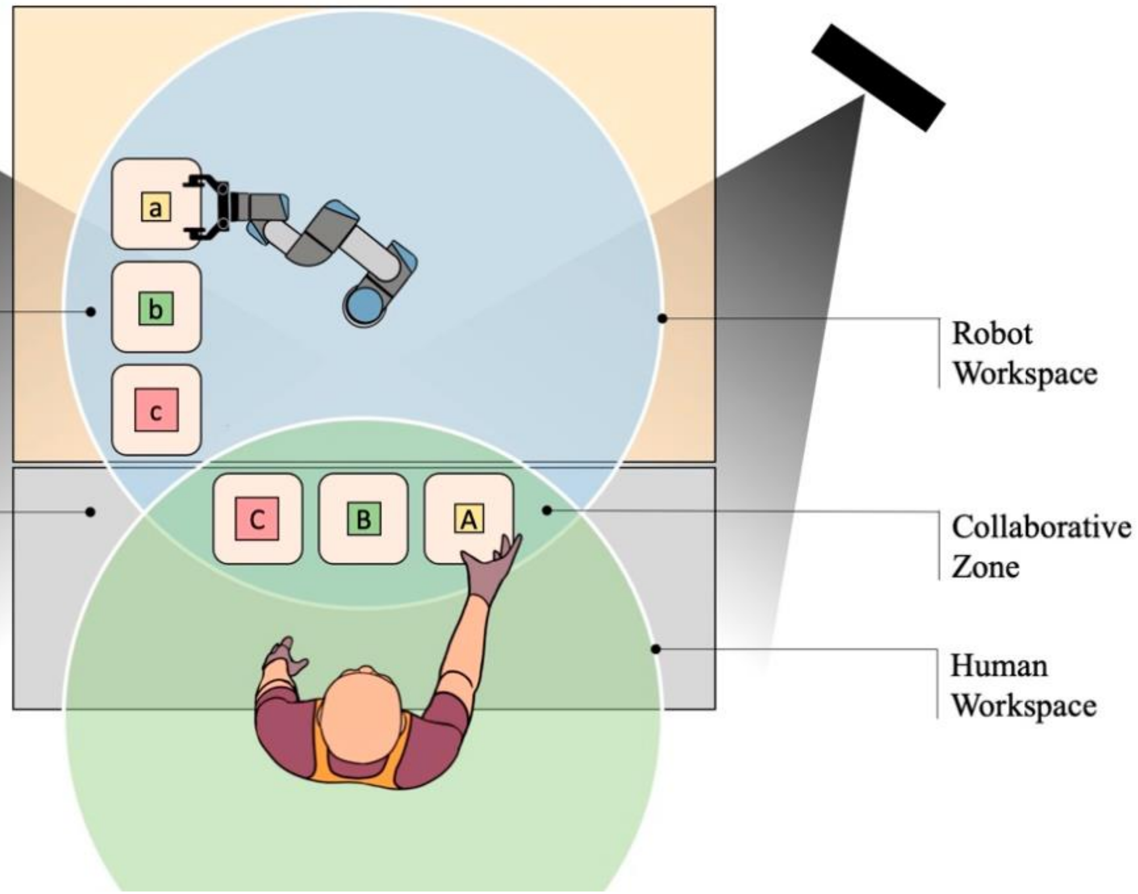
sensor pad

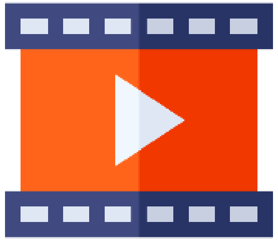
The capacitive proximity sensor detects approximating conductive or non-conductive objects without contact and initiates a reaction of the robot system.

[17]

Camera-based workspace monitoring

- Depth cameras are used to calculate the distance between worker and cobot
- Redundancy to enhance performance in case of occlusion
- Different safety strategies can be implemented:
  - Safety stop
  - Online path correction with obstacle avoidance
- This setup can also be used for collaboration

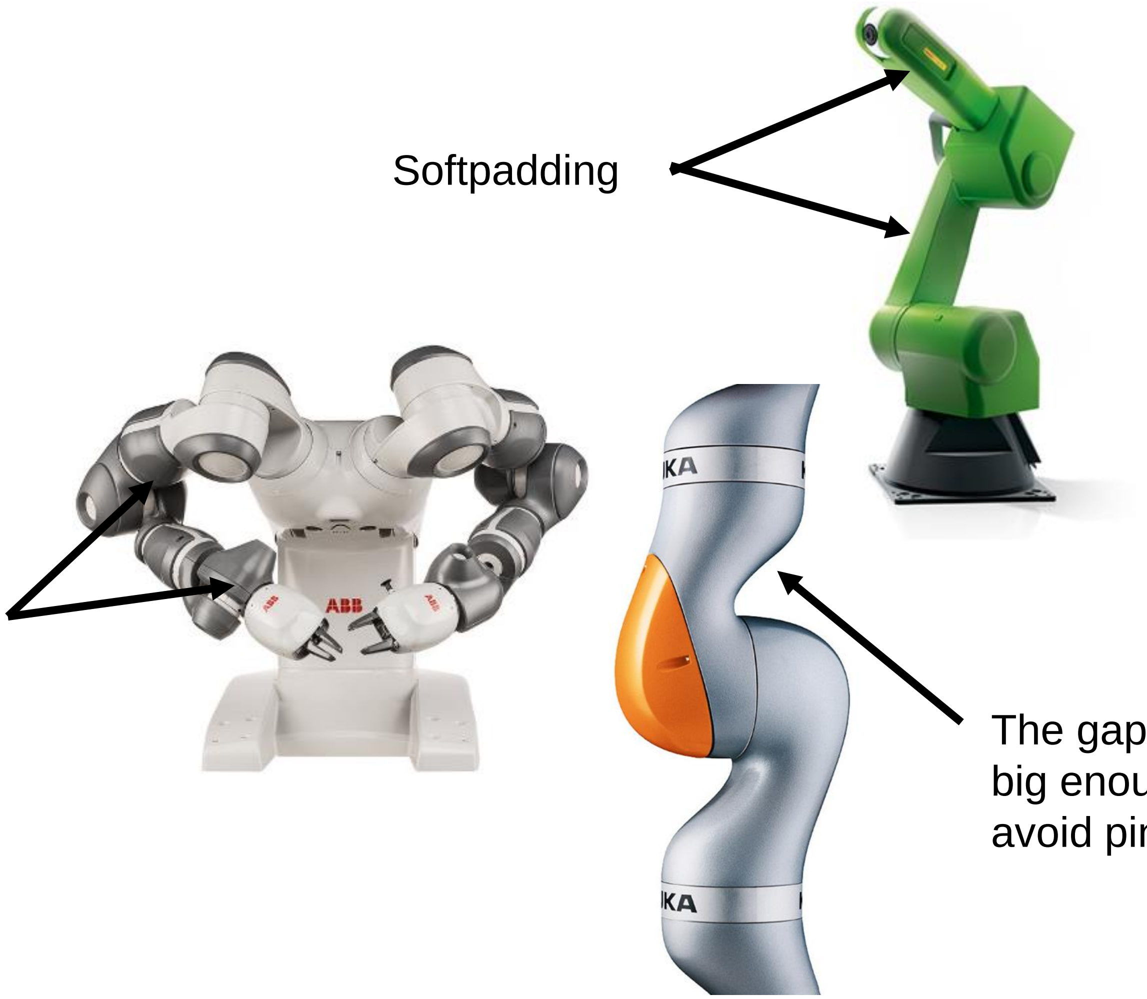




Design philosophy of HRC robot systems

Design reduces pinching risks

- Closed and rounded edges
- The gaps in between the joints are specially design to avoid pinching (like a human finger)
- Flexible paddings are used for the enclosure plastic and the robot arms are covered in it to minimize the released forced during collision



[18]

Low payload and fast velocity

According to ABB YuMi:
500g with up to 1500 mm/s

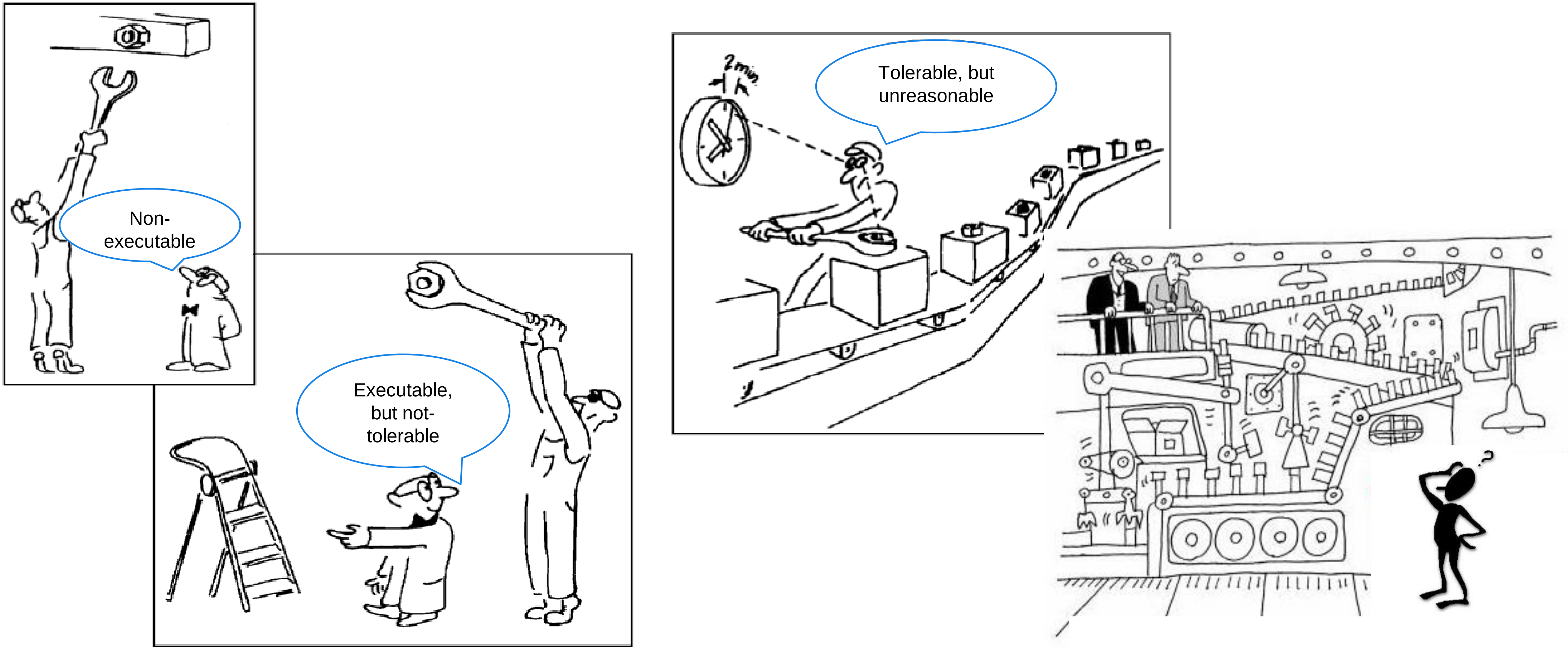
High payload and slow velocity

IPS TU Dortmund:

- 120 kg with a maximum of 100 mm/s
- Only the 6. axis allowed to move while using in HRC- mode

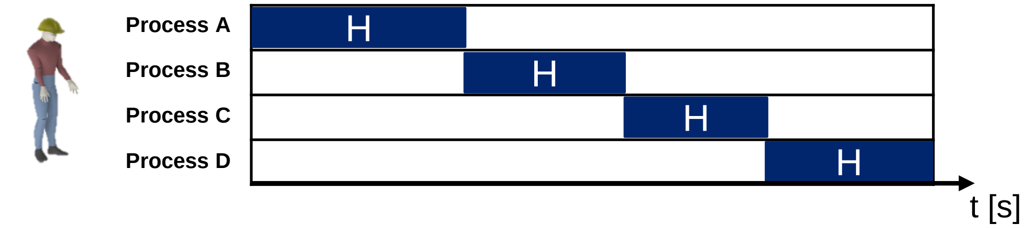
[19]

Performance limits of humans require assistance systems

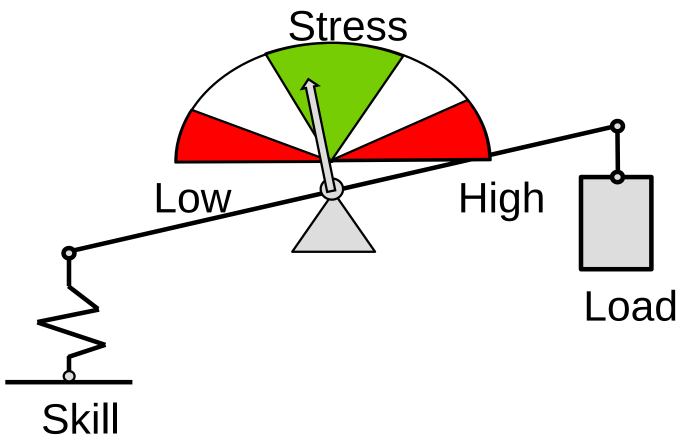


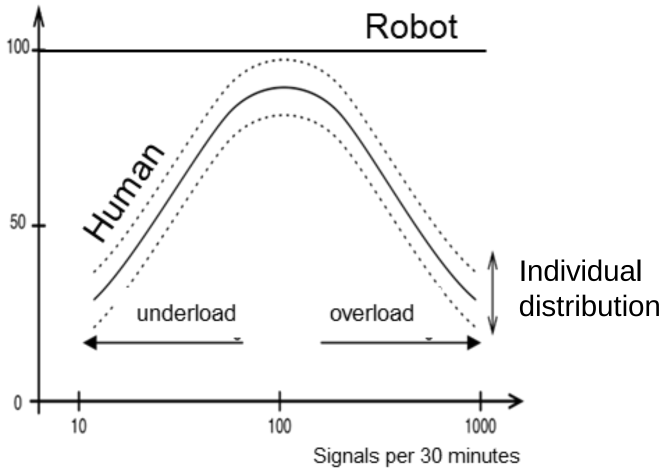
Work should be executable, tolerable, and reasonable.

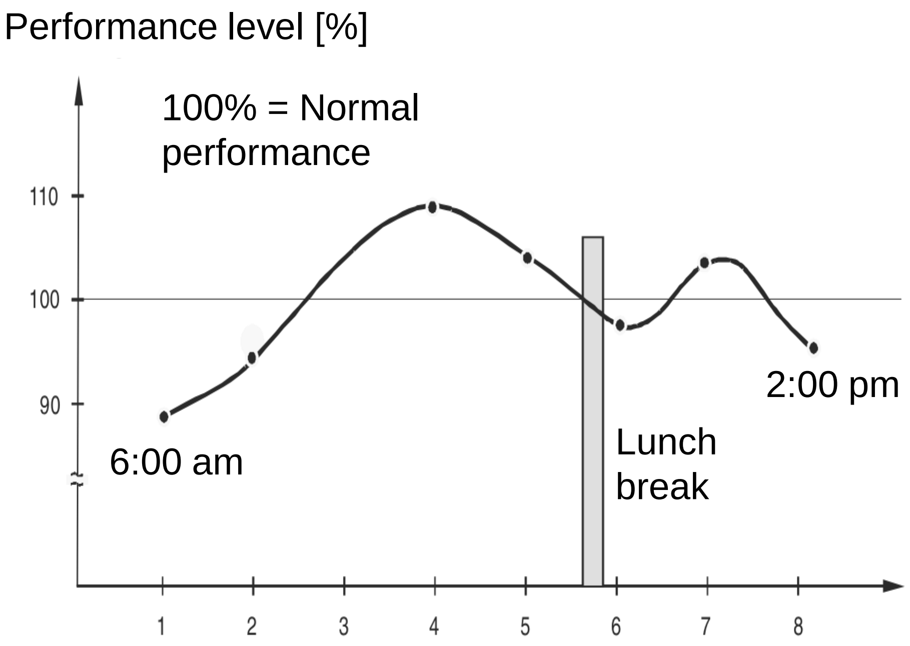
[20]



- Depending on the task, human and robots are differently efficient
- One approach to Human-Robot-Cooperation is skill based task sharing
- After identifying advantages and handicaps of both participants, the task can be divided and allocated to the more suited partner
- Task sharing is only recommended when both, human and robot, can work parallel on the task
- The following slides will show a few examples of those advantages and handicaps, in later chapters industrial examples will be discussed

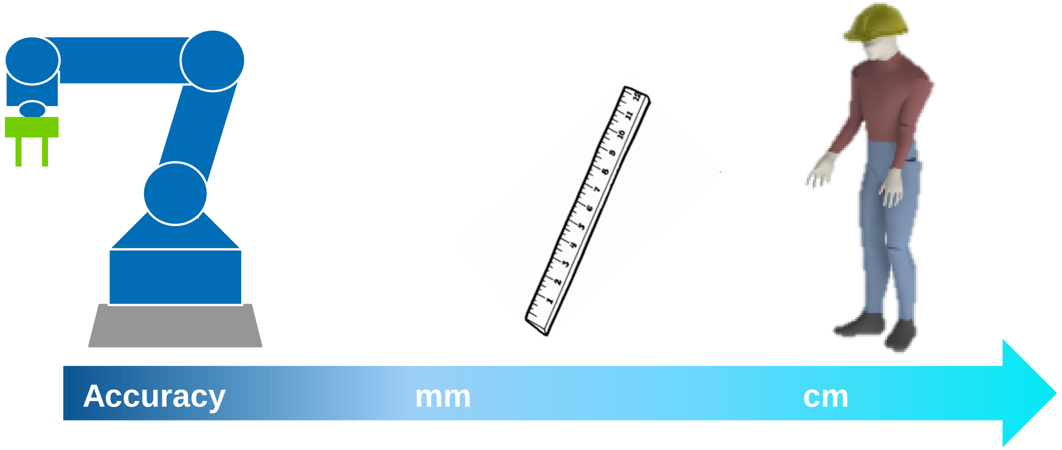




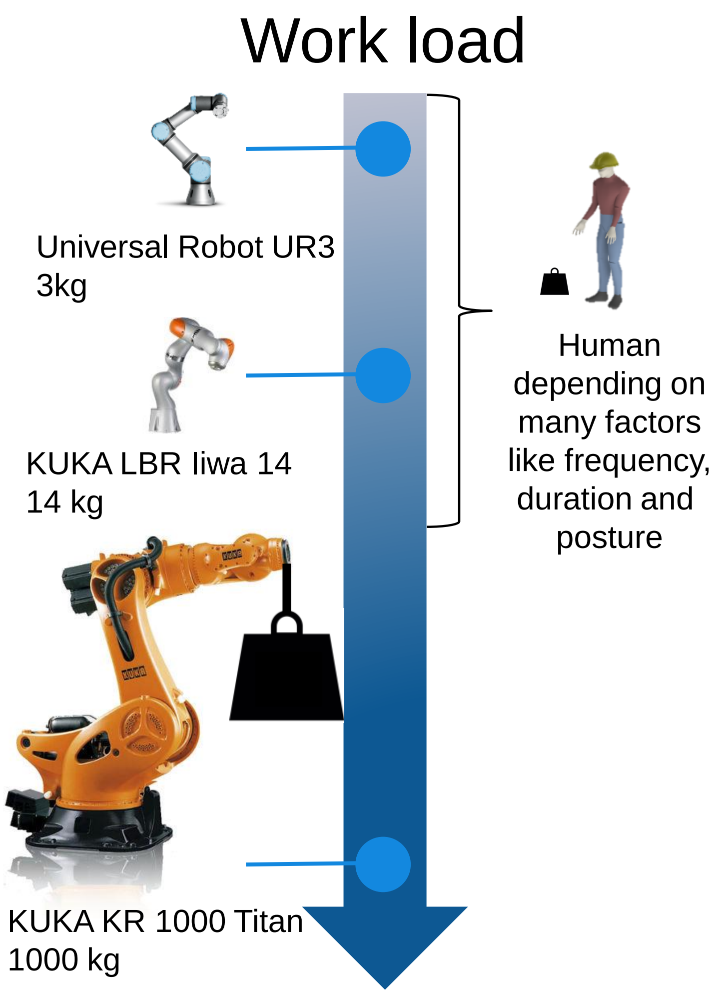


The performance of the human varies depending on the working time and the level of requirement

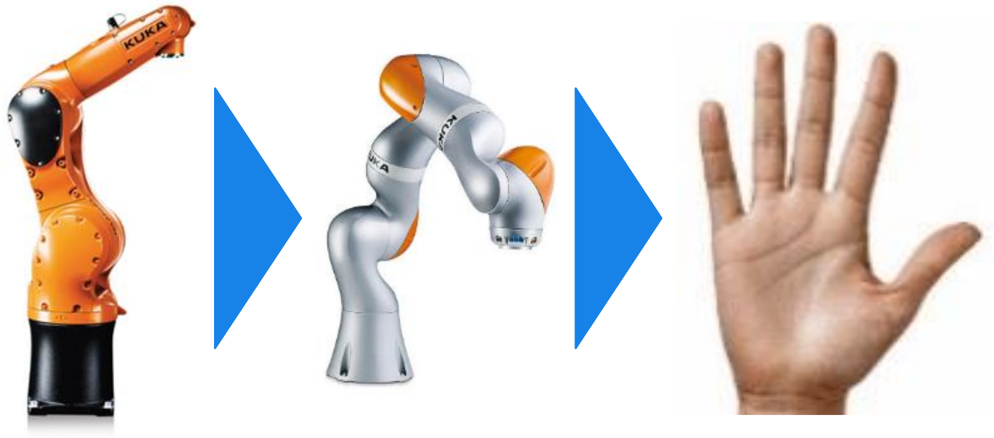
[21]

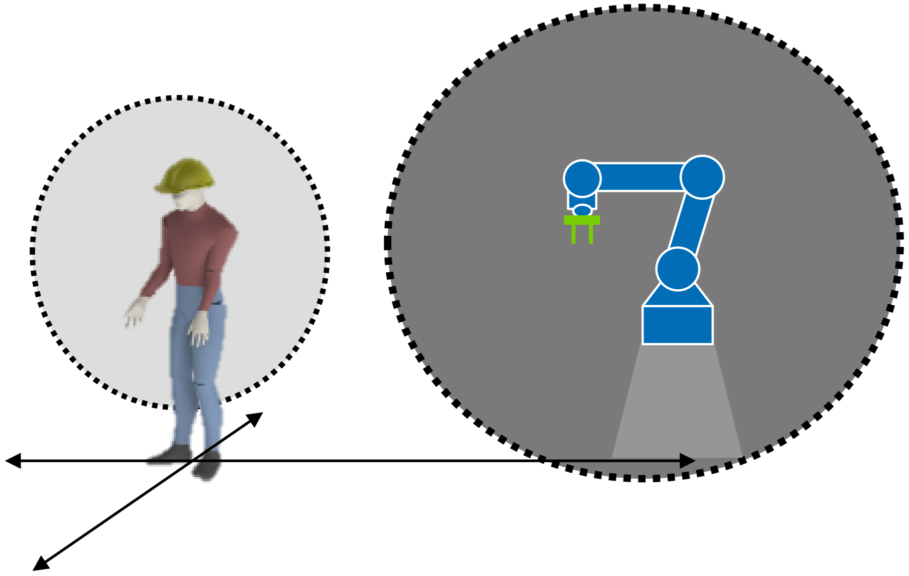


	Robot	Human
Accuracy	<1 mm	Few cm
Depending on	Calibration	Environment, skill, performance,….
Increased through	Better calibration, closed loop control	Measurement equipment, active and passive alignment



Humans accuracy is limited, they only can lift light weights and need time for recovery



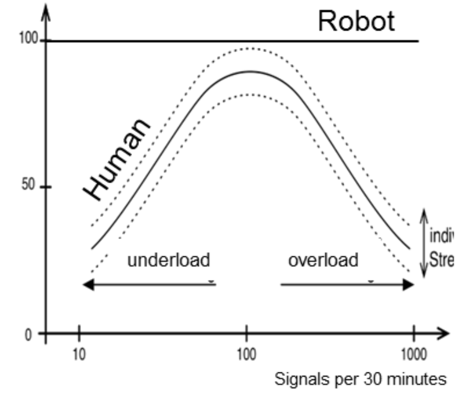


- Robots need special sensors to enable them for sensitive applications
- A human hand has 27 degrees of freedom and can feel slight deviations in pressure and force
- Humans can easily extend their workspace and adapt to the changed positioning
- Robots are fixed to keep the boundary conditions constant for the process

Because of their mobility and sensitivity human hands are easily capable of adapting to various tasks

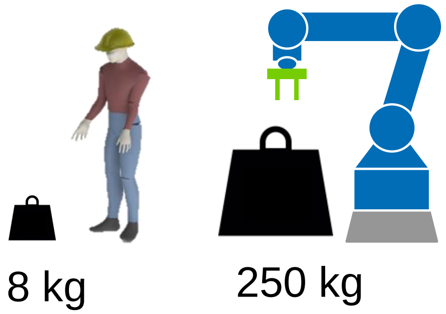
[22]

Attention



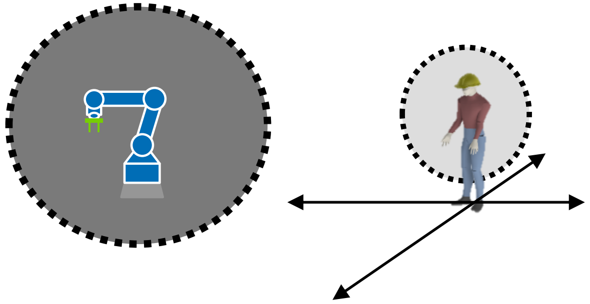
Accuracy

Strength

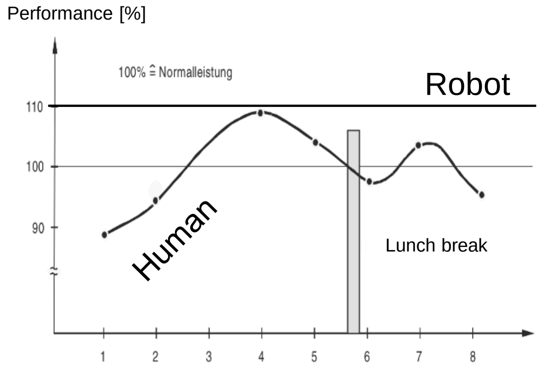


Sensitivity

Workspace

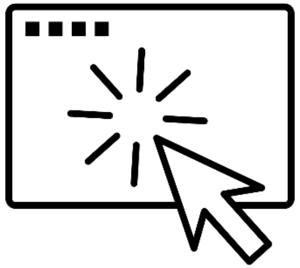


Performance level



[24]

Hybrid Team

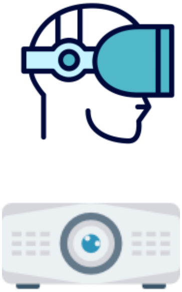
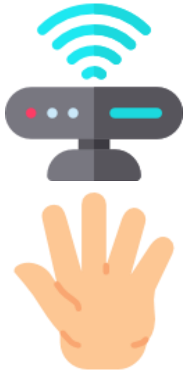
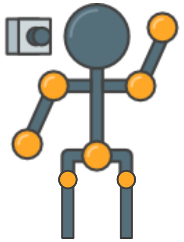


- Human and machine should interact in collaboration as a team
- In a good team, all members agree on their intentions - they coordinate in order to achieve a common goal.
- Prerequisites for the implementation of such scenarios are high-quality user interfaces in order to increase the confidence of the workers in the technical implementation.
- Secure workplace
    - Dynamic rather than static robot programming places demands on the control system, but also extended safety measures
- Flexible task sharing, configuration and programming
- Enable workers to configure robots via an intuitive operating concept with appropriate interfaces and devices

A natural and intuitive implementation of human-machine-interaction in the field of (semi) automated systems leads to a shift in the definition of production equipment not as an "instrument" but as a "partner" of the human being.

[26]

Machine

Type of information output			Type of information input			
Visual ▪ textual content ▪ image content ▪ Animation and Video ▪ Marking ▪ Light signal	**Acoustic** ▪ Voice output ▪ Indicating and warning sounds	**Haptic** ▪ Vibration	**Manual** ▪ Operating element/ button ▪ Force application	**Verbal** ▪ Voice input	**Motion** ▪ Optical motion recognition ▪ Measuring-technical gesture recognition	**Positional** ▪ Tracking system ▪ Optical position tracking
						

Human

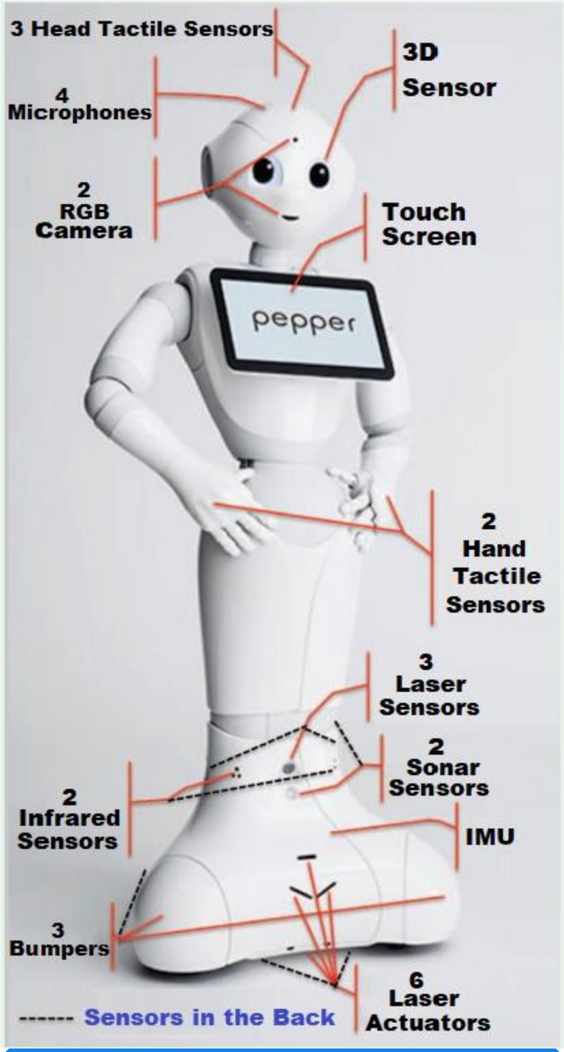
[28]

Output: Machine to Human

- **Visual:** Information (text, pictures, videos) can be presented on the touch screen of the robot
- **Acoustic**: The robot can talk with the help of built in speakers
- **Haptic**: Robot can shake hands to “say hello”

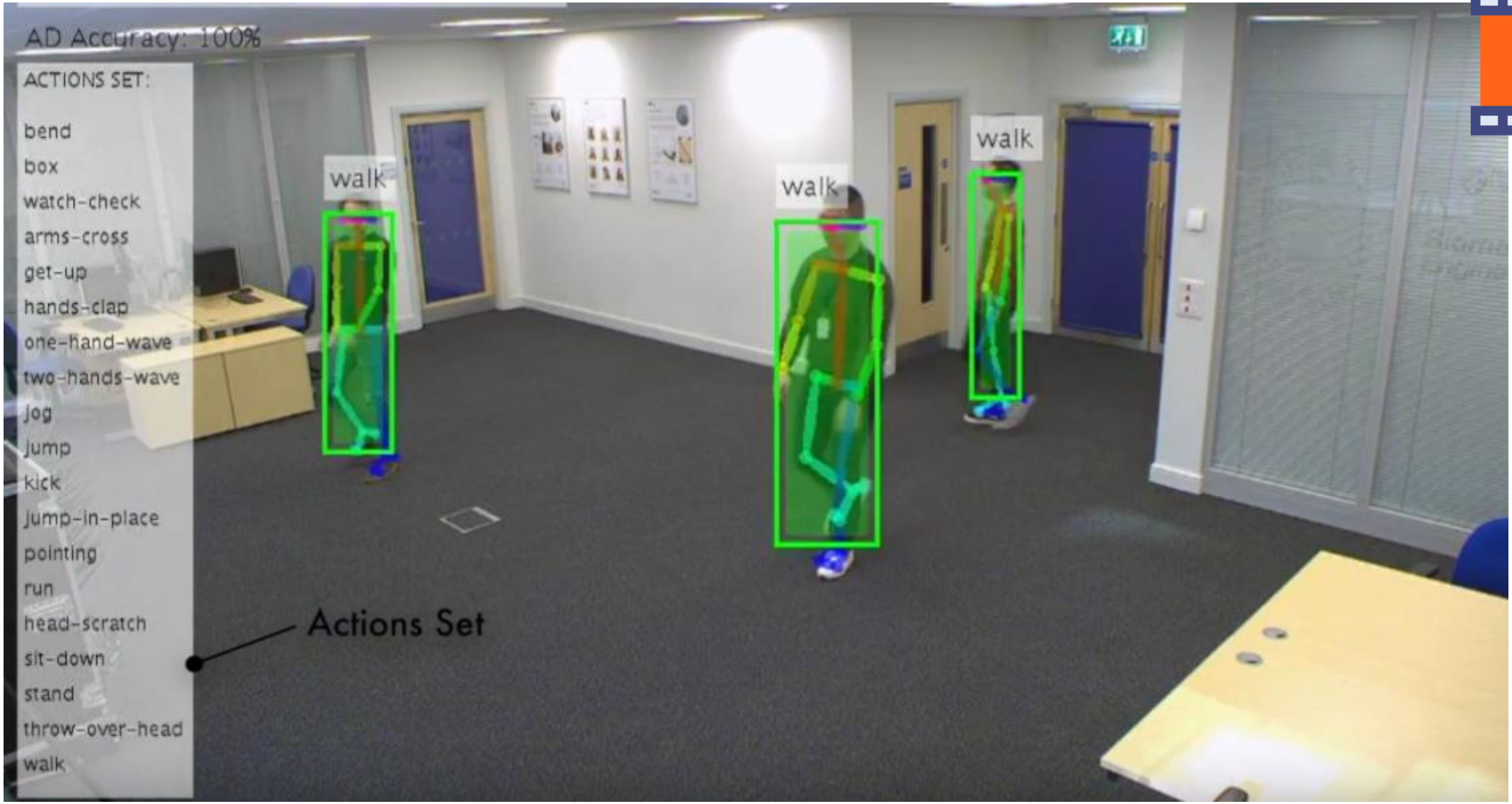
Input: Human to Machine

- **Manual**:
  - Commands can be triggered by touching buttons of the touchscreen
  - Tactile sensors on the head and hands of the robot react to touching
- **Verbal**:
  - Voice commands can be defined and will be recognized by Pepper using natural language processing or a conversation can be initialized (chatbot)
- **Motion**:
  - Gestures can be recognized with the RGB camera and trigger commands
- **Positional**:
  - The robot recognizes humans in the viewing field and can be programmed to follow the path of the human, triggers in dependency of the distance



Pepper Robot by SoftBank Robotics

[29]



Source: https://www.youtube.com/watch?v=7_mcWCB76Ps

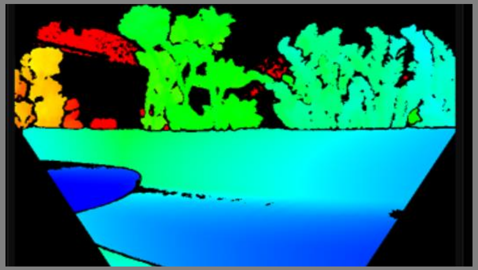
Action Recognition (AR)

Online Recognition
- Recognition of actions from a continuous data set
- Additional difficulty: Determination of the beginning and the end of an action
- Methods are often extensions of existing segmented recognition methods

Offline / Segmented Recognition
- Recognition of sequences with exactly one action
- Often used as a "benchmark" for action recognition methods
- Largest share of methods and data sets in current literature

RGB - Video

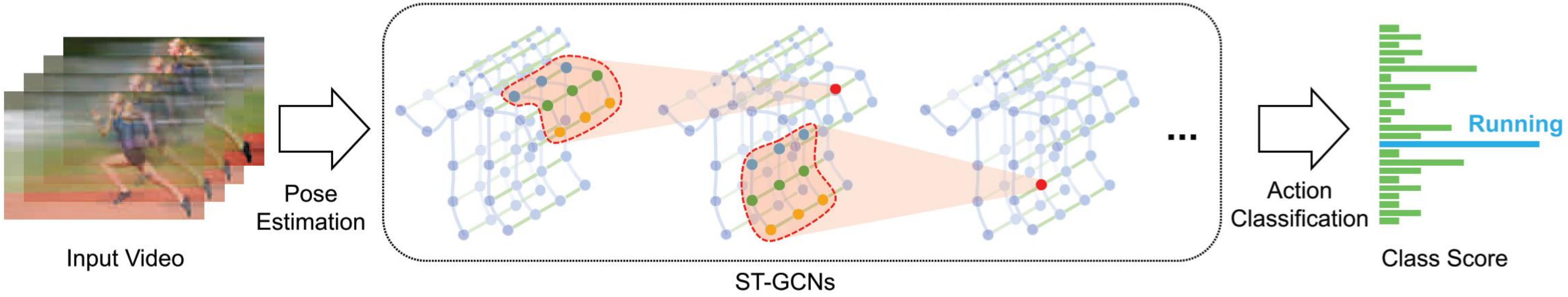
RGB+D - Video



Skeleton - data
- Modeled from RGB(+D) video data
  - Azure Kinect Body Tracking SDK
  - Various other networks
- From accelerometers
- More robust than video data, as the background / environment is irrelevant when training

[42,43]

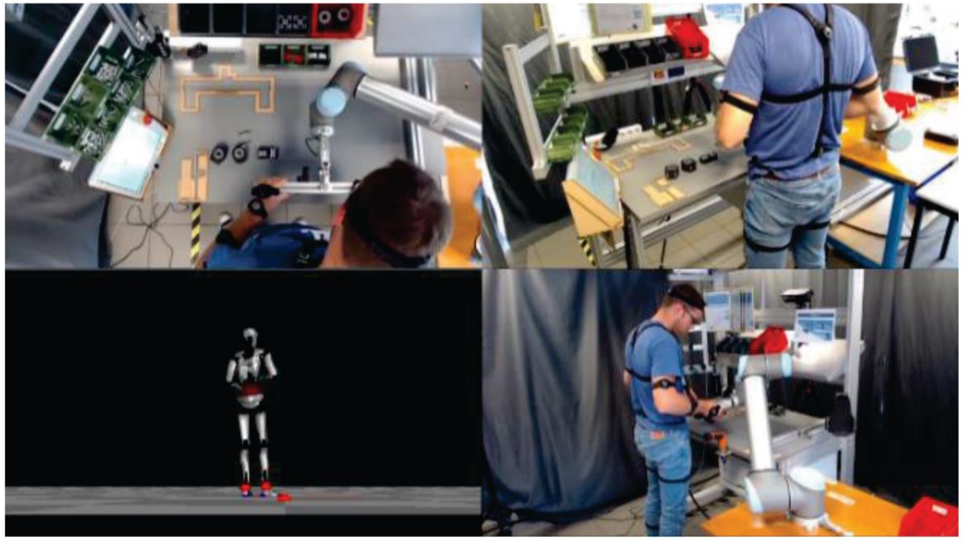
- Spatial Temporal Graph Convolutional Networks (STGCNs)
  - spatial temporal graphs as input
  - probability distribution of trained actions as output
  - not online capable (segmented AR)
  - highest achieved accuracy compared to other AR methods
- Spatial temporal graphs
  - body joints: points on the body to be detected (skeletal data)
  - spatial dimension: connection of adjacent body joints (spatial edges)
  - temporal dimension: connection of each body joint with its temporal predecessor and successor (temporal edge)
- Sliding Window (SW) method
  - SW of defined size is superimposed on the continuous skeleton data stream
  - skeleton data in SW form the spatial temporal graph
  - different actions are better recognized with different SW lengths
  - use of multiple SWs of different lengths and as many STGCNs

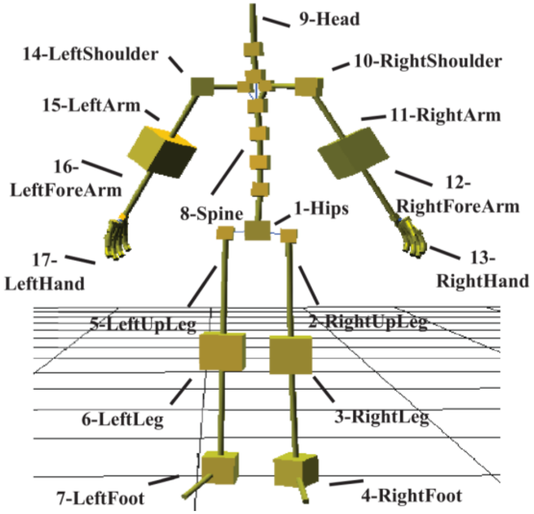


[44]

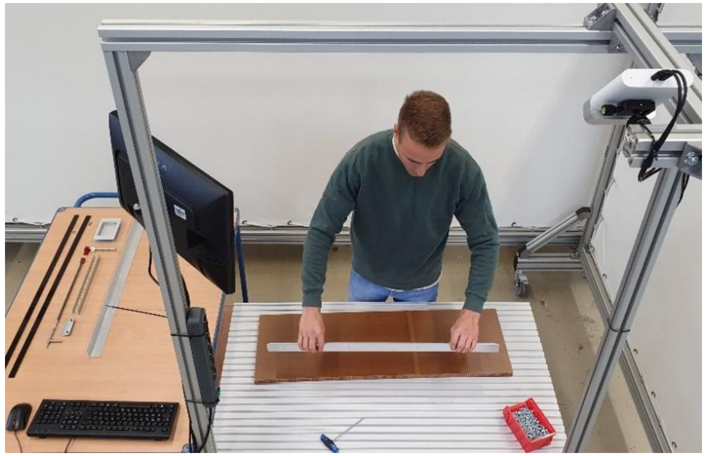
Examples for industrial Action Recognition

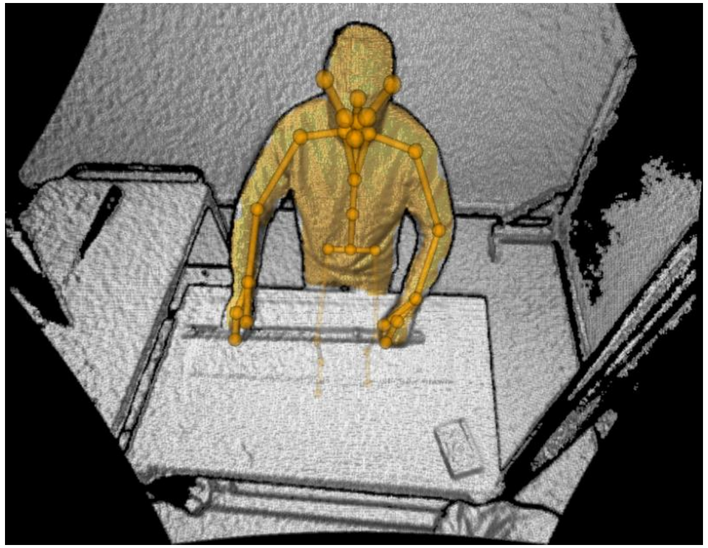
Industrial Human Action Recognition Dataset (InHARD)





Action Recognition for Cabin Aircraft Production





[45]

Standards help to configure safe HRC applications

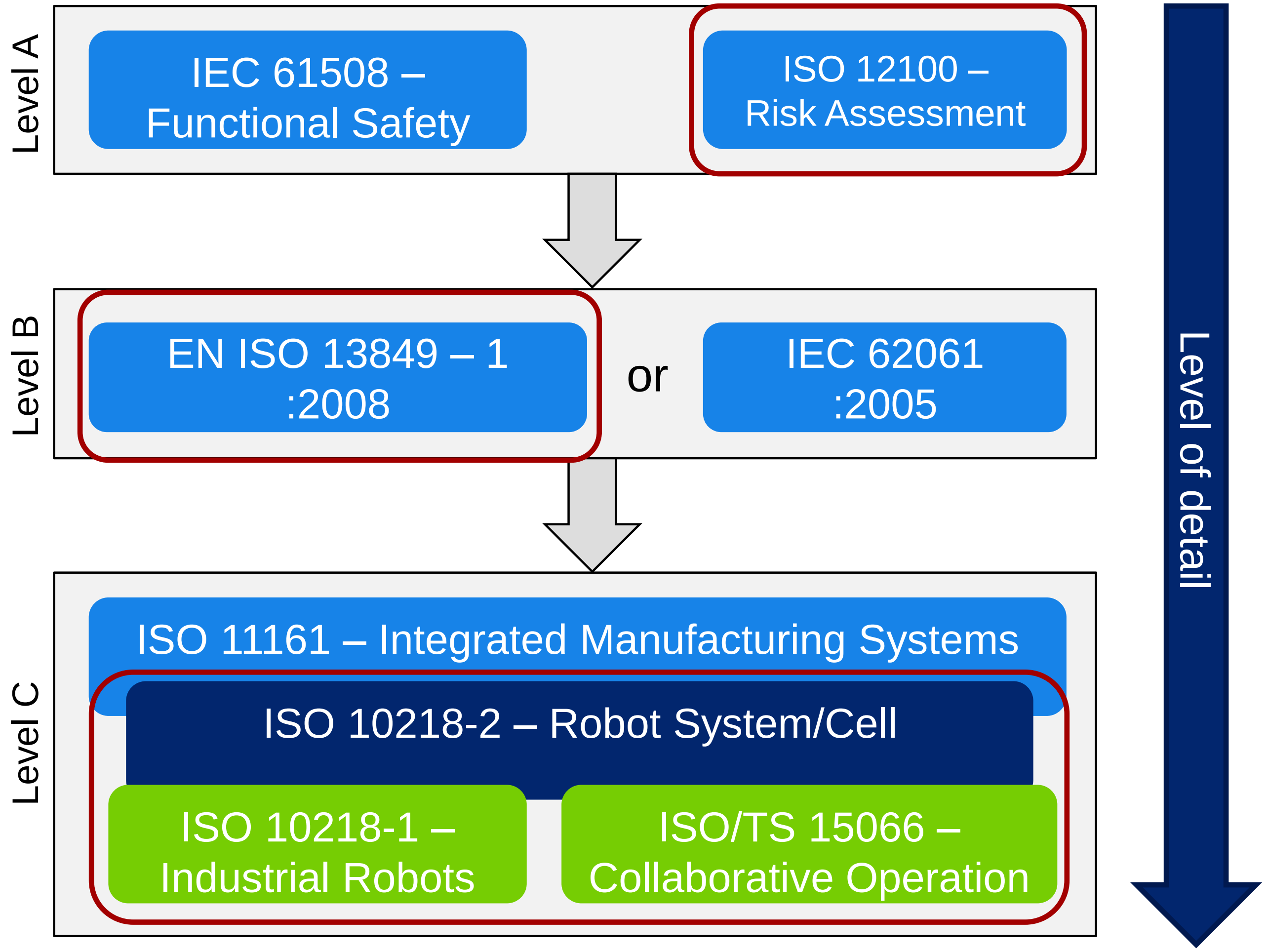
- In the standard EN ISO 10218-1:2011 it is determined that a robot is only a part of the robot system and therefore is not enough for a safe HRC application
- You always have to check the whole application, such as gripper and product
- To let a robot work as an HRC robot, you have to do a risk assessment beforehand and validate your concept
- The net standard ISO/TS 15066 supports the introduction of collaborating robot systems

Ein Roboter entlastet bei Überkopfarbeiten © Daimler

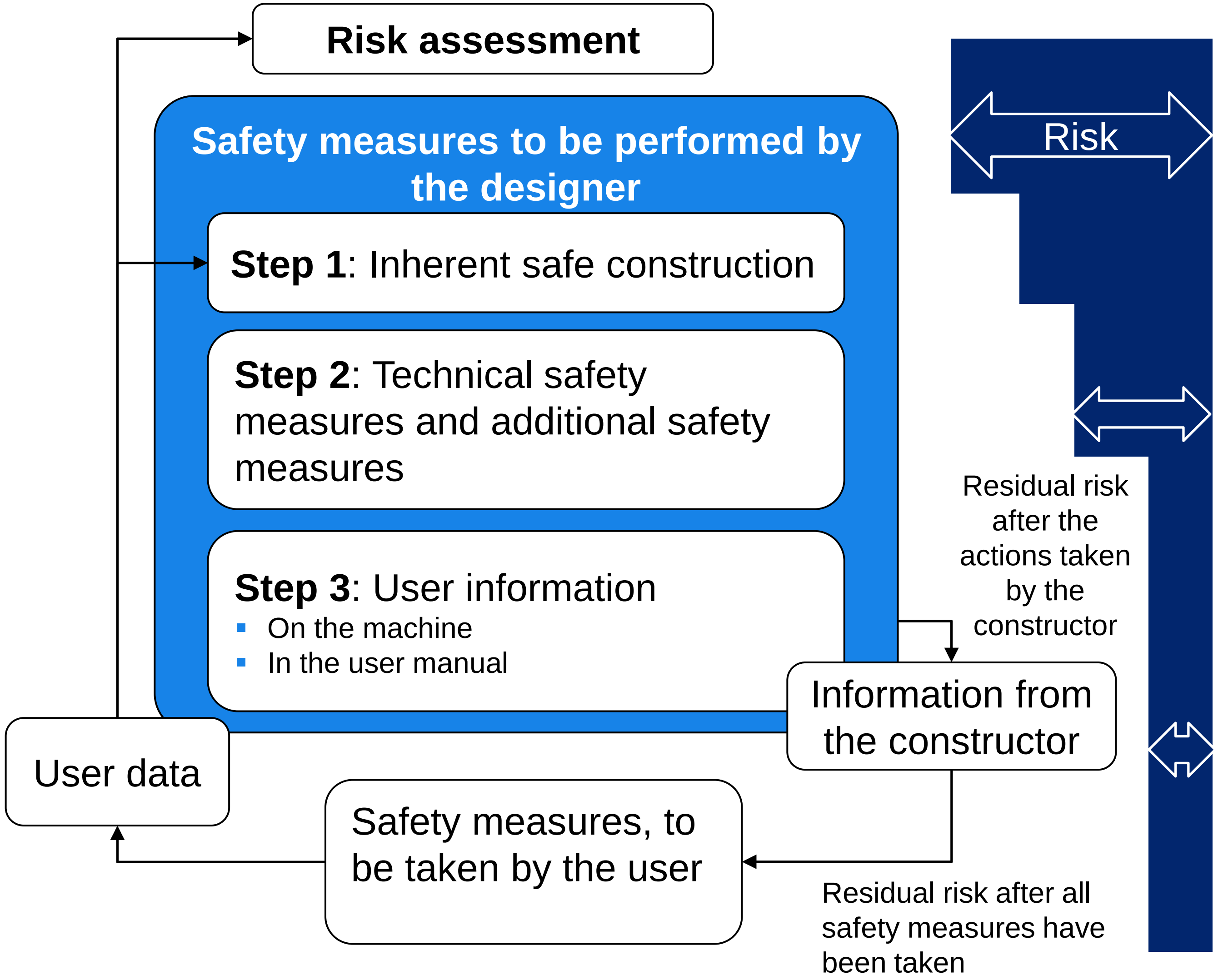
[30]

Overview of the different ISO standards and how they work

- Top Level standard is the first reference
- **A-level highest level standard**
  - Fundamental safety knowledge
  - Basic design features
  - General machine aspects
- **B-level**
  - More specific
  - Risk graph for estimating a danger according
  - Different types of machines
- **C-level**
  - Specific safety requirements
  - Specific kind of machine
    - Robot type



[31]



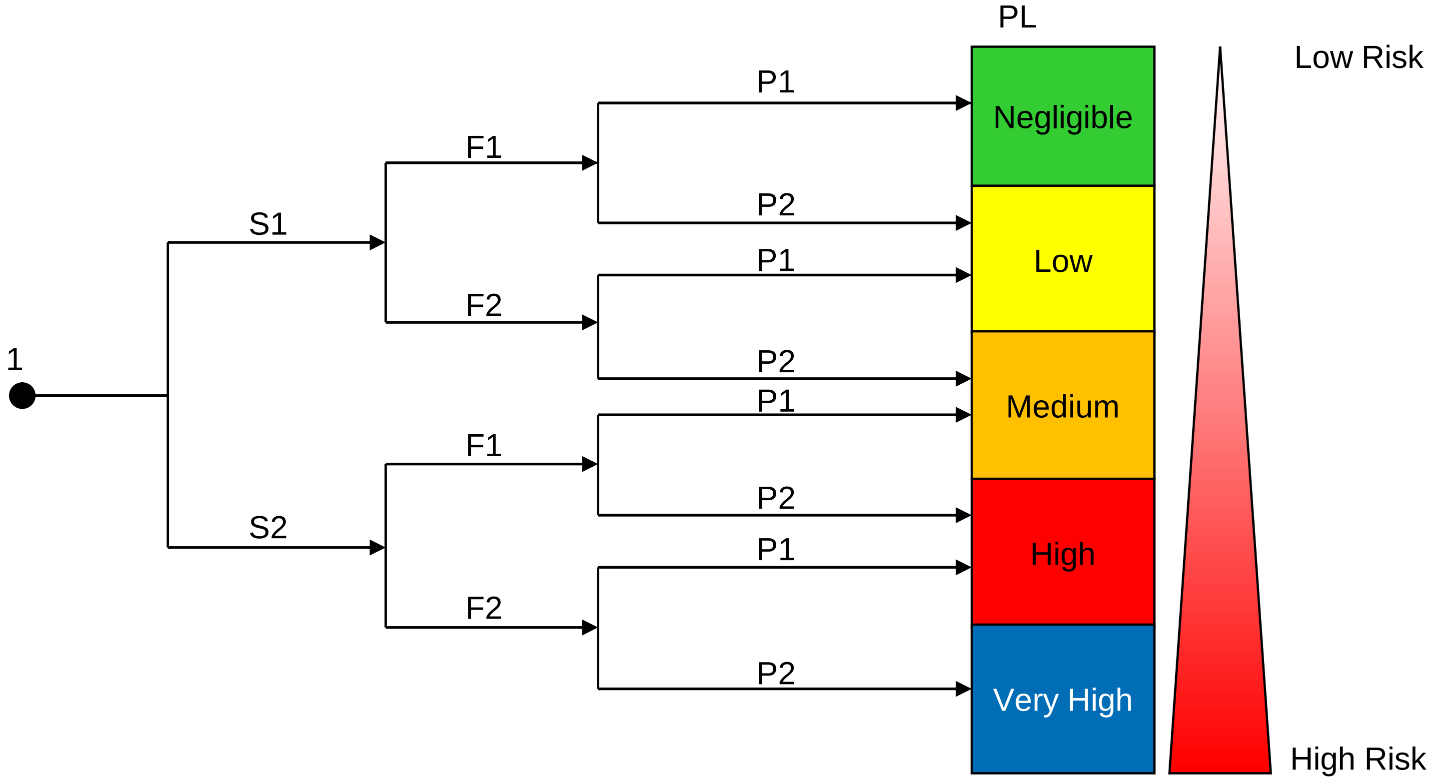
Fixed order of priority in risk reduction:

- **Constructive measures** that mitigate a risk, come first.
- With insufficient reduction **technical safety measures** are used.
- **User information** points to continue existing risks.

[32]

Risk graph for estimating a danger according to ISO 13849

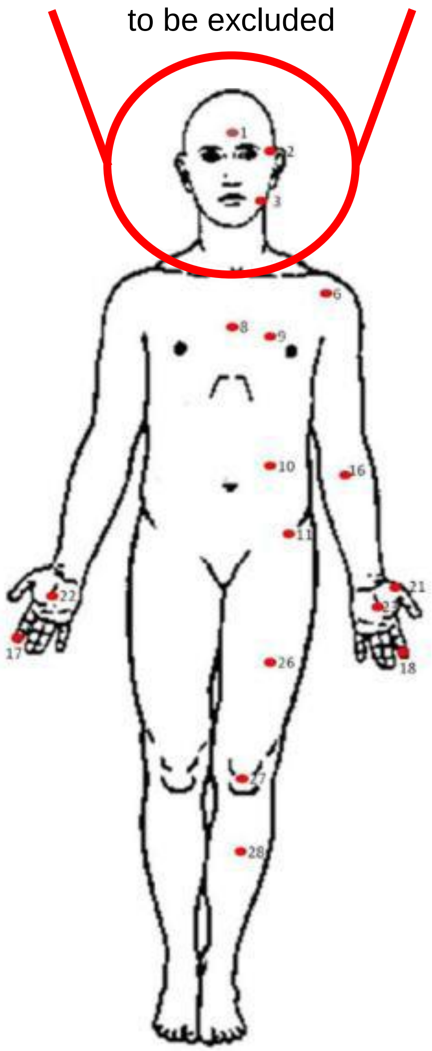
1. Seriousness of the injury (S)
2. Frequency and duration of the exposure to risk (F)
3. Possibility of avoiding the dangerous or limitation of the damage (P)



[33]

Body model for risk assessment

- The seriousness of an injury can be visualized by biomechanical limits.
- The injury data determined on the basis of external mechanical loads.
- First limits were determined by a simple body model.
- Limits were punctual checked by different control tests in the laboratory.
- The determined limits are regarded as provisional.



CRITICAL ZONE

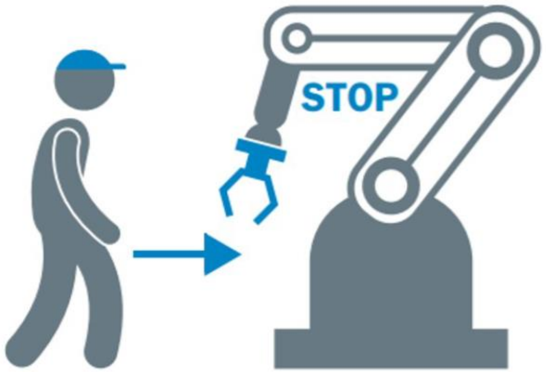
Body Region		Specific Body Area	Quasi-Static Contact: Peak Pressure p_s [N/cm2] (see NOTE 1)	Quasi-Static Contact: Force [N] (see NOTE 2)
Skull and forehead	1	Middle of forehead	125	130
	2	Temple	112	
Face	3	Masticatory muscle	110	65
Neck	4	Neck muscle	138	145
	5	Seventh neck muscle	205	
Back and shoulders	6	Shoulder joint	155	210
	7	Fifth lumbar vertebra	213	
Chest	8	Sternum	116	140
	9	Pectoral muscle	166	
Abdomen	10	Abdominal muscle	143	110
Pelvis	11	Pelvic bone	209	180
Upper arms and elbow joints	12	Deltoid muscle	192	150
	13	Humerus	216	
	16	Arm nerve	179	
Lower arms and wrist joints	14	Radial bone	192	160
	15	Forearm muscle	181	
Hands and fingers	17	Forefinger pad D	298	135
	18	Forefinger pad ND	273	
	19	Forefinger end joint D	275	
	20	Forefinger end joint ND	219	
	21	Thenar eminence	203	
	22	Palm D	256	
	23	Palm ND	260	
	24	Back of the hand D	197	
	25	Back of the hand ND	193	
Thighs and knees	26	Thigh muscle	246	220
	27	Kneecap	223	
Lower legs	28	Middle of shin	220	125
	29	Calf muscle	212	

Draft TS ISO 15066 2015

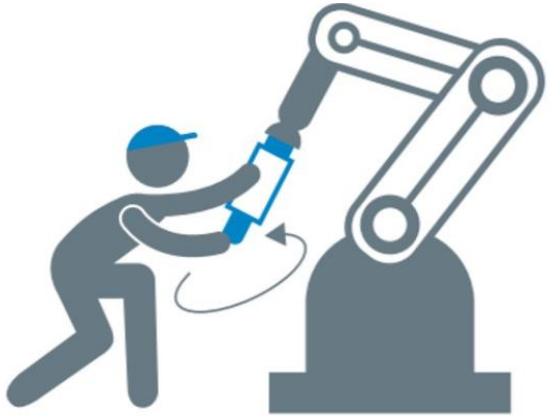
[34]

The four forms of collaboration identified by ISO 10218, ISO/TS 15066

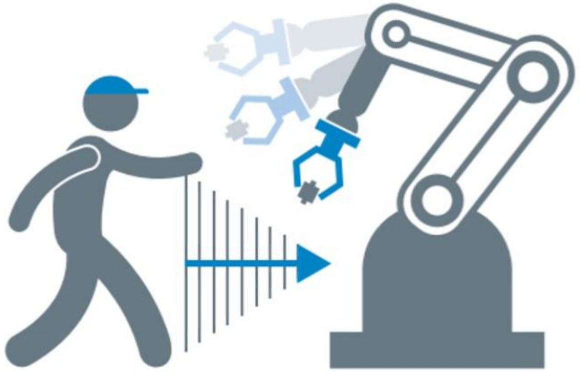
1 Safety-rated monitored stop



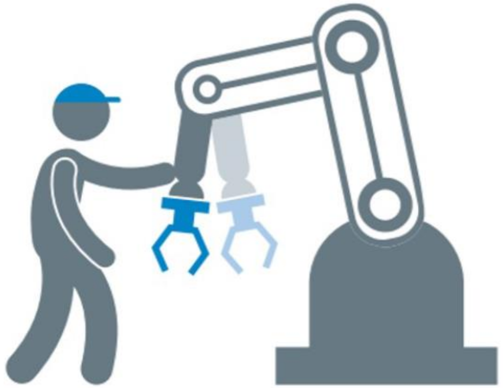
2 Hand-guiding



3 Speed and separation monitoring



4 Power and force limiting

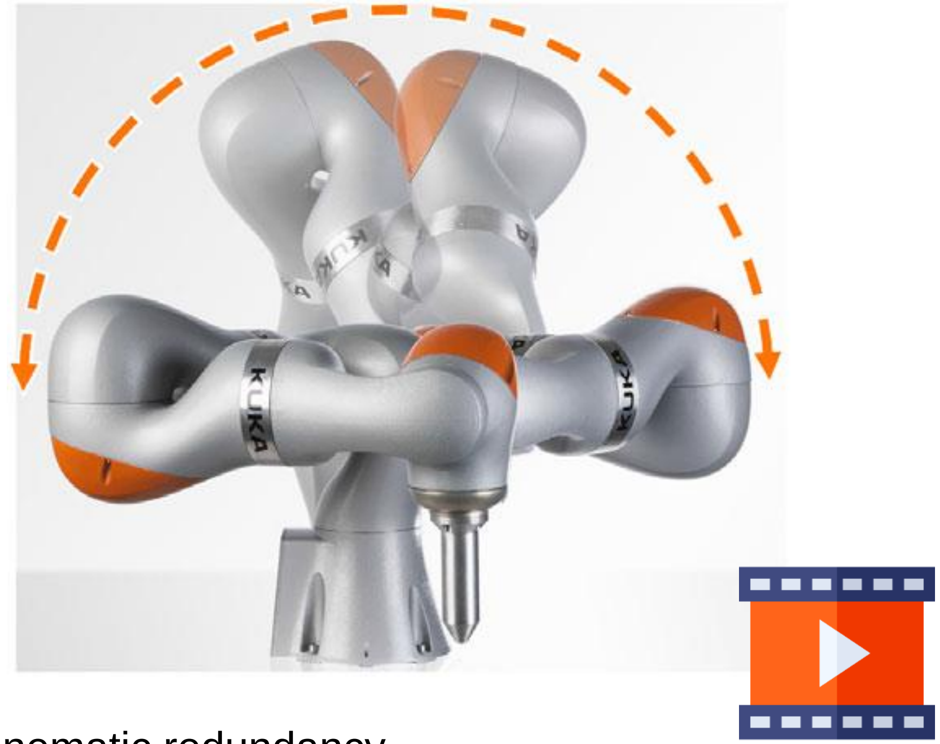


[35]

Overview of the different HRC robot systems available in the market

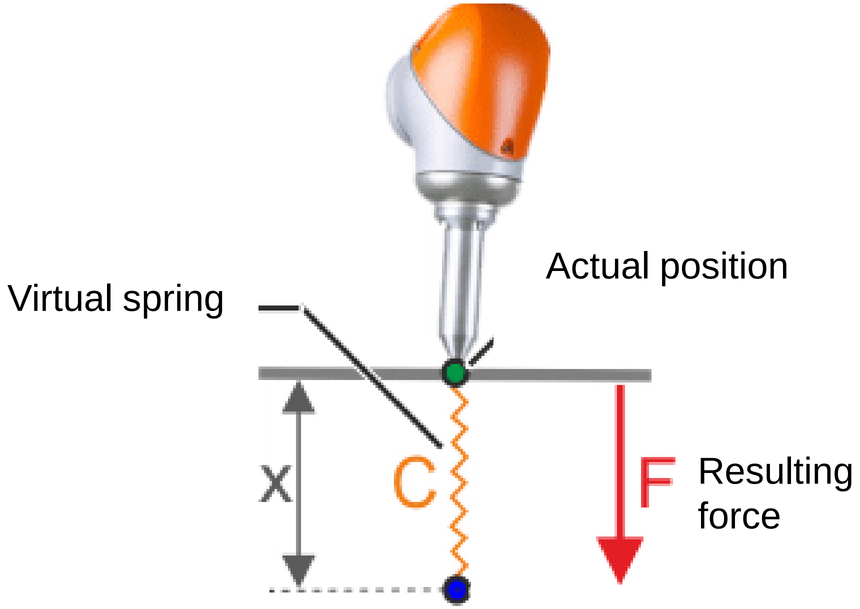
The Kuka iiwa is an approach to perform complex tasks via precise controllers and a large number of functionalities

Null space motion



- Kinematic redundancy
- Suitable for narrow workspace situations

Compliant robot

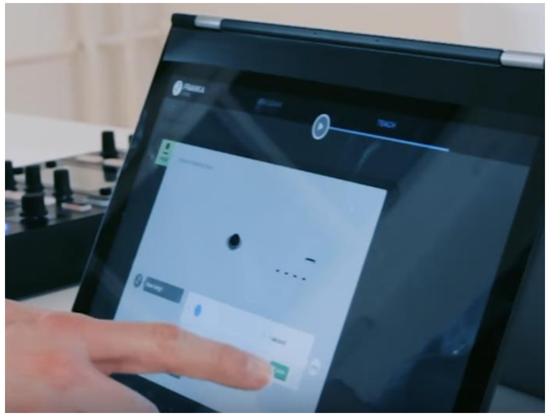


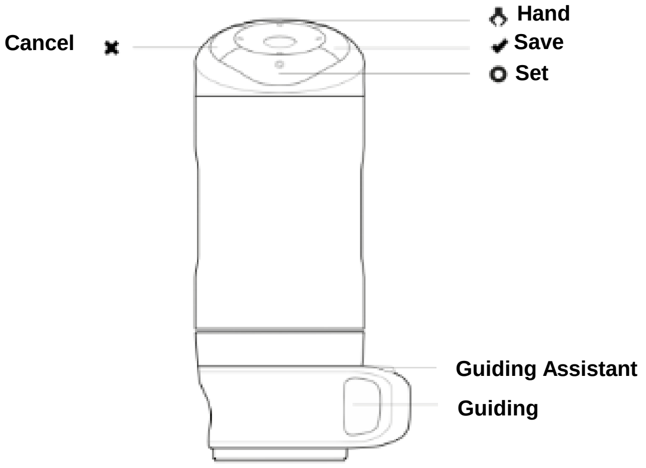
Images: Kuka

[38]

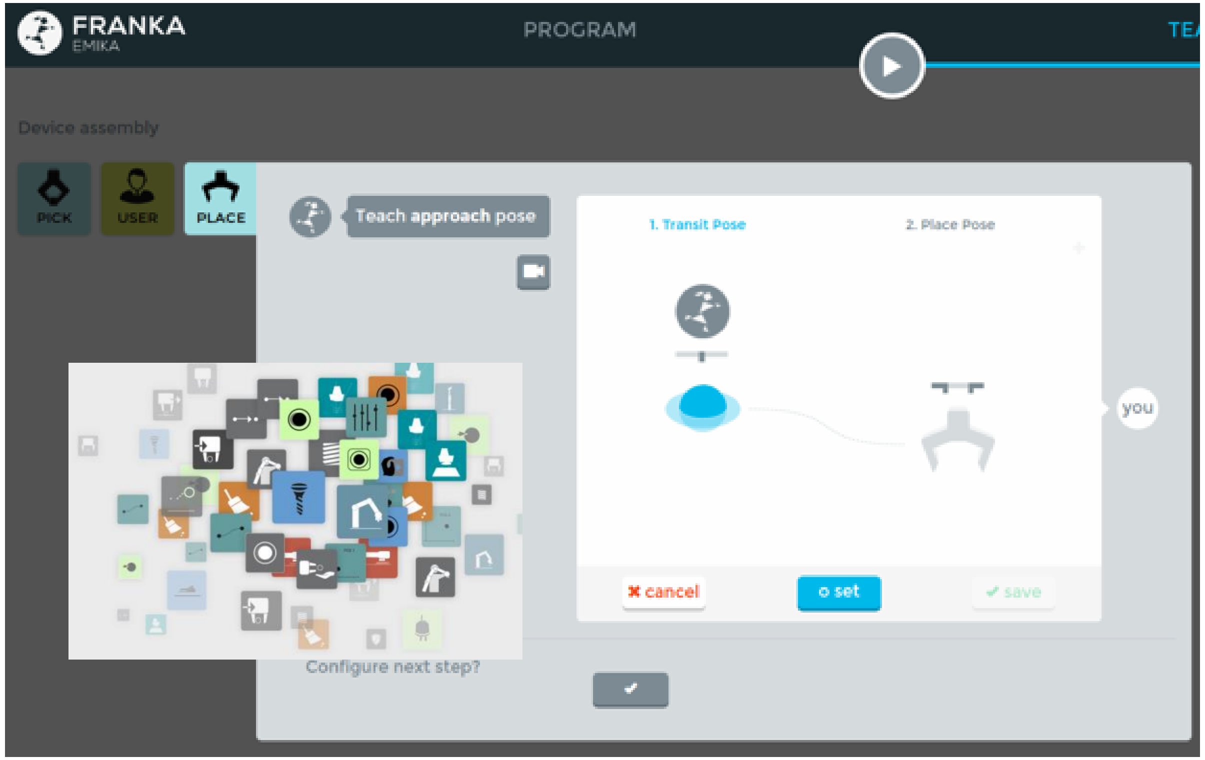
Franka allows for intuitive, APP based programming with high functionality and safety features

Teach-In





Programming: APP – Out of the box



[39]

Agenda

Adhesive application

- A Universal Robot with a dispenser applies adhesive on the rear window of a car

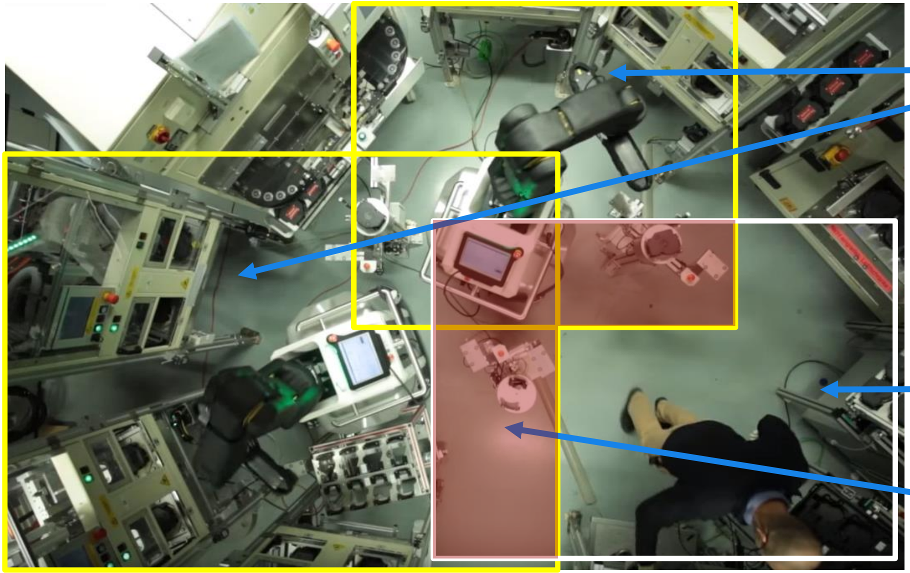
Partial automation of the assembly process

- The worker puts the rear window into the tray
- The worker starts the robot program
- The robot applies the adhesive
- The worker takes the processed window out of the tray and assembles it into the car body

[40]

Cooperating work during the assembly of electronic parts in production in Bosch Blaichach

- Flexible automation of an assembly line
- Loading and unloading of electronic control units
- Special gripper with sensitive skin enables a safe handling process
- Used in serial production since 2015



Workspaces of the robots

Workspace of the human

Common work space

[41]

- Through the use of robot systems with Human-Robot-Cooperation, it is possible to automate processes in a flexible, time sensitive, and need-based manor.
- Besides safety, shared workspaces need to have a flexible division of work as well as the willing cooperation of the operator.
- The HRC robot system qualifies for safe robot design with, special sensors and end-effectors, as well as adducted programming methods for Human-Robot-Cooperation.
- Risk assessment for Human-Robot-Cooperation by determining the relevant influencing quantities for injuries and for validation of the existing maximum loads for Human-Robot-Cooperation.
- In many large companies today, Human-Robot-Cooperation is already in industrial use.

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