LECTURE 3

Collaborative robotics: introduction

Paolo Rocco

Collaborative robotics

Source: Universal Robots

- This School is on (intelligent) collaborative robotics
- What is actually collaborative robotics?
- And why is it considered so important in the future of robotics?

Collaborative robotics

- Humans and robots collaborating at the same task
- Protective fences are not needed
- Particularly interesting for SMEs (reduced cost, reduced foot print)

Source: KUKA

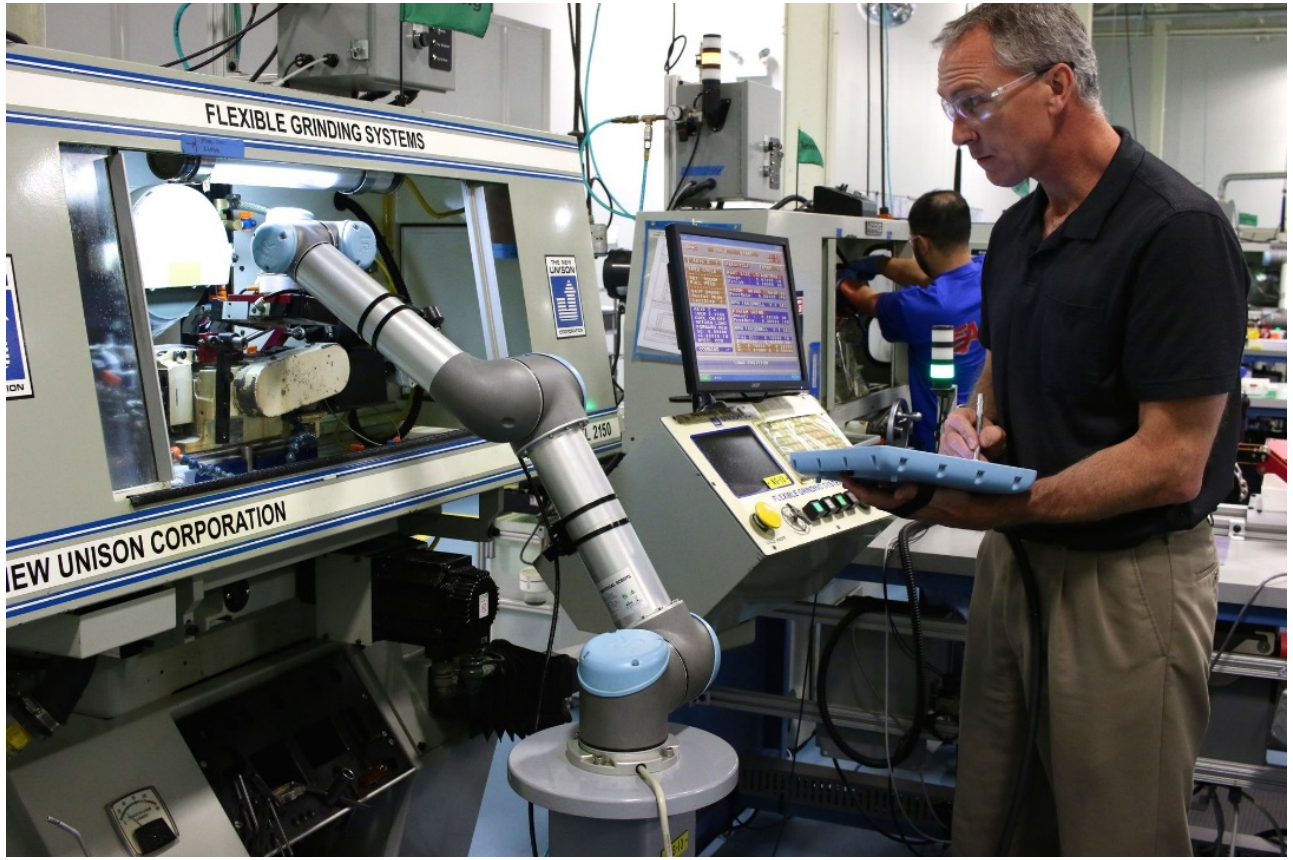
Collaborative robotics

- Redundant, dual arm manipulators, characterized by low inertia and low payload (reduced risk when impact)
- Still good precision available
- Good potential for assembly of electronic parts

Source: ABB

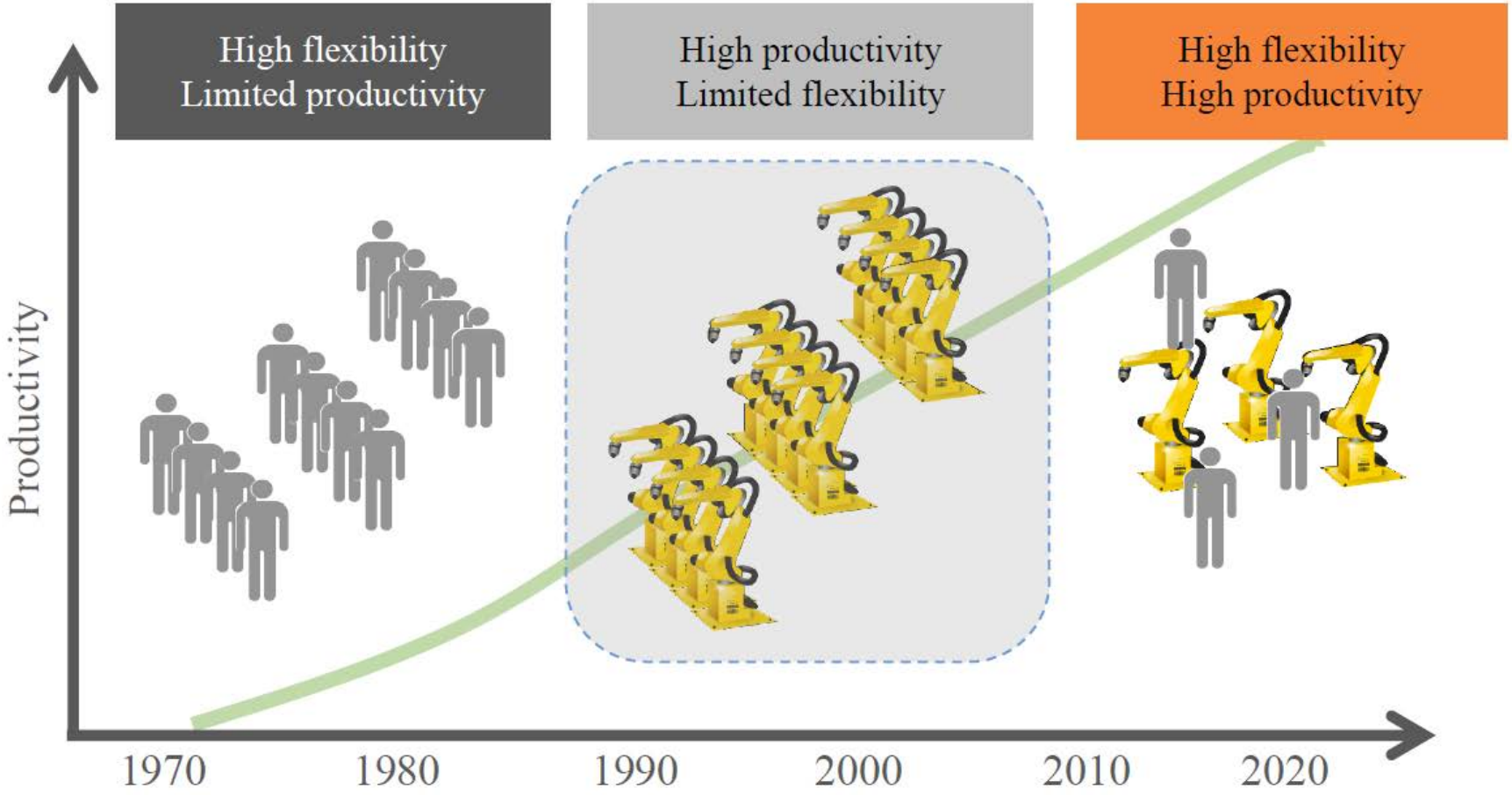
Collaborative robotics

- New programming interfaces
- Decrease of the deployment time
- High potential for SMEs

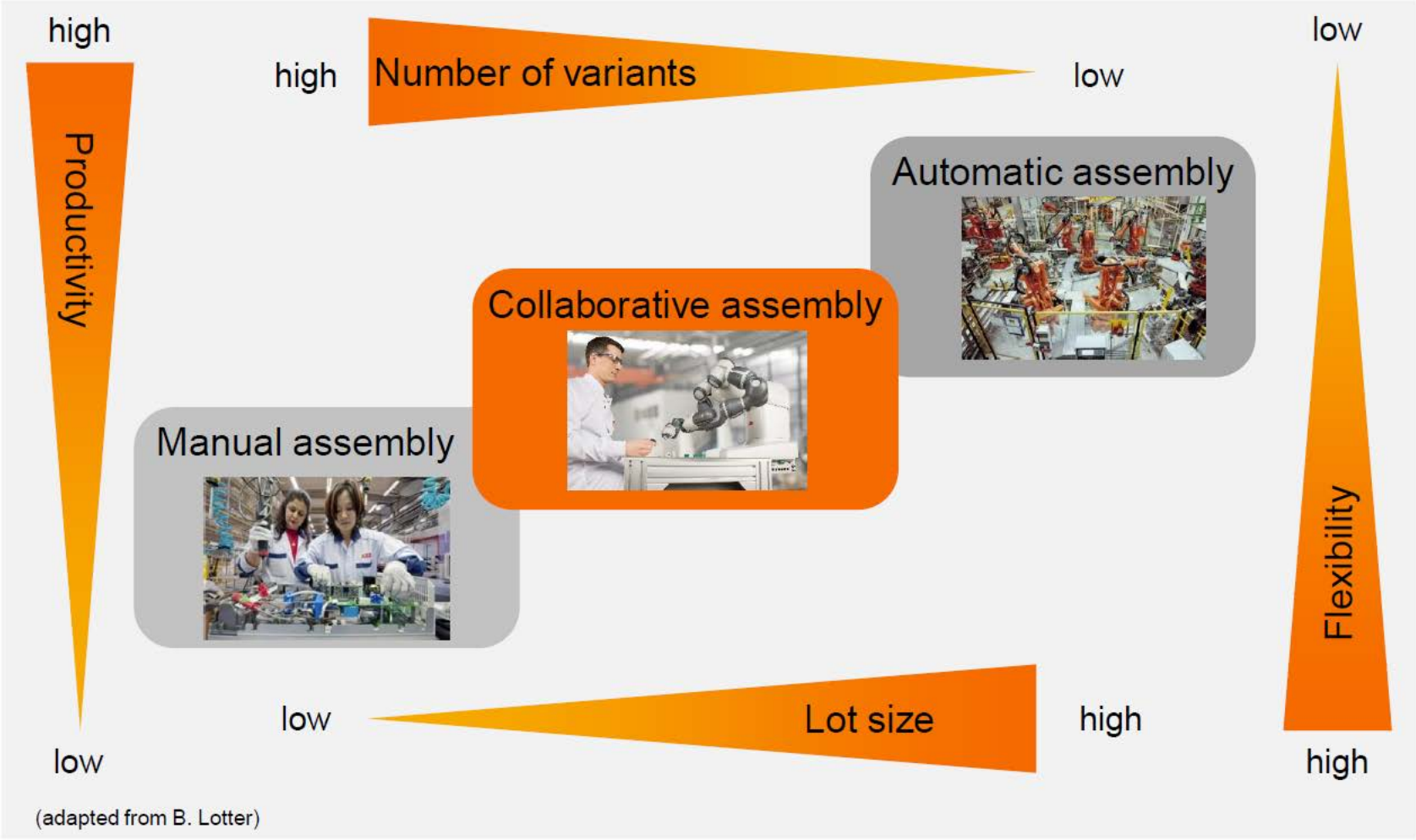


Source: Universal Robots

Why human-robot collaboration?



Collaborative assembly



Source: ABB Corporate Research

A bit of history of collaborative robotics

2000 | 2000 | 2002 | 2004 | 2006 | 2008 | 2010 | 2012 | 2014 | 2016 | 2017

1960 - 2000
Industrial robots are separated from humans; they requires significant investments and programming skills

2000
The world cobot enters the dictionary
cobot: noun. A collaborative robot designed to help workers on the job instead of replacing them. Source: Wall Street Journal, Jan 2000

2005
Universal Robots is founded in Denmark to develop an affordable, low-cost collaborative robot
UR5 was launched in 2008 and certified by TUV in 2014

2012
Rethink Robotics is founded and launches Baxter

2013
KUKA launches LBR iiwa

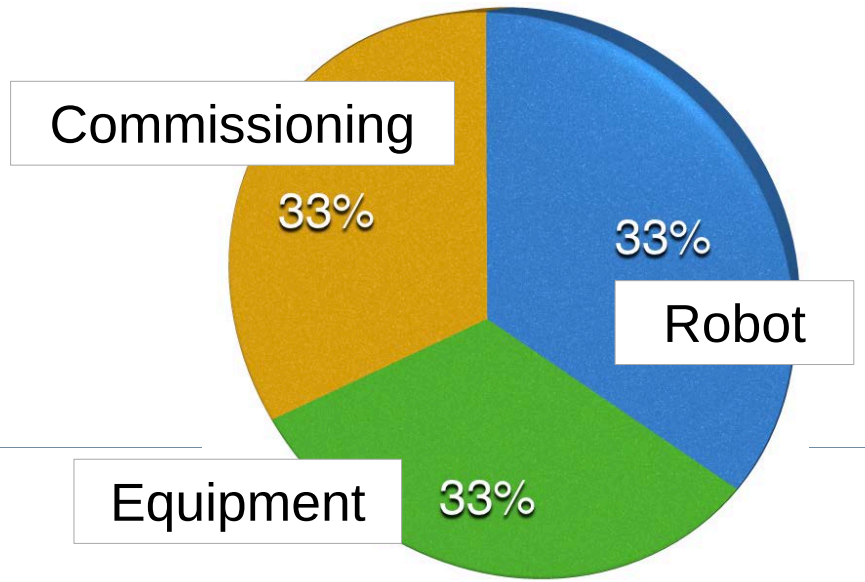
2015
ABB launches YuMi and acquires Gomtec

2016
ISO sets a new standard for cobots

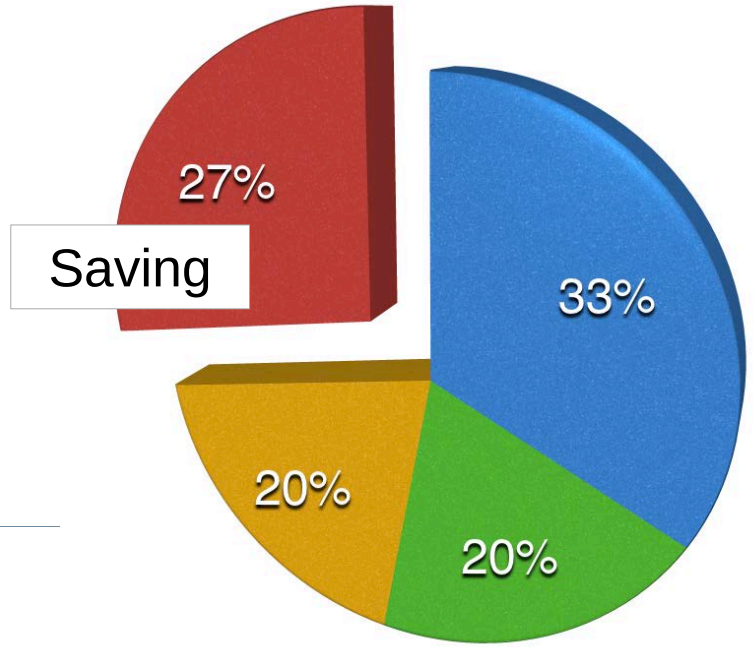
Installation costs of cobots

- Collaborative robots have no (or reduced) physical protection devices to allow the human operator to directly interact with them.
- The limited need of safeguarding devices allows a smaller footprint, making cobots more affordable, especially for SMEs, as compared with traditional industrial robots.

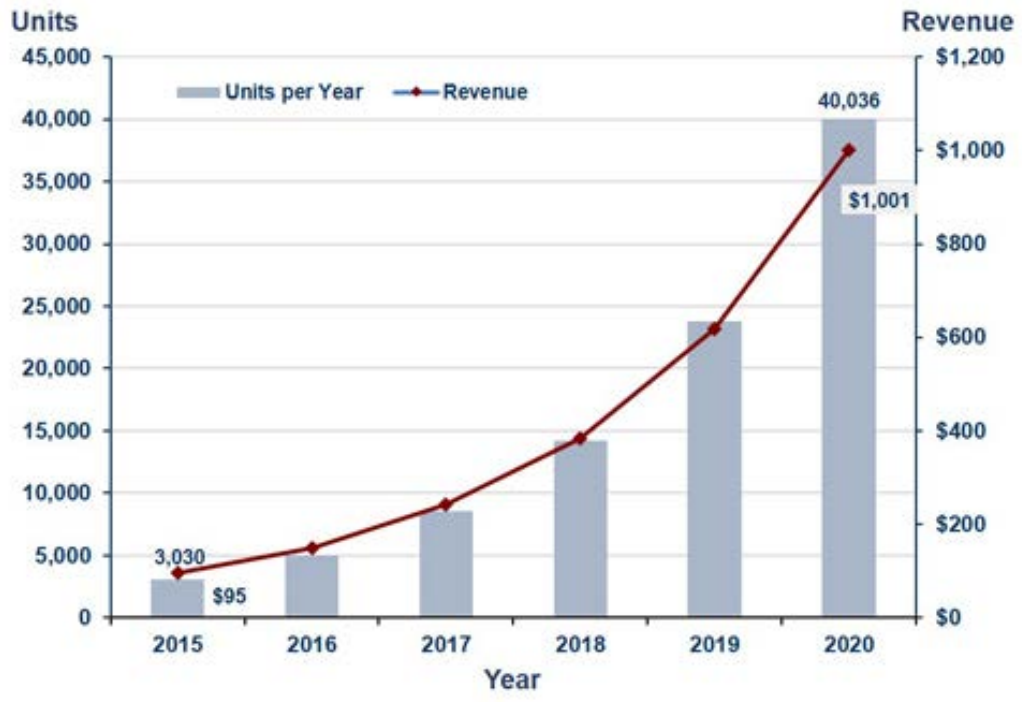
Industrial Robot



Collaborative Robot



Market of the cobots



ABI Research, Marker report on collaborative robotics, 2015

MATERIAL HANDLING
32%

CAGR 2016-2021:
+62% (expected)

Source: technavio

ASSEMBLY
28%

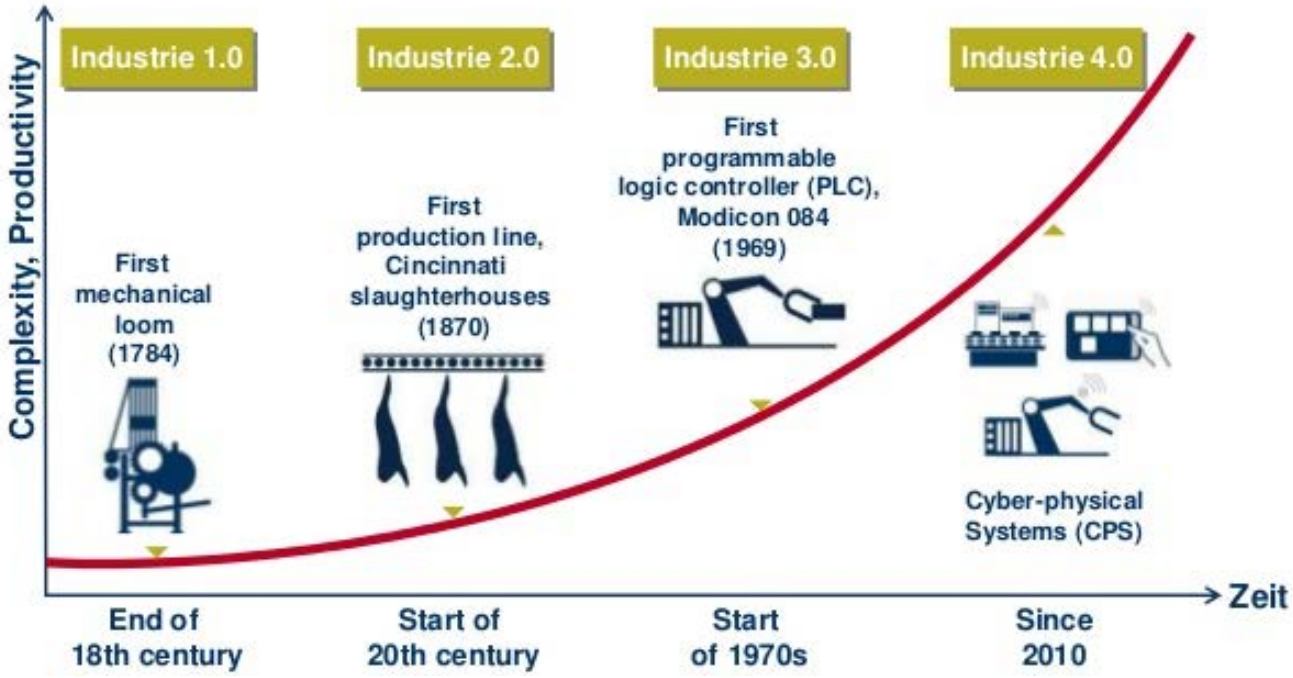
CAGR 2016-2021:
+62% (expected)

Source: technavio

Technavio's market research analysis

Industry 4.0

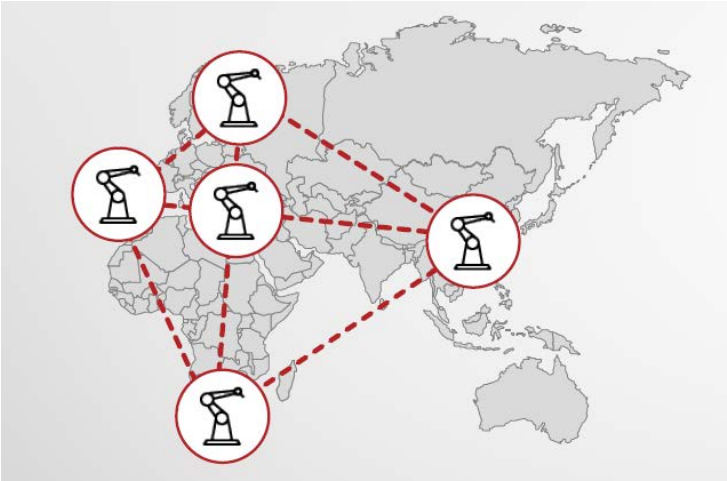
- Robots are key components in the manufacturing of Industry 4.0
- Integration of machinery, warehousing systems and production facilities as Cyber-Physical systems
- Flexibility, cost effectiveness and productivity in smart factories



Source: Bosch

Industry 4.0

Self-optimizing production



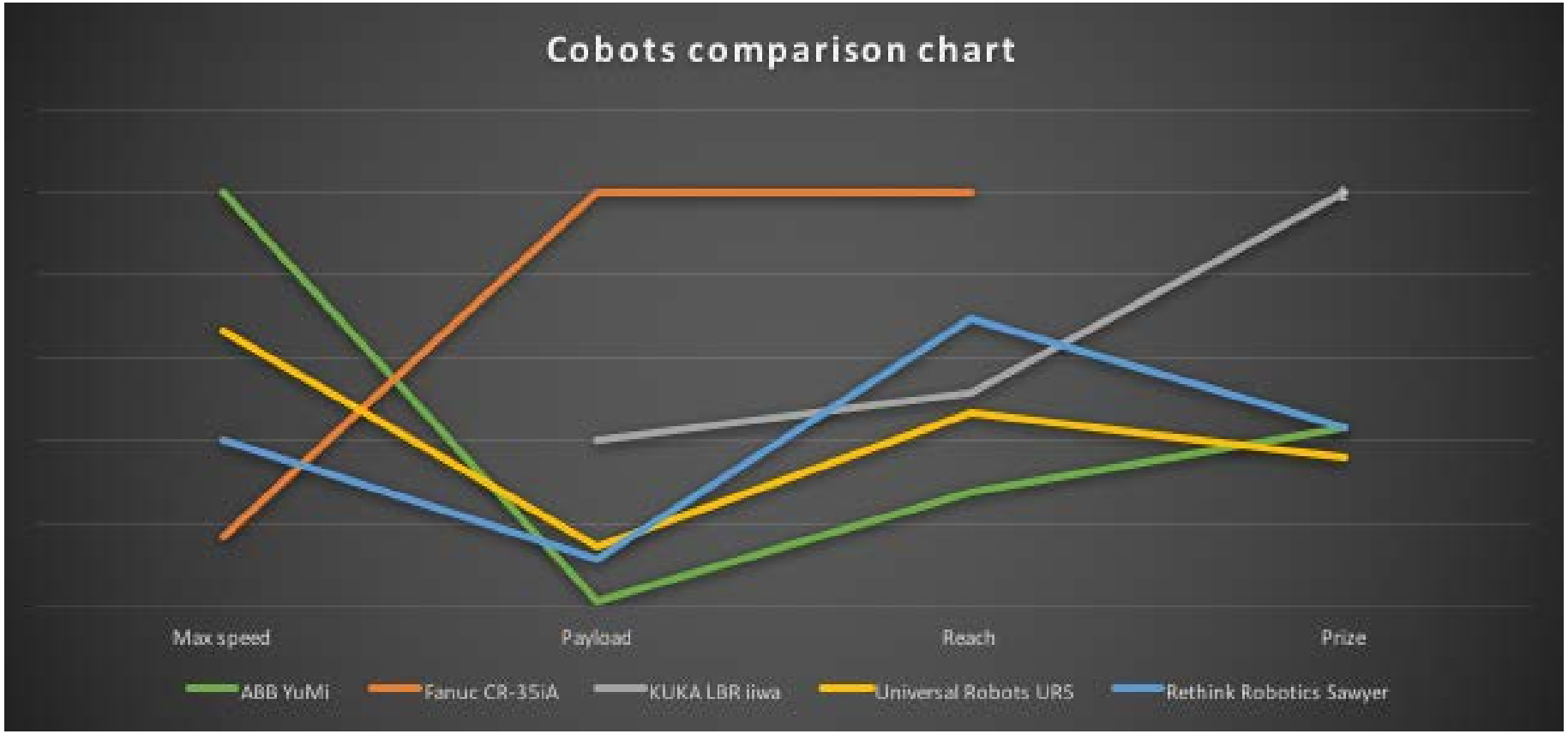
Robots doing the same task connect across all global locations so performance can be compared and improved at the click of a button

Self-programming robots

Robots automatically download what they need to get started from a cloud library and then start to optimize through “self-learning”

Source: IFR

Available cobots (comparison charts)

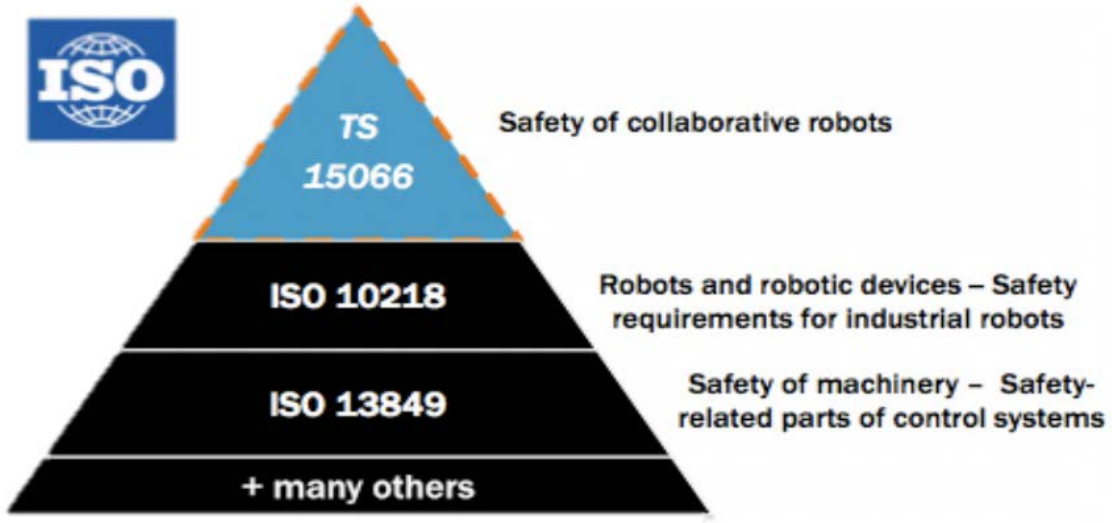


Successful adoption of cobots

Safety

- This robot is safe
- However it is not collaborative
- How can we guarantee safety while allowing for collaboration?

Safety standards for robotics



ISO 10218 “Robots and robotic devices — Safety requirements for industrial robots” is divided into:

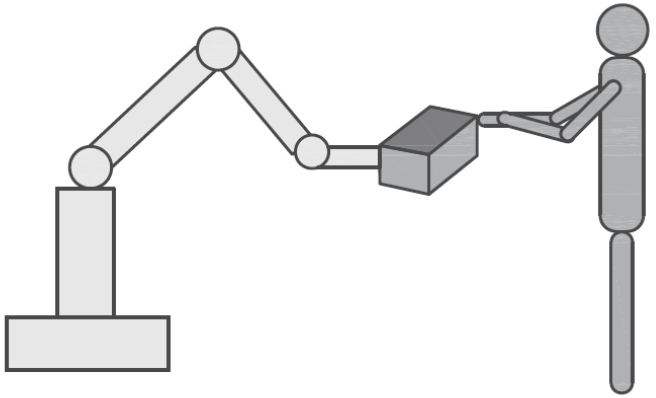
Part 1 “Robots”;

Part 2 “Robot systems and integration”.

ISO 10218-1 specifies requirements and guidelines for the inherent safe design, protective measures and information for use of industrial robots.

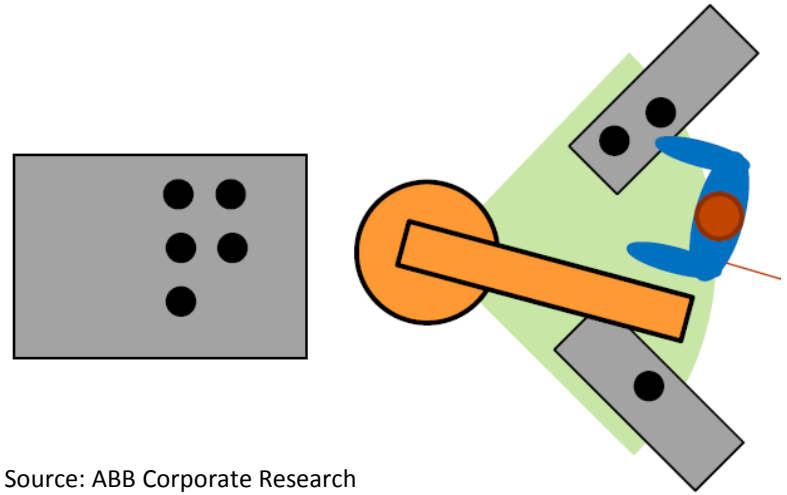
It describes basic hazards associated with robots and provides requirements to eliminate, or adequately reduce, the risks associated with these hazards.

Safety standards: definitions



Collaborative operation

- ISO 10218-1:2011, clause 3.4
- State in which purposely designed robots work in direct cooperation with a human within a defined workspace

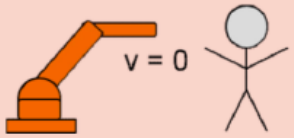
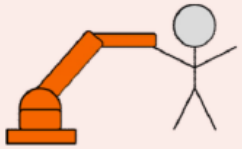
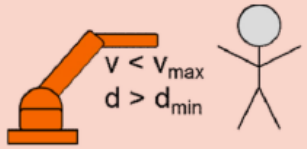


Source: ABB Corporate Research

Collaborative workspace

- ISO 10218-1:2011, clause 3.5
- Workspace within the safeguarded space where the robot and a human can perform tasks simultaneously during production operation

Types of collaborative operations

ISO 10218-1, clause	Type of collaborative operation	Main means of risk reduction	
5.10.2	Safety-rated monitored stop (Example: manual loading-station)	No robot motion when operator is in collaborative work space	
5.10.3	Hand guiding (Example: operation as assist device)	Robot motion only through direct input of operator	
5.10.4	Speed and separation monitoring (Example: replenishing parts containers)	Robot motion only when separation distance above minimum separation distance	
5.10.5	Power and force limiting by inherent design or control (Example: *ABB YuMi®* collaborative assembly robot)	In contact events, robot can only impart limited static and dynamics forces	

Source: ABB Corporate Research

Safety-rated monitored stop

A very conservative mode. Collaboration is limited with a robot in a stand-still position. Power is still enabled and the robot is ready to resume its motion.

- **Clauses in standards and TS**
  - ISO 10218-1, clause 5.10.2
  - ISO 10218-2, clause 5.11.5.2
  - ISO/TS 15066, clause 5.5.2
- **Risk reduction**
  - Ensure robot standstill whenever a worker is in collaborative workspace
- **Achieved by**
  - Supervised standstill - Category 2 stop (IEC 60204-1)
  - Category 0 stop in case of fault (IEC 60204-1)
- **Typical applications**
  - Loading / unloading end-effector

Source: ABB Corporate Research

Hand guiding

- **Clauses in standards and TS**
  - ISO 10218-1, clause 5.10.3
  - ISO 10218-2, clause 5.11.5.3
  - ISO/TS 15066, clause 5.5.3
- **Risk reduction**
  - Provide worker with direct control over robot motion at all times in collaborative workspace
- **Achieved by**
  - Controls close to end-effector
  - Input means for motion commands
  - Emergency stop (red button)
  - Enabling device (dead man)
- **Typical applications**
  - Lift assist, load positioning

Source: ABB Corporate Research

Speed and separation monitoring

- **Clauses in standards and TS**
  - ISO 10218-1, clause 5.10.4
  - ISO 10218-2, clause 5.11.5.4
  - ISO/TS 15066, clause 5.5.4
- **Risk reduction**
  - Maintain sufficient distance between worker and robot in collaborative workspace
- **Achieved by**
  - Supervision of distance, speed
  - Protective stop if minimum separation distance or speed limit is violated
- **Typical applications**
  - Working in common area on separate tasks

Source: ABB Corporate Research

Power and force limitation

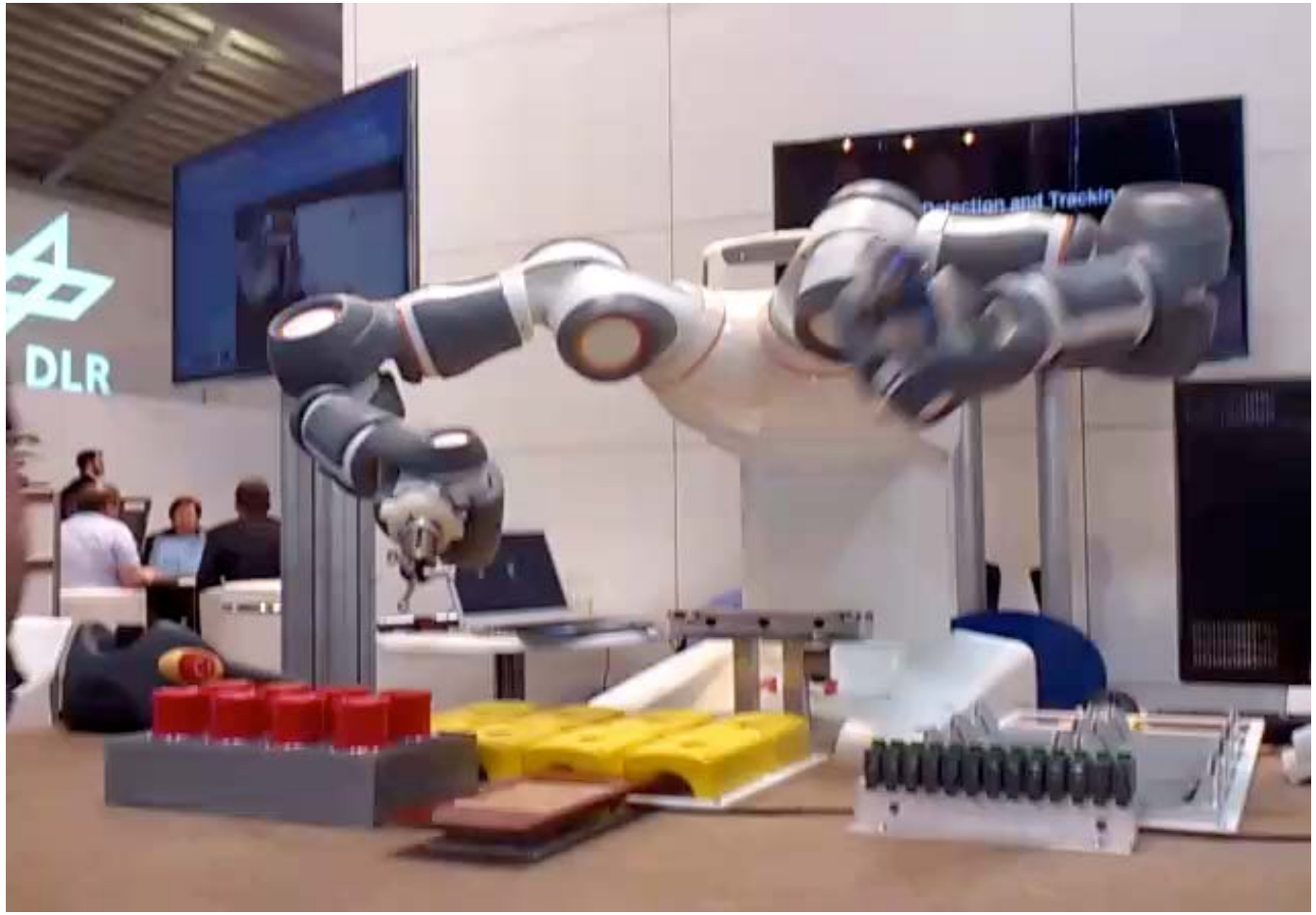
- **Clauses in standards and TS**
  - ISO 10218-1, clause 5.10.5
  - ISO 10218-2, clause 5.11.5.5
  - ISO/TS 15066, clause 5.5.5
- **Risk reduction**
  - Limiting mechanical loading of human-body parts by moving parts of robot, end-effector or work piece
- **Achieved by**
  - Low inertia, suitable geometry and material, sensory input, control functions, …
- **Typical applications**
  - Mixed environment, involving possibility of transient and/or quasi-static physical contact

Source: ABB Corporate Research

Robot as an element in the collaborative station

The robot is simply a component in a final collaborative robot system and is not in itself sufficient for a safe collaborative operation. The collaborative operation applications are dynamic and shall be determined by the risk assessment performed during the application system design.

Cobots as fellow co-workers

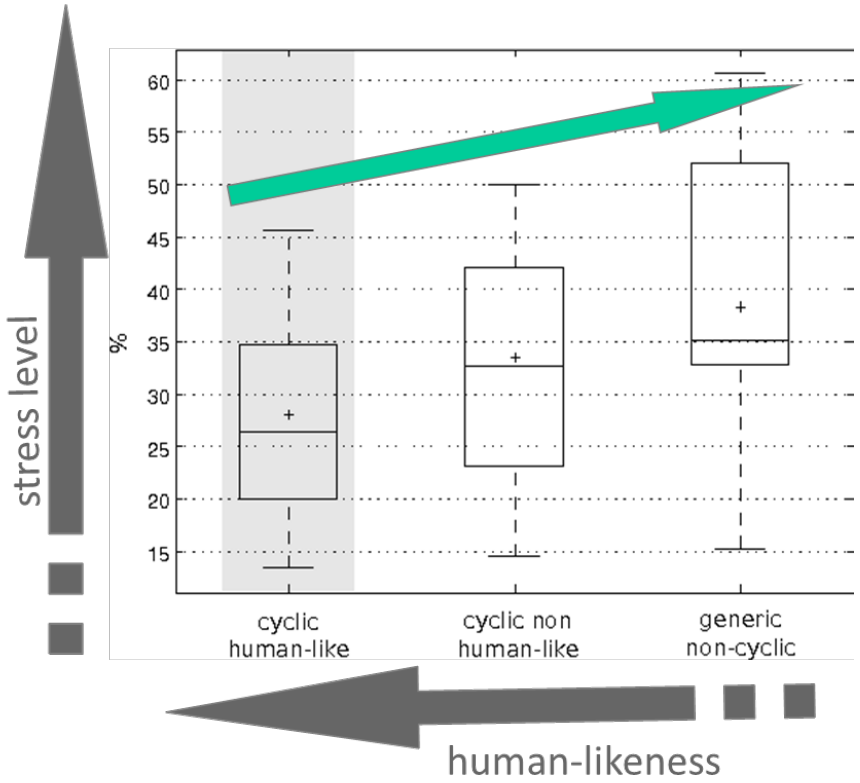


The robot moves with human-like motion profiles in order to minimize psychological stress in the worker.

Zanchettin, Bascetta, Rocco, IEEE RAM, 2013

Cobots as fellow co-workers

Through physiological signals we measured the stress induced by robot on an operator working elbow-to-elbow with the robot.

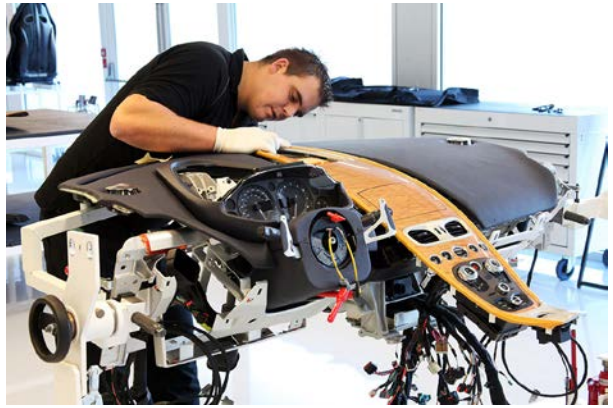


Zanchettin, Bascetta, Rocco, Applied Ergonomics, 2013

Cobots as assistive fellow co-workers

There are many examples of operations with poor ergonomics.

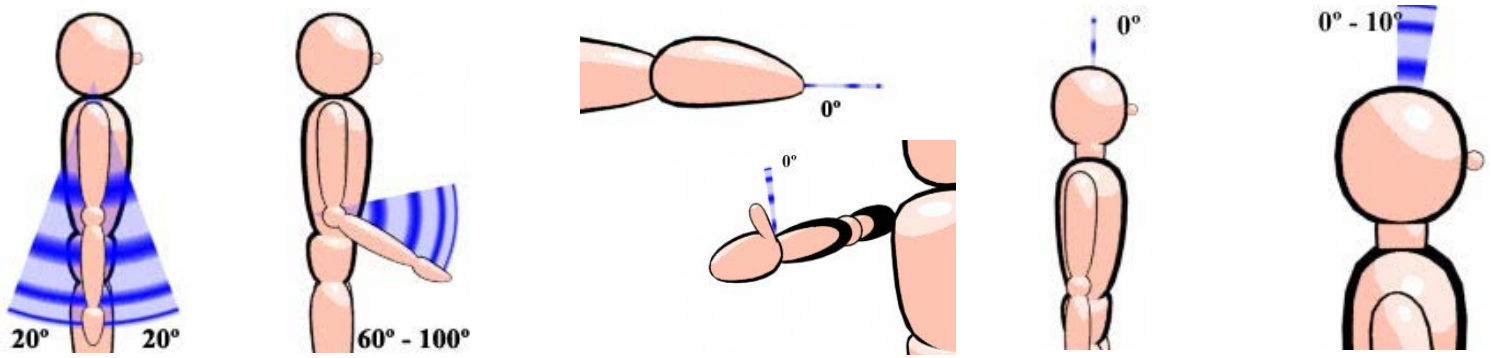
A collaborative robot might support the operator as an autonomous positioner of the workpiece in order to increase the ergonomics of the workstation and prevent from MuscoloSkeletal Disorders (MSD).



Cobots as assistive fellow co-workers

Collaborative robotics is one tool that we can use in the workplace to combat MSDs, and other health problems which are caused by poor ergonomics. The collaborative robot should handle the workpiece to the operator in a way that is ergonomic and natural.

RULA *Method (Rapid Upper Limb Assessment)* → Arms, Forearms, Wrists, Neck, Trunk, Legs → Risk level



Cobots as assistive fellow co-workers

Through a (redundant) vision system, the robot is able to track the position of the operator (based on his shoulders) and evaluate the best positioning of the workpiece that minimize the risk of musculoskeletal disorders (MSD), evaluated using the RULA index and a musculoskeletal model.

Ferraguti, Villa, Talignani Landi, Zanchettin, Rocco, Secchi, Robotica, 2019

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