Rome, November 25th 2019

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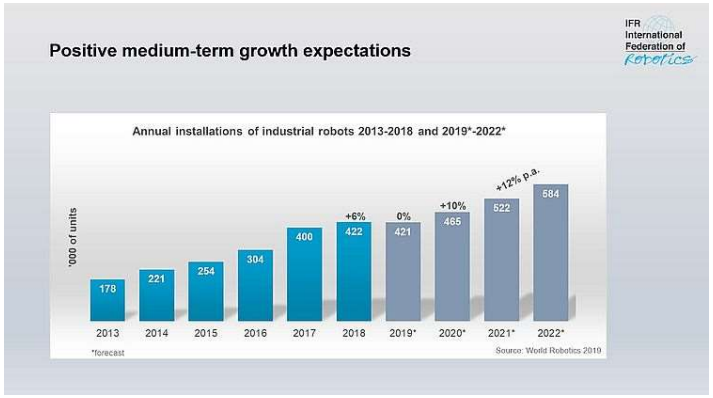
Emerging risks in industry 4.0: innovative approaches for safety and security

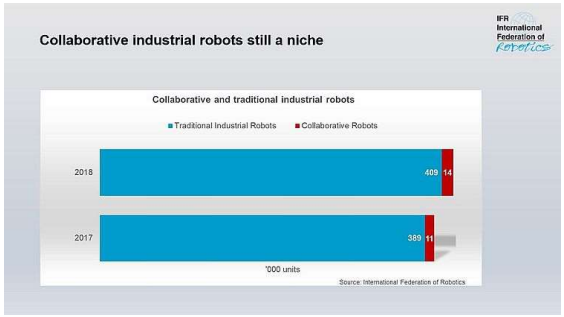
"Cobots: present and future"

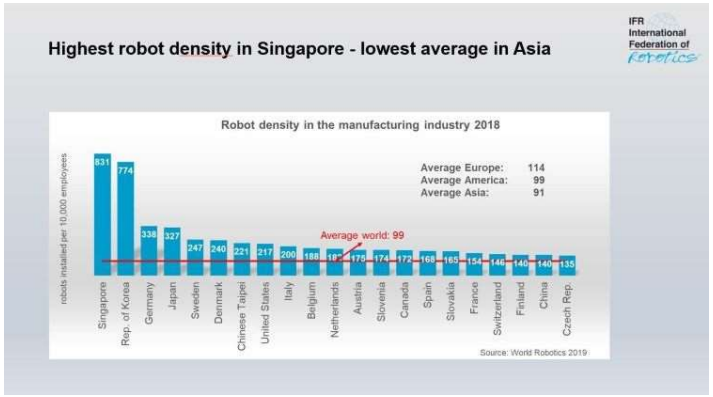
Department of technological innovations and safety of plants products and anthropic settlements

From IFR….What's about industrial use of collaborative robots (cobots)?



- ~ 422.000 units shipped in the world in 2018…14000 are cobots (3,3 %)
- ~ 400.000 units shipped in the world in 2017…11000 are cobots (2,8 %)





- ~ 9.800 units shipped in Italy in 2018…320 are cobots, assuming the 3,3 %
- ~ 7.800 units shipped in Italy in 2017…220 are cobots, assuming the 2,8 %

It's possible to presume that cobots in Italy are no more than 1000 units

Industrial robots and cobots

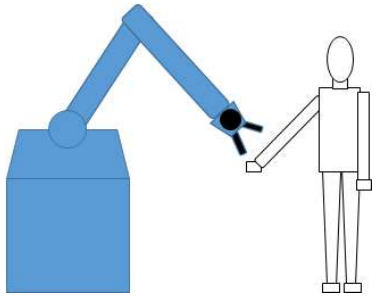
Industrial Robots: "automatically controlled, reprogrammable multipurpose manipulator programmable in three or more axes" (ISO 8373)

- Accuracy
- Speed
- Repeatibility
- Hazardous tasks
- Productivity

Collaborative Robots: "robot designed for direct interaction with a human within a defined collaborative workspace" (ISO 1021-2)

- Flexibility
- Cognitive skills

Related Standards



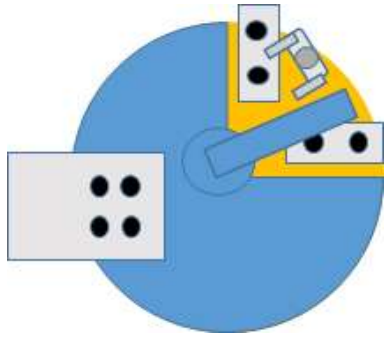
ISO 102018-1:2011: Robots and robotic devices - Safety requirements for industrial robots - Part 1: Robots

ISO 102018-2:2011: Robots and robotic devices - Safety requirements for industrial robots - Part 2: Robot systems and integration

ISO/TS 15066:2016: Robots and robotic devices - Collaborative robots

Some definitions……

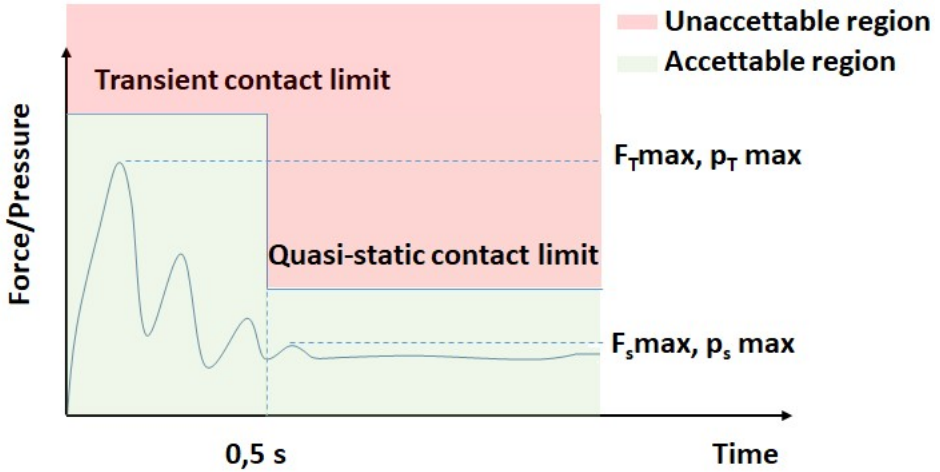
Collaborative operation: "state in which a purposely designed robot system and an operator work within a collaborative workspace" (ISO/TS 15066)



Collaborative workspace: "space within the operating space where the robot system (including the workpiece) and a human can perform tasks concurrently during production operation" (ISO/TS 15066)

Types of contact human-robot

Quasi static contact: "contact between an operator and part of a robot system, where the operator body part can be clamped between a moving part of a robot system and another fixed or moving part of the robot cell" (ISO/TS 15066)



Transient contact: "contact between an operator and part of a robot system, where the operator body part is not clamped and can recoil or retract from the moving part of the robot system" (ISO/TS 15066)

Safety distances

Protective separation distances: "shortest permissible distance between any moving hazardous part of the robot system and any human in the collaborative works pace" (ISO/TS 15066)

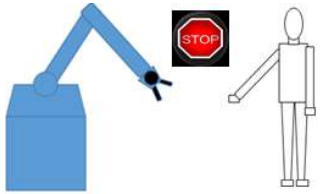
$$S_p = Sh + Sr + S_s + C + Zd + Zr$$

- S_h: distance due operator's change in location
- S_r: distance due to the robot's reaction time
- S_s: distance due to the robot sistem's stop
- C : intrusion distance in the sensing field
- Z_d: position uncertainty of the operator
- Z_r: position uncertainty of the robot

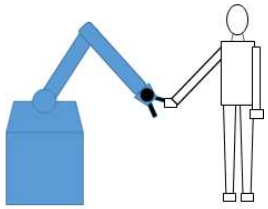
Note: S_p safety distance calculation is according EN ISO 13855

Collaborative Modes (ISO/TS 15066)

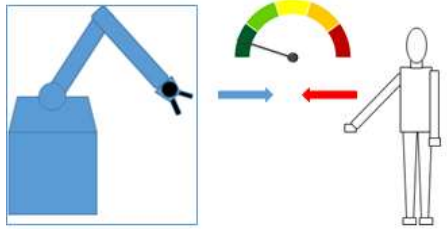
- **Safety-rated monitored stop - SMS**



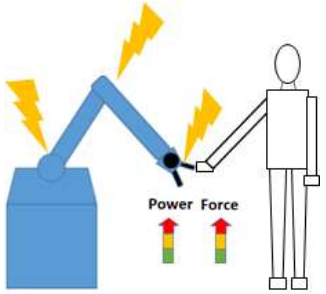
- **Hand Guiding -HG (or direct teach)**



- **Speed and Separation Monitoring - SSM (or Speed and Position Monitoring - SPM)**

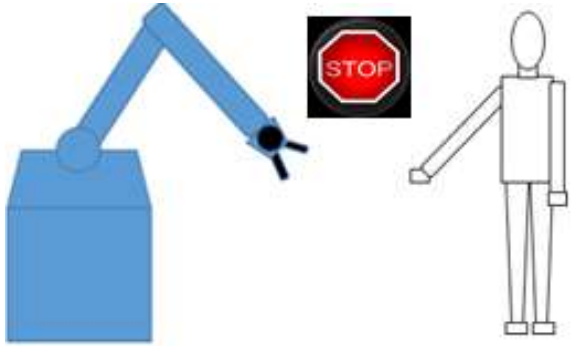


- **Power and Force Limiting - PFL**



Safety-rated monitored stop - SMS

- Robot motion in the collaborative workspace stops before an operator enters the collaborative workspace: the safety-rated monitored function is active;
- Robot system motion can restart, non collaboratively, without any additional intervention only after the operator is out the collaborative workspace;
- the safety-rated monitored function is a protective stop function realized in category 2 (monitored with actuator energized according IEC 60204). Any violation results in a stop in category 0 (actuator immediately de-energized).

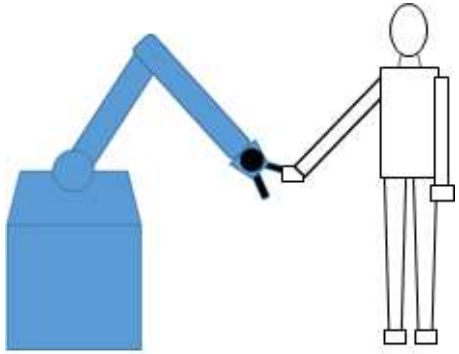


Robot motion or stop function		Operator's proximity to collaborative workspace	
		Outside	Inside
Robot's proximity to collaborative workspace	Outside	Continue	Continue
	Inside and moving	Continue	Protective stop
	Inside, at Safety - Rated Monitored Stop	Continue	Continue

Truth table for safety rated monitored stop operations

Hand Guiding -HG

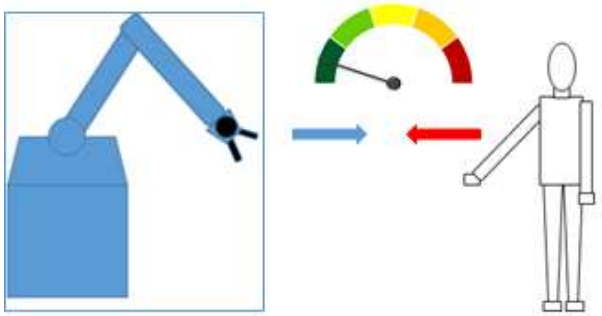
- The operator gets in touch with robot via a guiding device (direct teach mode) and drives robot motion;
- The following safety functions are active:
  - safety-rated monitored stop
  - safety rated monitored speed.



Additional features:

- Force amplification
- VR or AVR
- Tracking technologies
- ……..

Speed and Separation Monitoring - SSM

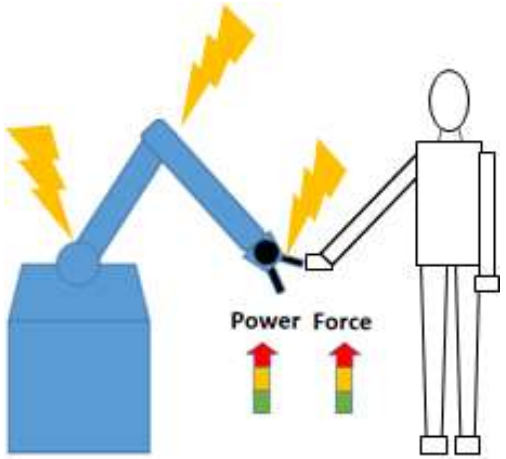


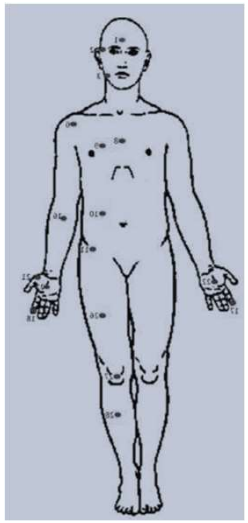
- Robot system and operator may move concurrently in collaborative workspace;
- The protective separation distance S_p between operator and robot shall be mantained at all times;
- Speed is lowered when operator and robot get closer and enhanced when they drift apart. If the minimum protective separation distance is violated a safety rated stop is initiated;
- The following safety functions are active:
  - safety-rated monitored stop
  - safety rated monitored speed.

$$S_p = Sh + Sr + S_s + C + Zd + Zr$$

Power and Force Limiting - PFL

- Robot system (workpiece included) and operator can have physical contact either intentionally or unintentionally;
- Possible contacts shall not result in an harm to the operator;
- The possible contacts are:
  - Transient contacts
  - Quasi static contacts
- Power and forces are limited by threshold limit values;
- A method to determine threshold limit values is indicated in Annex A of ISO 15066 (criteria developed by IFA)
- Contact exposure to sensitive body regions, including the skull, forehead, larynx, eyes, ears or face shall be prevented whenever reasonably practicable





Body model

Injury severity criteria

- The injury severity criteria were developed by fixing a body model;
- The first level of severity of AIS scale (like bruise) shall not be exceed (i.e. skin or soft tissue penetrations, bloody wounds, fractures….);
- The pressure pain thresholds is the minimum intensity of pressure that is perceived as painful;
- 100 healthy subjects were assessed at 29 body areas (12 body region);
- ISO/TS 15066 states max pressure and force values for specific body areas;
- Contact with **face, skull and forehead** are not accepted.

Interfaces & Programming

Programming interfaces

- Lead-through programming (traditional);
- Off-line programming (traditional);
- Walk through programming (evolving);
- Programming by demonstration (innovative);

Sensing interfaces

- Vision based programming (innovative);
- Vocal commanding (innovative);

AR/VR interfaces

- AR technologies (innovative);
- VR technologies (innovative);

Conclusion & open issues

- Safety of collaborative approach by risk assessment;
- Intuitive programming methods;

But until now…….

- Low autonomy and cognitive capabilities;
- Coordination and timing between human and robot is critical;
- Lack of high level of collaboration (handling, welding, automotive, assembly)
- The contact with workpiece is critical
- More tests to validate injury criteria are necessary
- Lack of diffusion in small and medium enterprises

Thank you for your attention