INDUSTRIAL ROBOTS AT THE EDGE

SAFETY CONSIDERATIONS

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SICK – worldwide one of theleading manufacturers of sensors and sensor solutions for industrial applications

SAFETY OF INDUSTRIAL ROBOTS
TECHNOLOGICAL DEVELOPMENT – THE STARTING POINT

Sensor Intelligence.

- Classic industrial robots result from the automation of remote manipulators

- At the time of their introduction the related risks where associated to the reliability of their control systems in combination with the possible harm sources:

  - Contact with movable elements resulting in; crushing, shearing, impact… injuries

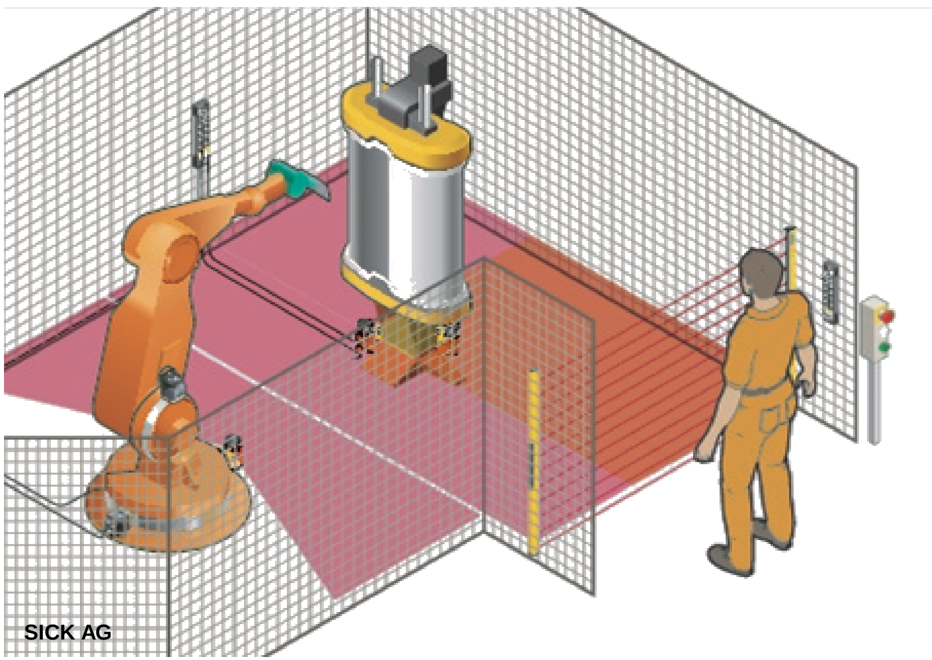
  - Exposure to process related hazards (welding, hot surfaces, sharp edges etc.)

- As a result, the physical separation of the person from the hazard was the most appropriate safety solution (Fencing, using fixed or movable interlocking guards)

SAFETY OF INDUSTRIAL ROBOTS

TECHNOLOGICAL DEVELOPMENT – THE CLASSIC INDUSTRIAL ROBOT

- The increased reliability of robot control systems reduced the risk in existing applications.
- Nevertheless, overall risk was increased due to the need for more flexible application (e.g. manual loading) and therefore for a less restricted (time/ space) interaction

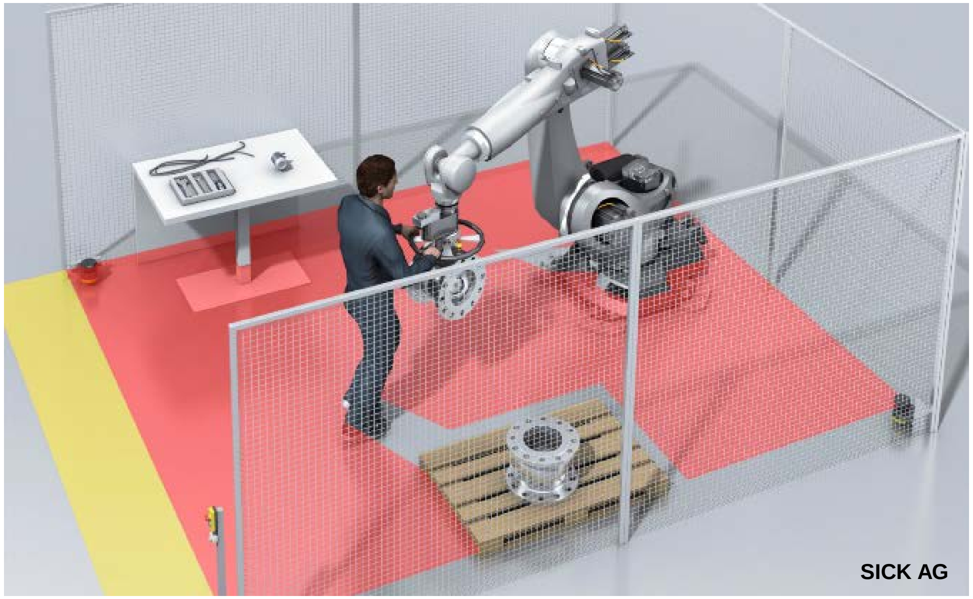


- As a result the fencing was "opened" to allow the required interaction, although
  - It requires to apply sensors (ESPE) to detect operators in hazardous zones and prevent any robot movement at the same time
  - Additional limiting of the robot movement (axis limiting) was necessary to reduce footprint

TECHNOLOGICAL DEVELOPMENT – THE COLLABORATIVE OPERATION

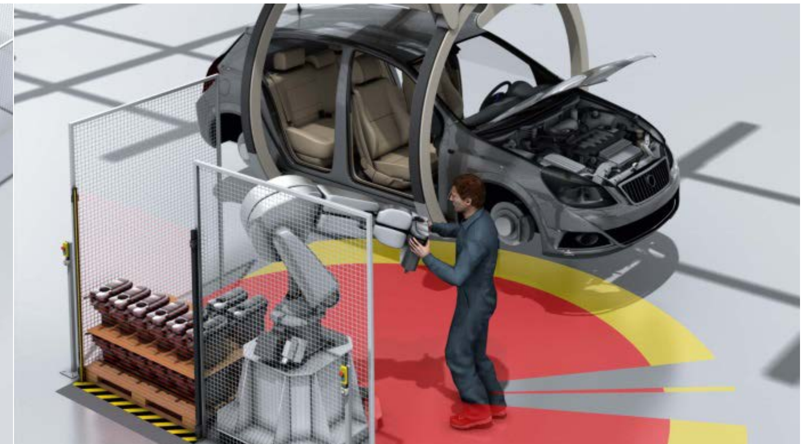
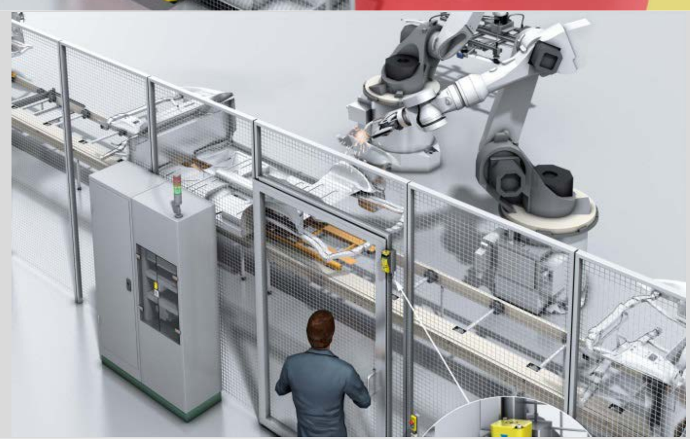
- With the developments in drive and motion control technology and their application to robot control systems the risk in existing applications can be further reduced by:
  - Adapting movement restriction (axis limiting) to the task and the momentary step of the process
  - Limiting power and force (speed) at certain steps such that a contact shall not lead to a harm

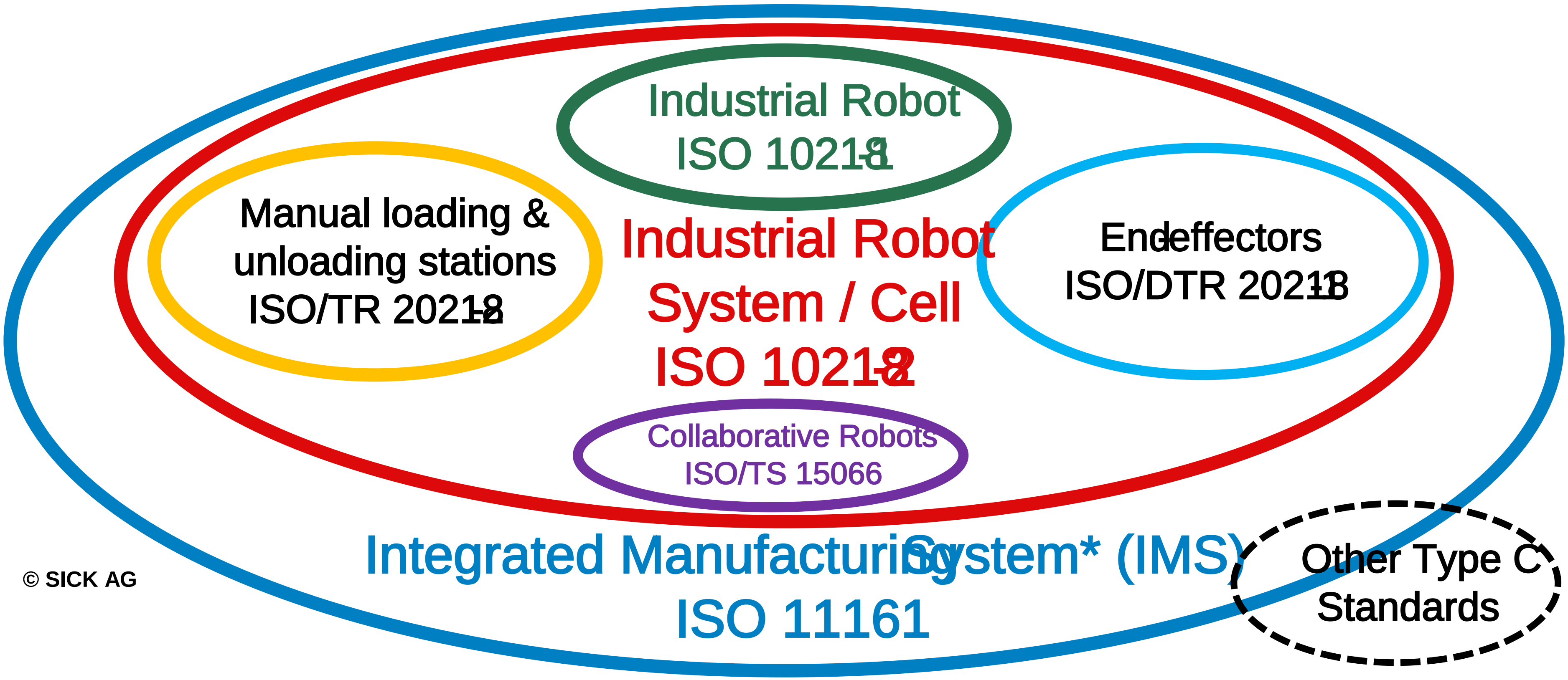
The aim is to allow humans to safely work with robots at in the same space. (Collaborative operation)



SAFETY OF INDUSTRIAL ROBOTS

HUMAN-ROBOT INTERACTION

	DIFFERENT TIME	SAME TIME
SHARED SPACE		
NO SHARED SPACE	NO INTERACTION	

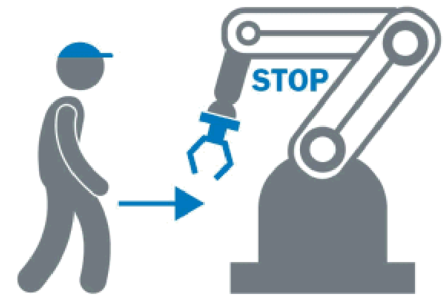


*** B1 Type Standard under revision by ISO/TC199-WG**

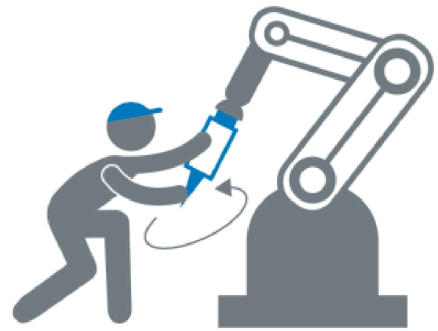
SAFETY OF INDUSTRIAL ROBOTS

METHODS FOR COLLABORATIVE OPERATION - ISO/TS 15066

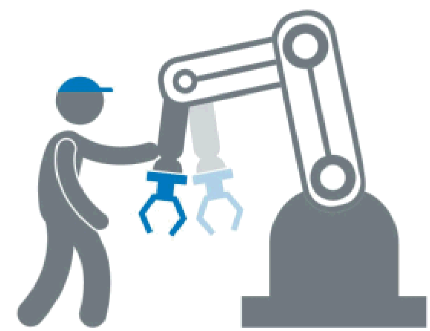
- Safety-rated monitored stop



- Hand guiding



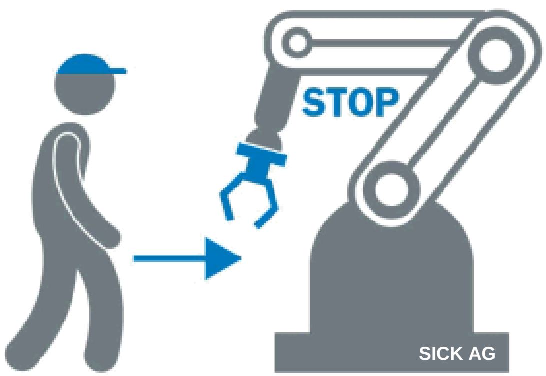
- Power and force limiting

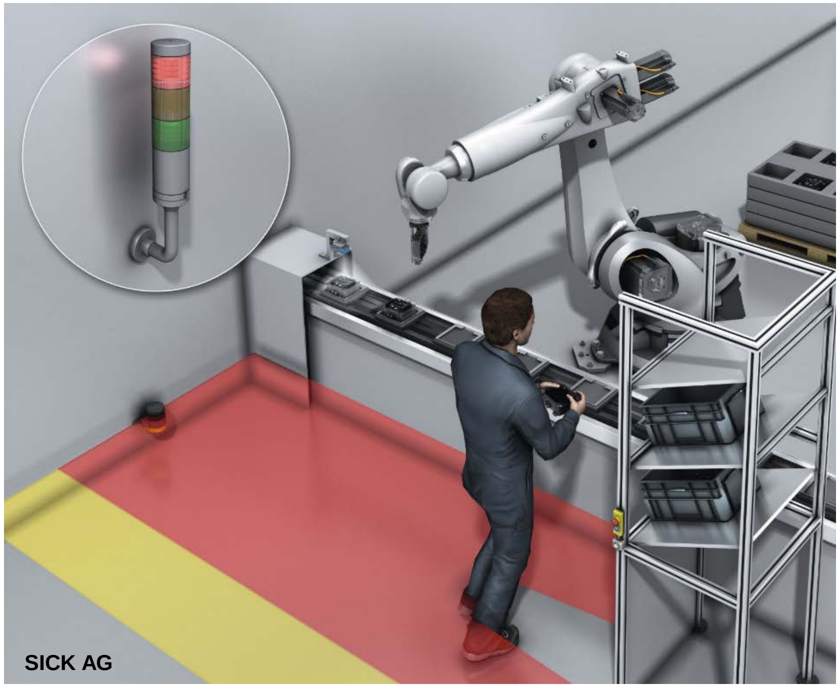


- Speed & separation monitoring

SAFETY OF INDUSTRIAL ROBOTS
COLLABORATIVE OPERATION – SAFE MONITORED STOP METHOD

- The robot in the collaborative workspace shall stop and remain stopped when a human is present
- Once stopped, this standstill shall be monitored by the safety-related control system
- Detection of the failure to safely maintain the stopped condition shall result in a category 0 stop.
- The robot may resume automatic operation when the human leaves the collaborative workspace.)

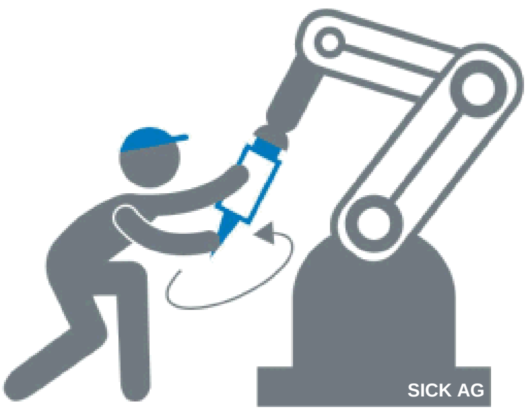


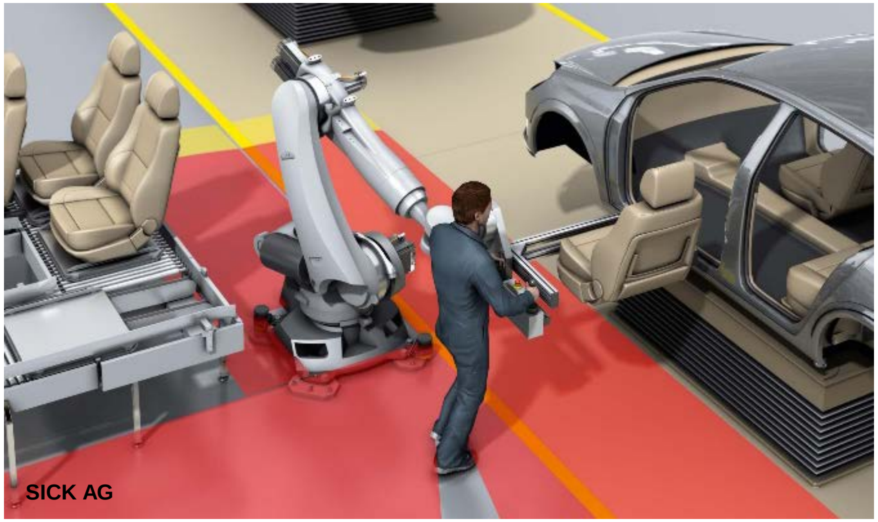


SAFETY OF INDUSTRIAL ROBOTS

COLLABORATIVE OPERATION – HAND GUIDING METHOD

- The robot in the collaborative workspace shall stop and remain stopped when a human is present
- Once stopped, this standstill shall be monitored by the safety-related control system
- Detection of the failure to safely maintain the stopped condition shall result in a category 0 stop.
- Robot operation shall only be possible under enabling control an with safely reduced speed sufficiently low to avoid injuries at any time !
- The robot may resume automatic operation when the human leaves the collaborative workspace.)

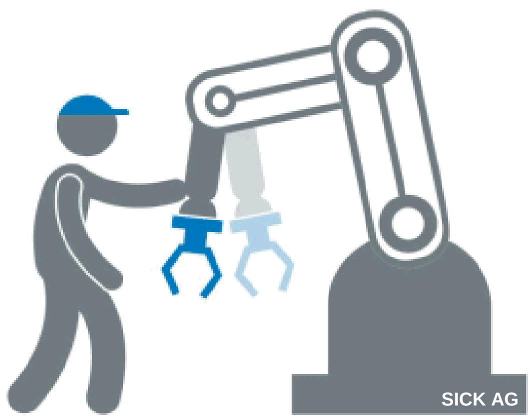




SAFETY OF INDUSTRIAL ROBOTS

COLLABORATIVE OPERATION – POWER & FORCE LIMITING METHOD

- Risk reduction is achieved through limitation of power and force applying one of the following:
  - inherent mechanical design (e.g. shape, clutches, small drives, limiting valves)
  - inherent control safety functions (e.g. force and torque measuring & limiting)
  - safeguarding through PSPE with low actuating pressure or ESPE for collision anticipation resulting in low contact forces

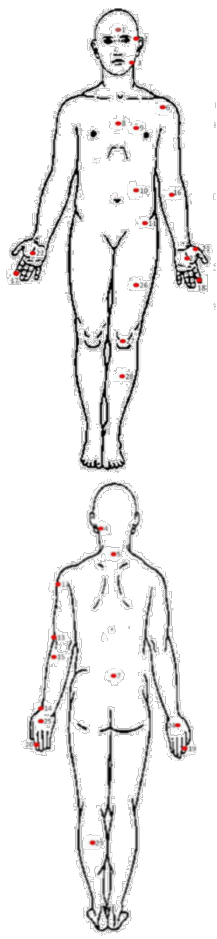


- For collaborative operation with power & force limiting three major problems need to be solved;

1. Contact with the head / face shall be prevented since limit values are not applicable to these body regions ! *

2. Consideration of other hazards since values are only applicable for crushing & impact hazards !

3. Alternatives where applications may require higher handling forces (torque) or speeds and the use of the standard limits is precluded !



Body region		Specific body area	Quasi static contact Maximum allowable pressure [N/cm²]	Quasi static contact Maximum allowable Force [N]	Transient contact Maximum allowable pressure or force Multiplier (PT)
Skull and Forehead	1	Mid of forehead	130	130	NOT ACCEPTABLE !
	2	Temple	110		
Face	3	Masticatory muscle	110	65	
Neck	4	Neck muscle	140	150	x 2
	5	7th neck muscle	210		
Back and Shoulders	6	Shoulder joint	160	210	
	7	5th lumbar vertebra	210		
Chest	8	Sternum	120	140	
	9	Pectoral muscle	170		
Abdomen	10	Abdominal muscle	140	110	
Pelvis	11	Pelvic bone	210	180	
Upper arms & elbow joints	12	Deltoid muscle	190	150	
	13	Humerus	220		
Lower arms & wrist joints	14	Radius bone	190	160	
	15	Forearm muscle	180		
	16	Arm nerve	180		
Hands & Fingers	17	Forefinger pad d	300	140	
	18	Forefinger pad nd	270		
	19	Forefinger end joint d	280		
	20	Forefinger end joint nd	220		
	21	Thenar eminence	200		
	22	Palm of the hand d	260		
	23	Palm of the hand nd	190		
	24	Back of the hand d	200		
	25	Back of the hand nd	190		
Thighs & knees	26	Thigh muscle	250	220	
	27	Kneecap	220		
Lower legs	28	Middle of shin	220	130	
	29	Calf muscle	210		ISO/TS 15066

(* including any reasonably foreseeable misuse

SAFE COLLABORATION BY LIMITING POWER & FORCE

SAFE INTERACTION BETWEEN ROBOTS (MACHINE) & HUMANS (OPERATORS)

- In most applications, the above mentioned criteria can not be achieved

- To make collaborative applications, using of power & force limiting, possible additional safeguarding can be used;

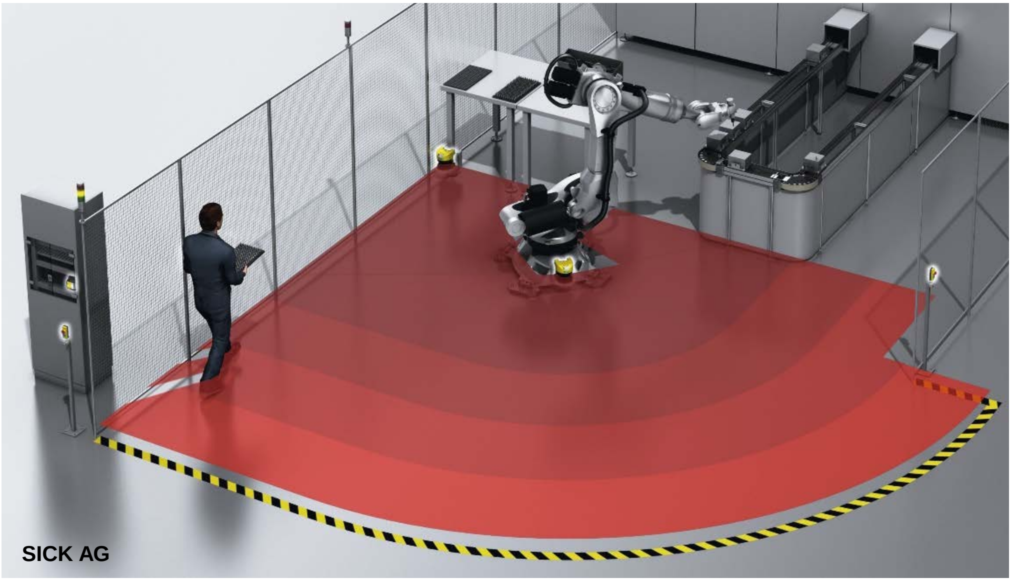
  - monitoring the scene & allowing higher speeds and accelerations where contact is not imminent
  - detecting imminent contacts & preventing those who may become hazardous
  - preventing the contact where injuries are related to other hazards (shearing, stabbing, etc.)
  - preventing contacts with the head/ face (or making those negligible ?)

SAFE COLLABORATION BY LIMITING POWER & FORCE

SAFE INTERACTION BETWEEN ROBOTS (MACHINE) & HUMANS (OPERATORS)

COLLABORATIVE OPERATION – SPEED & SEPARATION MONITORING

- Risk reduction is achieved by maintaining a minimum (protective) separation distance between operator & robot at all times. This can be achieved by reducing robot speed or altering the robot path
- Human detection in the collaborative workspace is required
- Any humans in the collaborative workspace shall be detected.
  Failure in detect and track all present humans shall lead to a protective stop.
- Failure to maintain the protective separation distance between human & robot shall result in a protective stop
- Standstill shall be monitored by the safety-related control system. Detection of the failure to safely maintain this condition shall result in a category 0 stop.
- The robot may resume automatic operation when the protective separation distance is achieved again



SAFETY COLLABORATION

TECHNOLOGICAL DEVELOPMENT – THE ROBOTIC COLLEAGUE !

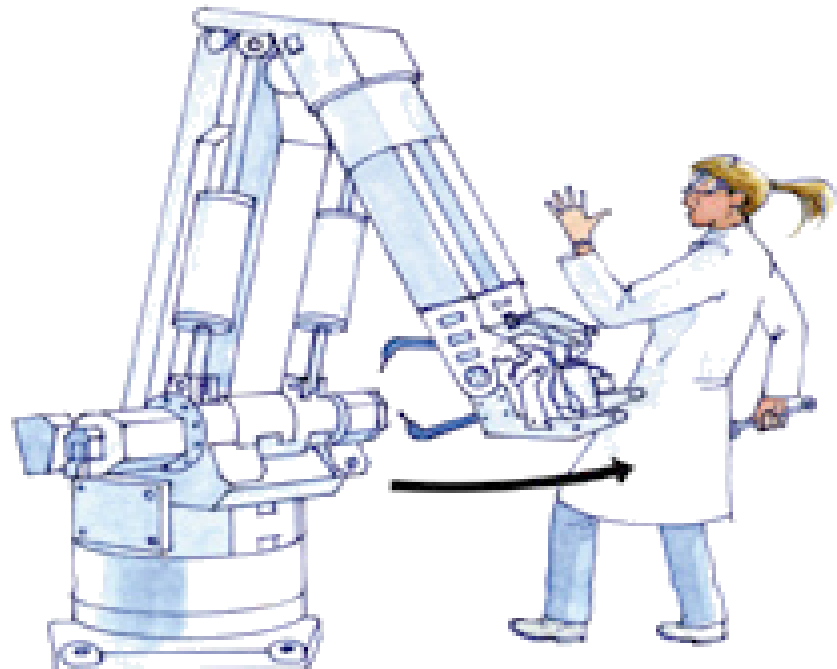
SICK
Sensor Intelligence.

- The aim of developments in industrial robotics is to allow a safe collaboration at any time
- This excludes the physical separation and introduces risks due to a possible unexpected behavior of the robot.
- The human operator expects a robot which behaves like a reasonable human colleague !
- The risk due to uncertainty is not only directly linked to the degree of autonomy of the robot
- It can also be the result of a complex program (large variety of pre-programmed output states)

SAFETY COLLABORATION

TECHNOLOGICAL DEVELOPMENT – THE IMPACT OF AI

- In future the autonomy degree will depend on the application of AI
- Even simple ANI will result in a large increase of uncertainty
- This will shift the source of the risks related to collaborative operations from the hardware characteristics of the robot to his behavior (application).
- The same will occur in service robotics, where unexpected robot actions & human reactions may lead to many hazardous situations



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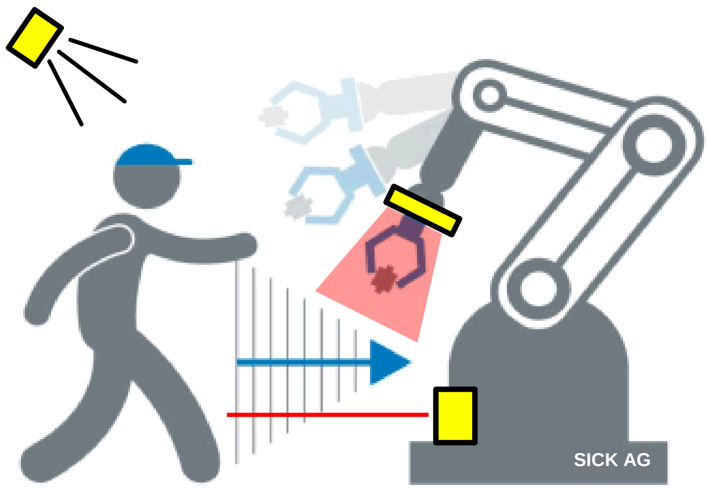
SAFETY COLLABORATION

TECHNOLOGICAL DEVELOPMENT – THE FUTURE OF SAFEGUARDING



- Safeguarding will mainly rely in the avoidance of potential hazardous actions by "taming" the autonomy of the robot
- This will require reliable sensors to provide accurate scene information for the control system.
- Classic safety devices will develop to systems where different appropriate sensors will provide information to logic subsystems (cloud based algorithms) to ensure safe robot behaviour
- The limitation of the force and pressure of contacts will provide the secondary risk reduction.

THANK YOU FOR YOU ATTENTION.

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