SICK AG WHITE PAPER

SAFE ROBOTICS – SAFETY IN COLLABORATIVE ROBOT SYSTEMS

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Introduction

Recent years have seen significant advancements in industrial automation applications in the fields of drive systems and object detection, paving the way for a new age of interaction between human and machine.

With regard to functional safety and the associated standards (IEC 61508, IEC 62061, and ISO 13849-1/-2, for example) [1, 2, 3, 4], innovations in robotics delivering optimized functions are also facilitating close collaboration between human and machine in the same workspace. Combining human abilities with those of robots in industrial environments creates production solutions that are characterized by better quality, lower costs, improved ergonomics, and faster working cycles, to name but a few examples (keyword Industry 4.0).

Taking the current status of the international standards that deal with the safety of industrial robots (ISO 10218-1/-2) [5, 6] and specifically the safety of robots for collaborative operation (ISO/TS 15066) [7] as our starting point, this white paper will explain the guidelines contained in these standards which apply to the development of safe collaborative robot applications. The white paper will also highlight the limits of today's technologies and consider the outlook with regard to requirements and upcoming developments.

Human-machine interaction and safety

In industrial manufacturing, there is an increasing need for flexible machines that are able to work autonomously and can be adapted to changing production conditions quickly and efficiently.

To protect persons against the dangers posed by their speed, movement, and force, robots usually work behind a barrier guards. However, if close interaction between human and machine is required, this effective standard method of physically separating the person at risk from the source of danger cannot be employed. For this reason, alternative methods must be applied to reduce risk.

Definitions – Terminology

The interaction of humans with active robots and devices that are similar to robots can be characterized based on two interaction parameters: space and time. If there is no common space and no common time in which the human being and the active robot move, the movements of the robot do not pose a risk and the situation is deemed “not interactive”. Situations in which humans and robots share a common space but at different times are deemed “cooperative”. The term “collaborative” is used to describe situations in which humans and robots are working in the same space at the same time.

Application	Different workspace	Shared workspace
Sequential processing	(not interactive)	Cooperation
Simultaneous processing	Coexistence	Collaboration

Robotics normative

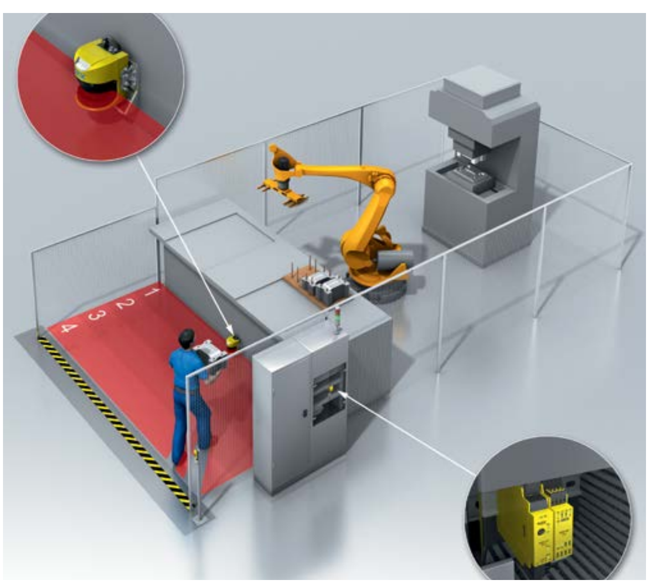
Region	Risk assessment	Robotics manufacturer	Robotics integrator	Collaborative robots
China	GB/T 15706-2012	GB 11291.1-2011	GB 11291.2-2013	GB 11291.2:2013
South Korea		KS B ISO 10218-1	KS B ISO 10218-2	
Japan	JIS B9700	JIS B8433-1	JIS B8433-2	JIS TS B0033
United States	ANSI/ISO 12100, ANSI B11.0	ANSI/RIA R15.06 (1st Half)	ANSI/RIA R15.06 (2nd Half)	RIA TR R15.606
Europe	EN ISO 12100	EN ISO 10218-1	EN ISO 10218-2	ISO/TS 15066
Taiwan		CNS 14490-1 B8013-1	CNS 14490-2 B8013-2	
Canada	CSA Z432, CAN/CSA-Z1002	CAN/CSA-Z434 (1st Half)	CAN/CSA-Z434 (2nd Half)	
Brasil	ABNT NBR ISO 12100	ABNT NBR ISO 10218-1/2	ABNT NBR ISO 10218-1/2	

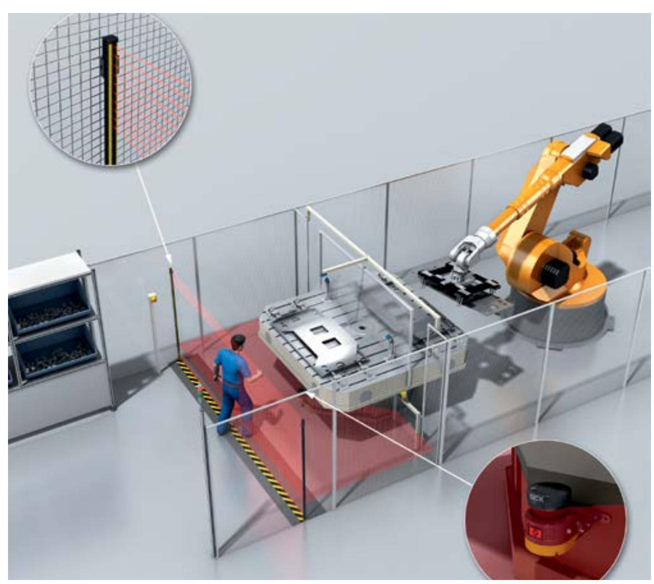
Coexistence

Even in industrial robot applications in which no human intervention is required during the production process, it will still be necessary for an operator to enter the robot's workspace, e.g., for the purpose of maintenance work. In applications of this type, the workspace must be fenced off and the access doors must be interlocked. The interlock must ensure that hazardous robot functions are shut down whenever an operator enters the hazardous area, and must be maintained as long as a person remains present inside the hazardous area or the access doors are opened.

Cooperation

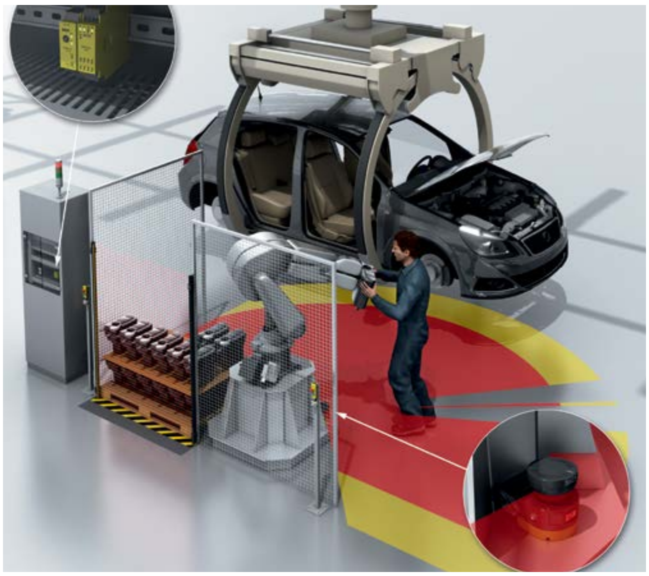
The processes involving an operator loading and unloading robot cells are a very common application for industrial robots. In cooperative application scenarios like this, operator and robot complete the necessary stages of the process in the same workspace at different times. Here too, technical safety measures are required. Depending on how the loading and unloading system is set up, it may be appropriate to use opto-electronic protective devices such as safety light curtains or safety laser scanners.





Collaboration

In certain applications, it is necessary for humans and active robots to interact in the same workspace at the same time. In these scenarios, which we call collaborative, the force, speed, and movement paths of the robot must be restricted. If they are available, inherent safety measures or additional safety measures such as limiting torque through the performance of the drives or safety-related parts of the system controller can be used to minimize risk. Force, speed, and movement paths must also be monitored and controlled based on the actual degree of risk. This degree of risk is also dependent upon the distance between human and robot. This application calls for reliable sensors that are able to detect human presence or determine the speed at which humans are moving towards the hazardous area and their distance from it. Essentially, these sensors have to be able to overcome the future challenges that are an inevitable consequence of the development of collaborative technologies.



Standards and requirements of safe collaborative robot applications

The robot system described in Part 2 of ISO 10218 consists of an industrial robot and its end effector, as well as arbitrary machine parts, equipment, devices, external auxiliary motion axes, and sensors to assist the robot in the completion of its tasks.

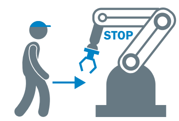
Fundamental requirements

There are a number of fundamental requirements to be met by the design of collaborative applications.

- The collaborative workspace must meet the following requirements:
  1. It must be laid out so that the operator is able to complete his or her tasks in a safe and problem-free manner, without being exposed to additional hazards posed by supplementary equipment or other machines in the workspace.
  2. There must be no risk of injury as a result of cutting, crushing, or stabbing. Nor must there be any risks posed by such things as hot surfaces or live parts which cannot be mitigated by reducing the speed, force, or power of the robot system. The same of course also applies to the associated supporting equipment and workpieces.
- The operating space of the robot must be positioned a minimum distance away from adjacent accessible areas in which there is a risk of crushing or jamming. If this is not possible, additional protective devices must be used.
- Wherever possible, safe axis limiting must be deployed in order to restrict the number of free movements of the robot in the space and thus to reduce the risk of personal injury.

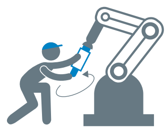
Collaborative operating modes according to ISO 10218-2 and ISO/TS 15066

Technical specification ISO/TS 15066 states four collaborative operating modes which can be used either individually or in combination, depending on the requirement of the application concerned and the design of the robot system:



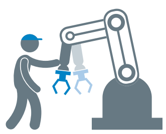
- Monitored safe stop

  The robot is stopped during interaction with the operator in the collaboration space. This status is monitored and the drive can remain energized.



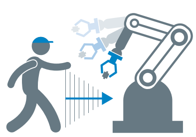
- Manual control

  The safety of the human-robot collaboration is assured by the robot being guided manually under control at an appropriately reduced speed.



- Force and power limitation – the path to collaboration

  Physical contact between the robot system (including the workpiece) and a person (operator) can take place either intentionally or unintentionally. The necessary safety is achieved by limiting the power and force to values at which injuries and risk are not to be expected. Collaboration based on limited power and force requires robots that have been designed specifically for this operating mode. Technical specification ISO/TS 15066 includes maximum values (biomechanical load limits) which must not be exceeded should the robot collide with body parts.



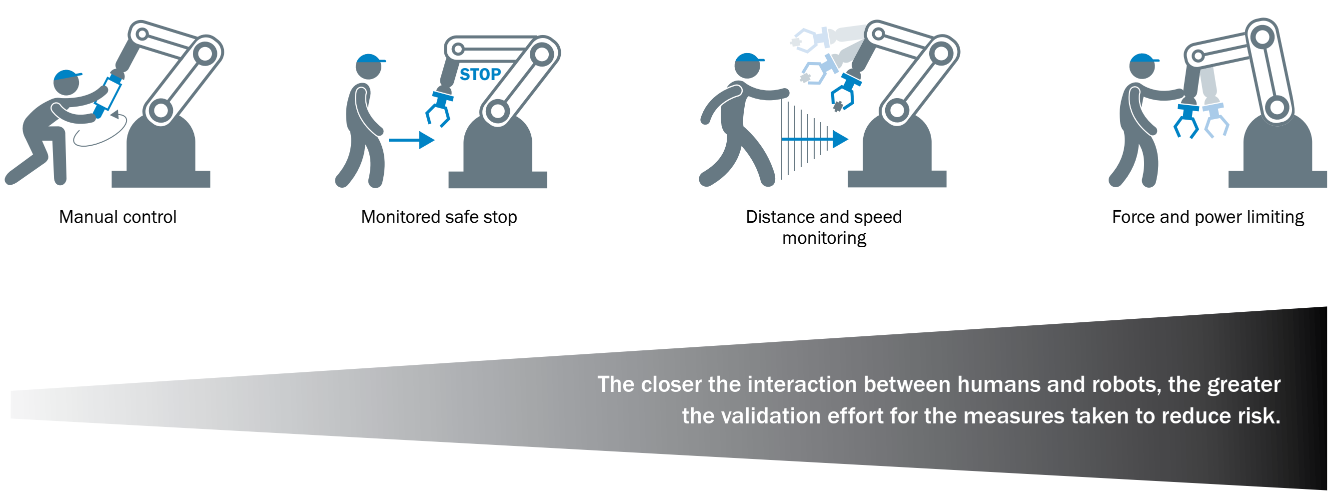
- Distance and speed monitoring – the future:

  The speed and movement paths (trajectory) of the robot are monitored and adjusted based on the speed and position of the operator in the safeguarded space.

In collaborative applications, one or more of the methods listed here must be selected in order to ensure the safety of all persons who are exposed to the potential hazards. The method(s) selected will depend on the application at hand.

Current requirements to be met by the operation of collaborative robot systems include the use of a suitable safety-related control system which conforms to PL d according to ISO 13849-1.

Validation effort for collaborative operating modes



Risk assessment

A great variety of robot models are available on today's market. They range from standard industrial robots to robots that have been designed specifically for collaborative operation (collaborative robots or “cobots”, as they are also known). Whenever robots are integrated into systems (with end effectors, etc.), a risk assessment of the entire robot system (full machine) must be carried out. The resulting measures derived to reduce risks shall then safeguard safe collaborative operation. This risk assessment must still be carried out even if the robot concerned has design features that reduce risk.

Risk reduction

The inherent safety measures that are typically used on collaborative robots include:

- Limiting the maximum permissible forces or torques, e.g., through drive dimensioning
- Setting up the robot interfaces in order to reduce the pressure impact or the collision forces transmitted (e.g., rounded robot surfaces, energy-absorbing padding)

However, the effectiveness of these inherent safety measures can be significantly impaired by the design of the robot tool, the support, the workpiece, or other machines inside the collaborative workspace.

Additional safety measures can be used to counter this, such as

- Limiting power (torque), force, or speed through the safety-related parts of the control system
- Using pressure-sensitive protective devices (PSPE) or electro-sensitive protective devices (ESPE) to stop or reverse robot movements

Conclusion

In the future, humans and robots will work even more closely together in automation applications where great flexibility is required (e.g., in small batch production where levels of variability are high). Manual assembly operations are being replaced by human-robot collaboration, in which the abilities of human and machine are the ideal complement for one another. Subsequently, the ergonomics of workspaces in which high levels of productivity are required can be improved. The limitation of speed and force that is necessary for safety must be harmonized with productivity requirements.

The design principles in ISO/TS 15066 supplement the requirements already formulated in ISO 10218-1/-2 and create a basis for the design of collaborative robot applications.

The products and devices that are currently on the market are not able to fully meet all of the requirements expected of safe and unhindered human-robot collaboration today. The development of new sensor and robot technologies, along with intelligent control systems, is a fundamental requirement for future collaborative robot applications.

No two applications that are currently being solved with human-robot collaboration are the same. A dedicated risk assessment is vital, even if the robots that are being used have been designed specifically for interaction with human beings. The fact that robot manufacturers are integrating measures for inherently safe design into their products does not relieve system integrators of their obligation as machine manufacturers to analyze and reduce potential risks. System manufacturers and integrators of robot systems have to perform thorough checks of the structural safety measures taken by robot manufacturers. They are also required to consider any hazards or risks that may remain and design the robot system according to the results of this risk assessment. As a result of the risk assessment, additional measures to reduce risk based on experience (e.g., safety light curtains or safety laser scanners, etc.) must be taken by the system manufacturer in order to achieve a collaborative application where all aspects have achieved acceptable residual risk.

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