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STANDARDIZATION IN HUMAN ROBOT INTERACTION

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Abstract

Standardization is an important consideration in the integration of robots in factories because of the need of know the risks of working with robots and determine the guidelines for working safely.

The goal of the ReBORN project is to demonstrate strategies and technologies that support a new paradigm for re-use of production equipment in old, renewed and new factories by designing processes easier and straight forward shortening ramp-up times.

Nowadays the research related to the field of human-robot interaction has gained importance and it seems interesting to use this concept in the re-designing of the factories. A human operator and a robot performing tasks jointly provide to the factories the best features and skills of each one. It is noteworthy that this approach between a human operator and a robot entail several risks that shall be considered and avoided by applying the corresponding safety standards.

Therefore, the work consists in mapping for the existing standards related to this field in order to apply them in the re-designing of the factories as well as assess if some safety and reliability concept is missing for use the collaborative robots given that the concept is relatively new and, if it is necessary, to propose some news standards.

Foreword

The aim of this document is to purpose guidelines of standardization in industrial collaborative robots. In order to accomplish this purpose it is necessary to search existing standards related to industrial robots and its implementation in the factories as well as asses if it is necessary to propose new standards.

This thesis is within the framework of the ReBORN project, which is a demo-targeted collaborative project carried out by consortia with participants from different countries. Its goal is to demonstrate strategies and technologies that support a new paradigm for re-use of production equipment in old, renewed and new factories by designing processes easier.

The work is therefore focused in the implementation of collaborative robots in these factories. Thereby the steps are to familiarize with collaborative robots, to search industrial standards related to industrial robots, to purpose these standards in the factory scenarios and asses if it is necessary to make aware new guidelines that are not taken in account in the existing standards.

I would like to express my gratitude to the head of the department of Computer Science and Engineering at the University of Oulu, Juha Röning, who has provide me the opportunity of work in this field of robotics and who has directed the thesis with his extensive experience in standardization. I would like to thank the *Institut de Robòtica i Informàtica de Barcelona* as well for the opportunity they gave me working with robots in the *HumanoidLab* project which was my first approach to the world of robotics and with which the first knowledge was acquired.

Oulu, 16th of December 2013
Nàdia Tolós Pons

List of Abbreviations and symbols

AGV Automated Guided Vehicle

AIS Abbreviated Injury Scale

AM Additive Manufacturing

ANSI American National Standards Institute

AOPD Active Opto-electronic Protective Devices

CEN European Committee for Standardization

CWS Collaborative Work Space

ESPE Electro Sensitive Protective Equipment

HRI Human Robot Interaction

IEC International Electrotechnical Commission

ISO International Organization for Standardization

ReBORN Innovative Reuse of modular knowledge Based devices and technologies for Old, Renewed and New factories. FP7-NMP 609223

RIA Robotic Industries Association

SC Subcommittee

TC Technical Committee

TCP Tool Centre Point

TS Technical Specification

Contents

List of Figures

List of Tables

Chapter 1

Introduction

The presence of robots in the industries has been increasing progressively and their incorporation has involved the improvement of the production in these factories[1]. The delegation to the robots of hard and hazard work moved away from the humans, usually in an exclusive workspace behind the fences. Nowadays, after the development of the robots and research that allowed controlling them, it is possible to contemplate Collaborative Robots in the factories. Thereby it is now able to carry out collaborative tasks between a robot and a human in the same work space. The approach of the robot to the human is an important step for the future development of the industry and it has to be treated with prudence given that work together entail some risks that need to be known, prevented and avoided by safe design of the work spaces. The process forwards is the standardization.

In particular this thesis is within the framework of the ReBORN project[2], which is a demo-targeted collaborative project carried out by consortia with participants from different countries. The ReBORN project expects to demonstrate new strategies and technologies that support a new paradigm for re-use of production equipment in old, renewed and new factories.

Therefore the aim of this study is to give guidelines of standardization in industrial collaborative robots. In order to achieve this objective it is necessary to know which are the existent standards related in collaborative robots, how the existent standards can be applied in the scenarios of the ReBORN project as well as make aware the companies what is ongoing in some standard guidelines which are under preparation. It is assessed if it is necessary to propose or develop new standards that are not taken in account in the existing standards.

Thus this study analyses the existent standards in order to apply them in collaborative robots in the factories.

Chapter 2

Collaborative Robots

2.1 Historical overview of Industrial Robots

The recent advancement of the industrial robotics has improved the capabilities of the robots such as areas reach and range of motion, the speed and acceleration, the communication with external equipment, the payload capacity and the weight of the robotic arms used in the factories. These progresses have allowed the robots more accuracy and widespread and their applications have been extended across several industrial sectors.

After the onset of the first industrial robot in the General Motor factory, in 1961, the robots are occupying more workstations in the factories, developing more hard tasks. In Figure 2.1 is shown a chronology of the Industrial Robotics development[3].

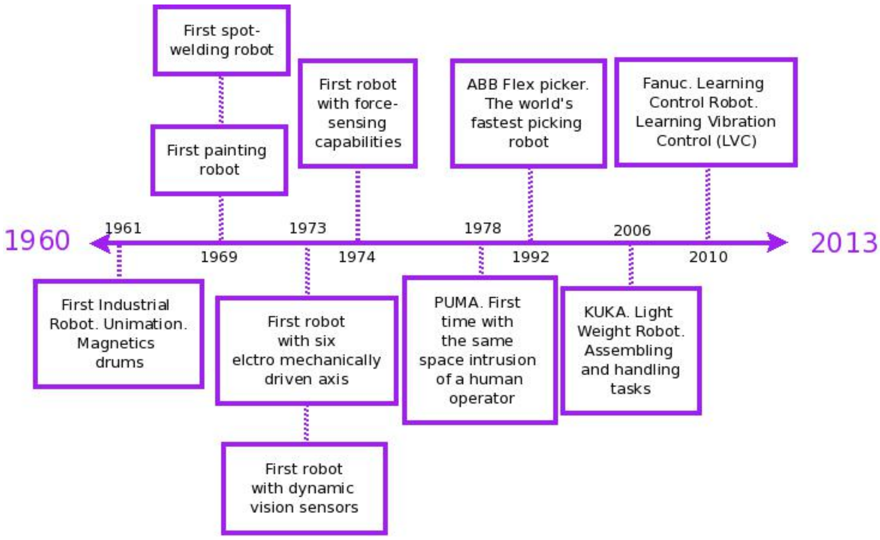

Figure 2.1: Chronology of Industrial Robotics developments

There was the misconception that robots would take away jobs from workers but they have created new jobs and have pulled employees from repetitive and monotonous works.

The tasks of the robots in the factories have been changing throughout history to adapt to new markets and new demands. In the past, factory production lines were automated for mass production lines. These assembly lines were created by Henry Ford for the automotive industry and led the industrial revolution introducing many industrial robots and specialized machines in the factories.

Recently, flexible manufacturing systems such as production cells are being introduced to the factories. Most of the tasks in the flexible manufactory rely in the workers and the robots used in these processes are specifics. Unlike in the line production, in the production cell, the entire product is assembled by one worker.

The robotics research has been changing according to the evolutions of human needs as well. When the robots were introduced in the factory processes, around 1960, industrial robots dominated the robotics research. The main areas of research were the kinematic calibration, the motion planning and the control of the interaction between manipulator and environment. Around 1990, new applications for robots appeared with the flexibility as main characteristic. The main areas of research were the ability to accommodate variations in product, size, shape and rigidity, the ability of self- adapt to the product and environment and the control systems with sufficient intelligence and problem-solving capacity in order to operate in dynamic environments with presence of uncertainty[4].

The robots have provided some important facets to the industry such as the untiring availability, the predictability, the reliability and the precision. With the robots it is possible to accomplish the typical company objectives such as high flexibility and productivity as well as constant and high product quality with short throughput times and low production costs[5]. Otherwise when they are compared with the human operators some features are missing. The robots do not have the ability of react to unforeseen circumstances or changing environments as well as to improve performance based on prior experience. These missing skills among others, have been the base for the development of collaborative robots, where robot and human operator can work together providing their best skills.

2.2 Classification of robots

A robot is an actuated mechanism programmable in two or more axes with a degree of autonomy, moving within its environment, to perform intended tasks. A robot includes the control system and interface of the control system[6]. The autonomy is the ability to perform intended tasks based on current state and sensing, without human intervention.

A first classification is according to the environment to be used and its purpose, distinguishing between industrial robots and service robots. In Figure 2.2 is shown a schematic with this classification[7].

2.2.1 Industrial robot

An industrial robot is an automatically controlled, reprogrammable, multipurpose manipulator, programmable in three or more axes, which can be either fixed in a place or mobile to be used in industrial automation applications. The industrial robot includes the manipulator, including actuators, and the controller, including teach pendant and any other communication interface. Figure 2.3 shows an example of industrial robot working in an automotive factory.

2.2.2 Service robot

A service robot is a robot that performs useful tasks for humans or equipment excluding industrial automation applications. Note that industrial automation applications include, but are not limited to, manufacturing, inspection, packaging, and assembly.

2.2.2.1 Personal service robot

A personal care robot is a service robot for personal use, used for a non-commercial task, usually by laypersons. In Figure 2.4 is shown a couple of service robots that are created for helping pedestrians in the cities.

2.2.2.2 Professional service robot

A professional robot is a service robot for professional use, used for a commercial task, usually operated by a properly trained operator. Figure 2.5 is shows an example of a medical robot assisting a doctor.

2.3 Collaborative Robots

A collaborative robot is a robot designed for direct actuation with a human and its goal in the industry is to provide flexible manufacturing environment of future mixture of human workers and robots.

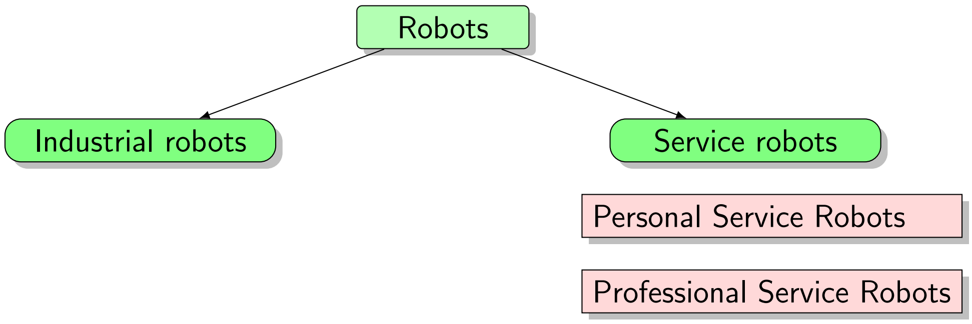

Figure 2.2: Classification of robots according to purpose

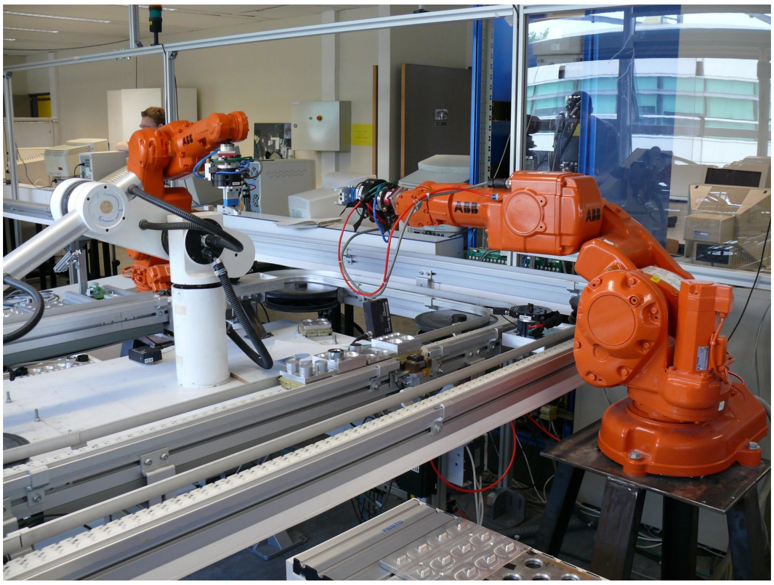

Figure 2.3: Industrial robot in an automotive factory

When a robot and a human are working in collaborative works, a portion of the workspace, the Collaborative Work Space (CWS) is shared for both. It means that there exists an inter-connected environment in which all the participants in dispersed locations can access and interact with each other just as inside a single entity.

2.4 Cooperation of human and machines in assembly lines

Flexibility and changeability of assembly processes require a close linkage between the worker and the robot. The interaction between a robot and a human worker allows to perform industrial handling and assembly tasks with cost-effectiveness.

Robots provide advantages such as operation without breaks and fatigue as well as high productivity in simple tasks, despite this the robot has limited activities for handling complex tasks. A human worker provides sensomotoric abilities

Figure 2.4: Service robots to assists pedestrians in urban centres

and quickly adaptation to new processes, but he has restricted force and precision. Thereby a robot assisted but a human guided assembly has various significant advantages improving productivity and ergonomics in specific complex processes. Therefore collaborative robots have to help the human workers instead of replacing them.

When working in collaborative operations, the dependability of the HRI (Human Worker Interaction) shall be assessed.[8] Due to the critical nature of the HRI, dependability must be enforced for the whole operational robot. The dependability of the HRI is integrated by the following attributes:

- Safety,
- Availability,
- Reliability,
- Integrity and
- Maintainability.

The safety and the absence of catastrophic consequences on the operators, is essential given the presence of humans in the collaborative operations. It shall be ensured during nominal operation of the robots as well as during presence of

Figure 2.5: Medical robot to assist a doctor to operate

faults. The reliability and the availability are the attributes that give to robot its usefulness. The robot shall be ready for carry out its intended tasks and able to complete these tasks successfully. Robot integrity is a prerequisite for safety, reliability and availability. The robot shall be protected against physical damages or corruption of its software and data. The maintainability aspects refers to the easiness of repair and upgrade.

Hybrid assembly systems can be classified into two groups[9] according the role of the robot and human worker:

- Workplace sharing systems and
- Workplace sharing systems at the same time.

2.4.1 Workplace sharing systems

In workplace sharing systems robot and human operator are both working in the same workspace performing handling and assembly task. They can work in the following configurations:

- The robot is performing an assembly task while the human worker is performing a handling task
- The robot is performing a handling task while the human worker is performing an assembling task

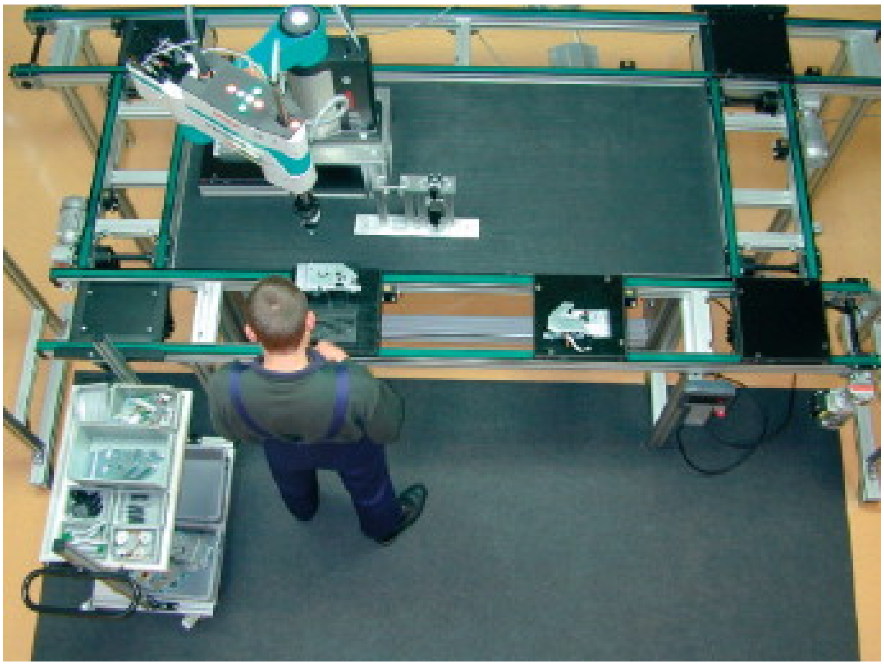

Figure 2.6: Example of a workplace sharing hybrid system

The interaction between robot and human is to avoid collisions. The robot shall stop when the distance to the human is less than the safe distance. Figure 2.6 shows an example of a workplace sharing hybrid system.

2.4.2 Workplace sharing systems at the same time

In workplace and time sharing systems robot and human worker are able to jointly perform handling and assembly task at the same time. They can work in the following configurations:

- The robot is performing an assembly task while the human worker is performing a handling task,
- The robot is performing a handling task while the human worker is performing an assembling task,
- The robot and the human worker are jointly performing a handling task and
- The robot and the human worker are jointly performing an assembly task.

The level of interaction between a robot and a human worker is higher than just the avoidance of collision because the robots are allowed to work in the same area at the same time as human workers performing jointly tasks and the worker can have contact with the robot. When the human worker is not in the shared

Figure 2.7: Example of a workplace and time sharing hybrid system

area, the robot is allowed to move at maximum speed. However, when the human worker is in the shared workspace, the robot has to change to cooperative mode.

This cooperative mode depends on the activity that they are performing but the speed of the robot among other parameters is described in the corresponding standards. Figure 2.7 shows an example of a workplace and time sharing hybrid system.

2.5 Basic collaborative operations

There exist different methods of collaborative operations related to the safety in order to reduce risks when human and robot are working in the CWS[10] [11].

- Safety-rated monitored stop,
- Hand guiding,
- Speed and separation monitoring and
- Power and Force limiting.

2.5.1 Safety-rated monitored stop

In this collaborative operation, when the worker is in the CWS, the robot is not allowed to move. It is only a workplace sharing and it is not permitted contact between robot and human operator.

2.5.2 Hand guiding

Basically robot guidance is still considered as allow-risk task and a safe speed monitoring is activated. Worker has absolutely control of the robot and the robot is only moved when it is activated by the worker. The robot speed is limited given that manual control from inside the safeguarded space is a reduced speed with a hold-to-run control and enabling device.

2.5.3 Speed and separation monitoring

The worker position is supervised and the speed and position of the robots is adapted at him in order to prevent contact. Furthermore, several indications are listed for tracking the human workers positions and velocity in order to identify and avoid a potential collision.

2.5.4 Power and Force limiting

This collaborative operation is full of interest because contact between human and robot is allowed but superintended. Therefore important aspects are the technological requirements, the medical and biomechanical requirements and the ergonomic requirements. Medical and biomechanical requirements try to investigate how to measure the risk and the potential danger for collaborator when an impact with the robot should be possible.

Combinations of these methods can be a good application in the industry. Practical applications of robot-human collaboration require supervision of the robot and it is available with controllers and sensors which provide information of the position of the human and predictions of braking distances. However research in biomechanical data is still scant. Thresholds for injuries need to be investigated in order to apply a Power and Force limiting method.

2.6 Hazards overview related to Collaborative Robots

Robots produce powerful and very rapid movements through their workspace. Hazards appear when unintended contact between robot and human exists. Therefore, in collaborative operations, where the operating space of robot and human is overlap, risks of accidents increase significantly. Thereby most of the accidents occur when the worker is in the robot workspace[12].

In order to improve safety in HRI, it is necessary to know where the danger lies, which are the endangered personnel, what the consequences of the injuries are and which factors have great impact on safety.

2.6.1 Causes of accidents

The causes of accidents can be classified in three categories:

- Engineering errors,
- Human mistakes and
- Poor environmental conditions.

Engineering errors include errors of the mechanism of the robot and errors made by the controller among others. Their consequences can be uncontrolled speed or abrupt motion or acceleration. This kind of errors cannot be predicted.

Human mistakes refer to fatigue, inattention or inadequate training program. These errors are more controllable than engineering errors.

Poor environmental conditions refer to adverse factors like extreme temperature, poor sensing in weather or lightning. These errors can cause incorrect responses of the robot.

2.6.2 Endangered personnel in the interaction with robots

The hazards of accidents are proportional between the amount of time a person spends in the proximity of a robot as well as inversely proportional to his level of experience[13].

Therefore the likelihood of injuries in robot operators is higher given that they are who spend most of time close to the robot and they are unprepared for unexpected robot behaviour.

However, the maintenance workers and the programmers, despite their high level of knowledge, also can get injured.

In Figure 2.8 is shown the role between degree of expertise and frequency of exposure.

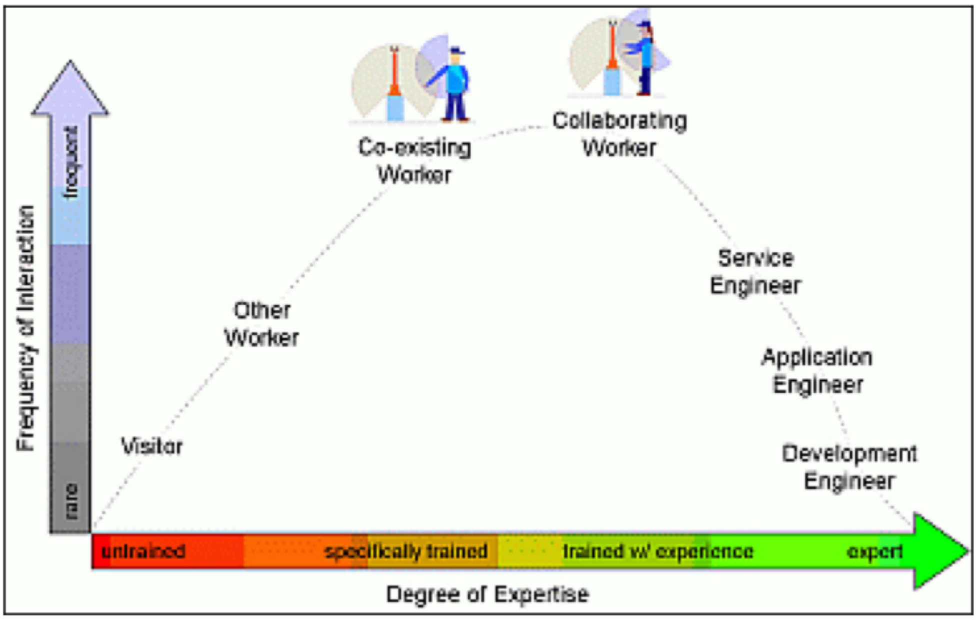

Figure 2.8: Roles of personnel, frequency of exposure and degree of expertise

2.6.3 Classification of injuries

According to [14] injuries can be classified by their type between pinch and impact. Pinch is when a robot traps the worker between itself and an object whereas impact is when the robot and worker collide.

Consequences are classified as no lost work-time, lost work-time and fatal injuries.

Otherwise the standard documents give an extensive classifications of hazards based on their origin. The most important hazards are mechanical, electrical, thermal and noised or others produced by vibration and radiation among others. However the hazards associated with robots are unique to a particular systems and it is difficult to apply regulations by standards.

Chapter 3

Standards

3.1 Introduction

Standards are instruments that help to design easily and correctly the work-cell in order to reduce risks and being safe. Common approach to safe application consists on designing a cell with all safe-sensors with the aim of simplify verification procedures.

Standards for functional safety in industry take responsibility of requirements for error prevention on Product development and Application as well as processes of certification of the Functional Safety Management.

Standards help level the market demands with lower costs by standardizing designs and allowing products to be global.

3.2 Safety on robots and cells

There are several institutions involved in drafting standards related to Industrial Robots. The most important institutions the American National Standards Institute (ANSI) and the International Organization for Standardization (ISO).

The ANSI is a private non-profit organization that oversees the development of voluntary consensus standards for products, services, processes, systems, and personnel in the United States[15]. The ANSI standards are based on market demand without oversight as to technical content. Unlike the ISO, the standards do not have to use the work of other ANSI Standards. In Figure 3.1 is shown the ANSI Standards related to Industrial Robots Framework.

ISO is the world's largest developer of voluntary International Standards. International Standards give state of the art specifications for products, services and good practices, helping to make industry more efficient and effective. Developed through global consensus, they help to break down barriers to international trade[16]. ISO standardization is highly structured and organized to minimize overlapping scopes. ISO standards are supposed to use the work of other standards and not *reinvent the wheel* in each new publication. In Figure 3.2 is shown the ISO Standards related to Industrial Robots Framework.

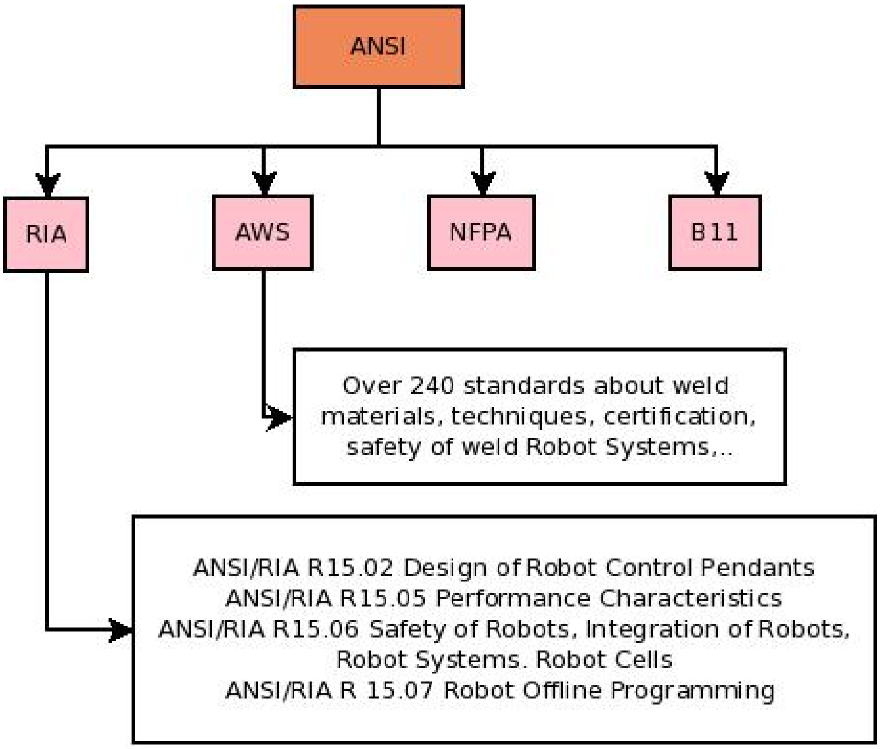

Figure 3.1: ANSI Standards related to Industrial robots Framework

3.3 Historical overview of Industrial Robots and safety requirements

Industrial robots have been used progressively in a widely range of applications. Their continual incorporation in the factories has supported successful production increases due to some factors. The constant speed and force robots are able to allow repeatability in manufacturing processes. Programming brings some flexibility when changes are needed in the assembly line. The delegation to the robots of hazard and hard work has contributed in the decrease of production costs[13].

In the other hand the safeguarding of the humans who work close to the robots, like either safety fences or safety systems, increases the production costs.

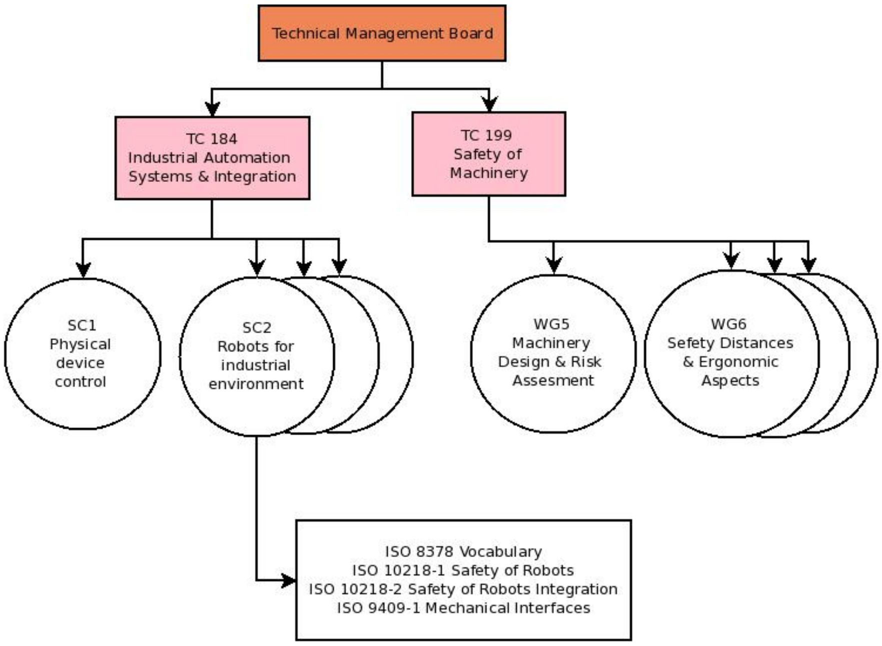

Figure 3.2: ISO Standards related to Industrial robots Framework

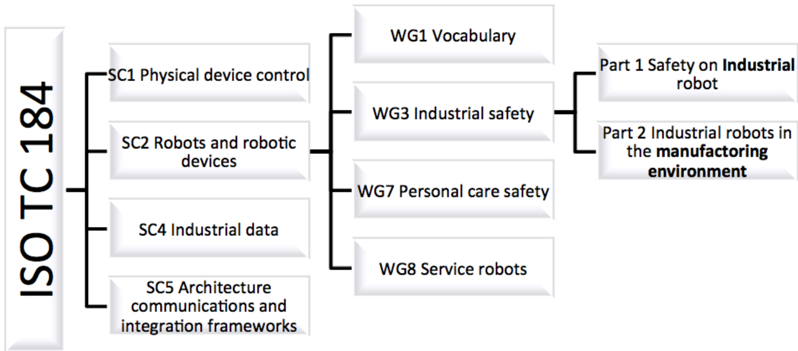

Figure 3.3: Organization of ISO TC 184

Safety has been an important concern in industrial robots during all of the development of industry technology. The first industrial robots were hydraulically powered and their control was simply and not truly reliable. Therefore the safety issue was locking the robot out of the reach of humans. These early robots really improved the work conditions in the factories because of the delegation of hard works to the robots.

To ensure safety in the workplace, work of standardization was started in the USA and Europe. The Robotic Industries Association (RIA) developed the R15.06 robot safety standard through the American National Standards Institute (ANSI). The International Organization for Standardization (ISO) developed, in 1992, the ISO 10218:1992. These were the first standards related in industrial robotics.

The development and expansion of industrial robots continued and electric drive robots with servo controls were extended in the factories. These robots provided better precision and repeatability and were used in several applications.

However the prevailing safety concept of cage humans off from the robot work space and not let anyone to them continued. Both standards had similar scope although RIA 15.06 provided information for the integrations and use of the robots whereas ISO 10218:1992 provided information about the requirements to the manufacturers of robots.

Despite these safety concepts, the need for humans to interact with robots was thought because of the maintenance interventions and setting. Each robot installation is specific and particular and therefore is difficult to assess the hazards and risks in order to develop a standard. For this reason, in the new methodology of ANSI/RIA 15.06-1999, was suggested the importance of understand these risks and select the properly safeguarding.

Thereby with this standard, new better guidance for human interaction with robots was given. Industrial robots and technologies continued developing and new elements of robot control appeared. Thus it was time to develop new standards to recognize the improvements and offer better advice in using robots in factories.

In 2006 the ISO 10218-1 was published. This standard was a comprehensive document for giving guidance to robot manufacturers in building suitable industrial robots. It was only dedicated to the robot.

In 2011 the ISO committee work continued with the publication of ISO 10218-1 and ISO 10218-2 simultaneously. Part 1 is a second edition of the standard published in 2006 and it is only dedicated to the robot whereas part 2 is dedicated to safety requirements for robot system and integration. Both documents are synchronized and allow the capabilities of new robots like the "Collaborative Robot", where human and robot work in close harmony with one another.

In 2012 a new version of R15.06 has been approved but is still in the ANSI review and approval process. This new document is a national adoption of ISO 10218-1/2.

It is worth noting that a new Technical Specification (ISO/TS15066) defining collaborative modes is under development No longer is the concept of forbidding access to the robot working space.

In Figure 3.4 is shown a timeline with the evolution of the standards related to industrial robots.

The benefits of the ISO 10218-1/2 revision are several but can be noted the great progress towards global harmonization. Part 1 is more safety embedded into robots compared with the 1999 version although it is difficult to envision requirements for technology that is not yet known. Part 2 is more realistic compared with the old version and risk assessment is required.

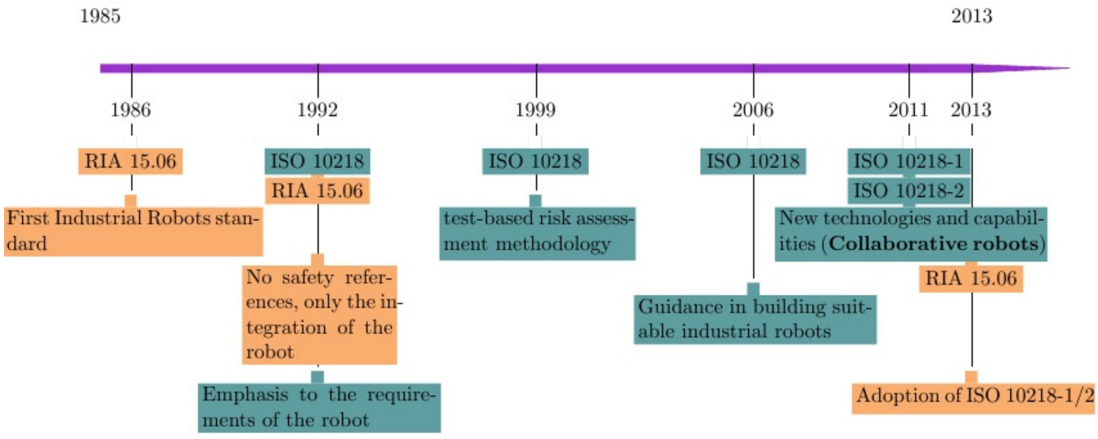

Figure 3.4: Industrial Robot Standards Timeline

3.3.1 ISO Standards. ISO TC 184/SC 2

The work is focused in ISO standards given that they are international standards, and the latest version is available and applicable.

ISO consists of many Technical Committees, which deal with different areas of interest, and each TC may have a few Subcommittees according to its need. ISO TC 184 deals with automatic system and integration and one of its subcommittees, SC 2, develops standards in robotic fields. The organization of TC 184 is shown in Figure 3.3.

3.3.1.1 WG1 Vocabulary

The main task is to define some fundamental terms reviewing the existing ones and adding new terms especially for the area of service robots.

- ISO 8373: Vocabulary for robots (it includes the new terminologies for service robots)
- ISO 11593: Vocabulary for automatic end-effector exchange systems
- ISO 14539: Vocabulary for object handling with grasp-type grippers
- ISO 9787: Typical coordinate systems

3.3.1.2 WG7 Personal care safety

The main task is the study of the need to develop a new service robot standard. The areas, which are under consideration, are the performance criteria, coordinate system, characteristics of mobile robots, modularity in hardware and software and robotic software for service robots.

- ISO 13482: Safety requirements for service robots, personal care robot

3.3.1.3 WG8 Service Robots

This Work Group deals with Service Robot but it has not provided any relevant standard yet.

3.3.1.4 WG3 Industrial Safety

The Work Group 3 deals with Industrial Robots. There are two separate tracks of work in progress. Part 1 addresses only the safety of industrial robot and Part 2 deals with the safety of industrial robot system and integration. Therefore Part 2 mainly addresses the safety issues when they install industrial robots in the manufacturing environments.

- ISO 9283: Performance criteria and related test methods
- ISO 13309: Informative guide on test equipment and metrology methods of operation for robot performance evaluation (in accordance with ISO 9283)
- ISO 9409: Detailed dimensions regarding mechanical interfaces o shafts and plates used in robot systems
- ISO 9409-1: Mechanical interfaces, plates
- ISO 9409-2: Mechanical interfaces, shafts
- ISO 9946: Detailed characteristic related to manipulators
- ISO 10218-1: Safety requirements, robot
- ISO 10218-2: Safety requirements, robot system and integration
- ISO 15066: Technical Specification (TS) on collaborative workspace

3.4 ISO 10218-1:2011 and ISO 10218-2

The ISO 10218-1 and ISO 10218-2 are type C-standard documents prepared by the Technical Committees ISO/TC 184 "Automation systems and integration" in collaboration with the Technical Committee CEN/TC 310"Advances automation technologies and their applications". A type C-standard is a Product safety standard which covers specific types giving detailed requirements for a particular machine. They are quite revolutionary with respect to previous standard on robot safety. In fact they introduce applications with:

- More than one coordinated robot under the control of one or more operators,
- Robot cooperates with human operator,
- Advanced programming tools,
- Dynamic workspace limiting and
- Collaborative workspace.

The standard details directives for robots and robotic workcells, describe basic hazards associate with robots and provide requirements to eliminate or reduce the associated risks as well as describe the requisites to achieve safety.

One of the basic principles at the basis of ISO 10218-1/2 consists on the fact that the robot and all the components must be realized in accordance with general safety principles as well as hazard identification and risk assessment are mandatory.

3.4.1 Hazard identification and risk assessment

When robots are used in factories hazards and risks of accidents appear. Special attention shall be paid in collaborative operations given the operating space of robot and human is shared and risks of accidents increase significantly. The following points must be observed when performing the risk analysis:

- Identify hazards: what are the hazards, who is at risk and what types of injuries,
- Evaluate hazards: probability the hazard will arise, preventing the hazard and limiting the effects of the hazard,
- Reduce hazards to a tolerable degree,

- Take technical and organizational measures and
- Describe residual risks.

A list of hazards that can present in robots is exposed in [17]. This risk assessment shall give particular consideration to:

- the intended operations or the robot like work, maintenance, teaching, setting or cleaning,
- unexpected start-up,
- access by personnel from all directions,
- reasonably foreseeable misuse of the robot,
- the effect of failure in the control system and
- hazards associated with the specific robot application.

Risks shall be eliminated or reduced by design or substitution, by safeguarding and other complementary measures. In [17], in accordance with [18], the hazards related in machinery are listed and classified according their origin. Thereby the significant hazards in industrial machinery are mechanical hazards, electrical hazards, thermal hazards, nose hazards, vibration hazards, radiation hazards, material or substance hazards, ergonomic hazards and environment hazards.

In order to reduce risks in industrial collaborative robots shall identify possible hazards susceptible to be present in these operations listed in [17].

3.4.1.1 Mechanical hazard

All the origins of mechanical hazards listed in [17] can occur in collaborative operations. Intended or unintended movements of any part of the robot or end effector, unexpected realize of potential energy as well as loose of clothing or long hair between robot and any fixes object among others, can origin accidents with potential consequences like crushing, shearing, cutting or trapping.

3.4.1.2 Electrical hazard

This kind of hazards is related with failures in electrical connections or confusions of voltages in the systems. Given the ReBORN scenario take place in welding factories, shall pay attention in the electrical hazards but they are not directly committed with robots.

3.4.1.3 Thermal hazards

Attention has to be given on hot surfaces associated with the end effector of the robot or workpieces. Their potential consequences are burns, fire and inhalation of toxic fumes among others.

3.4.1.4 Noise hazards

Accidents related in noise hazards while working in collaborative robots can occur if the ambient noise level is so high or distracting as to prevent hearing o understanding audible danger warning signals.

3.4.1.5 Ergonomic hazards

Poorly design, distribution or location of the teach pendant, operator panel or operation controls can cause the worker fatigue, stress or loss of awareness which their corresponding consequences of human error.

3.4.1.6 Hazards associated with environment in which the machine is used

Poor environment conditions can cause misidentification of real problems or failures in the functioning of the devices, like sensors.

The results of the risk evaluation must then be taken into account when designing and building the machine.

3.4.2 Design requirements

The necessary aspects that are mandatory to face when designing a safe Collaborative Robot are described in the following section.

3.4.2.1 System related

Safety-related control systems (electric hydraulic, pneumatic and software) shall comply with the performance requirements which levels and categories are described in ISO 13849-1:2006, 4.5.1 and the Safety Integrity Levels and hardware fault tolerances described in IEC 62061:2005, 5.2.4.

Requirements in those standards should be used for the respective safety-related systems for which they are intended.

3.4.2.2 Robot stopping functions

Every robot shall have a protective stop function and an independent emergency stop function. Optionally, an emergency stop output signal may be provided.

Each robot shall have one or more emergency stop functions as well as every control station capable of initiating robot motion shall have a manually initiated emergency stop function. This stop function shall comply with the following requirements:

- to comply with IEC 60204-1 requirements,
- to take precedence over all other robot controls,
- to cause all controlled hazards to stop,
- to remove drive power from the robot actuators,
- to provide capability for controlling hazards controlled by the robot system,
- to remain active until is reset and
- to be only reset by manual action that does not cause a retard after resetting, but only permit a restart to occur.

When an emergency stop output signal is provided, the output shall continue to function when the robot power is provided or an emergency stop signal shall be generated.

Each robot shall have one or more protective stop functions designed for the connection of external protective devices. External devices shall initiate this protective stop function when a sensor detects hazards and shall comply with the following requirements:

- to comply with IEC 60204-1 requirements,
- to stop motion, remove or control power to drive actuators,
- to allow for the control of any other hazard controlled by the robot and
- may be initiated manually or by control logic.

Table I: Comparison of emergency and protective stops

Parameter	Emergency stop	Protective stop
Location	Unobstructed access	Minimum safe distance formulas described in ISO 13855
Initiation	Manual	Manual, automatic or automatically initiated by a safe-related function
Safety-related system performance	Requirements described in ISO 13849	Requirements described in ISO 13849
Reset	Manual	Manual or automatic
Use frequency	Infrequent	Variable
Purpose	Emergency	Safeguarding or risk reduction
Effect	Remove energy sources to all hazards	Safely control the safeguarded hazard

3.4.2.3 Speed control

The Speed of the robot end effector and of the Tool Centre Point (TCP) shall be controllable and selectable. Three speed operations are defined in the standard ISO 10218-1: the Reduced speed control operation, the Safety-rated reduced speed control and the Safety-rated monitored speed.

The first one is used when operating under reduced speed control and speed or the TCP shall not exceed 250mm/s. The second one, when provided, the speed of the TCP does not exceed the limit for reduced speed (250mm/s) and a protective stop shall be issued when a fault occurs. The last one, when provided, the speed of the TCP shall be monitored and if the speed limit is selected, a protective stop shall be emitted.

Table II: Comparison of speed modes

Speed mode	TCP speed and other security measures
Reduced speed control	$< 250mm/s$
Safety-rated reduced speed control	$< 250mm/s$, Protective stop
Safety-rated monitored speed	$< limitspeed$, Protective stop

3.4.2.4 Operational modes

Operational modes shall be selected clearly identifiable and without ambiguity and shall exclusively allow one operating mode.

3.4.2.4.1 Automatic

In automatic mode the robot shall execute the task programme, activate the safeguarding measures and be prevented if any stop condition is detected. To switch from this mode the robot shall be stopped.

3.4.2.4.2 Manual reduced speed

Manual reduced speed mode shall allow the robot to be operated by human intervention. This mode is used when teaching and programming or verifying the robot and automatic mode is forbidden. When this mode is used inside the safeguard, it shall be performed with reduced speed and hold-to-run controls in conjunction with an enabling device such as pendants.

3.4.2.4.3 Manual high speed

Manual high speed mode can allow speed greater than 250mm/s but can only be used for programme verification. Given the high speed the robot shall have a means to select manual high speed which require an action in order to activate it and an additional confirming action as well as provide a pendant a means for operator for adjust the speed among other functions.

3.4.2.5 Pendant controls

The teaching control device or pendant is a communication interface manually controlled which allow initiating the motion of the robot from the safeguarding space.

3.4.2.6 Singularity protection

When motion of robots pass near singularities, high axis speeds can be produced which can be unexpected to an operator.

When it occurs the robot control shall stop the robot motion and provide a warning prior to the robot passing through or correcting for a singularity during coordinated motion or generate an audible or visible warning signal and continue to pass through the singularity with the speed of each link limited to $250mm/s$.

When the singularity can be controlled without creating hazard motion, no additional protection is required.

3.4.2.7 Movement without drive power

The robot shall be designed so that the axes are capable of being moved without drive power by a single person in case of emergency.

3.4.2.8 Automated Guided Vehicles

Automated Guided Vehicles (AGV) are vehicles that are equipped with automatic guidance systems and are capable of follow prescribed paths. Unlike traditional robots, AGVs are not manipulators, they are driverless vehicles that are programmed to follow a guidepath. In automated factories and facilities AGV's move pallets and containers.

There have been advances in navigation systems. First AGVs followed electromagnetic wires buried in the floor. When laser guided systems came into the market, these navigation systems allowed the AGV to determine its position in the plant based on the location of reflectors within the area. The future may be a global positioning system for positioning the AGVs in the floor of the factories with obstacle detection systems and emergency stops that stop the AGV if it contacts a person or obstacle.

ANSI B56.5 defines safety requirements for powered, unmanned automatic guided industrial vehicles. The standard requires that the users are responsible for all factors affecting the operation and maintenance. This responsibility includes load stability and marking the travel path on the floor, including turning and maneuvering clearances. There are also requirements for manufacturers.

Deviation from the travel path of more than $7.6mm$ for an external reference, or, more than $15.2mm$ for inertial guidance system shall, require an emergency stop. A loss of speed control also requires an emergency stop. Vehicle warning indicators, audible and/or visual, shall operate when the vehicle is in motion. Emergency controls are required which would stop the vehicle if there is a loss of speed control, loss of guidepath reference, or an object is detected in the direction of travel. Accessible emergency stop switches are required on the vehicle itself [19].

The following guidelines shall be used when working with AGVs [20]

- AGV travel paths should be clearly marked, including turning areas,
- Workers should be trained to watch out for AGVs and to keep clear of an AGV path if a vehicle is approaching,
- Companies should provide similar training for contractors that may be working in their plant,
- Weighted safety cones should be placed around a work area when working on or near an AGV travel path and
- Improve plant safety with regard to object detection/avoidance.

3.4.3 Protective measures

Protection measures encompass physical guards, software and devices used to block or limit access to work, or certain actions with respect to the work.

When design does not remove hazards or adequately removes the risks, it is necessary to apply the safeguarding. The safeguarding shall protect the access to hazardous areas by using guards and protective devices.

The best choice of protective measure is a device or system that provides the maximum protection with the minimum hindrance to normal machine operation. All aspects of machine use must be considered.

3.4.3.1 Guards and perimeter safeguarding

Guards and sensitive protective devices are used for perimeter safeguarding. The selected perimeter safeguarding has to contain all the hazards related or not with the robot system such other machinery and equipment processes, emission hazards and falling or ejected objects among others. The selection of the perimeter safeguarding shall consider the frequency of access, the maintenance, the proximity to the hazard and the process requirements.

The minimum distance that the hazards cannot be accessed, where the safeguards shall be installed, depends on the kind of safeguard and the process as well. Each different guard and protective device is regulated by its own standard. In the Figure 3.9 are shown the ISO standards which regulate the protective measures appeared in ISO 10218-2.

The guards are classified according on their mobility, lock and if they allow the access to operators or not. There are:

- Fixed distance guards,
- Interlocked movable guards,
- Movable guards with guard locking and
- Movable guards allowing access into the safeguarded space.

Appropriately selected movable guards can be interlocked to provide protection against projectiles, fluids, mists and other types of hazards, and are often used when access to the hazard is infrequent. Interlocked guards can also be locked to prevent access while the machine is in the middle of the cycle and when the machine takes a long time to come to a stop.

3.4.3.1.1 Fixed distance guards

Fixed guards shall only be removable by the use of a tool and its opening shall not allow a person to reach over, under around or through the guard and access a hazard. The height of the guard shall be at least 1400mm from adjacent walking surfaces. Figure 3.5 shows an example of a fixed guard.

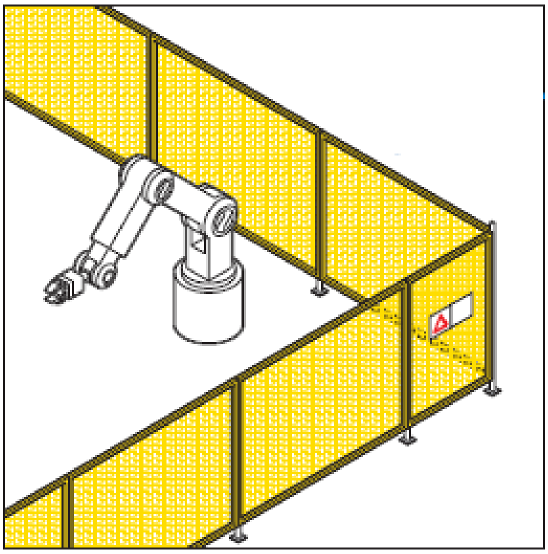

Figure 3.5: Fixed distance guard

3.4.3.1.2 Interlocked movable guards

Movable guards are provided to bring any hazards to a safe state before an operator can gain access to the hazard through the guard.

Movable guards at closed position prevent operators reaching hazardous areas and when they shall open laterally or away from the hazard and not into the safeguarded space. Figure 3.6 shows an example of interlocked movable guard.

3.4.3.1.3 Movable guards with guard locking

This movable guard allow the operator to open the guard and reach the hazard area before the hazard is brought to a safe state.

This guard locking only permit the actuation of hazardous machine function while the guard is closed and locked and has to keep the guard in the closed and locked position as long as the risk exists. Process parameters can be used as conditions for locking or unlocking. Figure 3.7 shows an example of movable guard with guard locking.

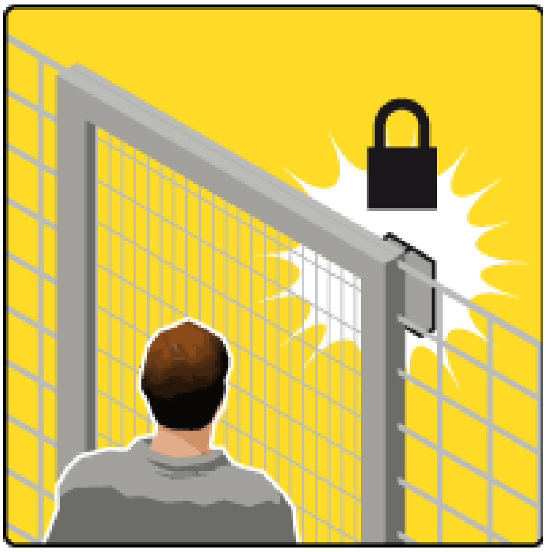

Figure 3.6: Interlocked movable guard

Figure 3.7: Movable guard with guard locking

3.4.3.1.4 Movable guards allowing access into the safeguarded space

The safeguarded spaces shall be designed preventing a person from being trapped inside. It can be accomplished by providing manual openings, movable guards from inside the safeguarded space or locking access gates in the open position. Figure 3.8 shows an example of movable guard allowing access into the safeguarded space.

3.4.3.2 Sensitive devices

Presence sensing devices such as light curtains, mats and scanners, provide quick and easy access to the hazard area and they are often selected when operators must frequently access the hazard area or when is not possible to provide a fixed

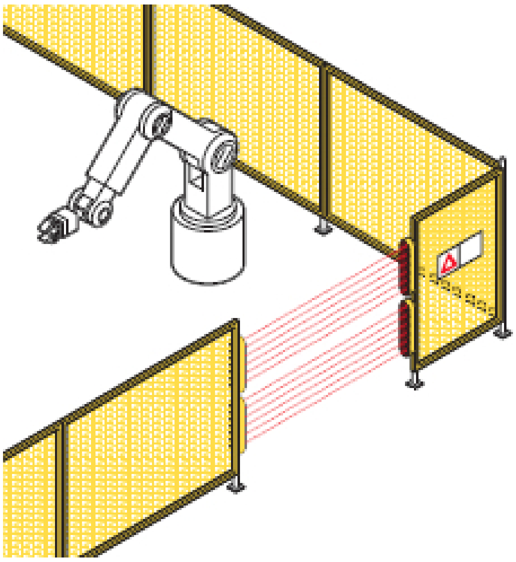

Figure 3.8: Movable guard allowing access into a safeguarded space

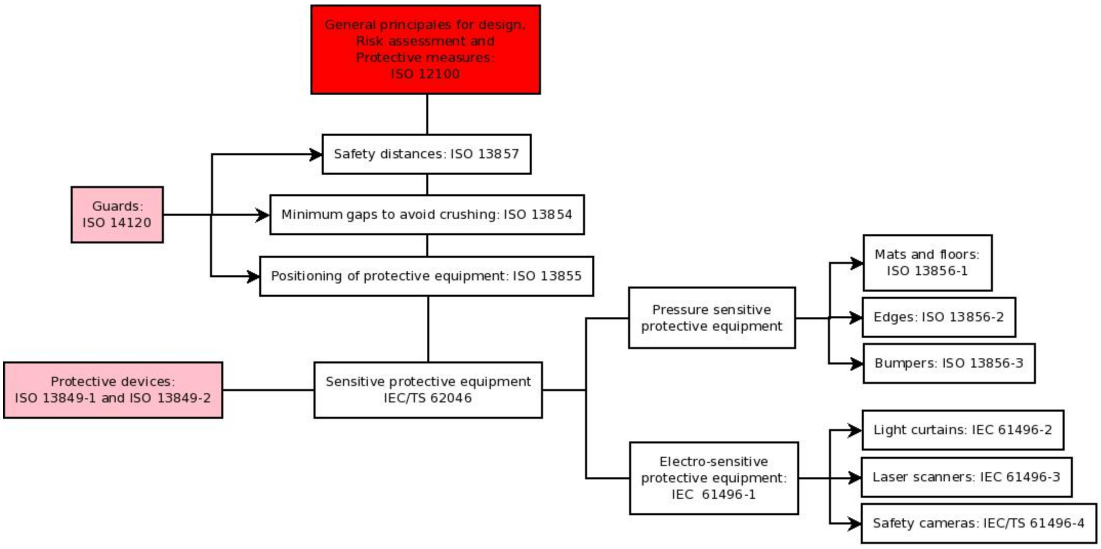

Figure 3.9: ISO standards of Industrial Robot Systems in ISO 10218-2

guarding. These types of devices do not provide protection against projectiles, mists, fluids, or other types of hazards.

When deciding how to protect a zone or area it is important to know exactly which safety functions are required. Usually there are two functions.

- Switch off or disable power when a person enters the hazard area and
- Prevent switching on or enabling of power when a person is in the hazard area.

This safety functions are linked but they are in fact two separate functions. To achieve the first point is needed a device which detects that a part of a person is beyond a certain point and gives a signal to turn off the power. If the person is then able to continue past this tripping point and their presence is no longer detected then the second point may not be achieved. In Figure 3.10 and Figure 3.11 are shown presence sensing devices detecting the full and partial body of an operator respectively.

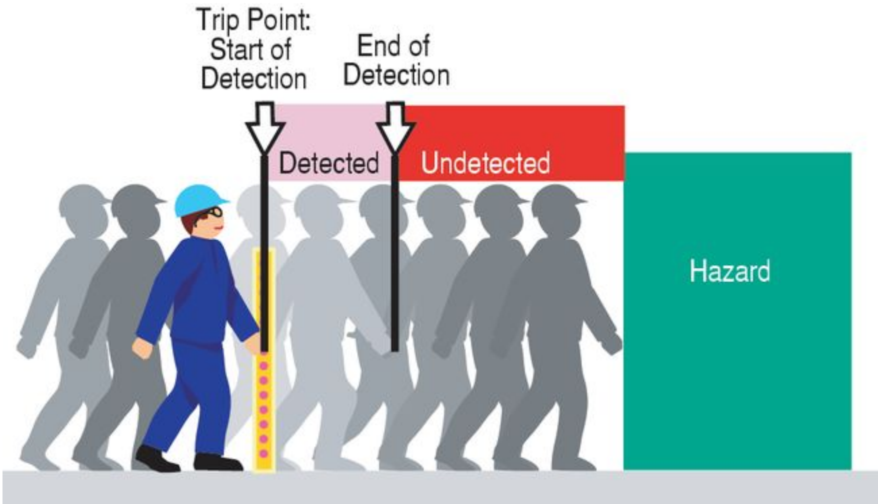

Figure 3.10: Full body detection

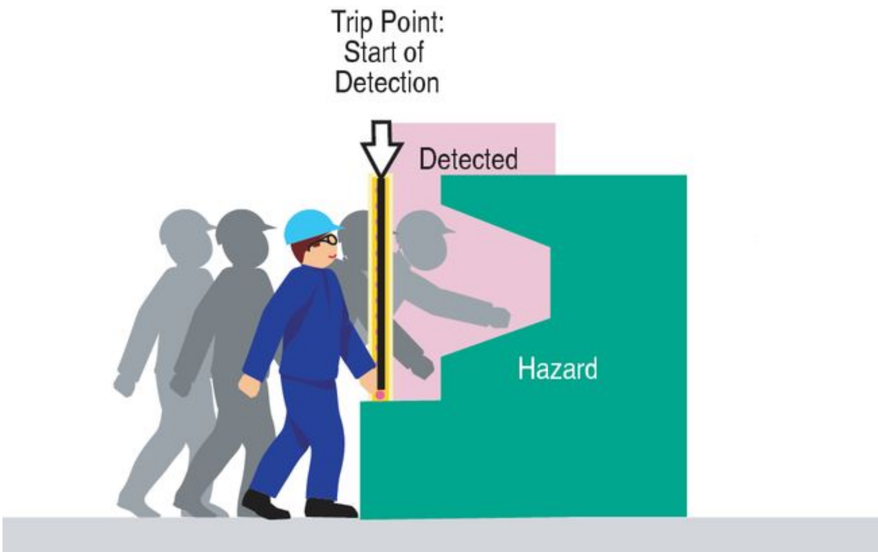

Figure 3.11: Partial body detection

3.4.3.2.1 Light curtains

Safety light curtains are photoelectric presence sensors specifically designed to protect personnel from injuries related to hazardous machine motion. Also known as AOPDs (Active Opto-electronic Protective Devices) or ESPE (Electro Sensitive Protective Equipment) allow for greater productivity and are the more ergonomically solution when compared to mechanical guards.

They are ideally suited for applications where personnel need frequent and easy access to a point of operation hazard. Figure 3.12 shows an example of vertical light curtain.

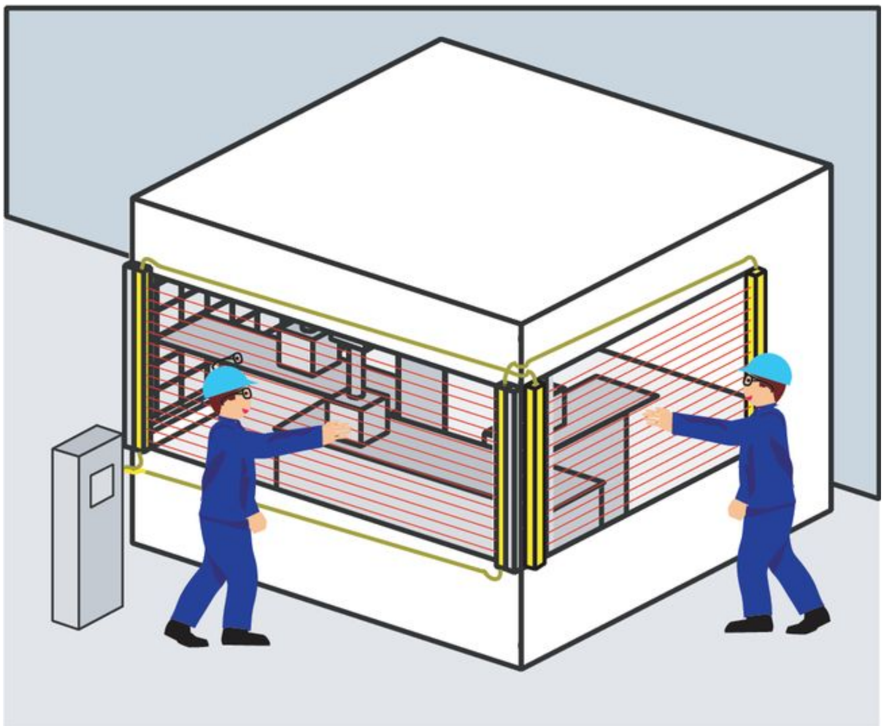

Figure 3.12: Light Curtain delimiting a safeguarding zone

3.4.3.2.2 Laser Scanners

Safety laser scanners use a rotating mirror that deflects light pulses over an arc, creating a plane of detection. The location of the object is determined by the angle of rotation of the mirror. The scanner can also detect the distance the object is from the scanner. By taking the measured distance and the location of the object, the laser scanner determines the exact position of the object.

The safety distance calculation must be used to determine the appropriate size of the safety zone. In Figure 3.13 is shown a laser scanner.

3.4.3.2.3 Pressure Sensitive Safety Mats

The Pressure Sensitive Safety Mats are used to provide guarding of a floor area around a machine. A matrix of interconnected mats is laid around the hazard area and pressure applied to the mat will cause the mat controller unit to switch off power to the hazard.

Pressure sensitive mats are often used within an enclosed area containing several machines such as flexible manufacturing or robotics cells. When cell access

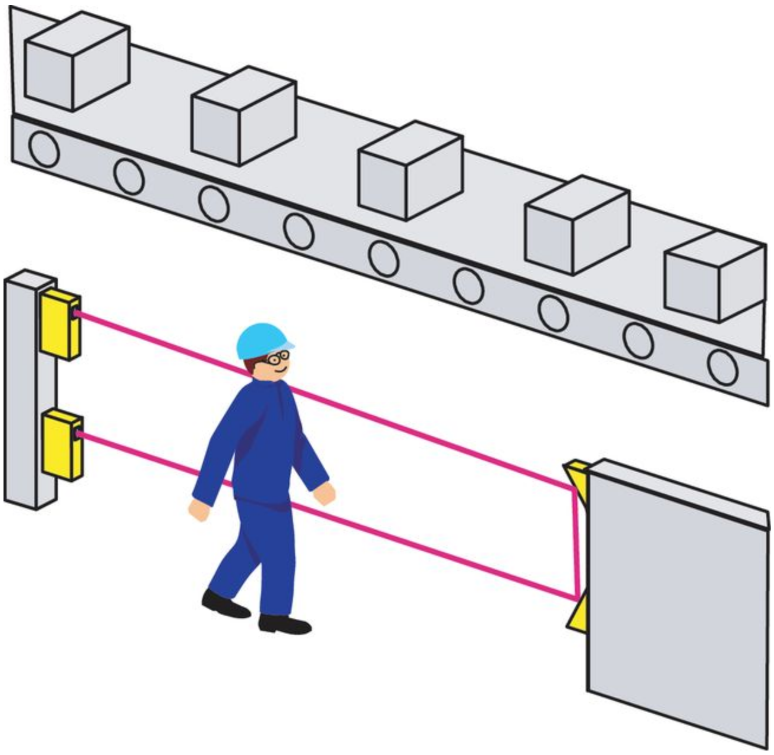

Figure 3.13: Laser Scanner delimiting a perimeter

is required they prevent dangerous motion if the operator strays from the safe area, or must get behind a piece of equipment. In Figure 3.14 is shown a safety mat detecting an operator by sensing the pressure.

3.4.3.2.4 Pressure Sensitive Edges

The Pressure Sensitive Edges are flexible edging strips that can be mounted to the edge of a moving part, such as a machine table or powered door that poses a risk of a crushing or shearing.

If the moving part strikes the operator, the flexible sensitive edge is depressed and will initiate a command to switch off the hazard power source. Sensitive edges can also be used to guard and if an operator becomes caught in the machine, contact with the sensitive edge will shut down machine power. Figure 3.15 shows a safety sensitive edge.

3.4.3.3 Muting

Muting is the automatically, temporary and controlled suspension of a safety function during a portion of cycle of the robot system. Sometimes the process requires that the machine stop when personnel enters the area, yet remain running when automatically-fed material enters. In such a case, a muting function is

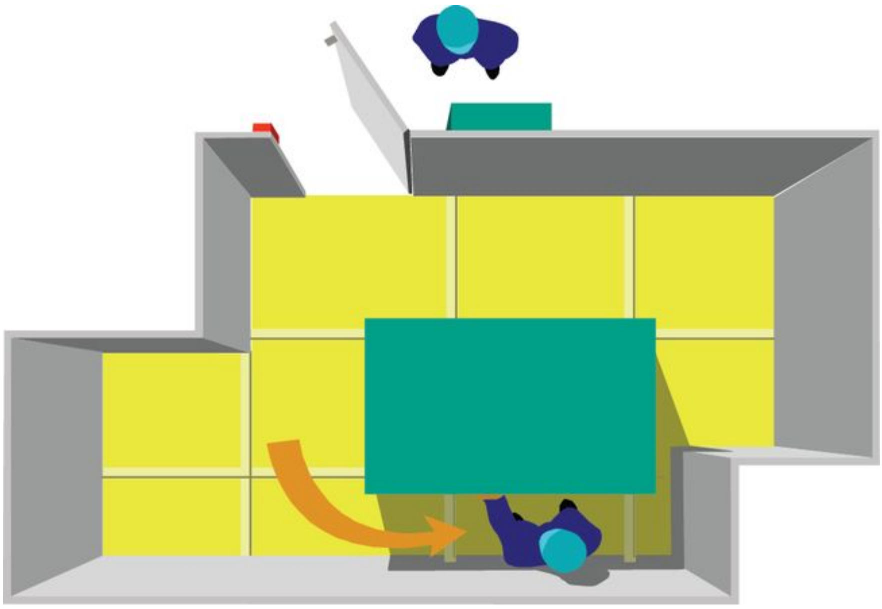

Figure 3.14: Safety mat detecting an operator

necessary. Muting is permitted during the non-hazardous portion of the machine cycle or must not expose people to a hazard.

Muting may be used in conjunction with any safeguarding devices such a protective stop.

In Figure 3.16 is shown an example of an access to robot cell accomplished by muting. The limit switches indicate the position of the robot and the safeguarding devices are muted when the robot is not in a hazardous position.

3.4.4 Traditional vs cooperative tasks

Traditionally, a human operator must be at the extern of safeguard space and only exeptionally his presence was allowed (e.g. maintenance operations...). Besides, even in this situations, strong restrictions were imposed like only trained operators were allowed, automatic mode was not permitted, the speed was to be below $250mm/s$ and no command from extern (except emergency stop) was permitted, among other supplementary measures.

The new cooperative tasks scenario allows human operator to enter in the safeguarded space and interacting with the robot. Some limitations are, of course, still present. The operator must have control over manipulator and some sensors has to limit interacting speed, force and energy.

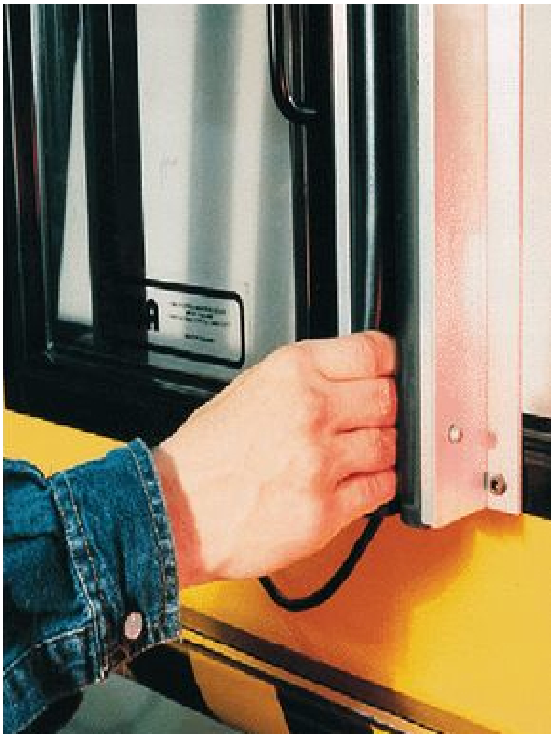

Figure 3.15: Safety Sensitive Edges

3.4.5 Collaborative Robot Operation

Collaboration is an operation between a person and a robot sharing common workspace. It can be only used for predetermined tasks and all the required protective measures shall be active.

Due the approach between robot and human protective measures shall be provided to ensure the safety of the operator because physical contact can occur during the operation.

The collaborative robots shall accomplish the protective measures mentioned in [21] and the designing requirements mentioned in [17] as well as should be labelled with a symbol as shown in Figure 3.17.

Regarding the collaborative workspaces, they have to be clearly identified with floor marks and signs. The design of these spaces shall be such that operators can perform the tasks without introduce additional hazards. Whenever possible, the range of possible free motions may be reduced by using protective measures such as safe-rated soft axes and space limiting among others.

The minimum clearance in the robot system shall be 500mm between the space of the robot to areas of building, structures or other machines or equipment. This clearance has to avoid trapping and pinch between the robot and the human operator. If it is not possible to provide this clearance additional protective measures shall be taken to stop the robot motion.

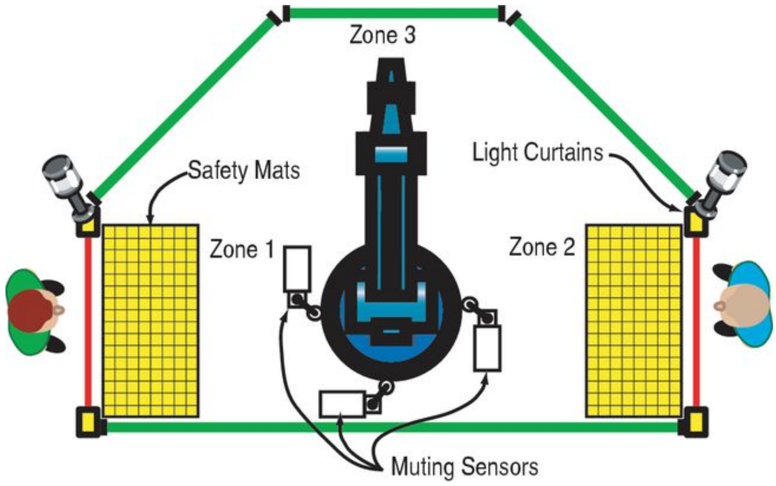

Figure 3.16: Muting of a robot cell

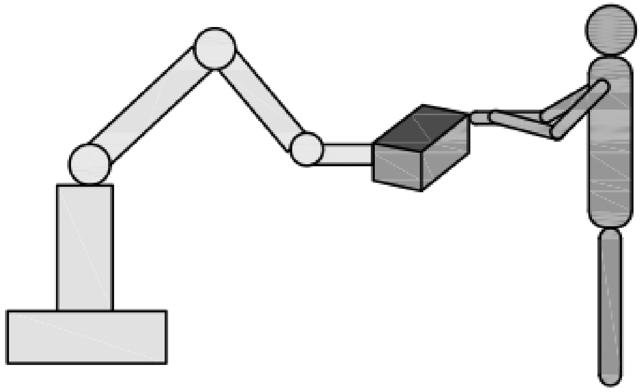

Figure 3.17: Suggested labelling design in ISO 10218-2:2011

Each operator or the presence monitoring system regulates the access to the collaborative space. There are different cases foreseen in the standards:

- robot stops when operator approaches,
- robot reduces speed when operator approaches,
- robot maintains a safe distance from the operator and
- robot is moved under direct operator control.

According the cases above-mentioned, in [21] are listed and described some Collaborative Modalities:

- Hand-over window,
- Interface window,
- Collaborative Workspace,

- Inspection and
- Hand-guided robot.

3.4.5.1 Hand-over window

In this modality, shown in Figure 3.18, the robot does not exit from the window and is not allowed any interruption of automatic operation during access. The velocity of the motion movements is limited when the robot is near the window and there are fixed or sensitive guards around the window.

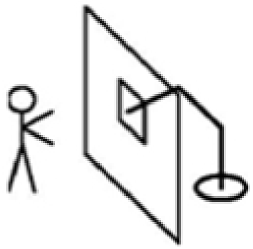

Figure 3.18: Collaborative task: Hand over window

3.4.5.2 Interface window

In this modality, shown in Figure 3.19, the operation is autonomous and automatic within safeguarded space. The robot stops at an interface window and can then be moved manually outside the interface. Around the workspace there are fixed or sensitive guards. Outside and near the window the speed and the workspace are reduced as well as, for guided movement, the control is hold-to-run.

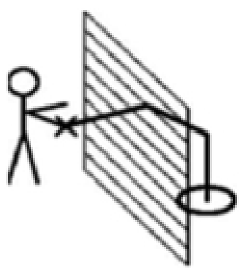

Figure 3.19: Collaborative task: Interface window

3.4.5.3 Collaborative Workspace

In this modality, shown in Figure 3.20, the autonomous automatic operation is performed within a common workspace. The robot reduces the speed and/or stops when a person enters in the collaborative workspace. The detection of the person is due to one or more sensors and the speed is reduced according to the distance between the operator and the robot. The robot stops safely when the prohibited space is accessed and it is possible restart automatically after clearance.

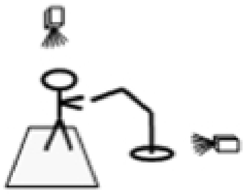

Figure 3.20: Collaborative task: Collaborative Workspace

3.4.5.4 Inspection

In this modality, shown in Figure 3.21, the autonomous automatic operation is performed within safeguarded space, a person can enter into the collaborative workspace while the robot continues operating with reduced speed and reduced travel. There are fixed or sensitive guards around the workspace as well as a person-detection system or enabling device in order to reduce the speed and reduce the workspace after entering in the workspace.

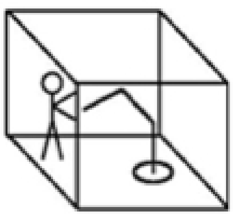

Figure 3.21: Collaborative task: Inspection

3.4.5.5 Hand-guided robot

This modality, shown in Figure 3.22, is a specific application of the workspace where the robot is moved by hand guiding along a path with reduced and safeguarded speed. The collaborative workspace depends on the hazards of the application and the hand guiding equipment is located near the end-effector.

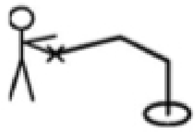

Figure 3.22: Collaborative task: Hand-guided robot

3.4.6 Verification and validation

The robot system manufacturer shall provide appropriate safeguarding devices in order to validate and certificate the design and construction of the robots.

The methods followed in the standards for verification and validation are:

- Visual inspection,
- Practical test,
- Measurement,
- Observation during operation,
- Review of application-specific schematics, circuit diagrams and design material,
- Review of task-based risk assessment and
- Review of specifications and information for use.

Each safety requirement or measure is listed in the standard and it has assigned the corresponding verification and/or validation methods. Using the appropiate method the requirements shall be evaluated to determine if they have been adequately met by the design and construction of the system.

Referring to the protective equipment, the verification and validation shall be done to mitigate identified hazards. Prevention of access to he hazard shall be achieved as well as the installed protective equipment and complementary protective measures provided such guards, size of openings and correct safety distances among others shall be verified.

Table III: Terminology changes in the new version of ISO 10218

Old version	New version
Robot	Robot, *NO end effector*
Robot system	Robot with end effector and any task equipment
Slow speed	Reduced speed
Safety stop	Protective stop
Teach mode	Manual reduced speed mode
APV	Manual high speed mode

3.4.7 News and differences in this revision of ISO 10218-1/2

In ISO 10218-1/2:2011 the enabling device language is enhanced because the interlocking devices for a shared hazards shall have the same span of control as well as designs must include allowance for additional enabling devices if warranted by the process.

According to the safety distance, it is based on worst anticipated stopping times. The clearance has augmented to $500mm$ required if risk assessment determines need due to personnel being exposed to pinch hazards for low speed manual tasks. If system has high speed manual use, the clearance is required like in the old versions of standard.

News aspects are introduced in this version, like control of simultaneous motions from single pendant, the span of control and requirements of providing access to perform tasks as well.

Some terminology changes has been done in this revision. In Table III are shown the new nomenclatures on the new version of the standard.

One of the most important topics in this version is the Collaborative Robot Operation, where are described general requirements as well as requirements for collaborative workspaces and operations in this workspace. For the first time ever, it is allowed to have contact between robot and human operator. The definitions of Collaborative Robot and Collaborative Workspace has been changed according this new permit.

3.5 Proposition of new standards

Having looked existing standards related to collaborative robots and have analysed what to take in mind when designing these robots, it is necessary to assess what has been missed or not taken into consideration in the standards when human operators and robots work jointly sharing the same workspace.

The main features of the collaborative robots is the direct physical interaction between human and robots and however, mechanically safe and powered robots need a considerable time for development and acceptance in the industry. The complexity results from the physical contact and between human and robot and the associated exchange of forces and energy.

In the existing standards are considered operational modes with their corresponding limited speeds, robot stopping functions such as protective and emergency stops, protective measures such as guards and safeguarding perimeters, sensitive devices such as laser scanners, light curtains and pressure mats, muting operations and pendants among other measures.

All this measures aim to ensure safety during collaborative operations by allowing or not the access to the operator at the collaborative workspace under the restrictions pertaining to the working mode being used but, one of the most important goals for the control of interaction among human and robot, is to ensure the stability of the system in spite of uncertainties and inaccuracies[22].

Unstable interactions of the robot can cause damages of workpieces or injuries of the operator. Stability of interaction is fundamental precaution for system safety. Any unexpected robot behaviour in the contact with environment, especially during contact transitions process, such as bouncing or oscillations, produces sensation of fear in the operator. Thereby the operator commonly interrupts the interaction instead to try to stabilize the robot.

The stability of the robots and measures for ensure it should be foreseen in the standards that allow collaborative robot operations.

Chapter 4

ReBORN production scenario

4.1 ReBORN project

The ReBORN is a demo-targeted collaborative project carried out by consortia with participants from different countries entitled *Innovative Reuse of modular knowledge Based devices and technologies for Old, Renewed and New factories.*

The vision of ReBORN is to demonstrate strategies and technologies that support a new paradigm for re-use of production equipment in old, renewed and new factories in order to maximize the efficiency of this re-use and to make the factory design process much easier and straight forward shortening ramp-up times and increasing production efficiency and flexibility.

This demonstration, based on the implementation of versatile and modular, task-driven plug&produce devices, will develop procedures for the re-use and models for factory layout design and adaptive configuration solutions by means of three main ideas: Strategies for Repair, Upgrade and Re-use of equipment and the (Re-)Design of factory layouts and flexible&adaptable production on shopfloor.

In order to develop the three main ideas ReBORN derives six specific strategic objectives:

- Versatile and modular plug&produce equipment with integrated intelligence for flexible production, self-state monitoring and optimal re-use,
- Strategies for re-use of production equipment in existing production systems,
- Models for innovative factory lay-out design techniques and adaptive reconfiguration,

- Design methodology for de-manufacturing, dismantling, recycling and value-chain extension incorporating prior expert knowledge and experience,
- Flexible and low-cost mechanical systems for fast and easy assembly and disassembly and
- Standardization and new business models for dynamic collaboration around modular components.

The goal of University of Oulu in this project is to research with the purpose of promote standardization of production equipment and components as well as develop standards with the purpose of standardize properties of single components and concepts of how to set up a factory composed of re-used equipment.

In order to research about the standardization needed in the project, knowing the properly scenarios and the technologies used by the factories involved in the project is needed.

4.2 Plant requirements

Collaborative operations are proposed to develop new strategies and technologies where humans can move around the robot when it is working as well as human operator is free to access to the product during robot operation in order to control the work progress.

Referring with the scenario, it shall demonstrate the possibility of introduce new elements in the production system in order to prove its extension and re-configuration. With this purpose, a modular plug&produce equipment for electrical industry with versatile components based on linear slides and welding control units, are brought for some partners involved in the project.

In order to prove the capabilities for factory planning and re-planning including old, renewed and new equipment, the demonstrator focuses in three scenarios:

- Demonstration of the re-use of factory planning and simulation procedures,
- Demonstration of the planning with old, renewed and new equipment and
- Demonstrations of the online connection between planning tool and versatile devices.

Related to the automotive industry, flexible low-cost grippers for lightweight to medium-weight components will be developed. The objective is the production and usage of flexible gripper based on Additive Manufacturing (AM). For this purpose, a proper gripper will be designed.

Complex fixtures for the automotive industry will be demostrated as well. its goal is to prove the approach for modular fixtures in the Body in White[1] of automotive industry and the flexibility on product variant handling. In Figure 4.1 is shown an example of body in white process.

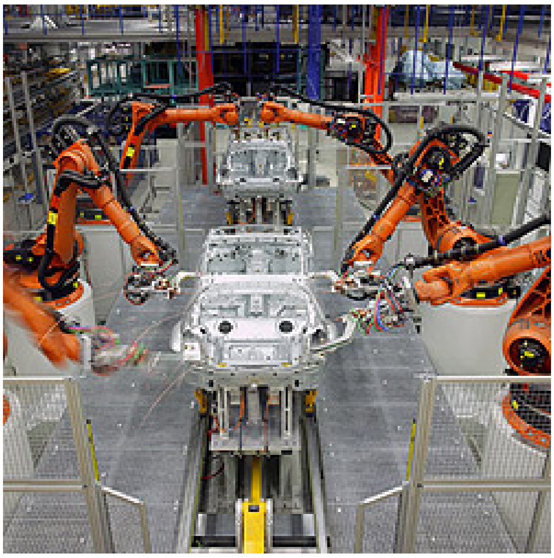

Figure 4.1: Example of body in white automotive process

Acording with the standards described in sections 3.4.2 and 3.4.3, when designing the workspace, attention shall be paid in the clearance between the robot and the physical elements, the position of the protective and stop buttons, the guards and the safeguarding perimeter as well as in the sensors used for tracking position of the operator.

Figures 4.2, 4.3 and 4.4 show how to set up the scenario with the different standardization processes.

4.3 Operation requirements

In collaborative operations, human can access to the robot workspace even when the robot is working and no physical fences are allowed. For this reason some safety requirements shall be applied:

- The worskpace around the robot is a collaborative space,

[1]Body in white refers to the stage in automotive design or automobile manufacturing in which a car body's sheet metal components have been welded together but before moving parts (doors, hoods, and deck lids as well as fenders) the motor, chassis sub-assemblies have been added and before painting

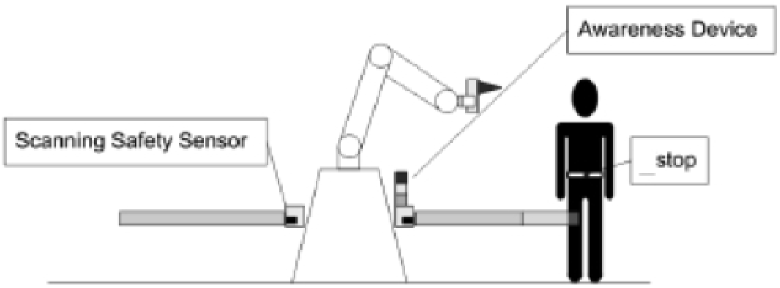

Figure 4.2: Example of sensors used for tracking the position of the operator

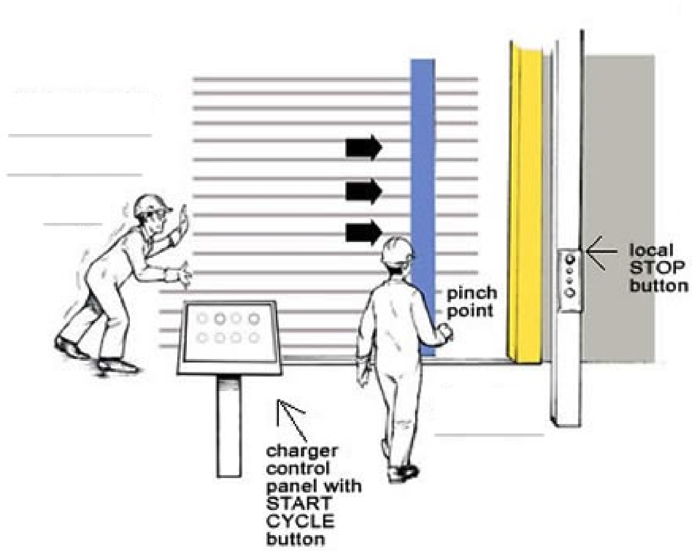

Figure 4.3: Example of the position of the stop and protective buttons

- Tracking of humans has to be guaranteed,
- Safe speed monitoring of the robot has to be guaranteed and
- Safety has to be designed taking in account that trained and non-trained operators should be in the collaborative workspaces.

Each different operation during the industrial process shall have defined its own technical specifications such as the workspace dimensions, the layout and, if it is needed, the devices or sensors used in the process.

The Operation workspace[2] and the Collaborative workspace[3] shall be clearly defined and identified.

[2]Operation workspace: areas close to the machine where the robot performs its operations and where only trained human operators can access.

[3]Collaborative workspace: all the cell area except the operations workspace. The robot should move fast if no human operators are inside the area as well as the speed is limited when an operator is inside the area. The motion of the operator should be tracked when he is inside the collaborative workspace.

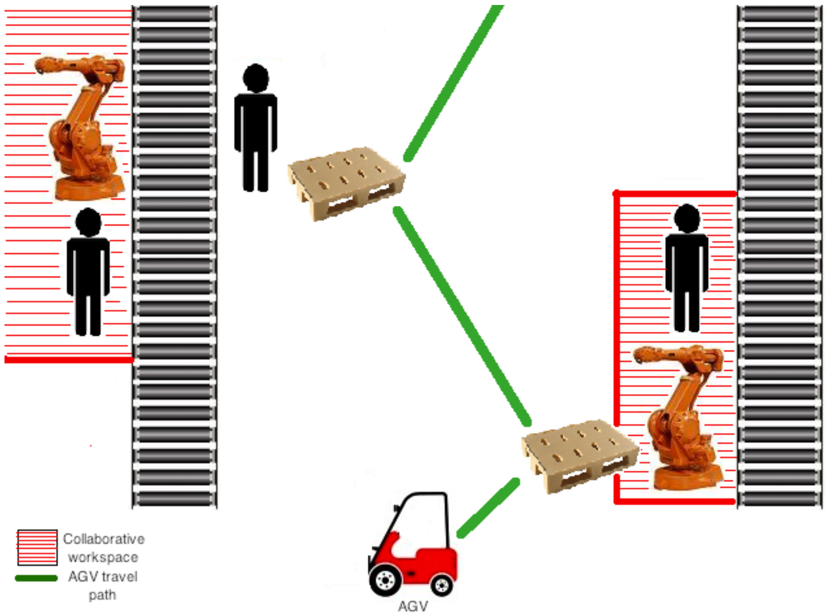

Figure 4.4: Example of Collaborative Workspace and AGV paths in a factory

4.4 Considerations what companies should take in account when working with collaborative robots

When working with collaborative robots, given the risks that the performing tasks jointly entails, basic principles of safety performance shall be satisfied. The parameters that shall be considered are the speed, the position and the force. When these conditions, specified in the standards, are accomplished, the robot can be used in collaborative tasks without fixed guards.

4.4.1 Manual reduced-speed mode

The manual mode allows program creation, storage, and testing of robot paths and positions. The manual mode is used when programming and when commissioning a robot system.

The actuating controls shall be labelled in order to clearly indicate the function and the speed of the robot end-effector and of the TCP shall be controllable and selectable speeds. As it is shown in section 3.4.2.4, three speed modes are described with its TCP speed and the corresponding security measures.

4.4.2 Speed and separation monitoring

In the existent standards [11] it is described how calculate the minimum separation distance as well as how establish the maximum safe speed. The robot controller has to implement methodologies to avoid potential collisions and notify the operator about the state of the robot.

4.4.3 Power and force limiting

The power and force limiting in collaborative tasks is important consideration because of the possibility of an impact between the human operator and the robot. Medical and biomechanical requirements try to investigate how to measure the risk and the potential danger for the collaborator. In fact, the Abbreviated Injury Scale[4] (AIS) is included in the standard documents.

Taking into account the collaborative use of robots, the injury risk for the sense organs shall be lowered through personal protective equipment such as protective clothes or goggles.

[4]AIS is an anatomical-based coding system created by the Association for the Advancement of Automotive Medicine to classify and describe the severity of specific individual injuries. It represents the threat to life associated with the injury rather than the comprehensive assessment of the severity of the injury. AIS code is on a scale of one to six, one being a minor injury and six being maximal (currently untreatable).

Chapter 5

Discussion

The activity of the standardization of industrial robots is booming due to the aim of the industries of perform collaborative tasks between robots and human operators. This new need of the society shall be standardized because of the risk involved in tasks where robot and human operator perform together in the same workspace.

This adaptation to the new roles in the industries is trying to involve all the security aspects in the standards. The current organizations in charge of develop standards are working with this objective. In this work it has been assessed the standards necessaries in order to work with collaborative robots as well as the lack of any aspect to consider when robot and human are carrying a task jointly.

It has been observed that the existing standards dealing with collaborative robots describe many forms of work and how to act in each of these. However there is no talk at any time what to do in case of instability or sudden movements of the robot, or the importance of avoiding them given that worker and robot work very close.

The organization of the institutions in charge of the standardization in committees and workgroups with concise topics makes easy to know exactly which standards you need in each case. Otherwise there are not so much publications related with standardization of the robots in the industries.

Standards are being developed at the same time that the collaborative robots and for this reason more experience is needed to know exactly what to consider in this field.

Chapter 6

Summary

Look for the existent standards related with collaborative robots and determine which guideline to follow in order to use them in the factories are the main objectives of this work as well as assess if it is necessary to consider more aspects which are not taken in account in the current normative.

Having analysed the hazards which can involve the collaborative tasks in factories (mechanical, electrical, thermal, ergonomic and noise) some design criteria have been established for the collaborative workspaces. Shall take in account, among others, the robot stopping functions, the speed control, the pendant control and the singularities protection. Guards and perimeter safeguarding as well as sensitive devices and muting functions shall be also considered.

In the standards many the operational modes are described, how to proceed and aspects to take in account. Nevertheless there is nothing related to uncertainties and inaccuracies of the robot which is considered essential in HRI. The importance of avoid this aspect and some guidelines for the human operator in case of instability should be considered in the standards.

This approach between human and robot is an important landmark for the development of the industry. Given the risks of working so close to the robots and performing tasks jointly is vital to limit what can be done and how in the workstations. That is why standardization plays an important role in the development of collaborative robots.

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