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White Paper

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Safety in Human-Robot Collaboration

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Safety in Human-Robot Collaboration – General Principles, Challenges, Outlook

Safety in Human-Robot Collaboration

General Principles, Challenges, Outlook

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Safety in Human-Robot Collaboration – General Principles, Challenges, Outlook

Safety in Human-Robot Collaboration

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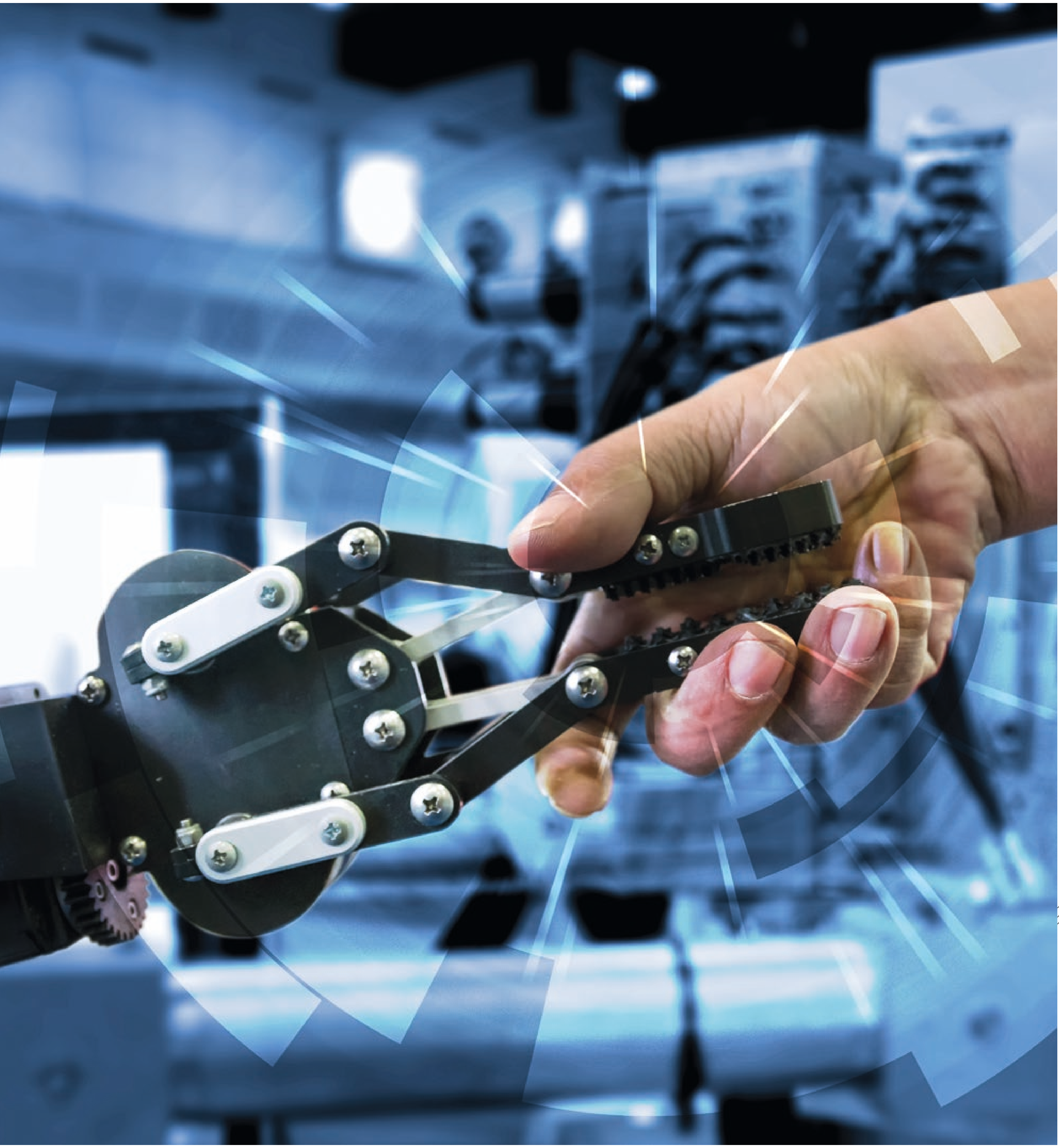


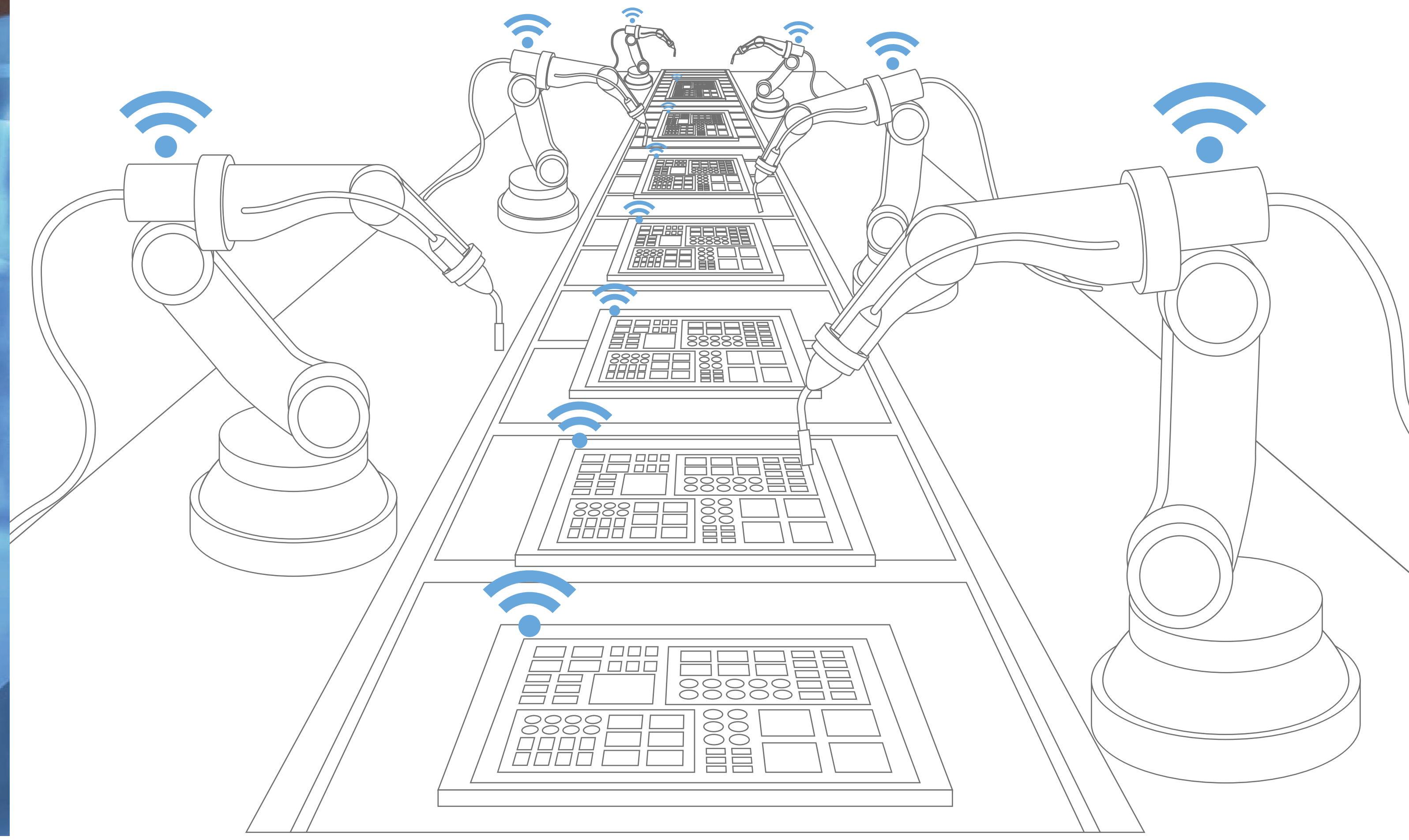
Abstract

The fourth industrial revolution

This first White Paper from the White Paper Series "Safety in Human-Robot Collaboration" by TÜV AUSTRIA and Fraunhofer Austria is an introduction to the concept of human-robot-collaboration, an overview of the current standardisation concept and an outlook on a jointly developed, **integrated safety & security concept,** which will facilitate **the adoption of HRC applications for manufacturing companies in the** future.

The advent of Human-Machine Collaboration (HRC) is deemed to be one of the key trends as part of the fourth industrial revolution. The quality of work and work efficiency in industrial processes can be enhanced by means of HRC since the individual characteristics of humans and robots are combined in one joint work system.

The safety of humans when interacting with networked machines is of primary concern - and numerous standards and guidelines support this. At the present time, there is still a lack of empirical values in the practical implementation of statutory requirements, particularly in terms of direct collaboration between human and machine and the integration of IT security. This results in significant implementation barriers for companies when introducing collaborative work systems.



Company	Model
ABB / Gomtec	Roberta
ABB Robotics	YuMi
Bionic Robots	BioRob
Bosch	Apas
F&P Robotics	P-Rob
Fanuc	CR-35iA OUR2
Kawada Industries	NEXTAGE
KUKA	iiwa7 R800 / 14 R820
Precise Automation	PAVP6
Precise Automation	PF400
Precise Automation	PP100
Rethink Robotics	Sawyer / Baxter
Smokie Robotics	OUR2
Stäubli	TX2-40
Universal Robots	UR3 / UR5 / UR10

Table 1: List of collaborative robots currently available on the market (status March 2016, makes no claim to be complete)

Smart Factory

Human and machine integrated and networked

The concept of the Smart Factory pursues the vision of an industrial production environment in which production plants and logistics systems largely organise themselves and humans cooperate with the technology around them in an integrative manner (1). What initially sounds rather abstract is already possible today: Two of the main approaches for achieving self-organisation and human-machine collaboration are the digital networking of all production resources so as to exchange information in real-time as well as human-robot collaboration.

Human-Robot Collaboration (HRC) describes the collaboration of humans and robots in a joint work system - without the presence of partitioning (e.g. mesh and fences) and non-partitioning protective devices (e.g. light curtain, light scanner). Humans and robots work at the same time on the same object and thus in genuine **collaboration**. Alternatively, they can be *cooperating*, which entails carrying out alternating tasks in the same location. In each case, there is a shared working space, however.

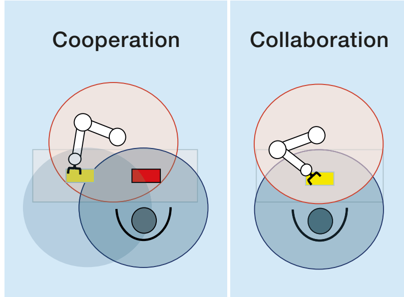


Fig. 1: Comparing types of HRC based on (7)

The added value of human-robot collaboration consists of using the strengths of humans such as hand-eye coordination, force regulation and the ability to solve problems independently alongside the strengths of a robot such as precision, tracking accuracy and no risk of fatigue, in one single process. The aim is to harness both resources in line with their actual abilities and to thereby achieve a more efficient overall process.

The combined use of humans and flexible robots also provides the option of cost-efficient automation for the operator; this is even the case for small to medium batch sizes and quantities in which a fixed fully automated system is not usually viable (2). Even companies who were previously unable to harness the potential for automation for financial reasons due to the higher level of individualisation or the wider variety of their products, can now benefit from this by means of HRC (see Figure 2)

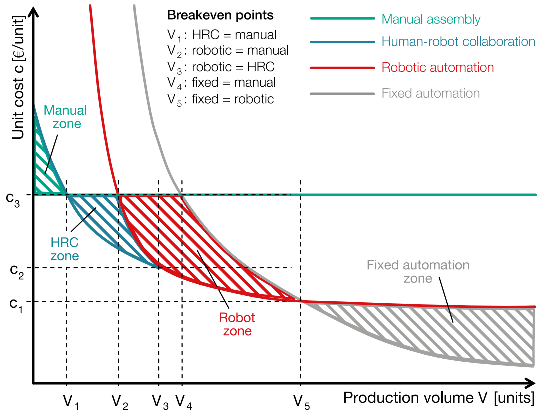


Fig. 2: Economical applicability of various production paradigms

Due to the dangers generally posed by machines and robots in particular, their working spaces were previously physically separated from those used by humans. This is the reason why still today, you will find either fully automated or, on the contrary, purely manual work systems in industry. Robots working in collaboration must therefore have safety devices which are capable of recognising that they are near humans even before actual contact is made and to react accordingly or to work with such little force that there is no unacceptable risk of injury for humans even in the event of a collision.

Specifically for collaborative operations, pioneering manufacturers are providing so-called *force and power-reducing* **lightweight robots**, often also referred to as *collaborative robots (see Table 1)*. They are designed for direct collaboration with humans within defined interactive spaces be means of inherent safety functions such as tactile or capacitive sensor technology for collision detection. In principal, conventional industrial robots can also be used for collaborative operations by enhancing the necessary safety equipment. Examples of such safety equipment are padded softcover coatings and sensor skins.

Alongside the functional safety of an HRC application via its safety-orientated monitoring and control, it is also information security, *IT security,* which has recently played a significant role with the increased networking of humans and systems. By incorporating the collaborative robot, for example in an industrial network, this data and these commands can be received, stored and processed from outside the work system. In particular if these commands have a direct impact on the configuration of a collaborative robot, these must be checked before execution with the aim of preventing the functional safety of the application being compromised by corrupt commands.

Statutory framework conditions

Introduction of HRC systems

Such a robot in itself does not provide any tangible benefit from the operator's perspective. It is only by integrating the correct tools and grippers, by appropriately installing the robot in the collaborative working space and finally by embedding the robot in the company's industrial communication network, that the robot can be used as a HRC application which is ready for operation.

As is the case with every machine (in industrial environments), the HRC application with the robot as its central element must also be treated and marketed in line with Machinery Directive 2006/42/EC (3), so that the operator can use it in a way which is not only safe, but also in conformity with the law.

Depending on the scope of the safety equipment, which is either delivered with the robot or which is yet to be implemented by the system integrator or operator as the manufacturer, the collaborative robot is either marketed as an "incomplete machine" or as a "machine" with the associated documents.

Notwithstanding the above, the application often results in the robot being linked with other (partial) machines in the collaborative work system for which, in turn, the safe function must be proven by the operator via the national occupational health and safety provisions (ASchG (law for the protection of health and safety) and AM-VO in Austria (Work Equipment Regulation)).

As a result, the entity that creates the HRC application (i.e. system integrator or the operator himself), must also determine its CE conformity and certify this.

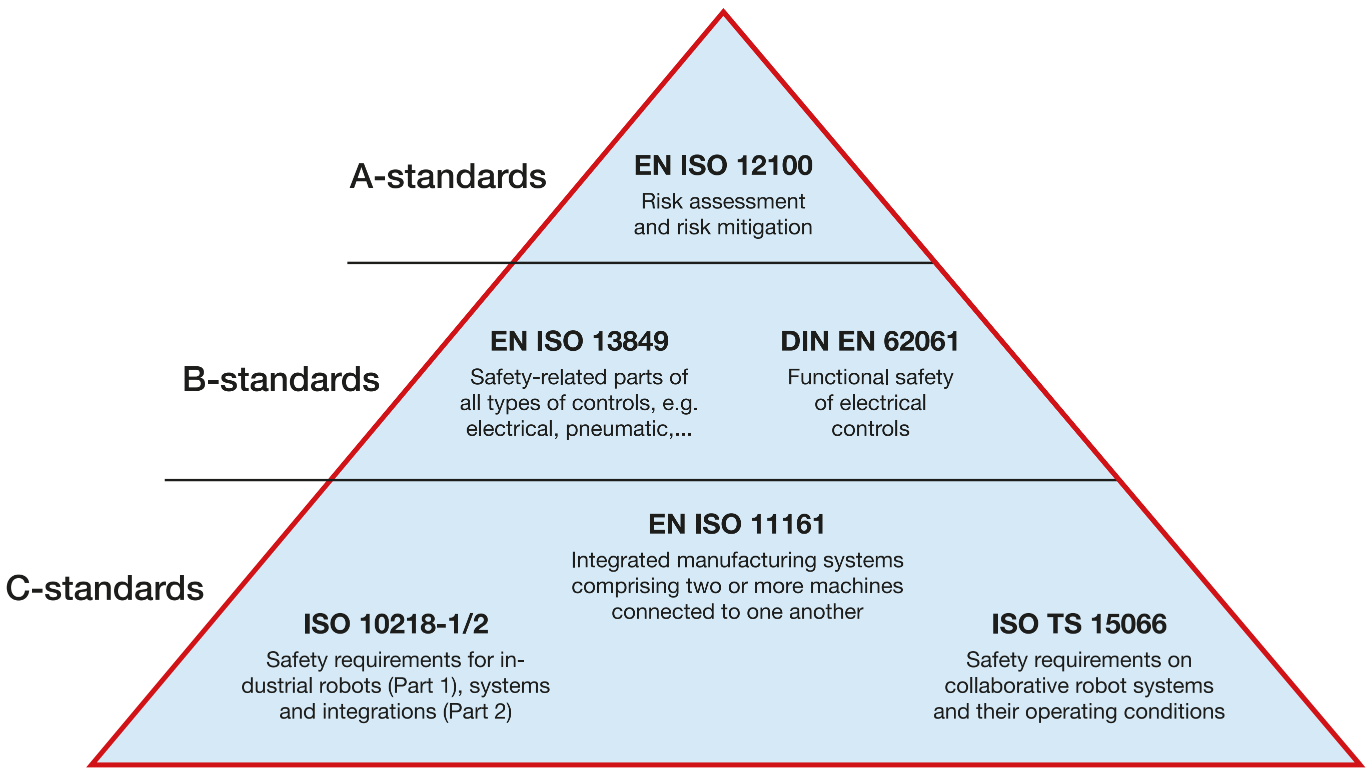


Fig. 3: Relevant standards from the perspective of an HRC application (excerpt)

The core element of a conformity assessment is the **risk assessment**. It depicts a structured procedure that is used to ascertain which safety requirements the HRC application has to fulfil in order to reduce the threat it poses to humans to an acceptable level.

The requirements arise from legally established safety objectives, which are not specific, in the form of EU product directives (i.e. the Machinery Directive). The solution approaches described in correspondingly harmonised standards serve to support compliance with these requirements.

The standards used in Europe are classified into groups. The only existing *A-standard*, ISO 12100, also describes, alongside previously valid design principles on safe construction, the procedure for assessing risks in accordance with the Machinery Directive and is binding for all machines. *B-Standards* describe general design aspects which apply to numerous machines. *C-Standards* are predominantly machine-specific and focus on measures for reducing risks which are associated with these specific machines and systems.

Alongside the robot-specific standards such as ISO 11161 or ISO 10218, the technical specification **ISO/TS 15066** , which first appeared in February 2016, is of great importance for HRC applications and it is the first ever standard specifically for HRC. It initially lists four possible forms of collaboration between human and robot (4):

– *Safety-monitored immediate stop:* The robot comes to a stop before a human enters the same working space and only starts up again when the human has left the working space again.

– *Manual guidance:* The robot only moves with direct manual operation on the part of the operator and it helps the operator in a passive manner. This may be the case as regards manually guided lifting aids or when teaching by directly moving the robotic arm.

– *Speed and distance monitoring:* When the distance between humans and robots is reduced, the speed of the robot is increasingly and gradually decreased, up to a standstill in cases of doubt.

– *Output and force limitation:* The forces exerted by the robot are limited to such an exent that no permanent injuries can occur even in the case of a collision. This is achieved by defining an acceptable level of performance and travelling speeds in advance.

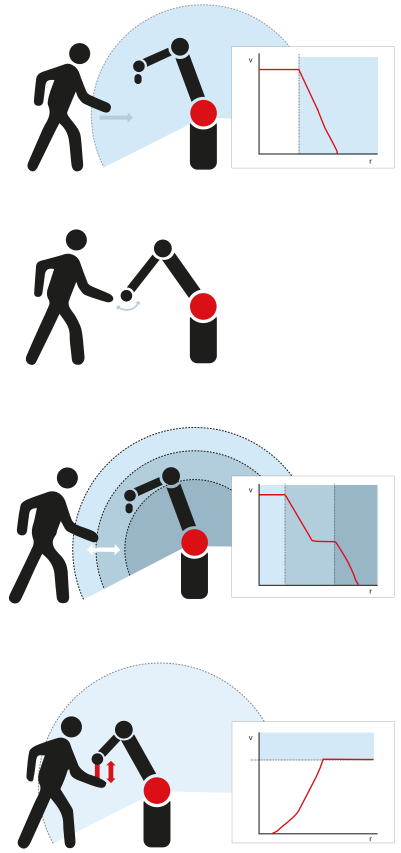


Fig. 4: Protection principles according to TS 15066

It is only in the latter form of collaboration, the **output and force limitation,** that an actual independent movement is possible in the same working space with the risk of unintentional contact between human and robot. This requires the above-mentioned robots with reduced output and force with the corresponding sensor technology for detecting an approaching object, or contact to be more precise, as well as variable safety parameters.

Given that a dynamic collision between human and robot is perfectly realistic in this form of collaboration, ISO/TS 15066 also proposes **force and pressure limit values** for various areas of the body. These can be used in order to derive the required limits for the robot performance and travelling speed, taking into consideration the specific moving masses and geometries and their potential risk to an area of the body in any given application.

Data protection regulations must also be noted as part of the legal framework for introducing HRC systems. This is mainly due to the fact that, inter alia, the biometric features of employees are increasingly being used for authentication and controlling purposes when operating HRC systems. Hence, HRC control systems for data applications are to be operated in line with the currently valid specifications of the GDP 2000 and, as of 28/5/2018, in accordance with the Basic Data Protection Act (DSGVO). This means that the appropriate protective measures are to be taken for the processed data sets.

Integration of IT security

Consistent guarantee of safety

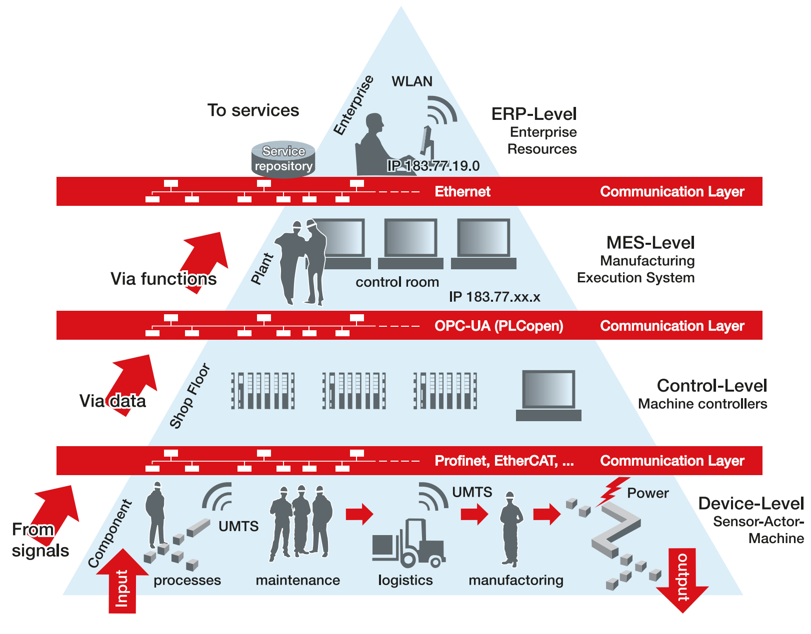


Fig. 5: Typical communication infrastructure. Source: OPC Foundation (9)

The standards listed in Figure 4, as an example, address the requirements for HRC applications with regard to the physical implementation of control and actuation, its programming as well as the working environment in general. The aforementioned integration of the robot or the HRC application into the industrial communication network is completely disregarded.

The HRC application represents a device-level resource within the plant's communication infrastructure (see Figure 5) and can communicate with the surroundings by means of various standards - starting with the digital E/A signal to the Ethernet/IP protocol.

Due to being TCP and IP-based, the latter supports consistent communication between, for instance the internet, company network and the device, e.g. the HRC application. This hereby facilitates remote access for information and evaluation purposes but also the supply of the robot with simple control commands, production orders or entire production programmes. That means that the way in which the robot behaves in the HRC application can be influenced externally. On the one hand, this results in potential threats for human-robot collaboration and, on the other hand, protection targets which, in keeping with classic IT systems or ISO 27001, are also relevant for HRC, such as for example (5):

– *integrity:* data and functions of the systems cannot be manipulated by others without being noticed
– *confidentiality:* unauthorised persons cannot have read access to the system's data and functions
– *availability:* necessary data and functions of the system are available when required

As is also the case for functional safety, numerous standards formulate recommendations for information security, compliance with which increases the safety of the system. **IEC 62443 on IT security in industrial automation systems** is, according to one HRC application operator, definitely of particular importance: it describes an approach to **assess the risk** of an automation plant - similar to ISO 12100, only with focus on information security.

Summary on the integration of legal framework and IT security
The prior observations demonstrate the current practice when dealing with various themes. Companies often process these challenges separately for the most part. By now, is should be clear that functional safety and information security are to be dealt with using an integrative approach, so that compliant, safe and secure operation is possible for both the manufacturer as well as the operator of an HRC application.

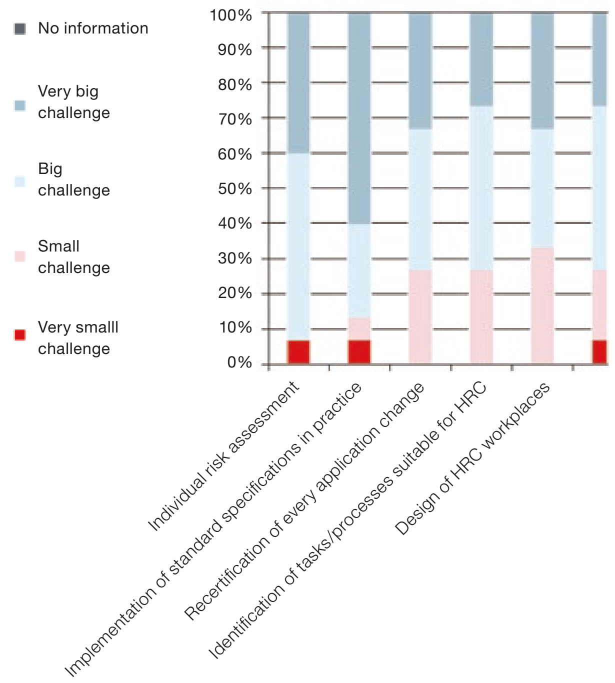
IEC 61508 gets to the heart of it: *"If the hazard analysis demonstrates that a malicious or non-authorised action that represents a threat to IT security is deemed as reasonably foreseeable, a threat analysis regarding IT security should be carried out. For risk analysis instructions within the scope of IT security, see the standards series IEC 62443 and ISO 27005."*

Likewise, both standards refer to the fact that all legal frameworks are complied with and thus the data protection aspects should be taken into account as early as the planning stages of a HRC system.

Many standards, many questions as regards implementation

Even if functional safety and information security have not been considered in an integrated manner until now, the observer gains the subjective impression that specifications on risk assessment as well as numerous standards and guidelines ought to be a useful aid as regards HRC implementation projects. However, a study carried out in 2016 among 15 robot manufacturers, 14 integrators as well as five user companies from Austria and Germany, all of whom already had experience with HRC, proves that the supposedly detailed normative aspect of safety actually represents the greatest obstacle to implementation for human-robot collaboration (6). Thus, 97% of study participants assess the future potential for HRC to be "high" or "very high" and view assembly processes as those with the most opportunities - an area which continues to be heavily characterised by manual work, even in Europe.

Fig. 6: Top 5 adoption barriers for HRC systems (6)



Nevertheless, HRC scenarios for industrial applications are still only identified in rare cases. From the perspective of robot manufacturers, the complexity of the application-specific risk assessment, uncertainties when interpreting and implementing specifications from the relevant standards and the necessity of reassessment and recertification for every change and adaptation to the application, represent the three greatest obstacles from a total of 16 queried obstacles, which hinder the HRC concept being more widely used.

The interviewed user companies confirm this perspective and, on the one hand, trace the difficulties back to a lack of in-house experience with HRC and to the scarce availability of publicly available guidelines and recommendations for standardised application design and risk analysis, on the other. At the same time, they prove the current need for action to support industry with planning and implementing safe HRC applications. An investigation by the Fraunhofer Institute of Labor Economics and Organization (IAO) even assumes that 20% of HRC applications that are used in manufacturing are not at all CE-conform (7).

Statistics and data on accidents at work with respect to robots provide a different perspective; for example from the Austrian AUVA (Austrian Workers' Compensation Board), or the German statutory accident insurance. But here, too, the variety of available protection and safety equipment on the market to operate robots and the standardisation situation, lead to the conclusion that there is a high level of safety in industrial robot operation. However, in reality, more than 500 reportable incidents arose in the period between 2011 and 2014:

	2011	*2012*	*2013*	*2014*	*fatal*
Austria	10	17	12	15	0
Germany	107	72	119	151	2

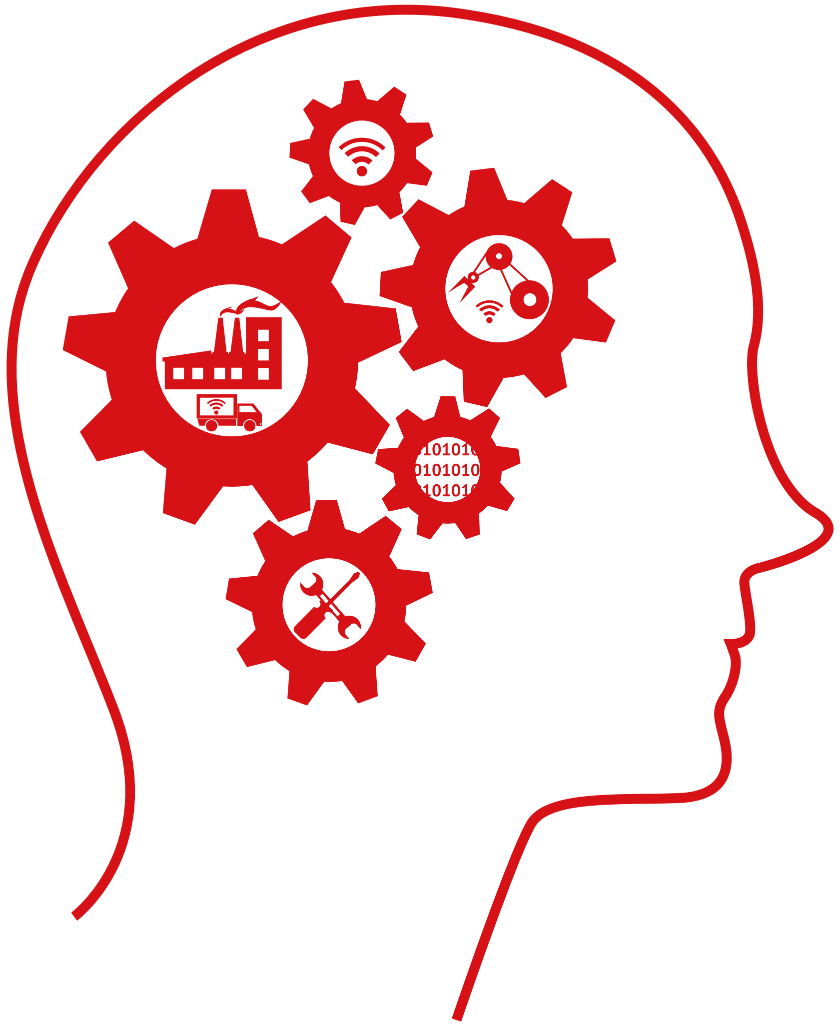
Table 2: Reportable accidents at work involving robots (source: AUVA - Statistics Department / DGUV - Statistics Section)

Many standards, many questions as regards implementation

Overall, the loss of control on the machine including unexpected start-up is the most common cause of accidents with robots, followed by uncoordinated, inappropriate movements of humans when working on and with the robot. Although this data does not reflect any accidents from what is still a relatively new, direct human-robot collboration, but rather those from classical automation scenarios. The data proves that there are still potential dangers involved with industrial robots in general, however.

Hands are the area of the body most often affected by accidents (37%), followed by the head (22%), and the upper extremities such shoulders, arms and wrists (20%). For the most part, superficial wounds and bruises are the most common injuries resulting from accidents. However, around 15% of cases are contusions as well as fractures in at least one out of ten accidents.

Accidents occur between humans and robots in exceptional situations, such as during set-up, maintenance and when remedying situations, more often than is the case during everyday operation. This indicates why it is important to pay special attention to these operational phases as regards protection even during the design stages of a human-robot collaboration.



Safety in Human-Robot Collaboration – General Principles, Challenges, Outlook

More safety during implementation

In view of the novelty surrounding the concept of human-robot collaboration and the prevalent, aforementioned difficulties for companies when implementing HRC systems, *TÜV AUSTRIA* and *Fraunhofer Austria Research* have made it their mission to more accurately identify potential weak points and, in doing so, answer the questions:

- *Which additional requirements that, to date, have not been formulated by standards and guidelines, can be imposed on the application in order to mitigate the risks of human-robot collaboration?*
- *Which requirements that are already formulated by standards and guidelines can be more closely defined in order to serve companies as an aid when planning, implementing and certifying HRC applications? For example: Which technologies and/or methods are available so as to support the fulfilment of a certain requirement?*

The goal of TÜV AUSTRIA and Fraunhofer Austria Research is to confront these questions in one integrated Safety & Security concept, which will be able to support companies in the future when implementing HRC applications.
A two-stage approach was implemented in order to identify the need for action:

1. Identification and formulation of requirements
Analysis, inter alia, of robot manuals and use cases, carrying out expert surveys, analyses of accidents when robots are involved. During this phase, it was possible to identify around 240 individual requirements, the fulfilment of which contributes to safety in human-robot collaboration.

2. Correlation analyses and identification of actual fields of action
Analysis of the coverage and level of detail of the identified requirements by the relevant standards and guidelines. The requirements not covered by standards, or, according to TÜV AUSTRIA and Fraunhofer Austria, the requirements with insufficient specification of the standards, can be divided into 18 fields of action:

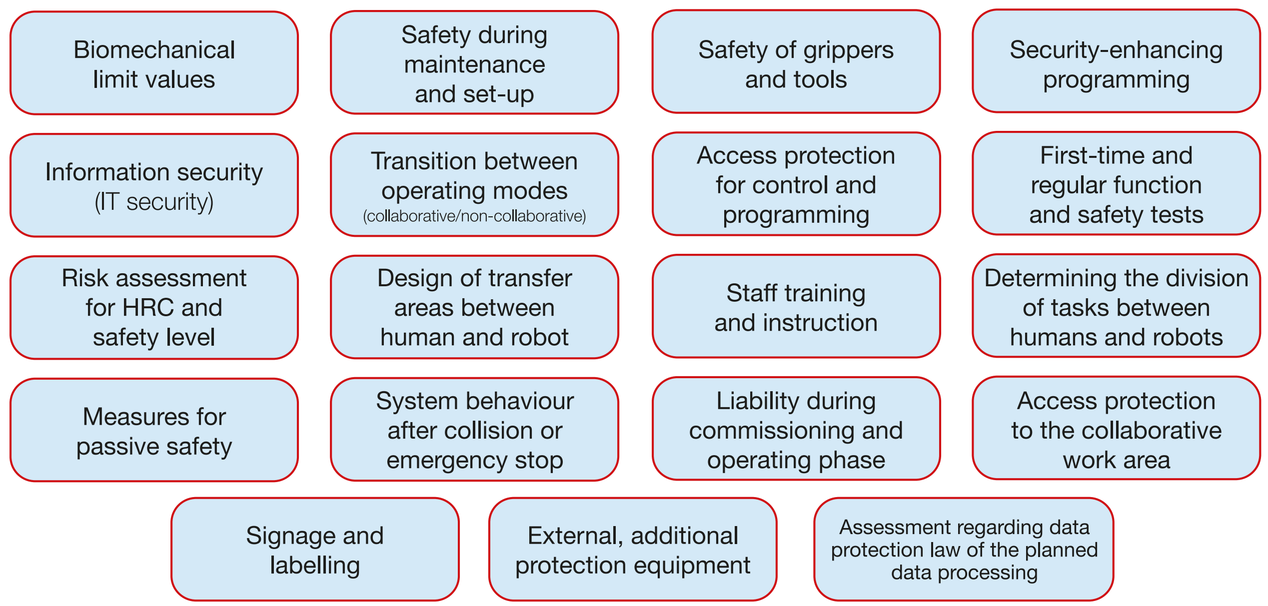


Fig. 7: Identified fields of action for increasing the safety in HRC applications

More safety during implementation

The areas of activity identified as part of the investigation cover a broad range of topics and affect active safety, passive safety, information security as well as organisation-related aspects, e.g. labelling and employee training.

The area of activity of **biomechanical limit values** clearly shows the difficulties that integrators and operators currently face when implementing standard specifications. With the advent of ISO/TS 15066, limit values were published for the first time in March 2016 as regards the stress on the human body within the context of a collision with a robot. These limit values were developed by means of empirical collision experiments in order to determine the pain sensitivity on the human-machine interface (8).

The data includes limits for force and pressure, i.e. force per area for all relevant areas of the body (see Figure 8).

If the mass of a moving load within an HRC application (for example, resulting from the weight of the moving part of the robot arm, of the robot end effector and the manipulated workpiece) and the parameterised robot speed is known, it is possible to calculate the acting forces, and the idea is to compare those with the limit values of ISO/TS 15066.

The pressure limit values are now normalised on a contact area of one square centimetre, however. A "flat" contact with uniform force distribution is also assumed. Of course, in reality, such an idealised example of contact is difficult to find, so that only measurements of the actually existing forces and pressures, by taking account of workpiece geometries and collision scenarios, are indicative of the compliance with biomechanical limit values - and the aid provided by the standard ends there and then.

The identification of such realistic collision scenarios, the selection of appropriate measurement methods and means or even the transmission of biomechanical limit values to geometric complex collision cases as well as the transfer of research results into the robot programme, thus for example the definition of speed and range limits, are not supported by the standard but rather are based on the assessor's experience which is still absent in many cases.

The topic "biomechanical limit values", as one of the identified fields of action, is intensively examined in the project led by TÜV AUSTRIA and Fraunhofer Austria Research in collaboration with other partners, both in theory as well as experimentally. The acquired knowledge will flow directly into developing an integrated safety & security concept.

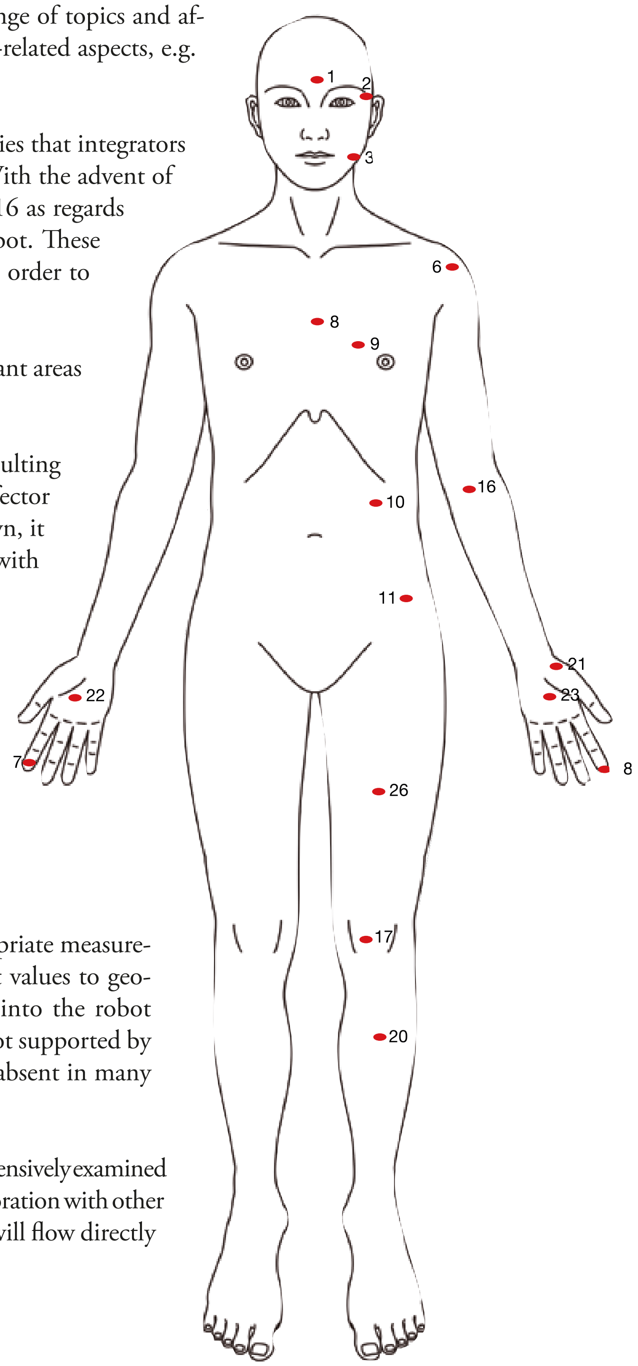


Fig. 8: Body model in accordance with ISO/TS 15066 (front side) (4)

Development of an integrated safety & security concept for human-robot collaboration

In reaction to the identified prevailing uncertainties of the manufacturing companies in Austria as regards designing, assessing and commissioning HRC applications and based on the identified areas of action, TÜV AUSTRIA and Fraunhofer Austria Research GmbH initiated a two-year, strongly application-orientated research project in May 2016.

The goal of the endeavour is to develop an **integrated safety and security concept**, which takes a holistic approach to all aspects related to machine safety of the HRC, i.e. safety, and also takes account of the future relevance of data and information security as well as data protection in a highly interconnected factory environment, i.e. security. It is less a question of developing fundamentally new provisions than it is of transferring the existing spectrum of regulatory guidelines and recommendations from the plant environments and the information security with relation to human-robot collaboration into one integrated safety concept and of specifying on the basis of preliminary examinations.

As a result, the industry is provided with a more transparent design guideline which describes the most important, that is, primarily the safety-relevant design parameters of an HRC application with regard to the layout and networking of the plant which is optimal from the outset, and in which the subsequent and absolutely essential risk assessment serves as a clear road map. This facilitates a speedy and simplified integration for companies.

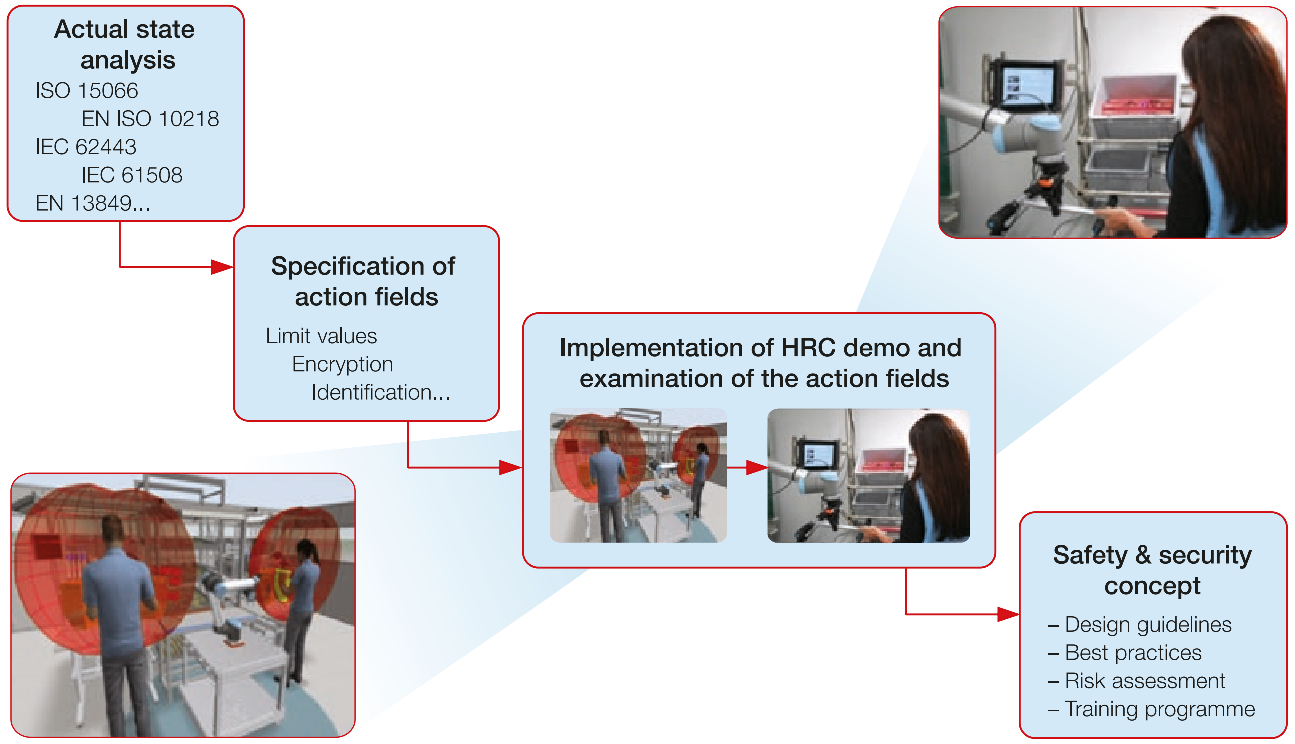


Fig. 9: Rough procedure for developing an integrated safety & security concept

Development of an integrated safety & security concept for human-robot collaboration

As regards content, the *integrated safety & security concept* covers all sections identified as part of the research, studies and accident analyses – from programming taking account of biomechanical collision limit values through to organisational measures such as access control to the collaboration area, and it is already innovative by virtue of its comprehensive nature alone.

Beyond this theoretical preparation, the concept for ensuring its accuracy, completeness and applicability over the entire project duration is tested, validated and adjusted on the basis of knowledge obtained as part of the specifically installed HRC applications in the *Technical University of Vienna Pilot Factory Industry 4.0* in Vienna-Aspern. The Pilot Factory Industry 4.0 provides an exemplary, but yet, integrated production environment of over 600 m² and offers the possibility of integrating the first prototype *Universal Robot UR5* into various departments within manufacturing, assembling and logistics processes both virtually and physically and of linking it to its surroundings via various communication protocols.

In the first scenario from autumn 2016, the assembly of a miniature truck will be implemented at a collaborative workplace where both human and robot work facing each other at the same time in the same work space.

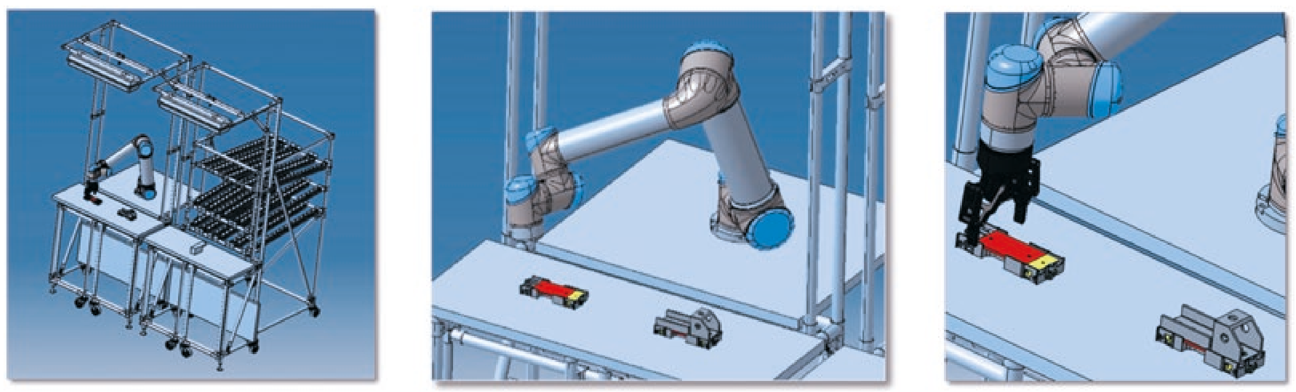
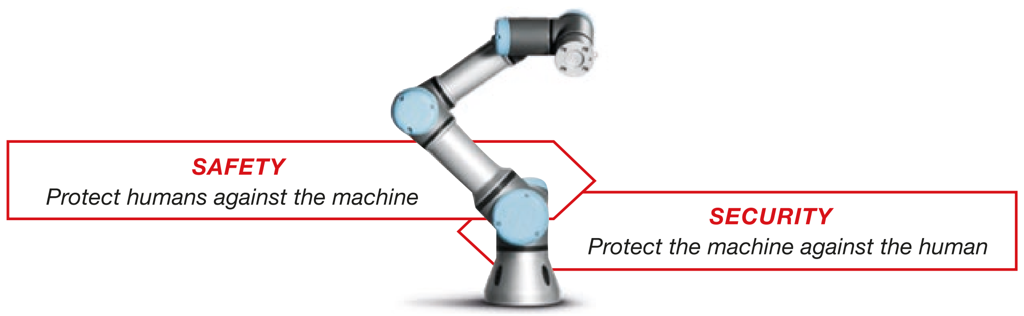


Fig. 10: Collaboration workplace in the Technical University of Vienna Pilot Factory Industry 4.0

The basis of this is a classic assembly system which depicts the frequently prevailing conditions in the manufacturing industry on the one hand, and guarantees the transferability of the project results, on the other.

The interim results from the development of the integrated safety & security concept for the human-robot collaboration are continually published by the project partner, and the final results are expected to be available in Spring 2018. Industrial companies interested in the exchange of know-how and project-based collaboration on the topic of designing, implementing and evaluating HRC applications can contact the project manager at any time.



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Austrian TÜV is a global company with branches in more than 40 countries around the world and with over 1,400 employees. Services range from safety of machinery and IT security to management system certification, the inspection of lifts and pressure equipment, plant safety, education and training, medical devices, electrical engineering, environmental expert reports, noise insulation surveys, carbon footprint evaluations, loss adjustments, app checks, all kinds of certifications and calibrations, product testing, technical due diligence and legal compliance checks through to inspections of stage installations, photovoltaic and wind turbines.

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Fraunhofer is the largest research organisation for application-orientated research in Europe with over 24,000 employees. The research fields are adapted to the needs of humans: health, security, communication, mobility, energy and environment. Therefore, the work of the researchers and developers at Fraunhofer has a major impact on human life in the future. They are creative, shape technology, design products, improve processes and open up new horizons. In Austria, 51 employees work on projects, particularly in the areas of production and logistics management as well as visual computing and specifically in the innovation of value-added processes by means of emerging technologies.

Contact partner for matters related to human-robot collaboration:
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Sources
(1) Acatech – German Academy of Science and Engineering: Implementation recommendations for the future project Industry 4.0, April 2013.
(2) Matthias Björn, Ding Hao: The Future of Human-Robot Collaboration, 2013.
(3) Machinery Directive - Directive 2006/42/EC of the European Parliament and of the Council from 17 May 2006 on machines and amending Directive 95/16/EC (revised version).
(4) ISO/TS 15066:2016(E): Technical Specification: Robots and robotic devices – collaborative robots. First Edition, 15/2/2016
(5) Palmin, A., Kobes, P.: Security Management and Security Transparency in Industrial Automation. IBSN 978-3-981406-2-1.
(6) Gaede, C.; Ranz, F.; Hummel, V.; Echelmeyer, W.: A Study on Challenges in the Implementation of Human-Robot-Collaboration, (being published).
(7) Bauer, W. (publisher): Lightweight Robots in Manual Assesmbly - Start simply. Fraunhofer Institute for Labor and Organization (ILO), 2016.
(8) Scientific Final Report on the Project FP-0317: "Collaborating Robots - Determining the Pain Sensitivity on the Human-Machine Interface." University Medical Center - Institute of Occupational, Social and Environmental Medicine, Mainz.
(9) Sebastian Wallner, Karlheinz Mayer: An Integrated IT Security Concept for Industry 4.0, 2016.

Figures
KUKA AG (cover photo), Fraunhofer Austria Research (Fig. 3, 7, 9, 10), Shutterstock (P. 4, 6, 7, 14, 16), Fotolia (P. 8), "Safe Human-Robot Collaboration Combines Expertise and Precision in Manufacturing" (Fig. 2), ATN Hölzel GmbH (Fig. 4), "An Integrated IT Security Concept for Industry 4.0 Infrastructures" based on OPC Foundation (Fig. 5), ISO/TS 15066 (Fig. 8).

WhitePaper

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