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Variables of application of collaborative robots in ergonomic assembly working stations

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Abstract: Over the years industrial robots had been used for numerous of repeatable tasks in different fields of industry, especially in automotive. Due to the safety reasons, robotized working stations had to be isolated by safety cell. Nowadays we can observe a strong trend of automation and robotization of production processes, which is considered as the fourth industrial revolution. Industry 4.0 has brought new opportunities and challenges. One of the key directions of Industry 4.0 is Human-Robot Collaboration (HRC). According to this concept, collaborative robot, which is equipped with appropriate safety and collision avoidance systems, can assist the human in the most effortable and monotonic tasks in the same workspace without additional safety guard. In this paper the characteristic of Human-Robot Collaboration (HRC), safety regulations, as well as application examples of collaborative robots are presented.

Keywords: collaborative robots, ergonomics

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1. Introduction

During the last few decades a great development of robotics could be observed, especially in relation to automotive industry. Industrial robots have been associated with automotive industry since early 1960s, when the first unit was installed in General Motors factory and it was used to lift the die-cast metal parts from the molds after forming process (Müller, Vette and Scholer, 2014). Since then, industrial robots have been widely used to automate a huge variety of production processes, including assembly operations, welding, painting, part transfer, die casting, etc. Over the years, due to the safety reasons and strict directives all industrial robots had to be separated from employees by protective cell. The most common industrial robots are characterized, among others, by high dynamic, accuracy and repeatability of positioning of large weight and power. As a result of mentioned hazards, humans were not allowed to share the workspace alongside with robots.

Apart from incontestable advantages of industrial robots, there are some limitations in terms of the type of tasks they can perform. Among others, low flexibility, high investment cost and low complexity of allocated task can be considered as the main drawbacks of conventional industrial robots (Kujawińska et al., 2018; Fast-Berglunda et al., 2016). Consequently, until today a significant number of assembly tasks, like for example engine assembly, are characterized by much lower Level of Automation (LoA) and must be supported by human (Schrötera et al., 2016; Patalas-Maliszewska and Kłos, 2018). Also, robots are used as supporting element in visual inspection tasks. Organization of visual inspection may have significant impact on the effectiveness of inspection (Kujawińska et al., 2018; Fast-Berglunda et al., 2016).

For years, the general strategy of the manufacturers has been to automate high volume production with small variety of product variants. Nevertheless, the automation of small and middle volume products is a problem that has been unsolved over the decades. The question, "How to face this challenge?", returns. The answer might be the Human-Robot Collaboration (HRC) as an element of Industry 4.0 intelligent system (Schrötera et al., 2016; Patalas-Maliszewska and Kłos, 2018).

In further parts of this paper characteristic of Human-Robot Collaboration, security systems of collaborative robots, safety regulations, as well as application examples are presented.

2. The fourth industrial revolution—robots come out of the safety cages

Industry 4.0 creates the production environment, which has been called "smart factory". According to this concept, humans and machines create the cyber-physical system, in which they communicate each other in order to organize themselves and cooperate (TUV Austria, 2017). The best example of human-machine interaction in modern production plants is the concept of Human-Robot Collaboration. Human-Robot Collaboration is defined as a direct interaction between human and robot who share the workspace (Ranza, Hummela and Sihnb, 2017; Hull and Minarcin, 2016). Robot can interact with human within workspace in different manners, which are presented in Figure 1.

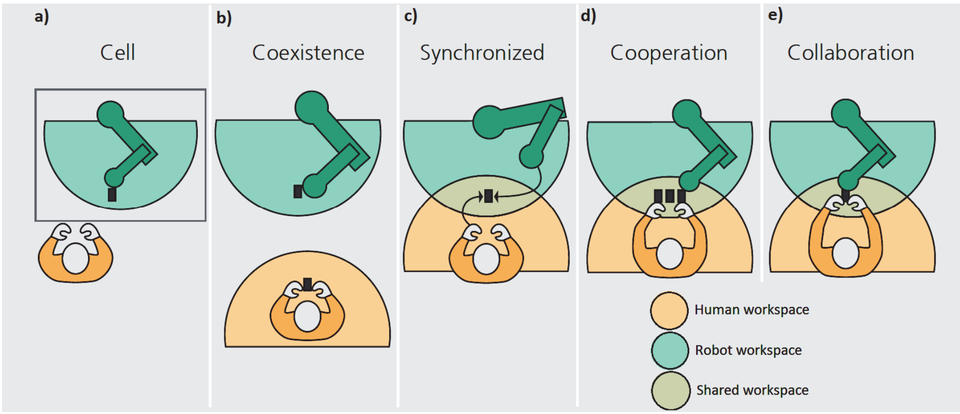

Figure 1. Different levels of interaction between human and robot within assembly station

S o u r c e: Bauer (ed.), Bender et al., 2016.

By coexistence the situation can be considered, where human and robot work alongside without the safety cage, but they do not share the workspace (Figure 1b). In synchronized process robot and human share the workspace, but the workflow of assembly object is organized in the way that only one of the partners is present in the operational area at any one time (Figure 1c). An example of such organization might be the collaborative robot which is applied to transport the assembly components. When object is delivered to the shared workspace, then employee can start the mounting process, while robot can prepare next part parallelly. Cooperation between human and robot takes place when both partners perform the assembly process in shared workspace at the same time, but they don't work simultaneously on the same component (Figure 1d). An example of such operation might be the assembly process of gear box, where human mounts the bearings in the housing and afterwards, robot installs the gear. The most advanced level of human-robot interaction is their collaboration, when both partners work simultaneously on the same component (Figure 1e).

The concept of collaborative robots (called also "cobots" or "co-robots"), which was initiated at the end of the last century, has redefined the safeguarding requirements concerning the robotized working station and robot by itself. Recently, the leading robot's manufacturers (Figure 2) have launched to the market collaborative robots equipped with advanced safety systems, which allow them to share the workspace with human without safety barriers (Ranza, Hummela and Sihnb, 2017).

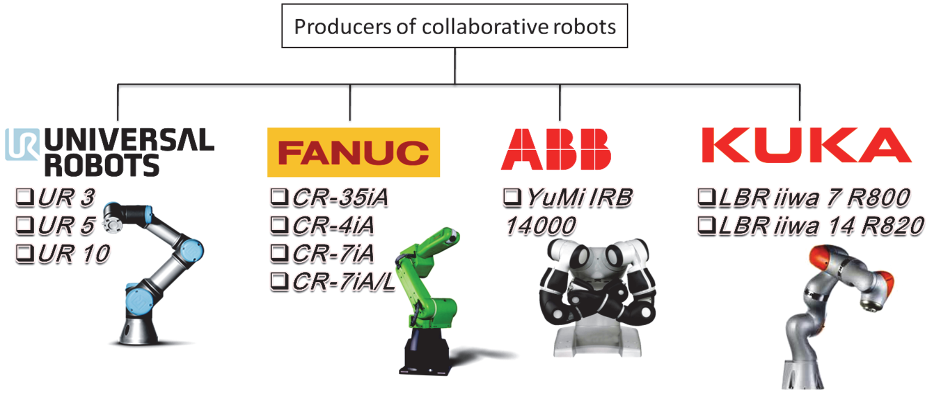

Figure 2. Main modern collaborative robots

S o u r c e: Authors' own elaboration based on: UR, 2009–2015; UR, 2018; FANUC, 2018; ABB, 2018; KUKA, 2018b.

High flexibility, adaptability and simplicity of use, that characterize modern collaborative robots, bring new opportunities to create effective and ergonomic assembly stations based on Human-Robot Collaboration. The added value of HRC is the synergy effect by combining the strengths of robot such as precision, repeatability of positioning and reliability alongside the human's strengths like fluent force regulation, cognitive skills, hand-eye coordination, ability to solve the problems and supervise the production process (TUV Austria, 2017; Ranza, Hummela and Sihnb, 2017). Therefore, HRC seems to be perfect solution for all fields of applications, where small and medium batches of products are manufactured (Figure 3). The marked intervals (V1–V5) on the ordinate indicate the production volume, ranging from unit to mass.

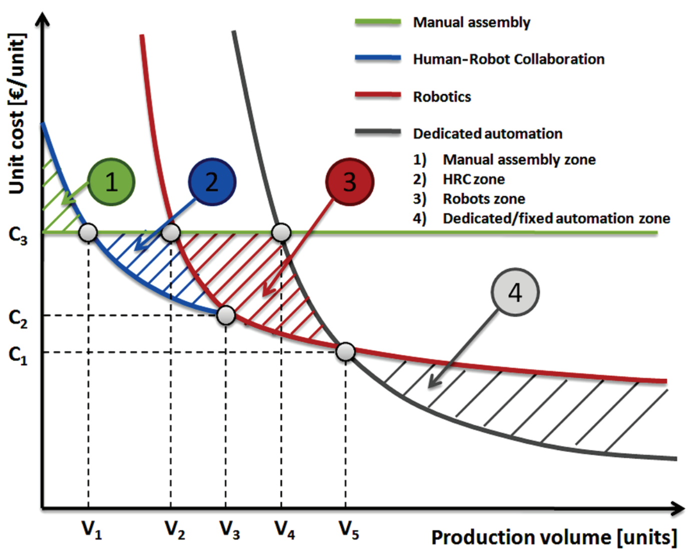

Figure 3. Profitability of automation solution depends on production volume

S o u r c e: TUV Austria, 2017.

In the face of decreasing birth rate and unemployment rate, even small and middle enterprises are looking for appropriate automation solutions for flexible production to keep them competitive on the market. Due to the high investment cost, low flexibility and long time of investment return, those companies couldn't afford the robotics or customized automation system, which were not profitable. Nowadays, more and more of them can take advantage from implementation of HRC on their production plants. Present trend in industry proves that companies prefer to implement flexible and fully adaptive automation solution, like collaborative robots, rather than fixed and highly specialized robotic cells.

3. Safety systems of collaborative robots

As long as human is involved in production process, the main point of automation system that has to be achieved is safe and reliable operation, while keeping possibly highest productivity. Consequently, all industrial robots that are dedicated to collaboration with human within shared workspace have to meet strict safety requirements. The main features of contemporary collaborative robots are presented in Figure 4.

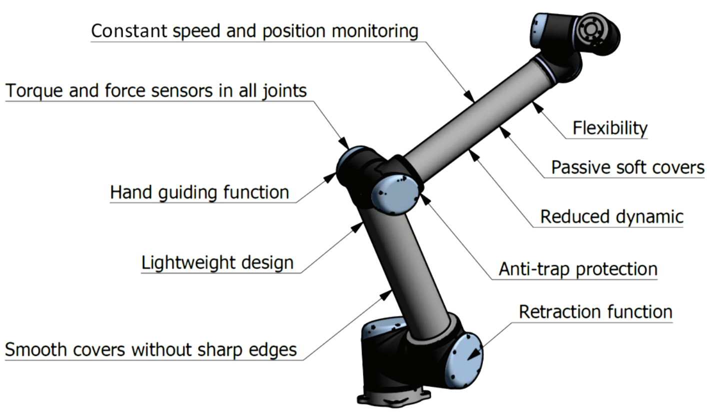

Figure 4. Main features of present-day collaborative robots

Source: Authors' own elaboration based on: UR, 2009–2015; UR, 2018; FANUC, 2018; ABB, 2018; KUKA, 2018b.

Most of the collaborative robots are characterized by lightweight design which reduces the energy accumulated during the operation. Lower kinetic energy decreases the risk of injury in case of unexpected collision with human. As a consequence, these robots are suitable mainly for small components, which weight does not exceed 10 kg. Fanuc CR-35iA might be considered as an exception, since it can handle with load up to 35 kg (FANUC, 2018). However, it is worth to mention that its mass is nearly 1000 kg, which is typical for traditional industrial robots (FANUC, 2018). Therefore, the operating speed is reduced comparing to other types of collaborative robots.

The primary protection system used in collaborative robots is constant monitoring of torque in all joints. In case of collision with unknown object or human, when the force threshold is exceeded, the robot stops immediately. The force limit can be adjusted depending on user needs and application.

To provide safe interaction with human all industrial robots have covers free of sharp edges. Body is usually made of soft materials to reduce the risk of injury in case of collision. The biggest robot from FANUC CR-series has additionally passive covers which reduce the contact pressure and ensure the energy absorption in the event of collision with human co-worker (FANUC, 2018).

Comparing to conventional industrial robots, cobots have significantly reduced dynamic and operating speed (which is monitored in real time), to reduce the kinetic energy accumulated during work. Despite the fact that linear speed of traditional robots can be even a few times higher than collaborative robots, Human-Robot Collaboration seems to be a good compromise between the productivity and safety.

4. Safety regulations

Both traditional industrial robot and collaborative robot are considered incomplete machines. The risk analysis and risk assessment refer to the entire workstation, including associated sensors, end effectors, co-workers, etc., which create complex and consistent system designed for particular application. The most important standards which refer to Human-Robot Collaboration are presented briefly in this paragraph.

European standards are classified into groups (Figure 5). ISO 12100 describes the basic guidelines for machinery designers to achieve safe construction. It also specifies the procedure of risk assessment in accordance with the Machinery Directive 2006/42/EC (TUV Austria, 2017). Standards from *B-group* refer to general aspects of machinery design. *C-standards* are associated with specific group of machines. Concerning the aspect of robotics and Human-Robot Collaboration, ISO 10218-1/2, ISO TS 15066 and EN ISO 11161 can be classified to *C-standards* group.

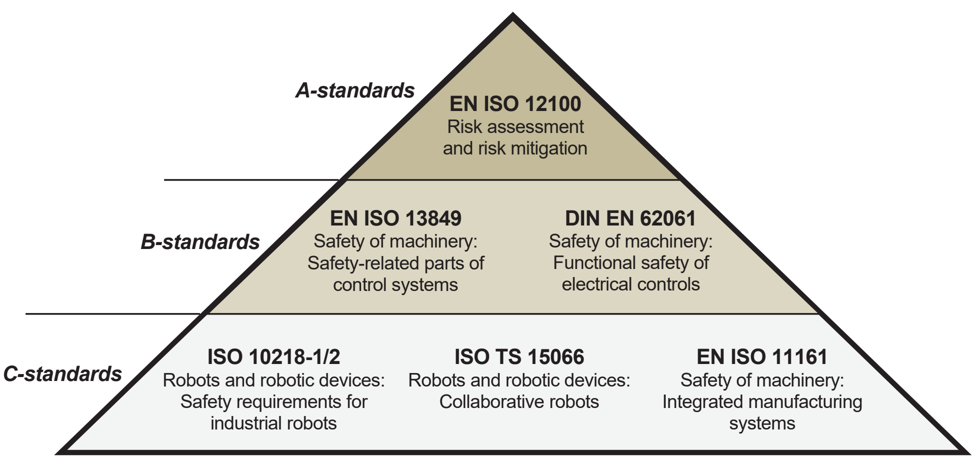

Figure 5. Pyramid of the relevant standards referring to Human-Robot Collaboration

Source: TUV Austria, 2017.

The first part of ISO 10218 describes the guidelines and requirements which have to be fulfilled in order to achieve safe design of industrial robots. ISO 10218-2 refers to the entire production environment, robotic system and robotic cells. Special attention should be paid on standard ISO TS 15066:2016, which specifies safety requirements for collaborative robots and workspace. According to ISO TS 15066, four possible forms of interaction between the human and collaborative robots can be distinguished (TUV Austria, 2017; ISO, 2016):

Safety-monitored immediate stop: the robot has safety zone which cannot be shared with human; when human enters the robot's workspace, it stops immediately; operation is continued when human leaves the workspace (Figure 6a).

Speed and distance monitoring: with decreasing distance between human and robot, the operational speed of robot is being gradually reduced; the robot can be stopped in case of unsafe distance from human (Figure 6b).

Output and force limitation: the dynamic of robot is limited to a value which provides safe operation alongside with human, even in case of collision; pain threshold for different parts of human body are defined in standard ISO TS 15066 and should be applied to the collaborative robots; when the limit is exceeded due to the collision, the robot should stop immediately (Figure 6c).

Manual guidance: the collaborative robot interacts with human in the passive manner, the robot arm is manually guided by human; an example might be the lifting of heavy components in order to reduce the physical load on human who is responsible only for guiding the robot's arm.

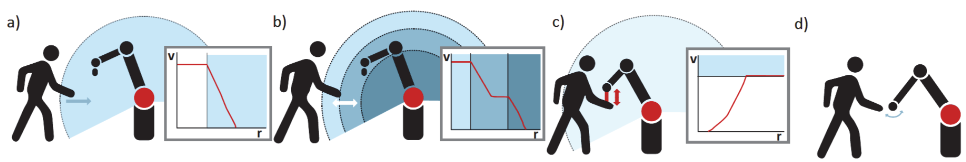

Figure 6. Possible forms of interaction between robot and human

S o u r c e: TUV Austria, 2017.

Despite the fact that collaborative robots have been significantly improved in recent years, in order to achieve strict safety regulations, Human-Robot Collaboration is still not common solution for automation of production processes (Müller, Vette and Mailahn, 2016). Very complicated and complex procedures of certification working station based on Human-Robot Collaboration seem to be the greatest obstacle from spreading collaborative robots in the industry (TUV Austria, 2017; Ranza, Hummela and Sihnb, 2017).

5. Application examples

Notwithstanding the above, a lot of research groups and companies have been focused on the enablement of collaborative work between human and robots. The reason of this effort is contemporary requirements of production to achieve high product customization by implementing flexible and highly reconfigurable production systems, which can be swiftly switched between different products of varying lot sizes. A few application examples of collaborative robots are presented in further part of this paragraph.

In the work by Grahn et al. (2016), the potential advantages of using collaborative robots in assembly process were described. Grahn et al. distinguished specific assembly tasks in car manufacturing in which collaborative robots could be used: placement of aero panels under a vehicle or aid the fitter in assembling the cover on engine block. Each of these operations can be supported by the robot to carry the heavy load and prevent human from non-ergonomic positions. Other examples of similar application, in which the collaborative robot is used to decrease the human physical efforts, were described by Gopinath et al. (Gopinath, Oreb and Johansen, 2017). The authors proposed the use of collaborative robot in assembly process of flywheel housing cover on the engine block. Another application presented by FANUC (2017) might be an assembly process of spare wheel in the car. KUKA introduced a collaborative robot into sensitive assembly line of bevel gears in BMW Group's Dingolfing Plant (KUKA, 2017; 2018a). This application is an example of cooperation between human and robot (according to Figure 1d). Human co-worker mounts the distance plates and bearings, afterwards she gives a confirmation (by pushing green *enable* button visible on Figure 7a) to the robot, that her task has been finished. Then, cobot installs a gear. The robot is equipped with special function for setting the proper mesh of the assembled gears. Collision detection is provided by torque sensors built-in robot joints (ISO TS 15066). When force threshold is exceeded, robot stops immediately (Figure 7b). The main advantages of described solution are better process flow and significantly reduced human workload. Implementation of such solutions often precedes simulations which consider not only safety but also production flow and scheduling (Varela et al., 2018; DPCCars, 2017).

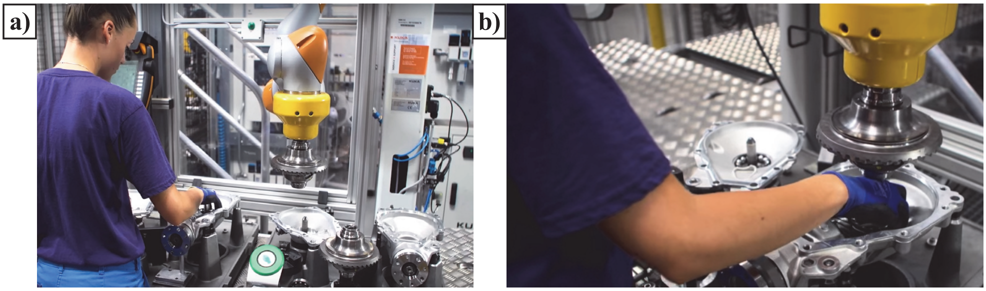

Figure 7. Assembly line of bevel gears based on HRC

Source: KUKA, 2017.

Collaborative robots can also be used in quality control process. For instance, UR units equipped with 3D scanners are used in BMW Dingolfing Plant for inspection of gaps in car bodies (Varela et al., 2018; DPCCars, 2017). Formerly this process was led manually by human equipped with feeler gauge.

6. Conclusion

In this paper the characteristic of Human-Robot Collaboration, safety regulations, as well as application examples of collaborative robots were presented. Human-Robot Collaboration is considered as a one of the key trends of the fourth industrial revolution. In recent years many research efforts have been taken to develop collaborative robots and put them into practice. Nowadays, especially small and middle enterprises are looking for flexible and fully adaptive automation solution, like collaborative robots, rather than highly specialized robotic cells.

Despite the significant development of *cobot's* safety systems, Human-Robot Collaboration is still rare solution on the market. From users and manufacturers perspective, complicated and complex certification procedures are the greatest obstacle to disseminate collaborative robots in the industry. In spite of the flexibility and adaptability of collaborative robots, every single application requires recertification and reassessment.

Notwithstanding the above, HRC brings great potential by combining the strengths of robot such as precision, repeatability of positioning and reliability alongside the human's strengths, among others, ability to solve the problems and supervise the production process. Combination of co-workers strong points leads to synergy effect (Figure 8).

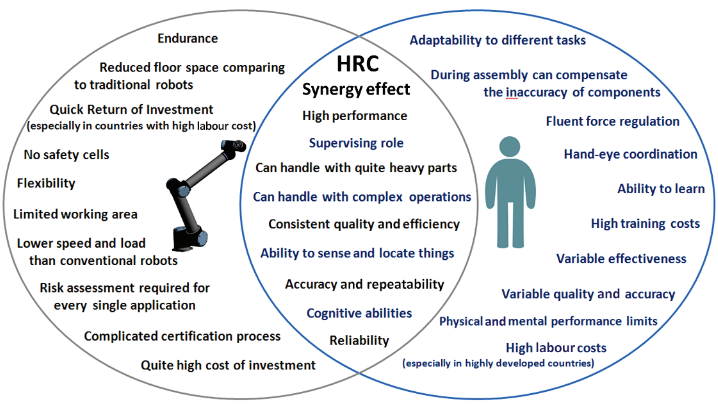

Figure 8. Human and collaborative robot characteristic

S o u r c e: Authors' own elaboration.

Presented examples show that automotive industry is leading field of application for Human-Robot Collaboration. Further research focused on security systems, safety regulations and certification are needed, before collaborative robots will be widely used in the industry.

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Zastosowanie robotów współpracujących w ergonomicznych stanowiskach montażowych

Abstrakt: Od wielu lat roboty przemysłowe były stosowane do wielu powtarzalnych zadań w różnych dziedzinach przemysłu, zwłaszcza w branży motoryzacyjnej. Ze względów bezpieczeństwa zrobotyzowane stanowiska pracy musiały zostać odizolowane w osobnych komórkach. Obecnie możemy zaobserwować silny trend automatyzacji i robotyzacji procesów produkcyjnych, uważany za czwartą rewolucję przemysłową. Przemysł 4.0 przyniósł nowe możliwości i wyzwania. Jednym z kluczowych kierunków przemysłu 4.0 jest „robot współpracujący" (Human-Robot Collaboration – HRC). Jest to robot wyposażony w odpowiednie systemy bezpieczeństwa. Może on pomóc człowiekowi w najbardziej wymagających i monotonnych zadaniach w tej samej przestrzeni roboczej bez dodatkowych zabezpieczeń. W niniejszym artykule przedstawiono charakterystykę Human-Robot Collaboration (HRC), przepisy bezpieczeństwa, a także przykłady zastosowań robotów współpracujących.

Słowa kluczowe: robot współpracujący, ergonomia