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Possibilities of Collaborative Robotics

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Thesis abstract

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The purpose of this thesis was to get acquainted with collaborative robotics, and to recognize the opportunities it provides. This thesis was made for a company BIS Braun, which operates in Stuttgart, Germany, in the field of robotics. The company has a long experience in the field of traditional industrial robots, but now they would like to expand their business into collaborative robots.

This thesis studied collaborative robotics, its history and the opportunities it provides, as well as the related safety standards. There was also a comparison between Yaskawa HC10 and Universal Robots UR10.

Keywords: cobot, collaborative robot, Yaskawa, Universal Robots, BIS Braun, robotics, Stuttgart, Germany

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Tämän opinnäytetyön tarkoituksena oli perehtyä yhteistyörobotiikkaan ja sen tarjoamiin mahdollisuuksiin. Opinnäytetyö tehtiin yritykselle BIS Braun, joka on Saksassa, Stuttgartissa toimiva robotiikka-alan yritys. Yrityksellä on pitkä kokemus perinteisistä teollisuusroboteista, mutta nyt se haluaa laajentaa toimintaansa yhteistyörobotteihin.

Opinnäytetyössä käytiin läpi yhteistyörobotiikkaa, sen tarjoamia hyötyjä, historiaa ja aiheeseen liittyviä turvallisuusstandardeja. Lisäksi vertailtiin Yaskawa HC10:tä ja Universal Robots UR10:tä.

Avainsanat: kobotti, yhteistyörobotti, Yaskawa, Universal Robots, BIS Braun, robotiikka, Stuttgart, Saksa

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Terms and Abbreviations

OSHA	Occupational Safety and Health Administration
GM	General Motors
Cobot	Collaborative robot. A robot that works in collaboration with humans.
Unimation	World’s first robotics company
IAD	Intelligent assist device. Another name for cobots.
ISO	International Organization for Standardization
IoT	Internet of Things. Network for machines and/or vehicles
DLR	German Aerospace Center
ROI	Return on Investment. Ratio between profit and investment
IIoT	Industrial Internet of Things
PPE	Personal protective equipment. Clothing or other equipment designed to protect its wearer.
PL	Performance Level. Hazardous situations can be divided into performance levels.
TÜV	Technischer Überwachungsverein, in English Technical Inspection Association.
PFL	Power and Force Limiting. A standard for collaborative robots.
TCP	Tool Center Point. A center point of the robot’s tool.

1 INTRODUCTION

Collaborative robots, or cobots, are becoming more and more popular in industry and there are good reasons for that. Cobots are rather advantageous in their cost effectiveness, which means that they are cheap, but have good return on investment. In cases which are too dangerous or complicated to be executed with human labor, but demand decision making and human presence, cobots are the solution.

Compared to robots, human workers have better ability to make decisions, they are more flexible and adapt faster to different situations. On the other hand robots do not get tired, they are powerful and they can handle dangerous items, which means, that they can be placed into dangerous places. Human-robot collaboration ensures the best features of both of them, which results in better efficiency, quality, capacity, cost, cycle times and safer working environment.

Small and medium sized enterprises often struggle with a certain matter. They cannot afford to fully automate their production lines, because traditional industrial robots require expensive safety features and need huge quantities to return the investment and make money. Cobots can be programmed fast and are cost effective even with smaller production quantities.

1.1 BIS Braun Industrie Service

BIS Braun is a robotics company that has been founded in 1996, and it aims to make competitive long-term solutions to its customers. BIS Braun is a company that provides their customers a robot with necessary accessories, to ease their production and/or needs. (BIS Braun. 2018)

Figure 1. BIS Braun logo

BIS Braun is located in Stuttgart, Germany. The logo of BIS Braun is shown in Figure 1.

1.1.1 Customers

The CEO of BIS Braun, Alex Braun says, that BIS Braun has won their current customer base through reliability, and by correctly communicating with the client, and that these aspects are also good marketing values. (Braun, A. 2018.)

Braun says that a typical customer of BIS Braun is either a supplier for automotive industry, a company working in construction industry, or in the field of medical technology. (Braun, A. 2018.)

2 HISTORY

“In the ‘90s, the Occupational Safety and Health Administration (OSHA) was concerned of the way GM and the manufacturing industry were handling ergonomic issues in their plants,” said Prasad Akella, who was one of the main characters in the development of cobots and the technologies related to those as he was working as a staff engineer at GM, in the interview of engineering.com. (Pittman, K. 28 October 2016.)

Problems in respect to ergonomics were becoming notable in the automotive industry, since it was affecting the manufacturers in of the United States. For General Motors the problems were most significant in the final assembly areas. (Pittman, K. 28 October 2016.)

“If you tried doing something as simple as picking up and installing a 40-pound car battery, one a minute for eight hours a day, 200 days a year, your back is going to start feeling very sore,” continued Akella in the interview of engineering.com (Pittman, K. 28 October 2016.)

Akella said in the interview of engineering.com: “OSHA said that the automotive industry had to address this important social problem and that GM, as an industry leader, had to lead the way. Steve Holland, who headed the Robotics Department, was tasked with solving the problem together with Jim Rucker, who headed the General Assembly Center.” (Pittman, K. 28 October 2016.)

“Just as GM had pushed the envelope on the design and use of industrial robots in 1961, working with Unimation, now three decades later GM set out to fulfill a need *to make safe robots that would work with people, not be caged*,” said Akella. Experts in the field of robotics from University of California, Berkeley and Northwestern University, as well as some GM employees were brought together by Akella and his team. (Pittman, K. 28 October 2016.)

At Northwestern University, the support of General Motors went to two Mechanical engineering professors Michael Peshkin and J. Edward Colgate, whose research resulted in collaborative robots. At UC Berkeley, the support to work on human power amplifiers went to Homayoon Kazerooni. These efforts resulted in devices which were later collectively called “intelligent assist devices”, like A Z-Lift Assist shown in Figure 2. (IAD). (Pittman, K. 28 October 2016.)

Figure 2. A Z-Lift Assist at GM (Pittman 28 October 2016.)

The goal of Colgate and Peshkin was to obtain better ergonomic working environment for human workers in a way, that would not create new risks as robots as risk factors. They came up with the idea of humans and robots working together both contributing best features of themselves. (Pittman, K. 28 October 2016.)

3 GENERAL INFORMATION ABOUT COLLABORATIVE ROBOTICS

People have an excellent ability to solve inaccurately defined tasks. Robots, on the other hand, have power, endurance and precision. The goal of collaboration is to combine the strengths of robot systems and people. As a result production processes become more and more efficient, the closer a man and a machine can work together. This increases the demands on safety. For example, previous concepts prevent people from getting access to the robot system during production. This often results in tasks that usually would be done with automated robot systems impossible when frequent human intervention is required. (Fuchs, M. 2018a.)

If humans and robots are to share the same workspace, more technical specifications will be required that go far beyond the conventional requirement of the ISO 10218-1 and ISO 10218-2 standards. The standard DIN ISO / TS 15066 serves this purpose and provides information about the requirements of further operating modes. Process parameters, such as power and speed of a robot system, are considered as special aspects of direct and indirect endangerment of a human. (Fuchs, M. 2018a.)

In a risk assessment, not only the robot system is illuminated, but also the environment where the robot is integrated in the workplace of the human being. It may also be an aim of this holistic view of human-robot collaboration that has improved posture results in ergonomic advantages for the employee in the facility. The risk assessment is thus an important aspect for the professional conception of safe robot systems. (Fuchs, M. 2018a.)

3.1 What is a Collaborative Robot?

Most people understand collaborative robotics to mean that a robot can be used without separating or non-separating guards and that it works in the immediate vicinity of humans. But that is a common misconception. (Fuchs, M. 2018a.)

There are four areas of collaborative robot functions according to DIN EN ISO 10218-2 and DIN ISO / TS 15066:

- safety monitored stop
- hand guiding
- speed and separation monitoring
- power and force limiting. (Fuchs, M. 2018a.)

Collaboration expresses the collaborative nature of a production process that humans and robots can work directly with each other. The robot is only one component in a holistic, collaborative plant system and is in itself inadequate for safe, collaborative operation. (Fuchs, M. 2018a.)

3.2 Internet of Things

The internet of things, or IoT, is a system, where a bunch of different computers, devices and digital as well as mechanical machines and even people or animals are connected via the internet. This also means, that data flow is possible without any physical interaction between people and/or machines, as Figure 3 implements. (Rouse, M. June 2018.)

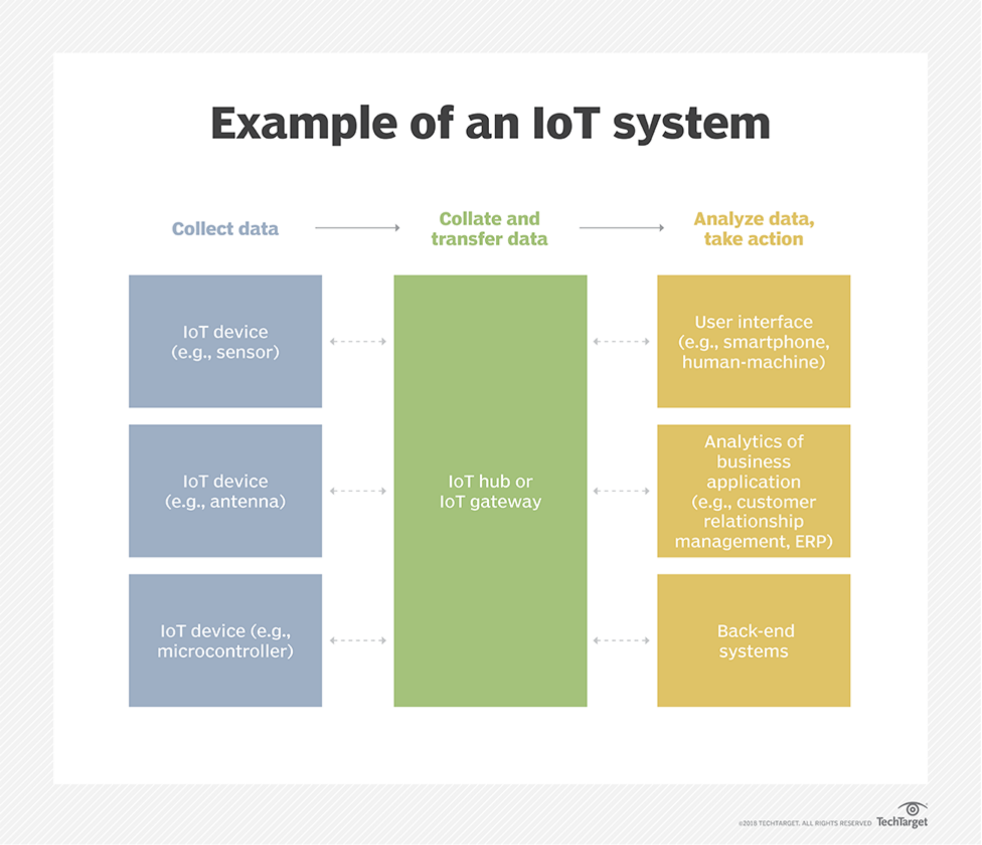

Figure 3. Example of an IoT system (Rouse, M. June 2018.)

An object in the internet of things can be whatever from a person with a hearth monitor implant to some animals with tracking chips. The point is that it has an assigned IP address, and it is able to receive and send data. (Rouse, M. June 2018.)

3.3 Collaborative robot manufacturers

Some of the manufacturers of collaborative robots are introduced. There are more manufacturers to the industry, but most important manufactures are listed.

3.3.1 ABB

ABB (ASEA Brown Boveri) is a Swedish-Swiss corporation, which operates in over 100 different countries and its headquarter is located in Zurich, Switzerland. The main business focus of ABB is in the areas of robotics, automation, power and heavy electrical equipment. (ABB. 2018)

Figure 4. ABB Yumi (ABB. 2018)

ABB’s collaborative robot ABB Yumi is shown in Figure 4. It is special, because it has two arms instead of one.

3.3.2 FANUC

FANUC is one of the most recognizable manufacturers of industrial robots. FANUC was founded as a subsidiary of Fujitsu, but nowadays it is a group of different companies, such as: FANUC Corporation of Japan, Fanuc America Corporation and FANUC Europe Corporation S.A. of Luxembourg. (FANUC. 2018.)

Figure 5. FANUC CR-35iA (International Federation of Robotics. 2019.)

FANUC’s cobot CR-35iA is special, because inside the shell is traditional FANUC robot (FANUC Europe. 2015). CR-35iA is shown in Figure 5.

3.3.3 KUKA

KUKA is an international provider of robots, which has around 14 thousand workers all over the globe. It was founded in 1898 by Johann Joseph Keller and Jakob Knappich in Augsburg, Germany. (KUKA. 2018.)

Figure 6. KUKA LBR iiwa (KUKA AG. 2019.)

When comparing to other cobots, KUKA LBR iiwa has seven axes instead of six, which makes it more flexible (KUKA AG. 2019). KUKA’s cobot KUKA LBR iiwa is shown in Figure 6.

3.3.4 Universal Robots

Universal Robots was founded in 2005 in Denmark by Esben Østergaard, Kasper Støy and Kristian Kassow. They have jumped into business directly with collaborative robots unlike most of the other manufacturers. On the other hand, Universal Robots is a relatively new corporation compared to most of its competitors. (Universal Robots. 2018a.)

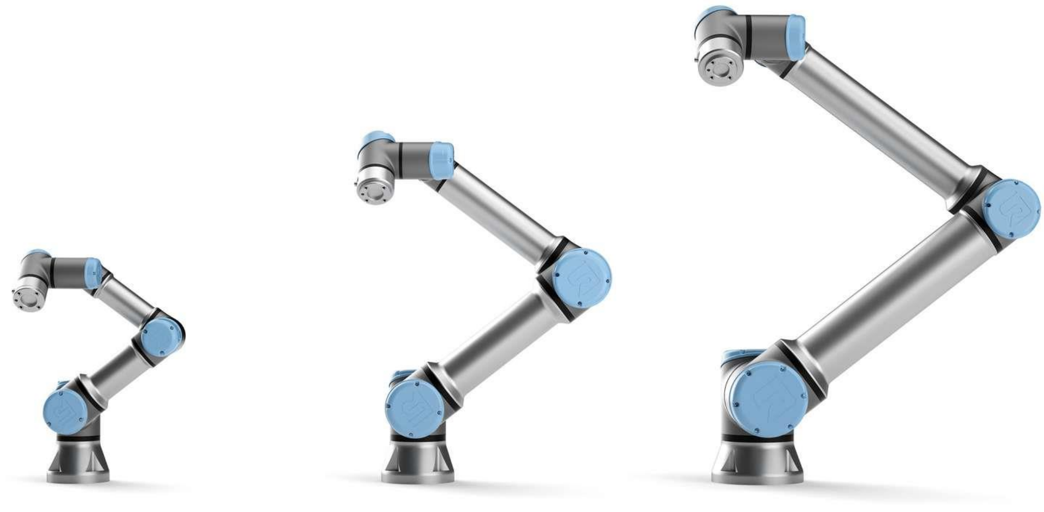

Figure 7. Universal Robots UR-series (Universal Robots. 2019a.)

Universal Robots' UR-series has three different robots: UR3, UR5 and UR10 (Universal Robots. 2019a). Universal Robots' UR-series is shown in Figure 7. UR10 is compared in this thesis to Yaskawa HC10.

3.3.5 Yaskawa Motoman

Yaskawa Motoman is an American subsidiary of the Japanese company Yaskawa Electric Corporation. Yaskawa has subsidiaries all over the world and for example the headquarters of its Europe division is in Munich. (Yaskawa. 2018a.)

Figure 8. Yaskawa HC10 (Yaskawa. 2018b)

Yaskawa’s collaborative robot Yaskawa HC10 is shown in Figure 8. Yaskawa HC10 is compared in this thesis to Universal Robots UR10.

4 COBOTS

Cobots have lots of benefits when compared to traditional industrial robots. The standards of collaborative robotics and some of the benefits and flaws are introduced.

4.1 Collaboration

Collaboration is the main benefit that cobots provide. Traditionally industrial robots work inside of safety fences with an operator placing the required parts into some external axis system. The operator leaves the workspace and robot does the work. With collaborative robots the operator does not need to leave the workspace, but can rather work alongside the cobot. This way time is spent more efficiently, which ensures financial savings. (Kundinger. 2017.)

4.2 Programming

Traditionally industrial robots need to be programmed with complex code, or row by row with a teach pendant, but with collaborative robots programming is made very simple. The user guides the robot by hand from point to point showing it the trajectory and/or points it needs to follow. New programs can be easily created and old programs can be easily modified. (Universal Robots. 2018b.)

4.3 Safety

German Space Agency (DLR) has conducted a study about cobots' ability to penetrate soft tissues. At first they stab a leg of a lamb with a screwdriver, steak knife, scissors and a kitchen knife. The first round goes without a collision detection, which shows the viewer how the robot pierces the tissue, as a traditional industrial robot would do. For the second round collision detection is used and only a kitchen knife penetrates the leg of a lamb in the depth of one millimeter. (Haddadin, S. albu-Schaffer & A. Hirzinger, G. 6 May 2010.)

During the third round they cut the lamb leg with a kitchen knife, which penetrated 101mm, and a scalpel, which penetrated 14mm, at the speed of 0,8m/s without collision detection, to implicate the damages those blades would do if they were used by traditional industrial robots. During the fourth round they did this with the same tools, but with collision detection, and neither of the tools penetrated the tissue. (Haddadin, S. albu-Schaffer & A. Hirzinger, G. 6 May 2010.)

During the fifth and last round, they tried a kitchen knife first at the speed of 0,25m/s, which is safe according to ISO-10218, for a human arm. To be sure the same knife was tried again with a human arm at the speed of 0,75m/s, and there was still no penetration. (Haddadin, S. albu-Schaffer & A. Hirzinger, G. 6 May 2010.)

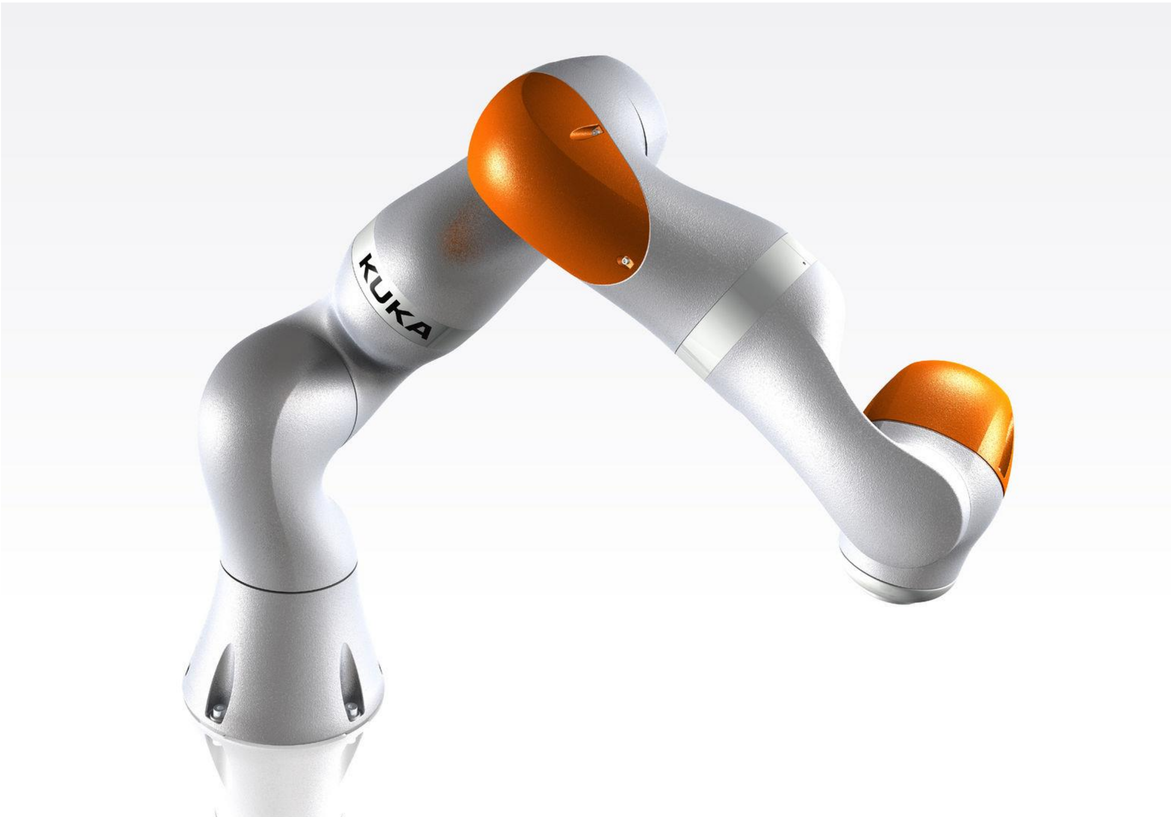

Figure 9. KUKA LBR iiwa (KUKA AG. 2018)

These results do not apply to every circumstance, but it is needless to say, that collaborative robots seem very safe. In the study DLR used KUKA LBR iiwa, which is shown in Figure 9.

4.4 Safely Handle Complex and Dangerous Tasks

When safety and complexity hold the highest importance, a collaborative robot may be the perfect companion. is the cobot is not only safe for the worker to work around with, but it is also able to perform dangerous and demanding tasks, that traditional industrial robots would not be able to do. (Kundinger. 2017.)

> Applications like steadying the motion of surgical tools or lab operations to prevent human error from causing unwanted motion are at the forefront of the collaborative robots industry. This paves the way for humans to rely on the inherent benefits of robots while improving complex and dangerous techniques. (Kundinger. 2017.)

4.5 Flexibility

Not having the need to install the robots inside cages or safety fences opens up many new opportunities. Cobots are able to share intricate working milieus with people without being restricted by cages, fences or external sensors. This makes it possible for different facilities to move the robots around the plant, where their capabilities can be best taken advantage of. Cobots are flexible and usually results in free floor space and lower implementing costs; especially for small and midsized companies. (Kundinger. 2017.)

4.6 Increased ROI

Approaching the issue from a financial aspect, robot industry has started to highlight a fast ROI being a benefit, especially in manufacturing industry. All the time new labor is less accessible, while the ROI cycle of robots decreases. Using Universal Robots as an example, the average ROI is 10.5 months, which is an outstanding number being so low, when compared to conventional robot cells. (Picket, L. 2018)

4.7 User friendliness

User friendliness has been one of the major focus areas in the field of collaborative robotics. What this practically means, is that as many people as possible would get themselves familiar with the robot, its setup and usage. This also allows the end-user the possibilities to redeploy the robot for new applications, and not having the need to get a certified programmer to do it. (Picket, L. 2018)

4.8 Cyber security

As collaborative robots have an ability of connectivity, and Industrial Internet of Things is becoming a greater matter every day in industry, is a critical risk borne, because when collaborative robots are connected to IIoT devices and share a work-space with a human, in a worst case scenario, a hacker would be able to control the cobot, which might lead even into lethal damage. Cyber security must be taken very seriously, when it comes to collaborative robots. Another great threat in collaborative robotics is the possibility to for a hacker to use the data flow through the cobot as a tool for their espionage. (Prosser, M. 21 November 2017.)

4.9 Standards

There are a lot of different kind of collaborative robots, and for each there is a certain standard. Cobots can be divided under the four following standards.

4.9.1 Safety-rated Monitored Stop

According to the standard of Safety-rated Monitored Stop, almost any industrial robot can be used as a collaborative robot. This makes Safety Monitored Stop the loosest standard for collaborative robots. Robot’s stop feature is used to cease the movement of the robot, when a human being enters the collaborative workspace. In other words, the robot works independently, but stops working, when the workspace is shared with a human. It can continue its work where it left it, when the human being has left the space. This has been shown as a truth table in table 1. (ISO-TS 15066. 2016)

Table 1. Truth table for safety-rated monitored stop operations (ISO-TS 15066. 2016)

Robot motion or stop function		Operator's proximity to collaborative workspace	
		Outside	Inside
Robot's proximity to collaborative workspace	Outside	Continue	Continue
	Inside and moving	Continue	Protective stop
	Inside, at Safety - Rated Monitored Stop	Continue	Continue

4.9.2 Hand Guiding

Hand guiding literally means guiding a robot by hand showing it the trajectory it should be following, where it should be picking an item and where it should place it; that is, of course, an example where the robot is used for a pick and place function. Before the hand guiding operation is permitted to be performed, a robot must achieve a safety-rated monitored stop. Usually this kind of cobots use end effector technology to sense their positions and the forces applied to their tooling. (ISO-TS 15066. 2016)

If the requirements of *3.3.4 Power and Force Limiting* are fulfilled in a hand guiding task, then *3.3.2 Hand Guiding* does not apply. Specific requirements can be found in ISO-TS 15066.

4.9.3 Speed and Separation Monitoring

Speed and Separation Monitoring means that the operator has an access to the shared workspace, while the robot is running, but as the operator gets closer to the robot, its speed reduces correspondingly. When the operator gets too close to the robot, the robot stops it movement completely, and when the operator moves further away from the robot, it may continue its movement again correspondingly increasing the speed. The graphical representation in Figure 11 implements how this method works. (ISO-TS 15066. 2016)

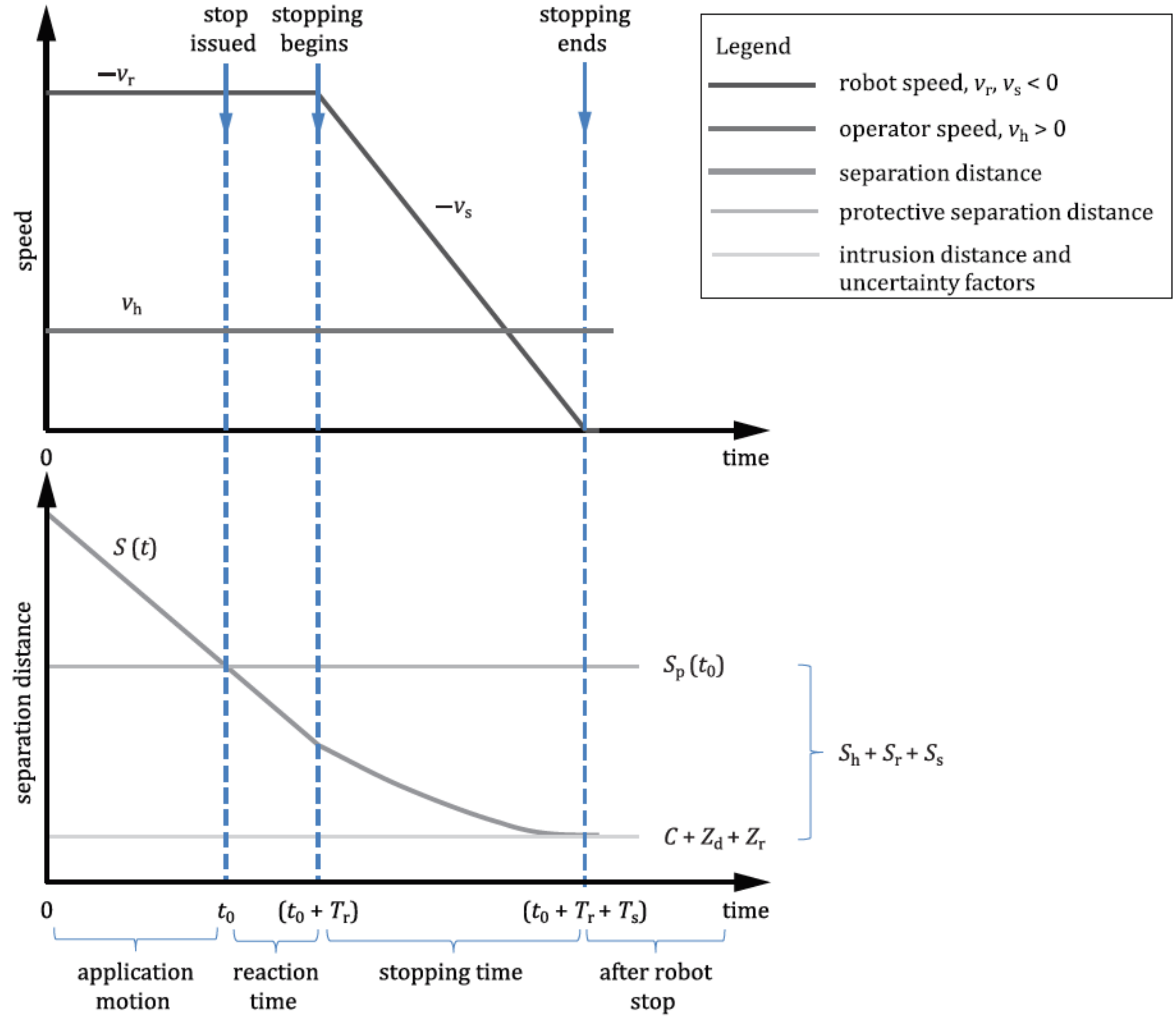

Figure 10. Graphical representation of the contributions to the protective separation distance between an operator and a robot (ISO-TS 15066. 2016)

The distance between a robot and the operator can be monitored, for example with lasers, making it possible for this application to be added to traditional industrial robots, which makes them collaborative robots. (ISO-TS 15066. 2016)

4.9.4 Power and Force Limiting

When compared to the different collaborative methods described above, power and force limiting is the most collaborative one. Actual contact between the robot system/its tooling and a human can take place. Under this method fall, for example, robots like Yaskawa's HC10 and Universal Robots' UR-series. They have built-in embedded sensors, which will detect any applied force in their joints. When a contact has occurred, the robot will either stop, or go back and wait for the obstacle to be gone from its way. (ISO-TS 15066. 2016.)

Usually these robots have internal cables and motors, and they have been designed so, that all the pinch points have been eliminated, which makes it even safer for a human worker to collaborate with the robot. Even though these robots are really safe to work around, they still require a risk assessment. (ISO-TS 15066. 2016.)

5 RISK ASSESSMENT

Procedure of risk assessment is graphically shown in Figure 12.

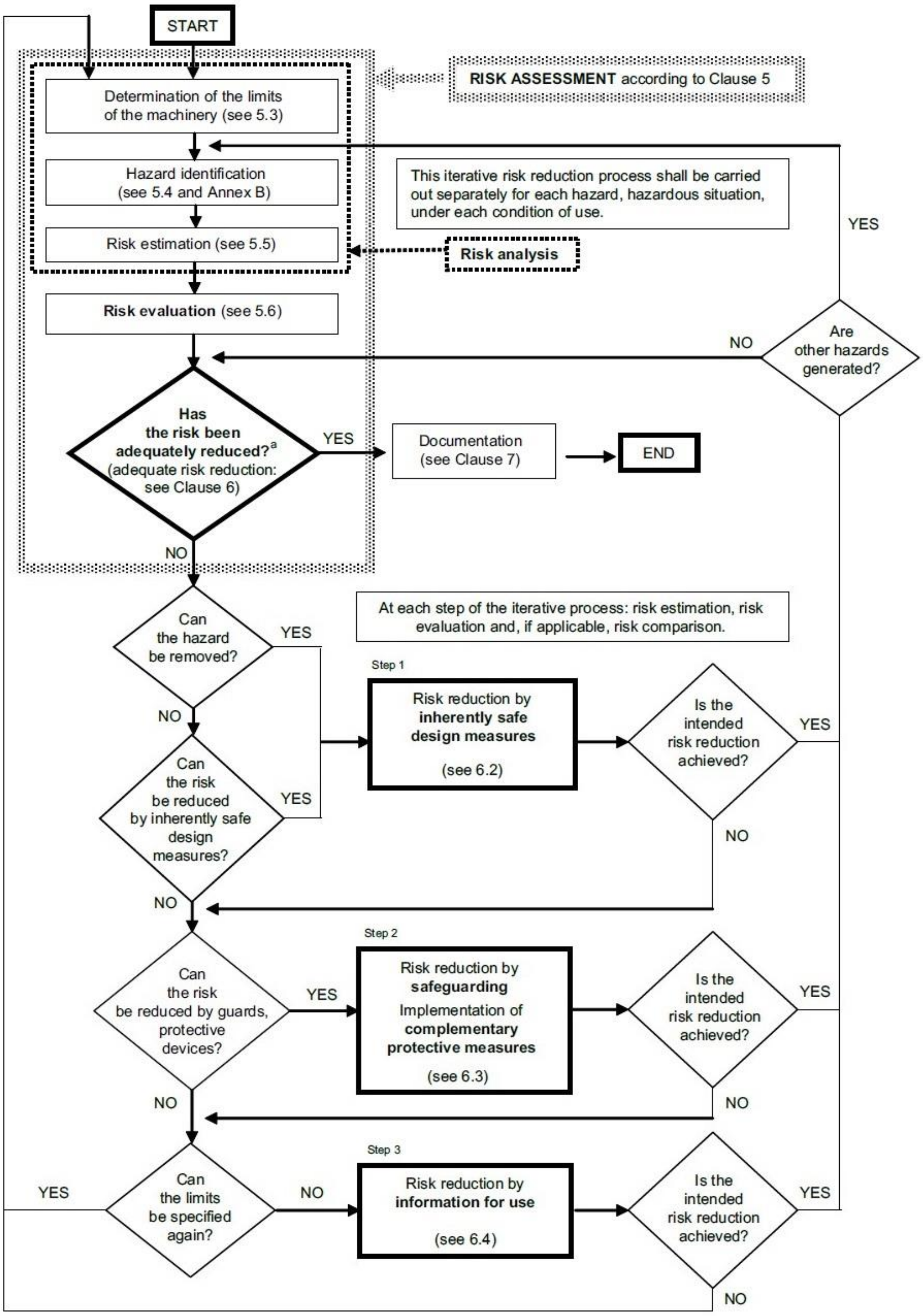

Figure 11. Risk assessment (EN ISO 12100:2010.)

Risk assessment needs to be done to every machinery to be installed.

5.1 General

Risk assessment consists of two parts: risk analysis and risk evaluation. Risk analysis consists of determining the limits of the machinery, identifying the hazards and estimating the risks.

Risk analysis is used to acquire information that is required for risk evaluation. This enables one to decide whether risk reduction is needed or not.

These decisions need to be by a qualitative, such as a scientific study, or when necessary, quantitative estimation regarding the hazards caused by the machinery. (EN ISO 12100:2010.)

> A quantitative approach can be appropriate when useful data is available. However, a quantitative approach is restricted by the useful data that are available and/or the limited resources of those conducting the risk assessment. Therefore, in many applications only qualitative risk estimation will be possible. (EN ISO 12100:2010.)

5.2 Information for risk assessment

Related to machinery description. The information for risk assessment should include at least information related to machinery description, which includes the user specifications, documentation of similar machine’s earlier plans, and when necessary all the information regarding the use of the machine.

Information related to machinery description also includes the anticipated machinery specifications, which include

- description of the whole lifecycle of the machinery,
- design drawings and other means, which explain the nature of the machinery, such as for what it is used etc.,
- the required sources of energy, and how are they provided.

Related to statutes, standards and other applicable documents. Risk assessment also requires applicable statutes, relevant standards, relevant technical specifications such as the range and speed of the machine, and relevant information related to safety.

Information related to user experiences. One should gather information of various accidents, information related to unusual cases or malfunction of the exact or similar machine.

Information if anyone has had any health related problems because of the machine. Problems can be caused for example by some chemical or material used by the machine.

One should also gather experiences by users of similar machines, and by possibilities, exchanging information between different users.

> An incident that has occurred and resulted in harm can be referred to as “an accident”, whereas an incident that has occurred and that did not result in harm can be referred to as a “near miss” or “dangerous occurrence” (EN ISO 12100:2010).

Relevant ergonomic principles. This information needs to be updated as the design moves forward or the machine is modified.

If there is enough information available about hazards and accident circumstances, comparing hazards of different type of machines is usually possible and useful.

> The absence of an accident history, a small number of accidents or low severity of accidents ought not to be taken as a presumption of a low risk (EN ISO 12100:2010).

When doing a quantitative analysis, data from databases, handbooks, laboratories, or manufacturers’ specifications may be used, but the applicability of the data must be reliable. If there is any uncertainty or concerns with these data, it must be informed in the documentation (for specific information clause 7 in EN ISO 12100:2010).

5.3 Determination of limits of machinery

In the beginning of risk assessment machinery limits are determined. All phases of machine's life cycle need to be considered. What this means, is that the qualities of the machine and its possible expansions, as well as people, environment or products need to be identified in terms of the limits of the machinery.

Machinery limits include

- use limits,
- space limits,
- time limits,
- other limits.

Use limits. When considering use limits, in addition to intended use of the machinery, also reasonable foreseeable misuse need to be taken into account. Also some limitations must be taken into account, such as a person not knowing how to use the machinery, or physical limitations, such as age or strength. (EN ISO 12100:2010)

Use limits are about people and what kind of hazards can they create with the machine.

Space limits. Aspects of space limits to consider are

- the range of movement,
- space required by people interacting with the machine; during operation or maintenance,
- human interaction such as the operator-machine interface, and
- the machine-power supply interface.

Time limits. Aspects of time limits to consider are the recommended service intervals, and lifetime of the machinery and/or some of its parts, also taking into consideration the foreseeable misuse of the machinery.

Other limits. Examples of other limits are properties of the materials to be processed, cleanliness limits, and environmental limits.

5.4 Hazard identification

When the limits are determined, it is time to systematically identify any reasonably foreseeable hazard, hazardous situation and/or hazardous event. These aspects need to be considered in every possible phase of a machine's lifetime. Reducing or removing the risks can be done after hazards are identified. (EN ISO 12100:2010)

5.5 Risk estimation

When hazards are identified risk estimation has to be done to all of the possible hazardous situations.

Elements of risk. The risk associated with a particular hazardous situation depends on the severity of harm, and the probability of occurrence of that harm, which is a function of

- the exposure of person(s) to the hazard,
- the occurrence of a hazardous event, and
- the technical and human possibilities to avoid or limit the harm.

The elements of risk are shown in Figure 13.

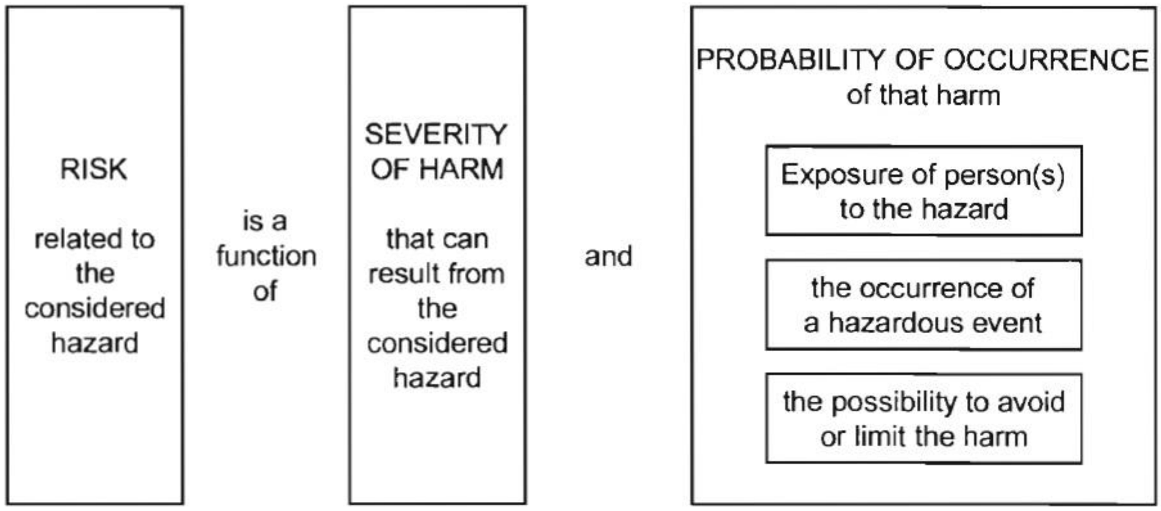

Figure 12. Elements of risk (EN ISO 12100:2010)

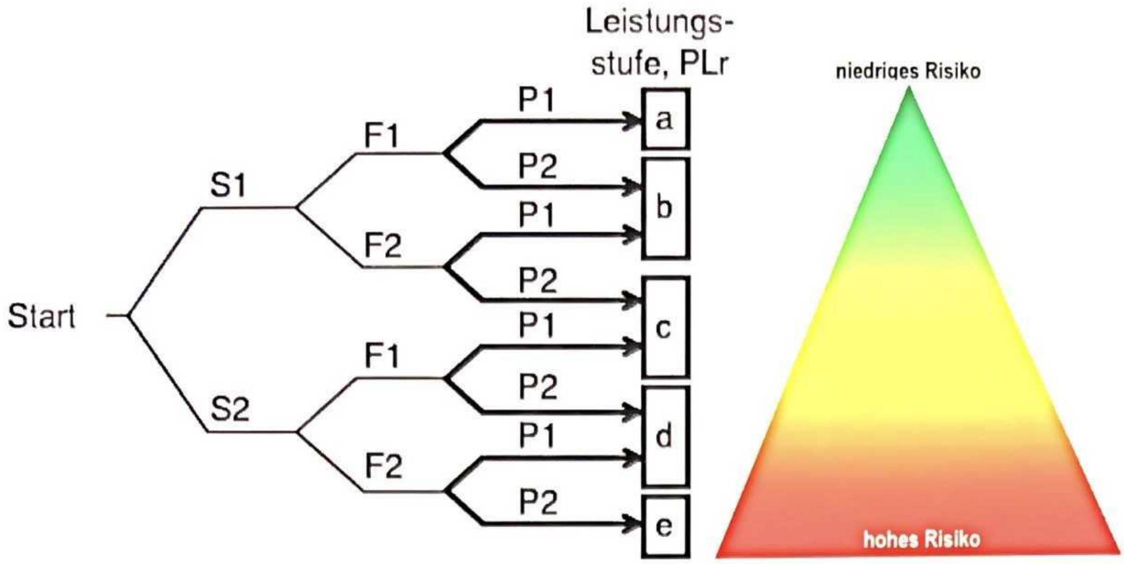

Figure 13. Performance Levels (Fuchs, M. 2018)

Every hazard is divided under the three following divisions: (Fuchs, M. 2018)

- S - severity of harm
  - S1 = slight
  - S2 = serious / death
- F - duration of exposure to hazard
  - F1 = rare / short time
  - F2 = frequent / long duration
- P - possibility to avoid or limit the harm

- P1 = possible under certain conditions
- P2 = hardly possible

By dividing the identified hazard under these divisions, PL (Performance Level) is gotten, as shown in Figure 14.

5.6 Risk evaluation

Risk evaluation is done to help to make the decision, whether or not risk reduction is needed. If risk reduction is needed, instructions of Figure 12 should be followed. It is also important to determine, if new risks are borne. (EN ISO 12100:2010)

6 UNIVERSAL ROBOTS UR10

UR10, which is shown in Figure 15, is the largest collaborative industrial robot arm of Universal Robots. It is designed to execute bigger tasks with precision and reliability. UR10 is a 6-axis robot which can carry through processes such as packaging, palletizing, assembly and pick and place. (Universal Robots. 2019b.)

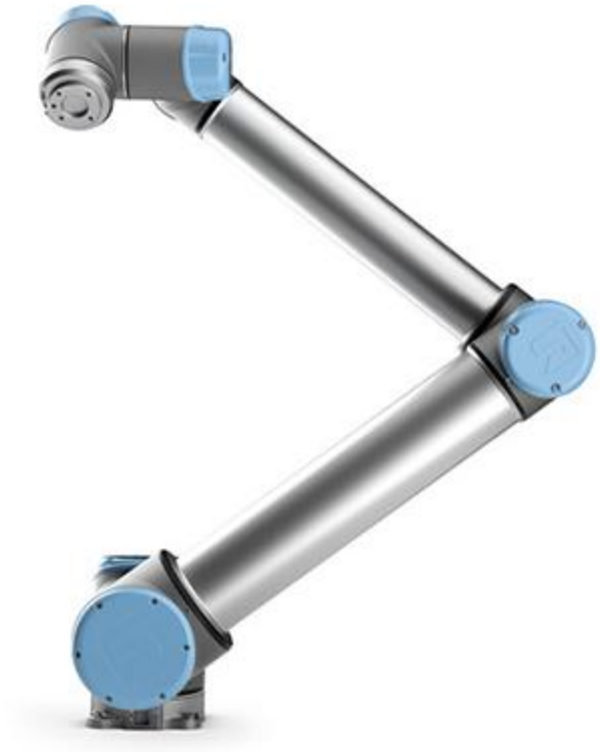

Figure 14. Universal Robots UR10 (Universal Robots. 2019b.)

UR10 uses PFL technology to ensure operator’s safety and it can be set-up fast without extra safety features, but it still needs a risk assessment.

6.1 Specifications

- 10kg payload
- 1300mm maximum reach

- 190mm footprint
- 33,5kg weight

6.2 PFL-Function

The PFL function interrupts the robot operation depending on the external force. When collaborative mode is enabled, the PFL function monitors the robot TCP and the external force of each axis. If the external force exceeds the preset limit value, the robot is stopped.

7 YASKAWA HC10

Yaskawa HC10, which is shown in Figure 16, is a collaborative robot working with six different axes and it is designed for lots of different applications, such as assembly, machine tending, material handling or packaging. It has power and force limiting technology to ensure safe working environment for the operator and it can be operated without any safety fences or other safety functions, but that naturally depends on risk assessment. (Yaskawa. 2018b.)

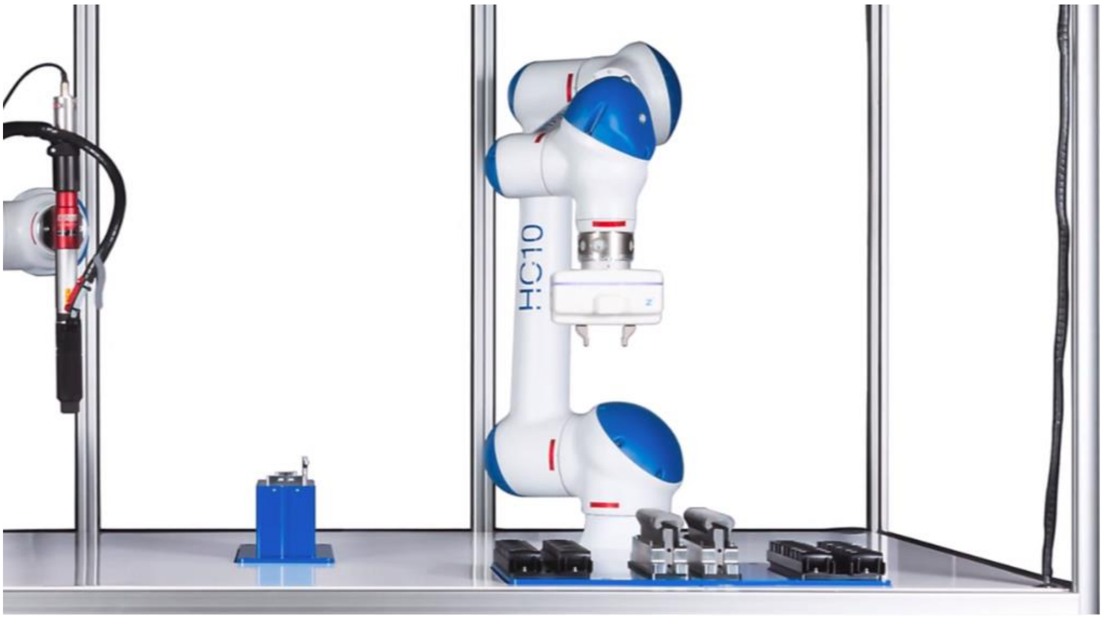

Figure 15. Yaskawa HC10 (Yaskawa. 2019.)

Yaskawa HC10 meets established safety standards including ISO 13849-1: Safety functions industrial robot controller, Category 3 PLd (TÜV-certified). It is controlled by Yaskawa's YRC1000 controller that is built to a global standard and does not require a transformer for input voltages ranging from 380VAC to 480VAC. (Yaskawa. 2018b.)

7.1 Specifications

- 10kg payload
- 1200mm maximum reach
- ±0,1mm repeatability

SPECIFICATIONS				
Axes	Maximum motion range [°]	Maximum speed [°/sec.]	Allowable moment [N•m]	Allowable moment of inertia [kg•m²]
S	±180	130	-	-
L	±180	130	-	-
U	+355/-5	180	-	-
R	±180	180	27.4	0.78
B	±180	250	27.4	0.78
T	±180	250	9.8	0.1

Figure 16. HC10 Specification table (Yaskawa. 2018b.)

7.2 Password Protection

The password protection function helps assure system safety by requiring each user to have a personal authorization registered to access the controller so as to control what operations may be performed by the users. The system administrator authorizes each user by assigning a login name and password, a security level and a timeout setting, thereby allowing a specific level of controller access. (Yaskawa. 2017.)

The administrator can register up to 100 user accounts. The user account information can be stored in a file (USRINFO.DAT). Only the system administrator can change registered user account information. (Yaskawa. 2017.)

The password protection function also enables to find out, by tracing the alarm history, which user has been logged in at the time of a particular alarm. (Yaskawa. 2017.)

7.3 PFL-Function

The PFL function interrupts the robot operation depending on the external force. When collaborative mode is enabled, the PFL function monitors the robot TCP and the external force of each axis. If the external force exceeds the preset limit value, the robot is stopped. The system is then set to the "Stop monitoring" status of the functional safety function.

7.4 Avoidance

The avoidance function pauses or moves the robot to protect it from the external force before the protection is interrupted by the PFL function. This feature allows the use of the robot with increased safety.

JOINT-Mode. Perform the avoidance operation based on the torque of the external force of each axis.

TRANSLATION-Mode. Perform the avoidance operation depending on the external force of the base coordinate of TCP.

The avoidance function is executed when the torque calculation value of the external force of each axis exceeds the startup threshold of the avoidance function and the interrupt JOB is executed for each mode.

The avoidance operation (torque calculation value of the external force of each axis > start threshold) is completed when the torque calculation value of the external force of each axis has fallen below the end threshold of the bypass function (joint). The process is also complete (calculation value of the external force of the TCP >

Start Threshold) when the external force calculation value of the TCP has fallen below the end threshold of the avoidance function (translation).

When the process is completed, the interrupt JOB is terminated and robot can continue with the previous JOB.

7.5 Direct Teach-Function

With the aid of the direct teach function, the robot can be moved manually directly when creating the JOB (teach-in). Apply the settings on the corresponding screen of the programming pendant. Operation is the same as for normal teach-in on the usual editing screen. Moving the robot to the teach-in position allows the robot to be moved by adding force to its joints by the programmer.

7.6 What is old

If user has knowledge of how to use the previous MOTOMAN –robots, then most likely they have no problem of using this cobot. The interface of the teach pendant is the same, as in the previous model, and it can be jogged and programmed in exactly the same way.

8 SUMMARY AND CONCLUSIONS

Future of collaborative robotics as well as future of BIS Braun are cogitated. Yaskawa HC10 and Universal Robots UR10 are compared.

8.1 Collaborative robotics in the future

At the moment collaborative robots are still in the very beginning of their popularity, but it has already grown a lot in the past years and it will continue to do so in the future. Production needs are developing to be more flexible and customizable in order for the companies to stay ahead of the competitors.

As mentioned before, this really interests small and medium enterprises, because development of cobots proceeds all the time – they become cheaper, more flexible and less dependent on the manufacturing quantities due to fast programmability and not having the need for expensive safety features.

8.2 BIS Braun location

The location of the company in respect to business is really good, because Stuttgart has a lot of industry. Potential to expand the business in a geographically small scale is outstanding. For example, Porsche and Mercedes-Benz hold their headquarters in Stuttgart. (Porsche AG. 2019) (Daimler AG. 2019)

8.3 BIS Braun’s potential to cobots

Most of the clients that were visited during this thesis are in the automotive industry, and most of these clients apply robotics into welding. That is a bit tricky, because when it comes to collaborative robots, welding is that kind of work that requires a lot of safety equipment, because there is a danger of getting burned and blind. In most cases the worker would not be able to work in a shared space with a robot, because of these dangers.

Collaborative robots still open up the field for new clients, even if it was for welding, because of their fast programmability. The clients would no longer need to be big manufacturers, but they could also be smaller companies. Cobots do not require large quantities of products to be efficient. (Kundinger. 2017)

But if BIS Braun wanted to start focusing on cobots on a larger scale, maybe even making it their main product, it would in principle be a very good and potential idea, because of the benefits the cobots provide, when they are compared to traditional industrial robots. One could even say they will revolutionize the whole industry of robotics. And besides, the hard part is already over, because BIS Braun already has what it takes to take over the market; credibility, reliability and expertise as a robot supplier.

8.4 Comparison between Yaskawa and Universal Robots

Different aspects of both cobots used are compared. The results are based on the research done during this thesis.

8.4.1 Teach pendant

The best feature in the teach pendant of Yaskawa YRC1000 is no doubt its light weight. Its cable is connected to the bottom left corner, which makes it possible to operate the teach pendant while seated. The teach pendant is very pleasant to use. Its outer look is almost the same as in the older models, and if the operator is familiar with Motoman robots, it is easy to learn to operate YRC1000 very easily.

Universal Robots’ teach pendant is heavy, when compared to Yaskawa’s one. Universal Robots does not have buttons in its teach pendant, so if the user is more comfortable operating a robot with just a touch screen, then Universal robots is a better choice. Yaskawa also has a touch screen in its teach pendant, but it is smaller. The cable solution in Universal Robots is poor, because the user cannot comfortably set the teach pendant onto the lap, when operating seated.

8.4.2 Programming

Code in Yaskawa is the same as it used to be; there are just a few new commands. But Universal Robots does not have a code at all. It has a program tree, which is easy to learn and clear, especially for people, who are new to robots.

Programming in Universal robots is arguably better, because they are fast, clear, simple and pleasant to look at. When comparing for example a program for palletizing, it turns out that Universal robots have templates for that, and for many other standard jobs, that are usually done with robots. This can potentially save hours of programming time.

8.4.3 Hand guiding

Hand guiding in Yaskawa HC10 is heavy and stiff, when compared to Universal robots, but in other aspects Yaskawa is better. When hand guiding the Universal robots, they can only be guided with a joint mode, but when doing hand guiding with Yaskawa, the operator gets to choose whether they would like to move the robot linearly, or by joints. It is also possible to guide only the last three axes for more precise guiding.

With both robots, a switch for releasing the axes needs to be pressed to guide the robot by hand, but with Yaskawa there is available an additional part to the HC10's wrist, that allows the user to press the dead man switch in there, so they can operate the robot with two hands. Even though Yaskawa has better qualities when it comes to hand guiding, Universal robots is still better, because it is so light and comfortable to guide the robot by hand.

8.4.4 Avoidance mode

Avoidance mode is one of the key features of Yaskawa HC10, and Universal robots lack that completely. Avoidance mode is the mode that can be used when operating the robot automatically so that when a human is being in the way of the robot, the robot uses its force sensors to detect it, and waits for the human operator to move away.

With some test runs on this avoidance mode there still were some problems. The robot was programmed to follow a trajectory, which was in the shape of a triangle. The triangle is shown in Figure 14 and it was made for the robot as a demo.

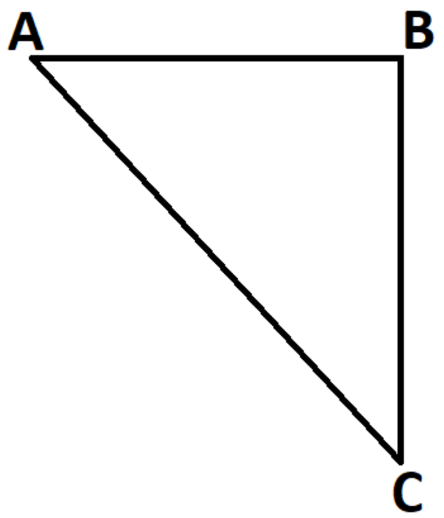

Figure 17. Triangle

When moving from point A to B, the avoidance mode worked perfectly, but basically to any other direction, it required way too much force from the human to move away; the robot was pushing the human, not the other way around – as it should be.

8.5 Summary

When all the aspects and functions are put together, Universal Robots UR10 is a better system. In hand guiding the axes are lighter to move, and overall it is fast compared to HC10, even though HC10 has the possibility to guide the robot by hand with both linear, and joint movement. In the end one of the biggest strengths of collaborative robotics is fast adaptation to different kind of situations, which makes it possible to produce small quantities efficiently.

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