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Robotics – Functionality and Application of Collaborative Robots

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COMMON ABBREVIATION

APAS	Automatic Production Assistance
AQUIAS	Work quality through individually adapted division of labour between service robots and severely/non-disabled production employees (Arbeitsqualität durch individuell angepasste Arbeitsteilung zwischen Servicerobotern und schwer-/nichtbehinderten Produktionsmitarbeitern)
DIN	German Institute of standards (Deutsches Institut für Normung)
EN	European Norm
HRC	Human Robot Collaboration
ID	Intellectual Disability
ISO	International Organization for Standardization
PL	Performance Level
PLC	Programmable Logic Controllers
ROI	Return of Investment
TAM	Technology Acceptance Model
TCP	Tool Center Point
TS	Technical Specification
USUS	Usability, Social Acceptance, User Experience and Social Impact
UTAUT	Unified Theory of Acceptance and Use of Technology
WfbM	Sheltered Workshop (Werkstatt für Behinderte Menschen)

Robotics - Functionality and Application of Collaborative Robots

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Collaborative Robots in Industrial Applications.

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Keywords:
Industrial robots, collaborative robots, cobots, robot applications

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1 INTRODUCTION

„If you always do what you've always done, you'll always get what you've always got. "
- Henry Ford –

… and this is the reason why society has to change continuously due to constantly changing circumstances in professional lives. Missing skilled workers, an aging society and high competitive pressure from Far Eastern countries represent the current challenges for the manufacturing sector in Germany. Therefore, robots have emerged in the industry to actively address these challenges. According to the Return of Investment (ROI) Calculator developed by RobotWorx, a robot system can usually work with 95 percent efficiency. Further, it outperforms normal employees by 20 to 25 percent on a working day. Automated robots ensure shorter cycle times, can take on dangerous and difficult work and ensure consistent quality [1].

According to Statista, there were 338 industrial robots per 10,000 employees in Germany in 2018. RobotWorx calculates the ROI for robot systems, or the break-even intersection, at 18 months, depending on the size of the initial investment, and therefore robot systems are very popular these days [1]. But the usage of robots has not only advantages: the purchase of industrial robots is expensive and involves ongoing costs for service and maintenance. Furthermore, appropriate expertise within a company is also required in order to be able to use conventional industrial robots effectively over a longer period. The adaptation of a production line, which is equipped with robots, requires time, know-how and causes high costs.

In this paper the first part explains what a smart robot is and what it has to do with the Gartner Hype Cycle and Industry 4.0. Then, the standards (or norms) and the different kinds of collaboration are described. Afterwards, the definition of industrial robots is explicated and then the relevant standards for a human robot are listed. Finally, some example applications of collaborative robot usages are explained, followed by a conclusion.

2 SMART ROBOTS

Smart Robots are a part of *Industry 4.0*, as well as a part of the Gartner Hype Cycle 2018 (Figure 1). The Gartner Hype Cycle in general shows modern technologies and their maturity level. Concerning to the hype cycle, every technology starts as an *Innovation Trigger* and reaches the *Peak of Inflated Expectations* after a while. Smart robots are in between those two phases, what can be seen in Figure 1 in the red rectangle. After a technology has reached the peak, it will decrease into the *Trough of Disillusionment*, where for example the technology *Augmented Reality* is at the moment. Then, after passing *Slope of Enlightenment*, the technology finally reaches the *Plateau of Productivity* [2, pp. 50-52].

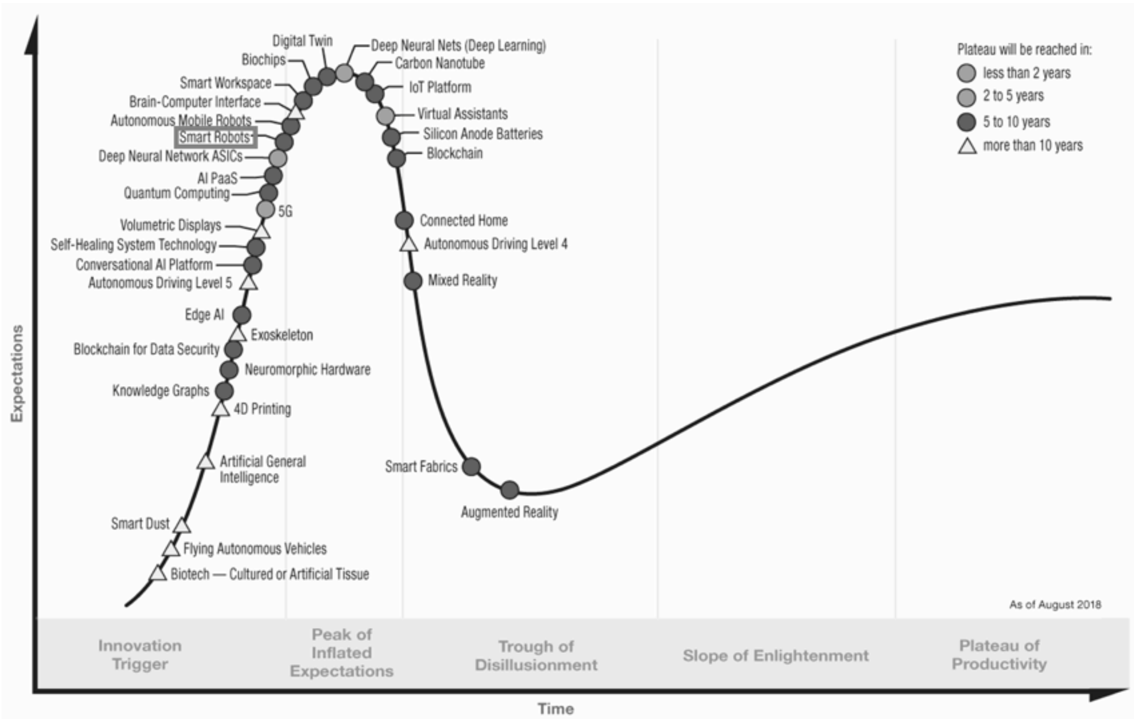

Figure 1: Gartner Hype Cycle 2018 [3]

3 STANDARDS (NORMS)

There are some kinds of standards, or norms, whereas a standard is usually a benchmark that defines products, services or processes. There are many different standards available all over the world and therefore only the most relevant ones are described in this chapter. Related to robotics, the mandatory standards are DIN, ISO and EN as well as combinations of them [4].

DIN

DIN Norms are developed by the German Institute of standardization (Deutsches Institut für Normung) and they contain standards for products and processes like quality, minimum requirements and many more. Moreover, interested and affected users of the standards can be part of the norm development team.

EN

During the last years, the tendency was that standards became more and more international. Therefore, EN stands for *European Norm* and is valid in the entire European Union. Its definition was established by CEN, the *European Committee for Standardization*. A combination of DIN and EN (e.g. DIN EN 1610) is also common. When there is a combination like DIN EN, that means that a German DIN norm was converted into a European norm without any changes in content.

ISO

Besides German and European norms there are also some standards that are valid worldwide. Usually they include ISO in their name that stands for *International Organization for Standardization*. In that organization international norms were developed in all areas, except in the fields of electronics and electrics. Again, in that case there can occur combinations like DIN ISO 2768 or DIN EN ISO 9001. Often the year of publication is written behind the norm, e.g. DIN ISO 9001:2015.

ISO TS

A special form of ISO is the ISO TS. Thereby, TS stands for *Technical Specification*. These norms are used for the definition of all technical requirements for a thing (e.g. material) and are valid international.

As it can be seen there are some standards that have their validity in different levels. Normally, robots have to follow some standards when they are developed and used. For collaborative functions there are additional standards. Which standards are relevant for (collaborative) robots can be seen in chapter 6.

4 KINDS OF COLLABORATION

There are four different kinds of human robot collaboration (HRC) available. The first is the *Safety-related Stop*, the second is called *Hand-guiding*. Then, the *Speed and Distance Monitoring* is the third HRC and finally *Power and Force Limitation* is the last one. In this chapter the four methods will be described briefly [5]. More details can be found also in the ISO TS 15066 [6].

Safety-related Stop (STO)

The *Safety-related Stop* is the kind of collaboration with the highest distance between the human being and the robot. In that case, the robot stops if the worker enters the defined workspace and continues when the worker has left again. Therefore, the worker has access only to the non-moving robot. How the collaboration looks like can be seen in Figure 2.

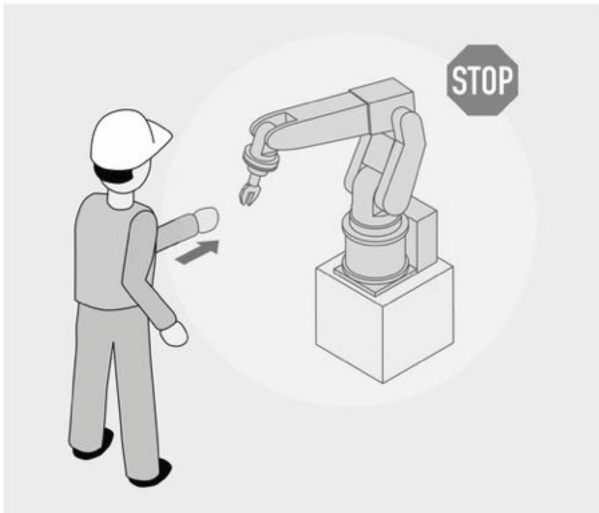

Figure 2: Safety-related Stop (STO) [5]

Hand-guiding

Hand-guiding is the way of collaboration, where the worker can touch the robot when it is not in operation mode and does not conduct a program. There, the robot is guided manually by the worker. This can happen remotely by using a kind of joystick or directly by moving the robots TCP (see chapter 5). How the collaboration looks like can be seen in Figure 3.

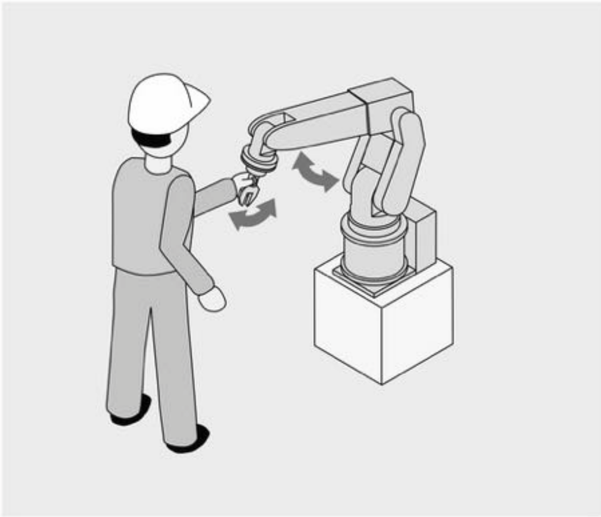

Figure 3: Hand-Guiding [5]

Speed and Distance Monitoring

The *Speed and Distance Monitoring* is the third kind of collaboration that is defined by the ISO TS 15066 [6]. Here, the intersection between the worker and the moving robot is avoided by the machine. To handle that, the distance between the robot and the worker are monitored constantly by laser scanners or camera systems. Then, the nearer the human being comes to the robot, the lower the distance of the moving robot will be. A schematic view of such a scenario can be seen in Figure 4.

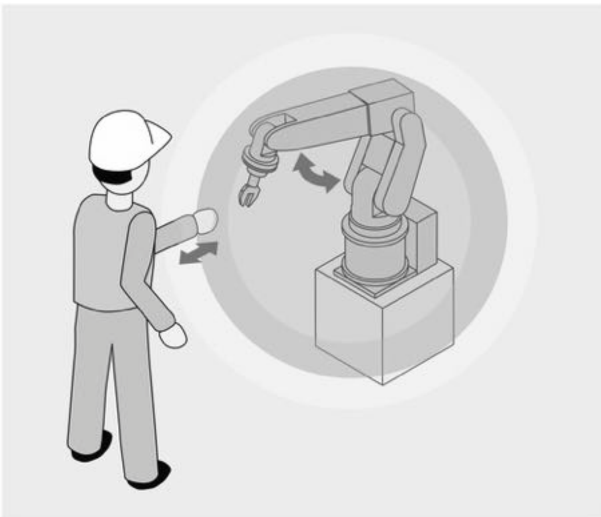

Figure 4: Speed and Distance Monitoring [5]

Power and Force Limitation

The *Power and Force Limitation* is the kind of collaboration with the closest distance between the human being and the robot. There, the forces between the worker and the robot are limited to be harmless for human beings.

The ISO TS 15066 [6] defines different regions and the authorized force when it comes to a collision. Thereby, the most sensitive region is the jaw muscle and the temporal bone, where a maximum pressure of 110 N / cm² are allowed when it comes to a contact with a robot. The allowed force for temporal bone is even 65 N. The maximum force for the hand region is limited to 140 N and therefore that is also the limitation for most of the grippers that are available on the market. How the collaboration between a worker and a robot looks like in case of Power and Force Limitation can be seen in Figure 5.

Figure 5: Power and Force Limitation [5]

Usually when we talk about HRC we use the fourth method to collaborate with robots, or sometimes the third one.

5 DEFINITION OF INDUSTRIAL ROBOTS

Concerning ISO 8373 [7] an industrial robot is a programmable manipulator that has at least three degrees of freedom and is used for industrial applications. Most of the industrial robot systems are vertically articulated robots, that have a share of around one third in the entire robot market [8].

The essential parts of a robot can be seen in Figure 6. There, the whole robot arm design and behavior is based on a human arm. At the bottom there is a *Base* where the robot is fixed usually with screws at the floor, at the ceiling, at the wall or at a robot cell. Further, industrial robots have some *Joints* with one degree of freedom each, so that the sequential segments can be combined movably. Then, the *Arm* is the cinematic chain of the robot that whereas at vertical articulated robots the three compact Joints are called *Wrist* [8].

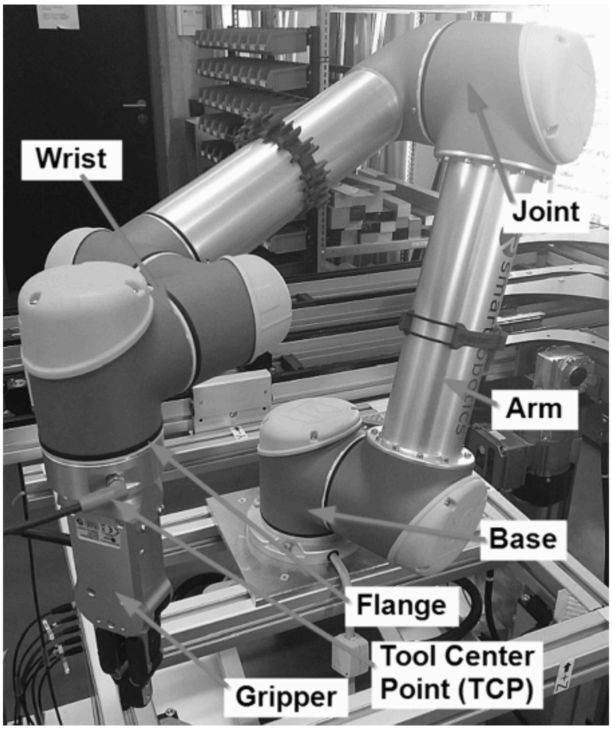

Figure 6: Essential Parts of a Robot Arm[8]

When it comes to the operation mode the robot arm is used to conduct a defined movement which is usually written in a robot program. Thereby, the movement always refers to a point in the 3D room, that is called *Tool Center Point*, or *TCP*. The *Flange* is the interface of the robot arm itself where the *Gripper* is mounted.

Referring to Pott and Dietz [8] the essential advantage of an industrial robot is that all the movements and actions are stored in a robot program that can be defined totally free. The more degrees of freedom the robot has, the more flexible it will be. A good example is the comparison to a linear guide unit. If changes are desired there, usually cost intensive and complex actions have to be done to adapt the hardware to the new scenario. With a robot, this is usually more cost-efficient because due to its flexibility, changes in a process can often be implemented by modifying the robot's software only.

[8]Own picture; content from [8, p. 3].

6 HUMAN ROBOT COLLABORATION

The *Human Robot Collaboration* (*HRC*) describes the interaction between human beings and robots related to the professional environment. There are some standards that are necessary for that kind of collaboration: EN ISO 12100, EN ISO 13849-1, EN ISO 13855, ISO 10218-1 and ISO TS 15066. Therefore, in this chapter the relevant standards will be explained roughly. What DIN, ISO etc. means can be seen in chapter 0.

EN ISO 12100

The EN ISO 12100 (title: Safety of machinery - General principles for design - Risk assessment and risk reduction) is a standard specification that contains information about the safety of machines. It is valid not only for robot systems but for all kinds of machines. Further, the topics risk evaluation and risk reduction are managed in the standard. It was reviewed in the year 2010 and there were also previous versions from 2003 and 2007. [9, 10]

EN ISO 13849-1

The EN ISO 13849-1 (title: Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design) is a norm for specific groups of machines with safety relevant control functions. It is valid for robot systems as well as for every other machine with safety relevant functions, including the development of the software. Thereby, it has to be considered that control parts in the definition of the standard does not only include Programmable Logic Controllers (PLC), but also sensors, actuators or other devices that handle with safety relevant functions and signals. In this standard some Performance Levels (PL) are described that reflect the measure of risk reduction. The latest version of the norm is from 2015 and the pre-version is from 2012. [10, 11]

EN ISO 13855

The EN ISO 13855 (title: Safety of machinery - Positioning of safeguards with respect to the approach speeds of parts of the human body) is a standard that cares for safety housing of machines. It defines what kind of safety appliance has to be implemented and how the safety housing has to behave when it comes to an incident. The latest version of the norm is from 2010. [12, 13]

EN ISO 10218-1 and EN ISO 10218-2

The EN ISO 10218-1 (title: Robots and robotic devices - Safety requirements for industrial robots - Part 1: Robots) and the EN ISO 10218-2 (title: Robots and robotic devices - Safety requirements for industrial robots - Part 2: Robot systems and integration) define behaviors of robots and robot systems in an industrial content.

In May 2021, there will be published new versions if the EN ISO 10218-1 and EN ISO 10218-2 that also include parts of the ISO TS 15066. The latest versions of the EN ISO 10218-1 and the EN ISO 10218-2 is from 2012. [14–16]

ISO TS 15066 [6]

The ISO TS 15066 (title: Robots and robotic devices - Collaborative robots) is a technical standard especially for collaborative robot systems. It is about safety when there is no safety housing like a fence or a light curtain. The target of this norm is to help manufacturers, integrators, users, insurances and certification facilities to handle collaborative robot systems. The latest version of the ISO TS 15066 was published in the year 2017. [6, 17]

As it can be seen there are some standards that have to be considered if a robot (system) is developed, maintained or used.

7 COLLABORATIVE ROBOT

There is a *Collaborative Robots Comparison Tool [18]* available that shows that there are around 100 collaborative robots on the global market available. A collaborative robot is a robot concerning its definition from chapter 5 that can collaborate with a human being in one of the four ways presented in chapter 4, or even the combination of them. Further, a collaborative robot has to consider the norms described in 6. In this article only collaborative robots with a *Power and Force Limitation* are relevant.

8 APPLICATIONS WITH COLLABORATIVE ROBOTS

In this chapter the applications are from the industrial environment only. Applications from the medicine or outdoor area as well as privately used robots are not considered. In the industrial environment, processes like gluing, assembling, welding, pick-and-place, packaging, quality inspection and more are often combined with Cobots.

Aircraft Assembly

The first example is from a research consortium that includes Fraunhofer IGP, University of Rostock and Airbus Operations GmbH and has the title *Human-Robot-Collaboration in the Final Aircraft Assembly – An Intelligent Assistance System for Mechanical Joining in the Manual Assembly* [19].

The challenge at the beginning was that in an aircraft assembly full rivets should be replaced by full punch rivets. Then, due to the high process forces involved in punch riveting, the tools have a high weight, which means that assembly would put high physical strain on the employees during manual handling. Because of this expected load of around eight kilograms the use of a collaborative robot was developed and implemented. This can be seen in Figure 7.

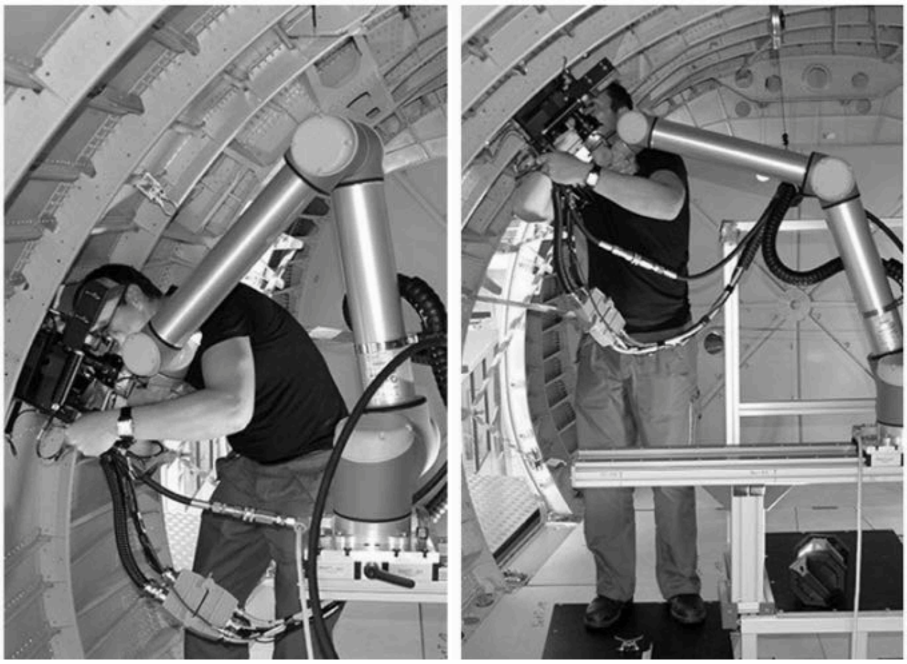

Figure 7: Human-Robot-Collaboration in Aircraft Assembly [19]

Gluing Process

The second example where a collaborative robot works together with a human being is at the BMW Group Facility in Dingolfing.

There, the origin scenario was that a blue-collar worker has to assemble the windows of a car. Therefore, the employee placed the left and the right-side windows. Then, some glue was applied manually using a hose and an application nozzle. To do so the worker had to run the hose around the two discs what was very uncomfortable because of the different sizes of the employees. After that, the final step was to smooth the glue to make the window tight because that needs to be done to fulfill the needed quality standards.

Nowadays, this complex assembly task was replaced, or expanded by a human-robot-application. Now, the worker just places the window in the exact position and the collaborative robot applies the glue on the discs. Then, the Cobot smooths the glue and the result is a reproductive and high-quality assembly. [20]

Figure 8: Gluing Process[9]

9 CONCLUSION

As it can be seen in the introduction there are many robots on the worldwide market and the tendency is increasing. In Germany, the reasons for that are the missing skilled workers, the aging society and the high global competition.

Therefore, smart robots are declared as a modern technology and that is why collaborative robots become more and more popular. There are different kinds of collaborations between humans and robots: safety-related stop, hand-guiding, speed distance monitoring and power and force limitation. Usually, the collaborative robots that can be purchased are based on the power and force limitation technology. How collaborative robots are used in real industrial applications can be seen in chapter 8. One application that is described is in the aircraft industry and one in the automotive environment. When the research on real applications was conducted it could be noticed that most of the applications were developed for fairs or demonstrations. Almost no applications from the industry can be found. Therefore, we are on the first moves concerning the usage of collaborative robots and there is a lot of potential within the next years.

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Acceptance and Usability of Cobots by people with Intellectual Disability.

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Keywords:

Collaborative Robots, Cobots, Acceptance, Usability, Intellectual Disability

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1 INTRODUCTION

„The next big thing is the one that makes the last big thing usable"
- Blake Ross –

Technology is a very fast and ever-growing concept of this era. The technology of today is highly advanced than that of yesterday and the technology of tomorrow would be even more advanced than that of today. In this lightning speed of development, it becomes important to keep an eye on the tracks we are running on. It is important to check the effectiveness and efficiency of the current technological systems and find new applications and solutions to the modern-day problems.

Collaborative Robots or the so called ‚Cobots' are rapidly finding their use not only in manufacturing industry, but also outside factory setting. A high rise in the Cobot market is therefore predicted appropriately. A report from Interact Analysis predicts the collaborative robot market to be worth US $7.5 billion by 2027 which would equate to roughly 29% of the global industrial robot market [1]. Such an explosive growth prediction calls for new innovative applications to be built. The flexibility and safety configurations of Cobots, enables them to enter various other fields of applications apart from industrial manufacturing. Collaborative Robots have already proved their competence in variety of sectors such as gardening, cooking, bartending, medical surgeries and as co-pilots for airplanes [2]. Thus, proving that Cobots have the capability to assist humans in their day-to-day tasks too.

Robots can work day in and day out without breaking a single sweat and with the exact same accuracy every time. They are machines that overcome the limitations of a human being. Robots work, better and faster than a normal human with all the motor and cognitive capabilities functioning properly. It is therefore evident, that Robots can help people with more than average limitations to do certain tasks, that people with less or without limitations can easily do. There have been certainly many innovations which have helped people with any kind of disability in accomplishing normal tasks. Technology has developed to the extent that people can now have a very well-functioning artificial limb in case of its absence. Intellectual disability is a condition which affects a person in almost all the aspects of his or her life.

This paper briefly describes the Experiment carried out in July-September 2019 by us at IWT Wirtschaft und Technik GmbH with an aim to find the level of Acceptance and Usability of Collaborative Robots by people with and without Intellectual Disability.
Beginning with the background of the research and necessary theory regarding Acceptance and Usability in general, the preparations done for the experiment are described wherein, important points and tips can be noted that are required to carry out an Experiment of such kind. Further, the outcomes of the Experiment are compared and discussed before finally concluding the section.

2 BACKGROUND

Many researches have been made with an idea of using Robots or even Cobots to help intellectually disabled people. Collaborative game among two children with autism and a humanoid robot has shown improved social behaviours among children playing with each other compared to before they did without the collaborative game with the robot [3]. The study interestingly found that all the participants exhibited an average decrease in the level of disability after collaborating with the Robots. More importantly, none of the participants was found to have any increased amount of disability in any of the activity cases. This goes on to endorse the use of Robotics technology to find solutions to the problems of disabled people.

Many inventions resulted in minimizing and in some cases eliminating the hurdles in a disabled person's life. There have been researches carried out with an aim of integrating Robots in lives of people with Disability. These advancements have empowered them to get closer every day to living a normal life. With intelligent robot protection devices, it is further possible to allow robots to work together with disabled workers [4]. The research performed at Lebenshilfe Donau-Iller e.V. at Ulm made a shared workspace between industrial Robots and workers at the Lebenshilfe for production of hydraulic pumps. The assembly line was modified to integrate the automation of the production with capabilities of disabled workers. Thus, a division of labour was achieved between industrial Robots and disabled people, which can be improved with introducing Cobots replacing traditional industrial Robots in such workshops.

The Robert Bosch GmbH along with Fraunhofer Institute for Industrial Engineering has been working on a project called AQUIAS in which they are making a research on how Collaborative Robots can be used to create attractive job opportunities for people with disabilities.

One of the outcomes of it is achieved along with ISAK GmbH that employs many severely disabled people, in that, the arduous task requiring heavy physical monotonous work has been handed over to Robot while the humans are responsible for planning, quality control and jobs full of variety. If a worker comes too close, with the help of intelligent sensor system APAS automatically stops without any contact at all.
The product manager of APAS Wolfgang Pomrehn said that, designing the processes for people with disability is helping them learn how human-machine interactions can be made better to constantly expand the spectrum of APAS applications [5].

Germany has number of sheltered workshops or the so called “Werkstatt für behinderte Menschen (WfbM)” across the country. In Germany, sheltered workshops are highly specialised facilities for vocational rehabilitation who enable people with disabilities to participate in working life. In more than 700 sheltered workshops with over 2,750 subsidiaries they provide vocational education, work opportunities and support in personal development for over 310,000 people with intellectual, psychological and severe and multiple disabilities [6]. These workers have a monthly wage of around 181 euros which is comparatively less than the payment of an average labour job. With the help of Robots, the efficiency and productivity of these workshops can be increased, eventually giving a rise to the income of people with disabilities working in these workshops.

3 ACCEPTANCE AND USABILITY

Acceptance and Usability are abstract phenomenon that depend from person to person. Evaluating the level of acceptance or usability is thus an approximate way of quantifying the level of accomplishment of the technology developers to meet the needs of people. It helps further to identify closer with the current user needs. Acceptance for humans could be defined as willingness of a person to agree to a situation, condition or a process and work with it which could be uncomfortable for them as a change from normality. Various models have been designed to evaluate Acceptance and Use of Technology beginning from TAM. Some of the most used models are Godspeed and UTAUT [7]. Based on an extensive analysis the UTAUT (Unified Theory of Acceptance and Use of Technology) model was developed. In the thorough research performed by Venkatesh and others [8], various papers and designed a common model called UTAUT for evaluating acceptance of technology have been assessed. Following factors from the UTAUT model were used to formulate the questions for testing acceptance of collaborative Robots by people with Intellectual Disability.

1. Performance Expectancy – Performance expectancy is defined as the degree to which an individual believes that using the system will help him or her to attain gains in job performance. This can include gains like greater level of satisfaction in job, promotion opportunities, speed up the work, an option to earn more money or improving quality of work and life.
2. Effort Expectancy – Effort Expectancy is defined as degree of ease associated with the use of system. Easier the technology is for the person to use and operate, lesser is the resistance from him for the change of technology. Thus, higher is the level of acceptance of a new technology.
3. Social Influence – Social Influence is defined as degree to which an individual perceives that important others believe he or she should use the new system. The opinions of people important to a person matter while they know that these people would always speak for their betterment. Opinions about themselves in other’s eyes may increase or deteriorate the level of acceptance of anything.
4. Facilitating Conditions – Facilitating conditions are defined as the degree to which an individual believes that the organizational and technical infrastructure is available for them to support use of the system. The basic means required to realize the introduction of new technology is availability of resources, knowledge and whatever means necessary.
5. Behavioural Intention – Behavioural Intention is defined as the willingness of an individual to incorporate the technology in his or her life. The above factors generally contribute towards shaping the intention of a person to use the technology. The willingness and the wish of a person to use a technology is an indicator of his acceptance.

Usability of a technology could be defined as the level of comfort or ease a person experiences while working with the corresponding technology in an instructed way. In general, usability can be divided into number of different factors. Weiss and others [9] suggested a framework of evaluating Social acceptance and Usability using various factors in the USUS evaluation framework. This framework is built based on evaluating various factors under Usability, Social acceptance, User experience and Societal impact. The research summaries following factors under Usability:

1. Effectiveness – The accuracy and completeness with which users achieve specified tasks.
2. Efficiency – The resources expended in relation to the accuracy and completeness with which users achieve goals.
3. Learnability – This means, how easy can a system be learned by novice users. This seems to be a key indicator for usability in human-robot interaction as robots are a technology people have almost no pre-experience with.
4. Flexibility – This describes the number of possible ways how the user can communicate with the system.
5. Robustness – It is the level of support provided to the user to enable a successful achievement of tasks and goals.
6. Utility – refers to how an interface can be used to reach a certain goal or to perform a certain task.

6 PREPARATION OF EXPERIMENT AND LESSONS LEARNT

The experiment carried out for evaluation of Acceptance and Usability of Collaborative Robots was prepared based on guidelines mentioned in [10]. Some of the important points or the lessons learnt during the preparation phase are summarised below briefly.
The experiment was carried out in two phases. The first part took place in the final week of July 2019 wherein the Participants without any disability were invited to the Lernfabrik at IWT Wirtschaft und Technik GmbH, Friedrichshafen.

The second part with the workers of WfbM was conducted in the first half of September by travelling to the workshops the Stiftung at Liebenau, the Integrations Workshop Oberschwaben at Weingarten and Workshop at Lindenberg in the state of Baden Württemberg. A total of 63 participants across different ages and from different backgrounds participated in the first phase of experiment.

This phase included participants without any intellectual or physical difficulty in which, 37 of the total number were males and 26 were females. 33 of the Total participants reported to have had a technical education background, while the other 30 had no background of technological education. The second phase was carried out with a total of 32 participants with varying level of intellectual disability across different ages and from all three sheltered workshops. The division of age was done in three groups: younger than 22 years, 22 to 39 years of age and third was 40 and older. Wehmeyer [11] and Tanis [12] mention that based on the level of development of minds of people with intellectual disability, they can be grouped according to their age as done in this Project.

The flow of the experiment was predefined after brainstorming sessions. Importance of each step was noted, and a chronological order of steps was designed considering the requirements and expected effect of each step. The final order of steps designed for participants were as follows:

The participants were invited in a batch of 5 to 8 people per batch. The process was same of every batch.

1. Presentation of the overview, procedure of Experiment and necessary information
2. Video of how to assemble the parts completely manually
3. Completion of the task manually by every participant individually
4. Filling up Pre-Questionnaire to record their expectations and level of acceptance before performing the actual task.
5. Video presentation of how to assemble the parts together with the Robot. They were explained which parts are mounted by robot and which ones should be mounted by them.
6. Completion of the actual collaborative task together with the Robot individually.
7. Filling up Post-Questionnaire wherein they answered questions indicating their level of Acceptance of the Cobot technology and on their experience determining the Usability of the Robot.

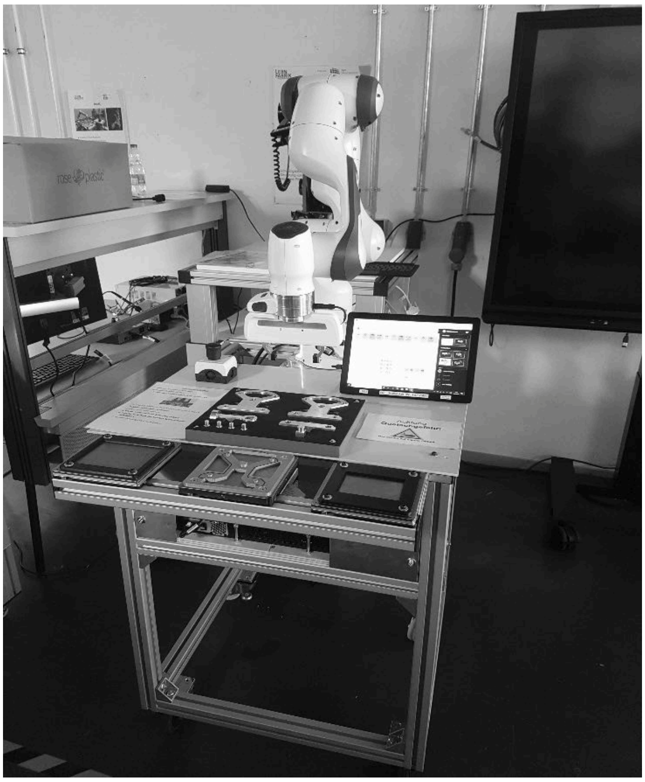

Figure 9: Robot Cell

The Experiment task was assembly of a simple kit in which the Robot and Human contributed specific steps towards the complete assembly. A standard product Cranfield Assembly Benchmark was therefore selected to be assembled for the task. The Robot used was Panda from Franka Emika. Franka Emika Panda is a Robotic Arm with 7 degrees of Freedom. Weighing up to 18 kg, the Robot can lift a maximum weight of 3 kg. It has a maximum reach of 855 mm. The general power consumption is 60 Watts with a maximum rating of 350W. The Robot was programmed to perform specific steps as per the results of task allocation process used.

The task allocation method used here is inspired from the findings of Tsarouchi [13] that focusses more on the reaction and opinion of people working together with a collaborative Robot rather than complex technical algorithms. It is a series of decision-making processes based on certain criteria which can further be developed into an algorithm to be computed.

a) Resource suitability – Check if the resource is suitable for executing the task under consideration.
b) Resource availability – Check if the resource is available to execute the task. In case the first resource is still busy working with previous task, the current one can be assigned to the other resource provided it has passed the suitability test.
c) Operating time – The resource with minimum operating time is assigned the task.

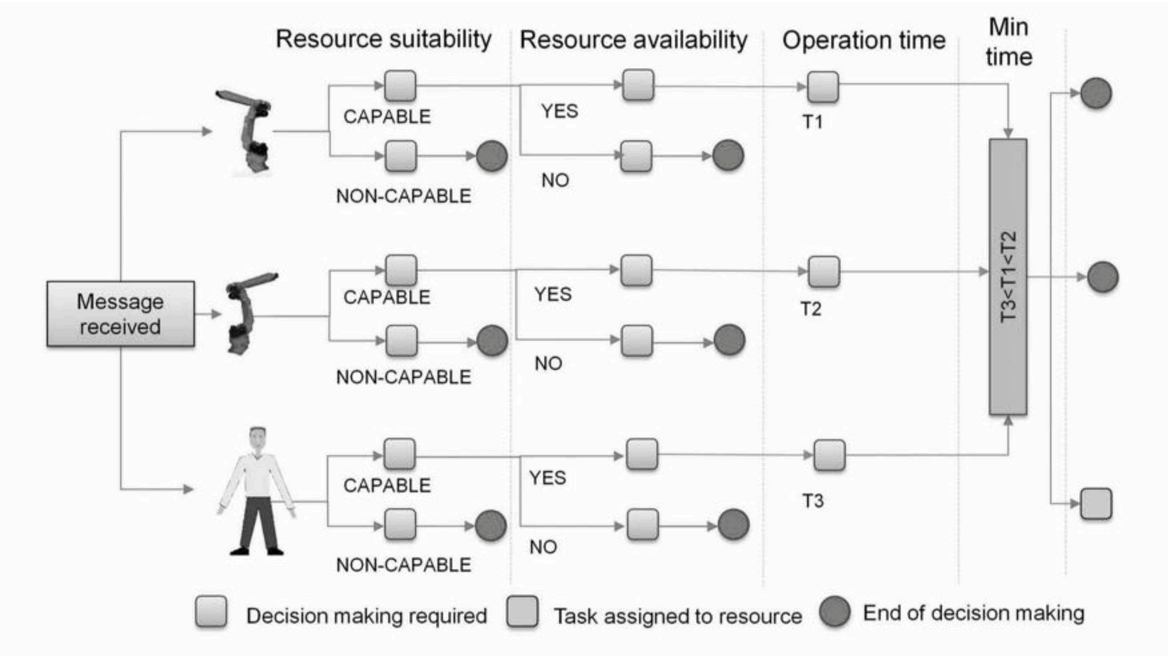

Figure 10: Task Allocation [10]

Designing the Questionnaires is the most crucial task concerning projects for evaluation of Acceptance and Technology. In order to get reliable and valid answers, it is very important to frame the questions in a way that is easily understandable to the participants. A lot of study was done for formulating correct questions. As discussed above, number of models were studied and eventually, the commonly used models for Acceptance and Usability were chosen to form the basic structure of questionnaires. It is good practice in the social sciences to ask multiple questions about the same concept in order to be able to check the participants' consistency and the questionnaire's reliability [14]. Therefore, at least three questions were asked in context of each factor or concept and a mean of the responses to these questions could represent the factor in the evaluation phase. An added bonus to using the SUS is that recent psychometric analyses shows that items 4 and 10 reliably measure the dimension of perceived "Learnability" [15]. Hence it was chosen for evaluation in this project.

The questions asked could be basically be categorised into following three types:

1. Personal – Questions such as gender, age, technical background, experience with robots etc.
2. Specific – Questions based on various factors pertaining to evaluate Acceptance of the technology.
3. Experience – Questions based on the experience of user of working together with a Robot.

An observation sheet was developed to record live activities of the participants while performing the experiment. The time taken was recorded for each participant and later analysed. Further, this observation sheet consisted of the examiner's perspective of the participant.

For people with ID, it is not easy to conduct an experiment involving a questionnaire. Self-report measures require that people with ID understand questions, form responses independent of the interviewer (e.g. suggestibility) or response format (e.g. order) and communicate responses. Allowing interviewers to paraphrase and/or expand upon items appears to help adolescents and adults with ID reliably respond to Likert-type scales [16].

It was thus decided that, questions will be asked to them in form of an interview so that they can be explained, and an appropriate response can be expected. It is widely acknowledged that vocabulary and meaning should be clear and simple [17]. Questions asking people how they think others view or evaluate them are difficult for many people [17]. It was therefore expected that these questions were answered neutral on the Likert scale.

Figure 11: Participant performing the task

The questionnaires used in this study required to be answered on a 5-point Likert scale. Although Likert-type scales are widely used among the general population because they offer an efficient method for capturing a wide range of response variance, little is known about whether people with ID can reliably and validly categorize and distinguish subtle differences (e.g. 'None' to 'A Little', 'Medium' and 'A Lot') in their behaviours and attitudes on Likert-type scales [16]. A very detailed analysis is performed by Hartley and McLean on reliability and validity of Likert scales for people with Intellectual disability. The paper suggests number of methods to try to overcome these hurdles. It may be better to ask about one element at a time [17]. When individuals are able to make direct comparisons, and there are a number of items that are to be ranked, dichotomous choices can be given, where each item is paired with every other item [17]. Thus, the participants were asked to answer if the agreed or disagreed or did not have an opinion for a statement and then they were asked how strongly they felt about agreeing or disagreeing. In cases where participant's response seemed to be inconsistent, he or she was asked to further clarify the reason for their choice of answer.

Likert-type scales should include pictorial representations of response alternatives, a single set of one or two word response descriptors, clarifying questions, and Pre-tests, and are best used with adolescents and adults with borderline IQ to mild ID [16]. Thus, pictorial representations of options were developed. Participants were asked questions and were then asked to point to one of the following pictures to denote their response.

Figure 12: Own Picture, Pictorial representation of Likert scale data

Adolescents and adults with ID have a tendency to choose the most positive response alternative in Likert-type scales [16]. Screening questions concerning concrete activities whose frequency has been established from informants might be used in pre-test sessions to ascertain the ability of individuals to make such judgments [17]. A small test questionnaire called Pre-test questionnaire was therefore developed to help participants with ID to distinguish between the Likert scale options.

4 OBSERVATIONS AND DISCUSSION

The data received from questionnaires was a 5-point Likert scale data ranging from Strongly Disagree to Strongly Agree. Data from 95 participants was collected and stored in a tabulated format. Several tests were performed on the data using SPSS software. After complete procedure of Data Analysis, following observations were made.

Significant differences in answers of the three groups have been recorded for the factors Performance Expectancy, Facilitating Conditions, Behavioural Intention, Condition and Usability whereas, Effort Expectancy, Social Influence and Perceived safety do not show any significant difference. Thus, it can be inferred that participants in three groups scored almost equally under these three factors. The group of people with disability scored higher or equal than the other two groups. Although, the difference is minimal, it can be inferred that acceptance of the Cobots by disabled people under these three factors is at least same as acceptance by people without disability.

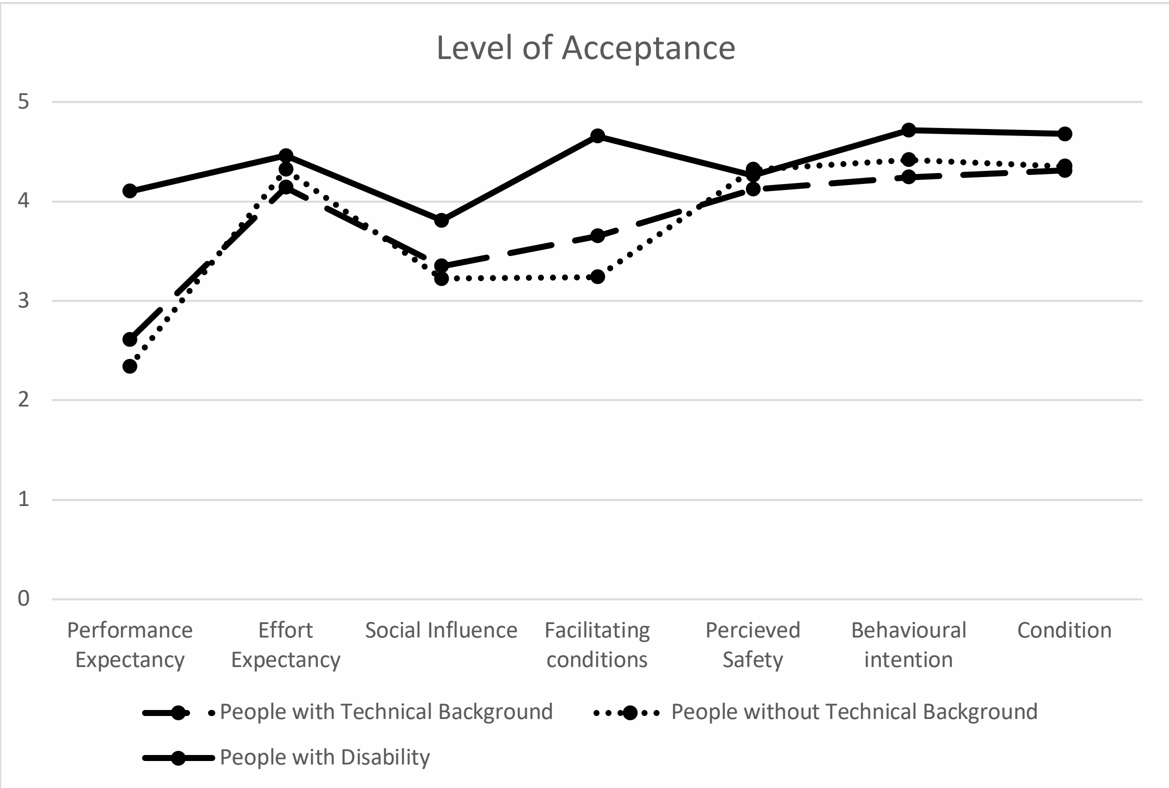

Figure 13: Results of Acceptance test

For every factor, a significant difference between the group of disabled people and the other two groups is recorded. There is no difference between the group with technical background and the group without technical background for any factor. Thus, it can be inferred that the factors Performance Expectancy, Facilitating Conditions, Behavioural Intention, Condition and Usability depend on whether a person has a disability or not.

Reading from the graphs, clearly, people with disability accepted the idea of working together with Cobots much more than participants without disability did. Looking closely, we can see that except for Performance Expectancy, all other scores for Acceptance are above average. Thus, concluding that people gladly worked with the Robot for the task. However, the disabled people have scored significantly lower than people without disability for Usability. This indicates that although, they accepted working with the Cobot, the task was not as easy or user friendly for them as it was for the others.

Another important test was performed to evaluate if there was any difference of opinion of participants before and after the test. For the group of people with disability, except Social Influence and Perceived Safety, all other factors reported a significant change in the levels before and after performing the task. The important fact to notice however is that for all the factors, the participants have scored higher after the task than before. Thus, we can clearly conclude that the level of Acceptance of Cobots by People with Disability increased after experiencing working together with the Robot.

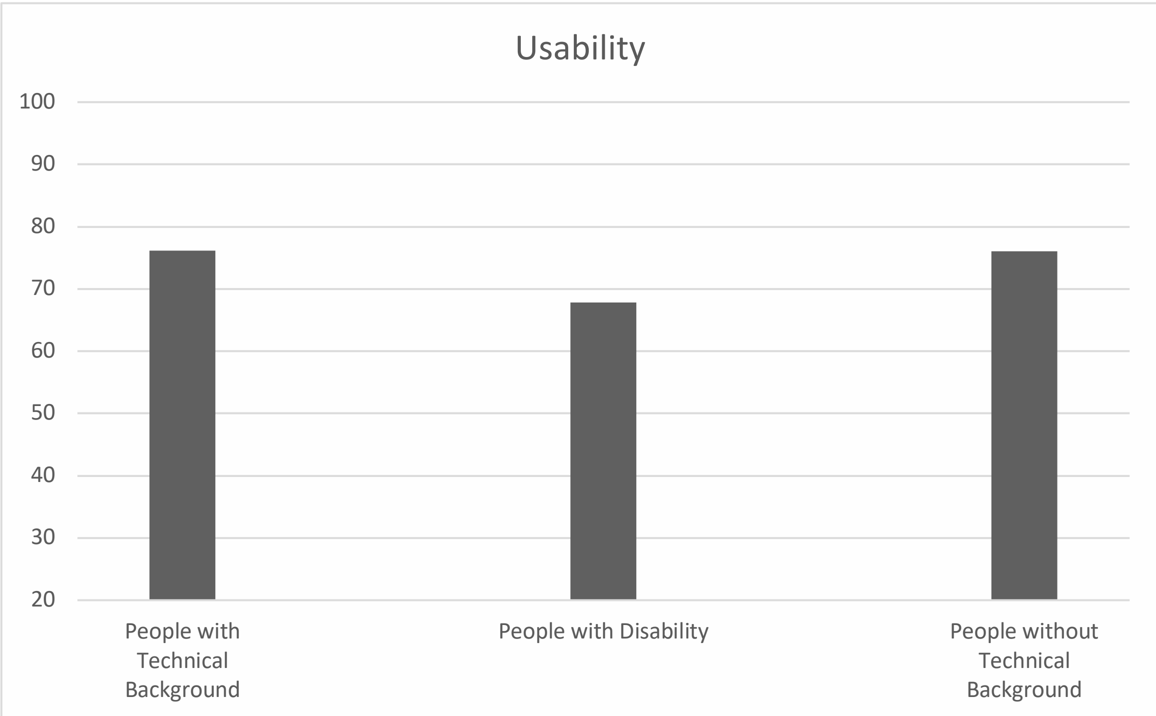

Figure 14: Results of Usability test

5 CONCLUSION

The society is moving forwards with developing technology every day. Germany is one of the leading countries when it comes to installing Robots in automation of industries. The market of Collaborative Robots has been predicted to rise highly in future undertaking many tasks which are currently done by industrial robots. It is thus eminent that collaborative applications of such robots would receive higher level of acceptance by people.

One such area of application of Cobots was tested during this project for its acceptance and usability. Given the number of sheltered workshops for people with disability in Germany, integrating Cobots in the working life of disabled people would bring firstly, simplification in lives of people with disability and secondly number of opportunities of developing specific applications for different sheltered workshops. The tests performed in this experiment conclude that the people with disability have a much more positive attitude towards working together with a robot. For almost all the factors considered in this test, people with disability showed a higher level of Acceptance of the technology of Collaborative Robots. However, work needs to be done to make the robotic systems more usable for disabled people. The features of the Robot used in this experiment allow us to configure the programs suiting to the needs of the user, but with limitations. So far, it can be inferred that along with some technical help, people with disability see it helpful and rewarding when they work together with Collaborative Robots.

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