TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Mechanical and Industrial Engineering

GLUING PROCESS ROBOTIZATION FOR PASSIVE ANTENNA ASSEMBLY UNIT

PASSIIVSE ANTENNI KOOSTU LIIMIMISE PROTSESSI ROBOTISEERIMINE

MASTER THESIS

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Tallinn 2023

AUTHOR’S DECLARATION

Hereby I declare that I have written this thesis independently.
No academic degree has been applied for based on this material. All works, major viewpoints and data of the other authors used in this thesis have been referenced.

“2” January 2023

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Department of Mechanical and Industrial Engineering

THESIS TASK

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Thesis topic:
(in English) Gluing process robotization for passive antenna assembly unit
(in Estonian) Passiivse antenni koostu liimimise protsessi robotiseerimine

Thesis main objectives:

1. To study the assembly process robotization possibilities and to find out the criteria for suitability analysis
2. To analyze collaborative robots implementation possibilities for assembly robotization and the role of humans in man-robot cooperation
3. To design the principles for efficient robot-cell application implementation in the assembly process

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Master`s thesis structure. Research objectives. State of the Art. Robotization task description	26.09.2022
2.	Main topics of the master`s thesis: robotization suitability analysis, robot-cell design, human role in cobot oriented workplace, efficiency analysis	09.12.2022
3.	Completion of master’s thesis. Updating and making corrections. Formalization of work.	21.12.2022

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CONTENTS

PREFACE

The thesis was written based on the author's use-case research for the “Industrial Robotics and Advanced Manufacturing” course at TalTech last spring. This thesis represents the extended version of the previously mentioned assignment. The idea for the thesis topic was chosen from the author's previous work experience.

The author would like to express his most significant appreciation to his supervisor Jüri Riives. Thank you for your time and constant support.

Keywords: robotization, gluing, production, master thesis.

List of abbreviations and symbols

2G	Second Generation
3D	3-dimensional
3G	Third Generation
4G	Fourth Generation
5G	Fifth Generation
AAS	Advanced Antenna System
EOAT	End of Arm Tooling
EUR	Euro (currency)
Gbps	Gigabits per second
HRC	Human-Robot collaboration
ISO	International Standard Organisation
kg	kilogram
KPI	Key Performance Indication
Mbps	Megabits per second
m	Meter
ml	Milliliter
mm	Millimeter
mm/s	Millimeter per second
MNOs	Mobile Network Operators
OEE	Overall Equipment Effectiveness
PCB	Printed Circuit Board
ROI	Return on Investment
SCARA	Selective Compliance Assembly Robot Arm
s	Second
SMEs	Small and Medium Enterprises
UPVC	Unplasticized Polyvinyl Chloride
V	Volt

1. INTRODUCTION

Latest reports show that mobile data traffic is constantly growing. It means that mobile network operators should start increasing capacity and speed to fulfil customers' future demands [1]. Fourth generation (4G) is one of the most used mobile network standards; it allows to transfer of data with a maximum speed of 100 Mbps. From a regular customer perspective, the 4G network allows one to watch high-quality videos, video chat and stream all other types of internet content. As mentioned previously, mobile data traffic is increasing, and the 4G network will not be able to fulfil the request of customers. Fortunately, the next generation of mobile networks has already been developed and is rapidly implemented by mobile network operators across the globe. Fifth generation (5G) is the mobile network standard for transmitting data up to 10 Gbps. 5G network is not only solving the problem of growing data traffic, but also it opens new opportunities for customers, such as the application of Augmented Reality, Virtual Reality, self-driving, cloud services and intelligent factories [2].

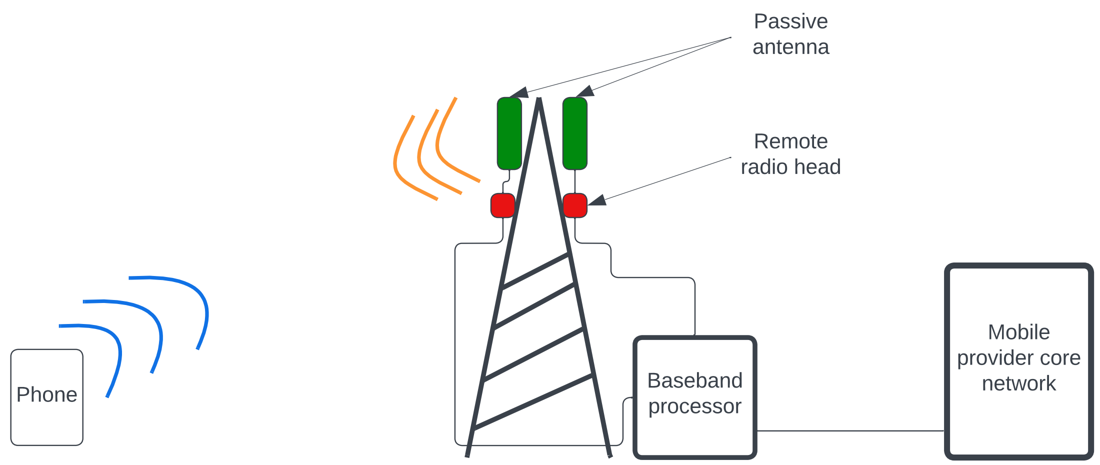


Figure 1.1 Work principle of traditional mobile network

To summarise, a conventional mobile network includes three essential elements [3]:

- Device connected to the network
- The base station consists of the mast, passive antenna, remote radio head and baseband processor
- Mobile provider core network

Everything starts with the device sending an analog signal to the base station located at the high point. The antenna of the base station receives the analog signal. It transfers it to the remote radio head, where the analog signal is converted to a digital one and sent to the baseband processor. The baseband processor processes the signal and sends it to the core mobile provider network. After receiving the signal, the mobile provider's core network fulfils the request contained in the signal. It sends a new signal the same way back to the device, converting a digital signal to an analog in the remote radio head. This type of communication happens thousands of times per second.

Current trends in the telecommunication industry show growing demand for decreasing amounts as well as dimensions of equipment needed for setting up the base station [4]. Commonly new equipment is installed on the already existing base stations, which are occupied by the equipment of the previous generation of mobile networks. In addition, some mobile network operators (MNOs) do not have their own masts and are renting out places for equipment on the masts of different MNOs. The price for renting space is calculated based on the dimensions of the equipment [5]. Besides, for alleviation of the installation process, there is a request to make equipment lightweight. Telecommunication hardware suppliers answer to that trend with the release of advanced antenna systems (AAS) to the market. AAS is a combination of passive antenna and remote radio head, which are enclosed into one unit, allowing not only to reduce the volume of equipment but also decrease power consumption. AAS stands to be a foundation for 5G networks [6].

Figure 1.2 Comparison of AAS manufactured by Nokia (on the left) [7] and passive antenna manufactured by Varius (on the right) [8].

As for now, there needs to be more information regarding the mechanical structure of AAS in open sources. However, illustrations show similarities between AAS and passive antennas. Both antennas have plastic covers through which the signal is transmitted. In the production of passive antennas, adhesive bonding is a widely used process as it firmly seals electronics inside a plastic housing. Keeping in mind the fact that AAS should be lightweight and capable of working outside it is very likely that adhesive bonding will be used or already used during their production as well. For ensuring quality and increasing production capacity automation of adhesive bonding is essential.

This thesis focuses on robotization adhesive bonding using a passive antenna as a basis. The author analyses the possibilities of robotizing the gluing process in the manufacturing procedure of the antenna assembly, chooses an expedient robot and the necessary work tools and plans a robotic workspace. During the execution process, it becomes clear that the usage of collaborative robots is more rational. Based on the nature of the product and production process, the workspace has been designed and human-robot interaction has been defined.

2. PRODUCT AND MANUFACTURING PROCESS DESCRIPTION

2.1 Product description

For this work, the author has chosen a passive antenna - SISO-700/2700-12/15 DBI manufactured by Varius. It is an outdoor antenna designed to support second-generation (2G), third-generation (3G) and 4G standards. This antenna was chosen due to the availability of technical data and video materials for the disassembly process in open sources [9]. Based on that information author created a simplified 3-dimensional (3D) model of the antenna using the computer-aided design software SolidWorks.

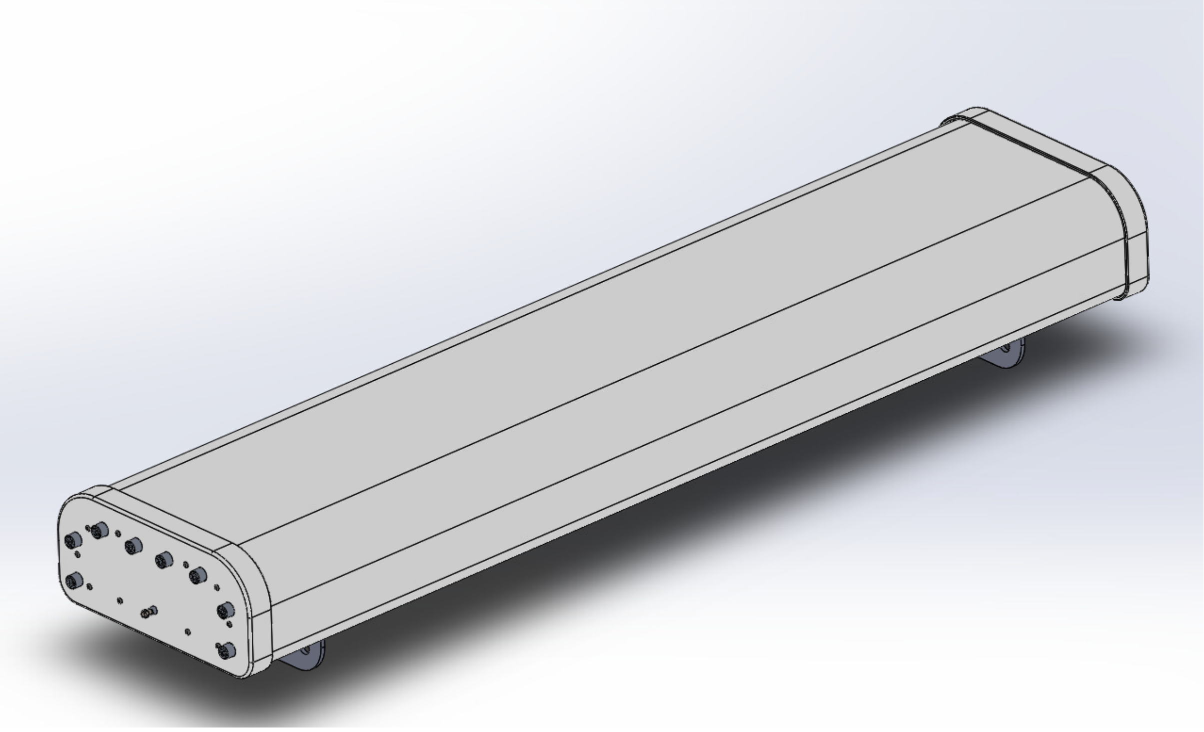


Figure 2.1.1 Simplified 3D model of SISO-700/2700-12/15 DBI

General technical data of SISO-700/2700-12/15 DBI:
Length x Width x Height: 1220 x 285 x 130 mm
Weight: 8,7 kg

The antenna consists of:

- Unplasticized Polyvinyl Chloride (UPVC) housing
- Top and bottom UPVC covers
- Aluminium frame
- Printed circuit board (PCB)
- Mounting brackets

PCB is populated with different electrical components, ones of which are diploes. Dipoles are transmitting and receiving radio signals through UPVC housing from connected devices. PCB is placed on an aluminium frame which is giving robustness to the construction and is connected to the bottom connectors via cables. On the back side of the unit mounting brackets are affixed. The top and bottom covers enclose electronics from precipitation. Also grounding cable is always connected to the antenna to protect it from the danger of high voltage.

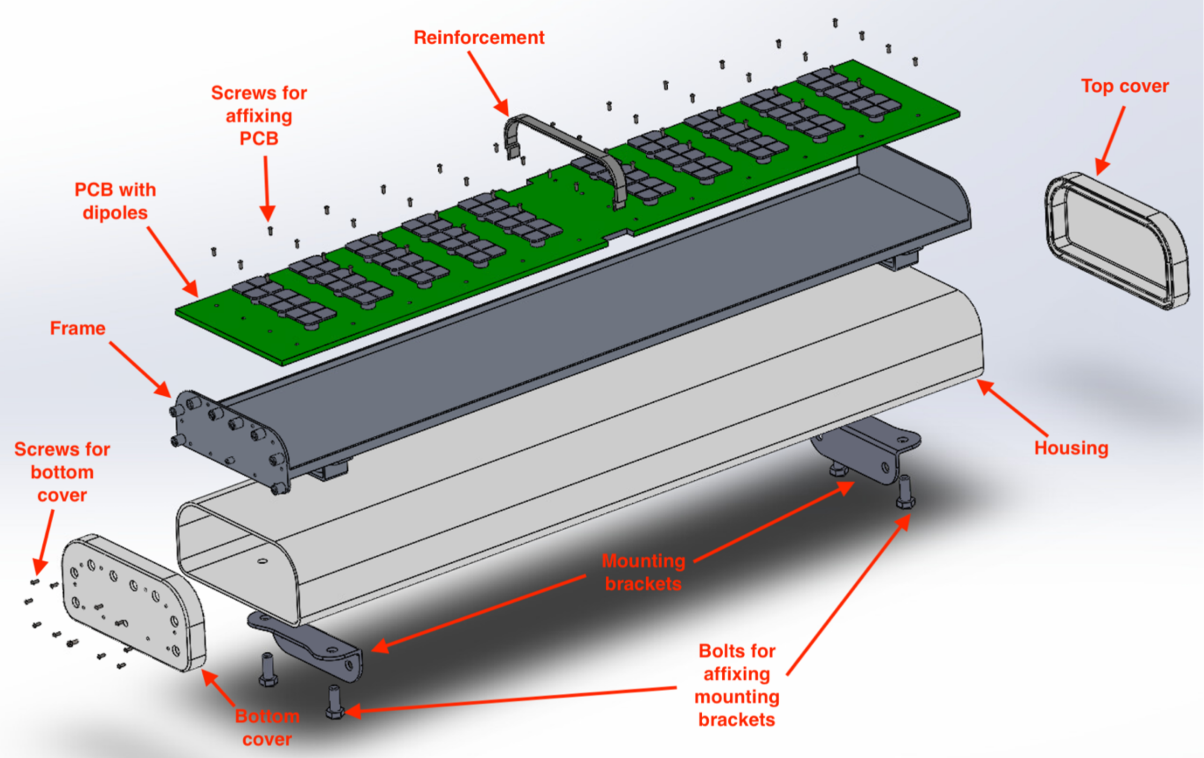


Figure 2.1.2 Exploded view of SISO-700/2700-12/15 DBI (cables not shown)

2.2 Assembly process description

The process of formation of movable or non-movable connections of the different parts is called an assembly. Movable connections are determined by the possibility of component movement and in most cases are detachable, which allows disassembly and reassembly of the connection. Non-movable connections firmly link components and do not allow any movement. Non-movable connections are both detachable and non-detachable [10]. Overall, assembly operation is divided into 2 main groups: general assembly and sub-assembly. The scope of general assembly involves the final product itself and sub-assembly focuses on the assembly of the items which are considered to be components for the final product. A big role in the creation of a link between components plays material of these, as it is one of the key factors for understanding the applicability of certain assembly techniques. Assembly techniques are categorized as [11]:

- Fastening – link is created by external hardware such as bolts, nuts, washers etc. This technique is most suitable for the assembly of parts which are not permanent and require service or adjustments. As parts are not permanent, broken or damaged components can be easily replaced with functional ones, increasing the lifespan of the product and minimizing the necessity of buying new ones.
- Welding – a process of using heat or compression to create a joint between components. A method is mainly applicable for the assembly of metal components, but it is also used for linking non-metal components – ceramics and plastics. Welding joints are stiff but non-detachable. Implementation of welding requires unique equipment and protective supplies, as the process is dangerous for a human being.
- Soldering - operation used to obtain a permanent connection of components from various materials by introducing between these components a molten material that has a lower melting point than the material of the components to be joined. As a result, mechanical and electrical contact is formed, capable of carrying mechanical loads. Same to welding joints, soldered joints are also non-detachable.
- Adhesive bonding – method of linking elements, which is based on the adhesion of the adhesive layer and the material being bonded. Adhesive fills in the gap between the parts and creates a strong connection with the non-detachable element.

Onwards author will focus on adhesive bonding only as this technique is applicable to the product chosen above.

In modern days adhesives are used in the production of numerous things. Adhesives can be found in automotive, aerospace, electronics, construction, furniture industries and even in medicine. Such a wide variety is caused by the advantages of adhesives.

The primary benefit of using adhesive is that its application to the surface does not damage or deform the material. In addition, bonded joints are light weighted, if compared to the mechanical ones, do not cause stress concentration, provide better stress transfer and can be used there, where other joining technologies are not applicable.

On the other hand, adhesives have limitations, some adhesives have limited storage time and require a special environment for storage. The long curing time of some adhesives requires the use of fixtures to support the bonding load, disassembly of bonded joints is generally impossible without damaging material and adhesive materials are commonly toxic and fire hazardous [12].

The process of adhesive bonding starts with a selection of adhesive [13]. In order to choose the right adhesive following parameters should be considered:

- Substrate type – each substrate has its own physical and chemical properties and will behave differently with the substrate with which is going to be bonded.
- Mechanical stresses – all forces applied to the bond should be examined.
- Environmental conditions – including temperature, amount of UV light, humidity etc.
- Hardening time – some adhesives have very low hardening time, which can speed up the assembly time, but at the same time can create extra scrap due to mistakes during assembly.
- Safety – through modern adhesives are becoming more human friendly, some adhesives still consist of toxic elements. For the application of these adhesives, special conditions should be established. For instance, extra ventilation or respirators for human personnel.

Secondly, the necessity for surface preparation is reviewed. The most common methods for surface preparation are [14]:

- Degreasing – removing all the loosely held dirt with the help of an easily vaporized solvent.
- Abrasion – sandblasting or sandpaper is used for the removal of dirt, oxide layers and other contaminants.
- Chemical treatment – special chemicals are applied to the surface for improved adhesion.

After the surface preparation step, adhesive can be applied to the surface of the component and attachment of the second component is followed. For some bonded joints additional mechanical load should be applied with the aim of improving the quality of joint. On condition that after hardening, the joint passes the quality check adhesive bonding process is considered to be successful. If during quality inspection defects are found, then bonded joint is repaired or scraped and the process starts from the beginning.

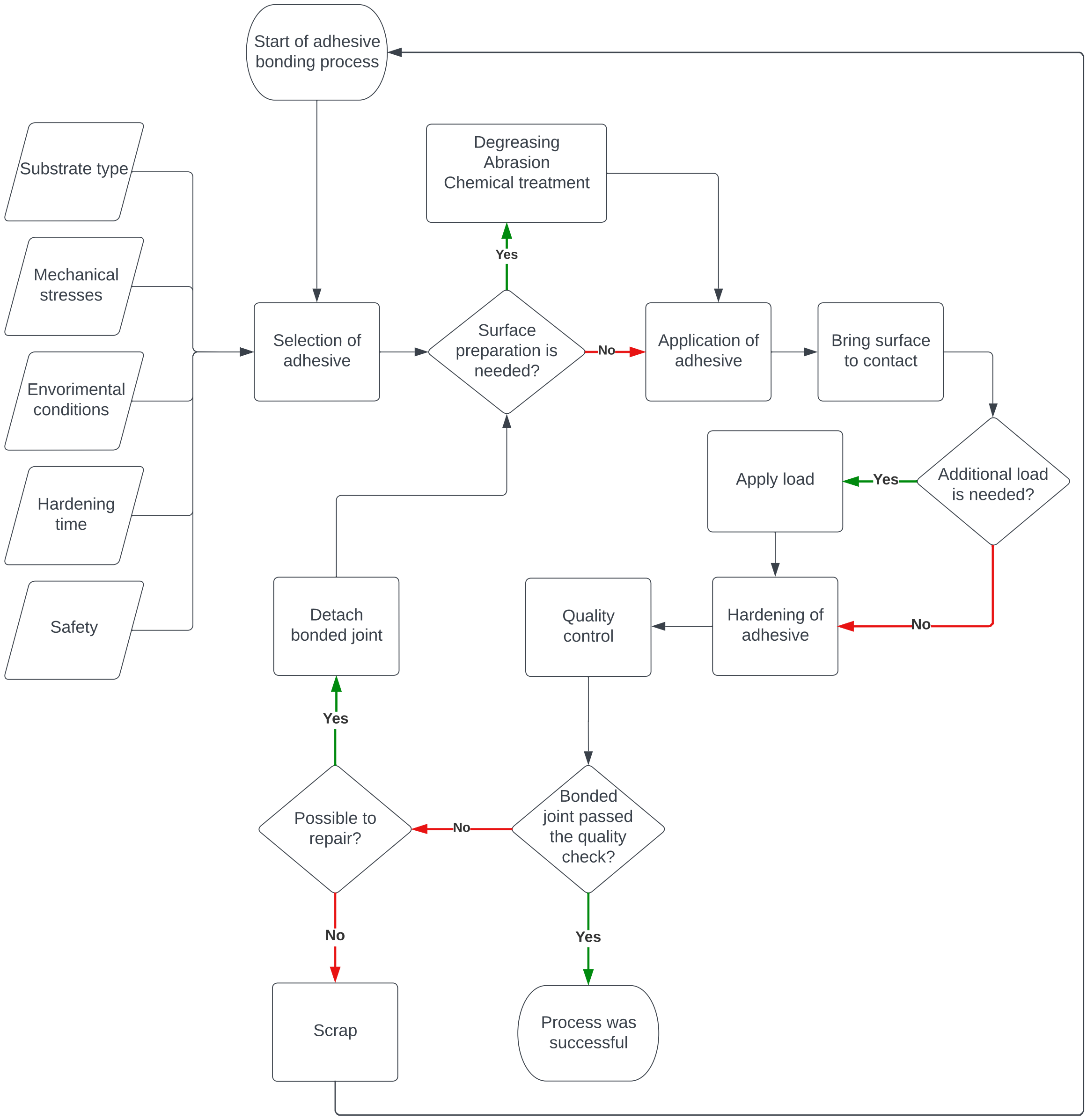


Figure 2.2.1 Flowchart of adhesive bonding process

The assembly flow of the antenna starts with the placement of the PCB into the aluminium frame and affixing of it, after that cables are linked from PCB to the connectors on the bottom side of the unit, and lastly reinforcement is attached to the frame. Succeeding with sub-assembly, the process continues with frame positioning inside of the housing, and then mounting brackets are fastened. During the final assembly step top and bottom covers are joined to the housing using adhesive and screws on the bottom cover are affixed. Before sending the antenna to a customer, it passes 2 tests: functional test and air leakage test. The functional test examines the radio parameters of the antenna while the air leakage test is checking antenna sealing. If the product fails on any test it goes to repair.

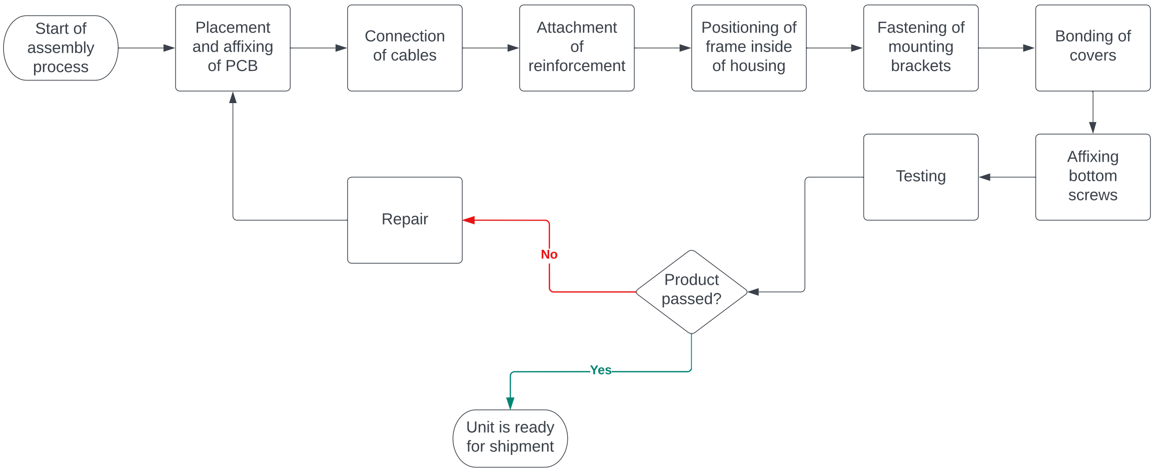


Figure 2.2.2 Flowchart of the assembly process

For this particular antenna type adhesive bonding is used during the assembly process due to following reasons:

- Adhesive will easily fill the gap between the cover and housing, as a result, PCB will be encapsulated from moisture.
- A bonded joint is lighter than the mechanical one, consequently, the mass of the unit will be smaller
- From an aesthetic point of view unseen connection points to which adhesive bonding refers, make a product look final.

3. ROBOTIZATION SUITABILITY ANALYSIS

Currently, there is a vast number of different industrial robots that robot manufacturers offer. The nomenclature of these is constantly increasing. The definition is needed to recognise the meaning of industrial robots. International Standard Organisation (ISO) [15] and various robotics organisations: Association of Advancing Automation [16], The British Automation and Robot Association [17], Japan Industrial Robot Association [18] consider a robot to be a device capable of performing operations automatically, normally done by a human operator and which manipulator is controlled by flexible programming systems. The meaning of a robot will finally be formed by the end effector, which can perform the planned task.

3.1 Robotization justification

In the current production process dispensing of the glue on the covers is done by workers using a manual dispensing gun. This process has the longest operational time of 160 - 180 seconds per cover and commonly manually dispensed covers do not obtain the desired quality because workers cannot provide a continuous glue flow into the covers' grooves, leading to a repeat of operation. Additionally, pressing dispensing gun's trigger requires constant hand tension, which can lead to injuries in the long-term perspective.

Figure 3.1.1 Manual dispensing gun [19]

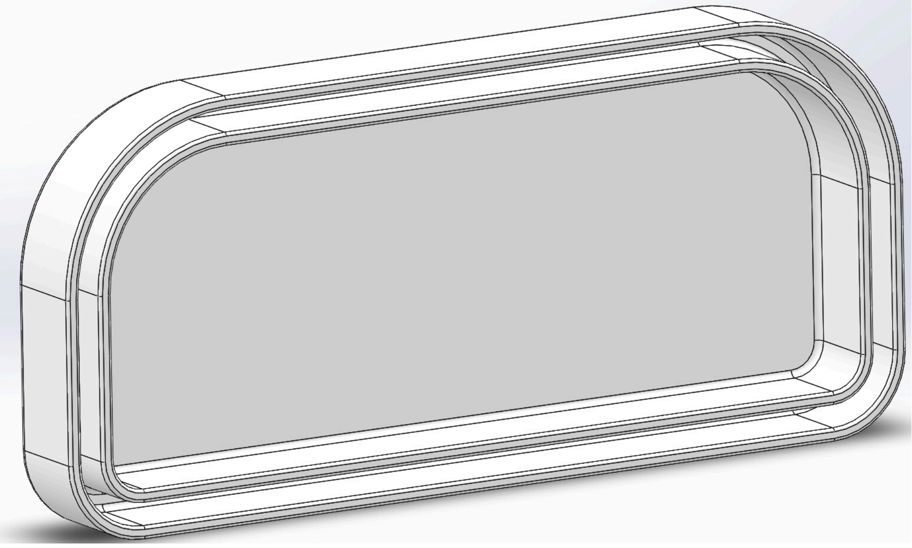


Figure 3.1.2 Cover of antenna

This issue can be solved with the implementation of the robot. Firstly, the robot will secure that flow of the glue is continuous. Secondly, robotization of this process in future will reduce consumable costs because every time, the robot will apply only the needed amount of glue. Thirdly, if a robot does this operation, it will minimise man labour and workers will have more spare time for completing other operations. And finally, robots will always deliver consistent quality.

However, a feasibility analysis of assembly process robotization should be conducted before robot implementation. The analysis results will show if there is a real need for robotization.

As a basis for feasibility analysis author took a template developed by the Innovative Manufacturing Engineering Systems Competence Center. An analysis is generic and consists of four categories: technology, products, objectives and situation in the company, experience and opportunities of the company. Each category consists of 5 questions and is distributed based on pre-defined answer points. The Sum of points from each category will show the expediency of robotization. In the end, all the points will be summarised and an aggregate decision will be made.

Table 3.1.1 Assessment within the category

Range of points	Conclusion
5-12	Robotization is not needed
12-18	Moderate expediency
18-25	Robotization is essential

Table 3.1.2 Aggregate assessment

Sum of points	Conclusion
5-40	No need
41-55	Moderately necessary
56-75	Reasonable enough
76-100	Very expedient

Table 3.1.3 Feasibility analysis of assembly process robotization

Technology	Handling of assembly components		
	[✓ No experience (1 point)]	Solution is developed (3 points)	Solution is used for assembly automatization (5 points)
	Feeding of assembly components		
	[✓ No solution (1 point)]	Solution exists and is implemented to some extend (3 points)	Different types of feeding mechanisms are used (5 points)
	Is it possible to use group or standard technology solutions?		
	No (1 point)	[✓ For some extend (3 points)]	Possibilities for optimizing the assembly process have been analyzed (5 points)
	Is there a need for takt time synchronization?		
	No (1 point)	For some extend (3 points)	[✓ It is needed (5 points)]
	Is there a demand for decreasing cycle time?		
	No (1 point)	For some extend (3 points)	[✓ Yes (5 points)]
TOTAL:	**15 points**	**CONCULUSION:**	**Moderate expediency**

Products	Formation level of product families		
	[✓ Weak (1 point)]	Average (3 points)	Large (5 points)
	Design for cost-effective assembly is part of product development process?		
	No (1 point)	[✓ Conditionally possible to add (3 points)]	Yes, it already works (5 points)
	Number of products in assembly process		
	Small (individual production) (1 point)	[✓ Medium (serial production) (3 points)]	Large (large series or mass production) (5 points)
	Nomenclature of products		
	Large (individual production)	[✓ Medium (serial production) (3 points)]	Small (large series or mass production)

	(1 point)	🟩	(5 points)
	Robotization will disturb production rhythm?		
	Yes (1 point)	For some extend (3 points)	[✓ No (5 points)]
TOTAL:	**15 points**	**CONCULUSION:**	**Moderate expediency**

Objectives and situation in the company	Is there a need for new labour?		
	No need for new labour (1 point)	[✓ Need exists (3 points)]	There is a shortage of labour (5 points)
	Improvement of product quality is needed?		
	Not needed (1 point)	Need exists (3 points)	[✓ Urgently needed (5 points)]
	Assembly operation is a bottleneck?		
	No (1 point)	[✓ Occasionally (3 points)]	Constant bottleneck (5 points)
	Increase of production output		
	Not needed (1 point)	[✓ Need exists (3 points)]	Urgently needed (5 points)
	Current assembly equipment and process are amortized or outdated		
	No (1 point)	[✓ There is a need for updated (3 points)]	Updated is urgently needed (5 points)
TOTAL:	**17 points**	**CONCULUSION:**	**Moderate expediency**

Experiences and opportunities of the company	Experience in digitalization		
	Slight (1 point)	Some experience (3 points)	[✓ Several solutions are implemented (ERP, MES, CAD, etc.) (5 points)]
	Experience in robotization		
	[✓ No experience (1 point)]	Company uses 1-2 robots (3 points)	Company has broad knowledge and experience (5 points)
	Financing opportunities		
	Few, state support is needed (1 point)	[✓ Average (3 points)]	Sufficient to implement even large-scale projects (5 points)
	Experiences in the implementation of investment projects		
	Slight (1 point)	[✓ Average (3 points)]	Large (5 points)
	Experience and competence of robot operators and technicians		
	[✓ Few (1 point)]	Average (3 points)	Great skills and knowledge (5 points)
TOTAL:	**13 points**	**CONCULUSION:**	**Moderate expediency**

Table 3.1.4 Assessment results within the categories

Category	**Conclusion**
Technology	15 points (60%) - Moderate expediency
Products	15 points (60%) - Moderate expediency
Objectives	17 points (68%) - Moderate expediency
Opportunities	13 points (52%) - Moderate expediency

Table 3.1.5 Aggregate assessment results

Sum of points	Conclusion
62	Reasonable enough

Based on analysis results, the company demonstrated interest towards robotization, understanding benefits of it and showed a desire for development, despite a lack of experience. Additionally, the company is ready to reorganise already established internal processes. From now on, the topic of robotization should be included in all phases of the product life cycle, especially during the product design stage. To conclude, the analysis confirmed the reasonable necessity for robotization of the company's assembly process.

Before moving forward, the robot job should be described. The main goal of robotization is to make the robot precisely dispense one component glue on the two covers. From a robot operator's perspective, they should place lids into the fixture, which is located in front of the robot, scan QR-codes inside of the covers, which contain the serial number, and based on information from the QR-code robot should start dispensing the glue. After every finished program robot should take a photo of dispensed covers and save it to the cloud with a serial number. To avoid movement of the fixture, the fixture should be affixed to the floor.

3.2 Collaborative robots versus industrial robots

Both industrial and collaborative robots are suitable for fulfilling needed goal, but each has advantages and disadvantages. Table 1.6 shows a comparison between those.

Table 3.2.1 Qualitative comparison of collaborative robots and industrial robots

Features	**Collaborative robots**	**Industrial robots**
Price	Low	High
Footprint	Small	Big
Return on Investment (ROI)	Quick	Slow
Reprogramming	Easy and relatively quick	Hard and time consuming
Safety equipment	Built-in	Purchased separately
Payload	Small	High
Maintenance	Quicker and cheaper	Slower and more expensive
Usability	High	Low
Precision	High	Low
Operation speed	Slow	High
Mobility	High	Low
People competence	Low	High

If we compare collaborative robots with industrial robots within the framework of above-mentioned features, we will see that cobots (collaborative robots) are more relevant. Cobots are less expensive, which means that the Return on Investment (ROI) period is smaller, they do not occupy a lot of floor space, are easily reprogrammable, can work within the same environment as production workers and have a lower maintenance cost. For small and medium-sized enterprises (SMEs), producing a high mix of products with low volumes, the ability to adjust cobots for completing other tasks and straightforward relocation is a significant benefit. European Union regulations cause cobot suppliers to follow specific safety standard [20] to mitigate the risk of human injury. Standard describes the necessity of implementing safety features into robot software and hardware by the robot manufacturer. However, not always built-in safety features are sufficient. A risk assessment should be conducted to establish the need for additional safety equipment. Last but not least, the competence of people interacting with cobots can be grown faster, as cobots are more user-friendly and do not frighten people due to successful industrial design.

Regarding glue dispensing, accuracy can become a problem as after performing a needed task for a long time, the cobot can start completing the required program less precisely. Fortunately, this risk can be mitigated by regular maintenance and implementation of camera calibration into the program. Additionally, extra ventilation may be considered part of occupational safety and health requirements due to the possible toxicity of the glue.

Currently, cobots can be found across numerous industries: automotive, aerospace, agriculture, electronics, healthcare etc [21]. Cobots are ideally suitable for repetitive tasks such as machine tending, quality control, material handling, assembly etc. Implementation of cobots helps to reduce incidents at workplaces and improve quality. Moreover, there is a constant increase in the cost of manual labour and a decrease of people available on the market, so the deployment of collaborative robots will alleviate these risks in the long run for companies. Governments are also supporting and stimulating enterprises to robotize their productions as a part of the Fourth Industrial Revolution to help enterprises stay competitive on the market [22].

Next Move Strategy Consulting forecasts the collaborative robot market to be worth 1990.2 millions of dollars by the end of 2030, growing at a Compound Annual Growth Rate of 11.8% between 2022 and 2030 [23]. This can indicate that more companies are expected to implement cobots for their needs. Due to the constant development of cobots, cobot manufacturers will deliver cobots with improved characteristics to the market, which will fulfil occurring requests from customers. Finally, technology will become even cheaper and more affordable for enterprises.

3.3 Robotic assembly in Human-robot collaboration

The latest manufacturing industry trends show rapid robotisation development within the Industry 4.0 scope. However, not all activities of human labour can be replaced by a robot. On the other hand, acceleration of the production process can be achieved by partial robotization. Human-robot collaboration (HRC) is a process of purposeful, mutual and safe activity of humans and robots, which appeared due to partial robotization. To understand the possibilities of HRC's existing assembly process, products should be evaluated within HRC automation.

For this particular work author chose a methodology developed by Malik [24]. Methodology studies product and process based on six assessments: Component (Cp), Mounting (Mt), Feeding (Fd), Safety (Sf), Fastening (Ft) and Miscellaneous (Misc). Considering all of the potential of HRC for the assembly step is calculated. Malik suggests examining human-robot collaboration if the potential is above 70%.

The author divided the studied product into six parts: frame with affixed PCB #1, housing #2, brackets #3, bolts #4, covers #5, and bottom screws #6 (Fig 1). For this case, a frame with an affixed PCB is considered one part due to the complexity of their subassembly.

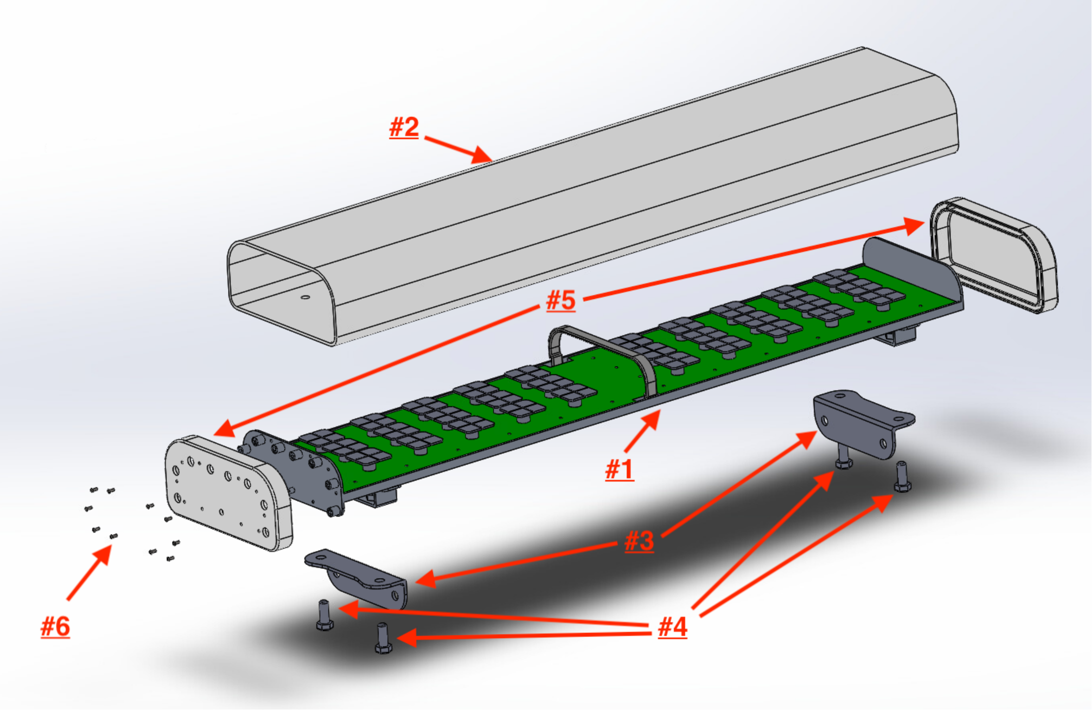


Figure 3.3.1 Components used for evaluation

Table 3.1.1 Evaluated HRC potential for each task

Component name	**Cp**	**Mt**	**Fd**	**Sf**	**Fs**	**Misc**	**Potential**
Frame with PCB	25	75	25	50	100	50	54,2%
Housing	68,75	75	25	50	75	33,3	54,5%
Brackets	100	50	12,5	50	75	66,6	59,0%
Bolts	100	50	25	75	75	66,6	65,3%
Covers	75	75	87,5	75	50	83,3	74,3%
Bottom screws	100	75	37,5	75	75	66,6	71,5%

The further author conducted calculations described by Malik. Results showed that the assembly of covers and fastening of bottom screws could be done by a robot, while a human should execute all other tasks. Onwards author will focus only on the assembly of covers.

Human-robot interaction is a field of study that focuses on how humans and robots can work together and communicate. Studies show that human behaviour changes while interacting with robots. This factor is critical as successful execution of a task for both humans and robots is pending on that [25]. The ultimate goal is to create a seamless and intuitive interaction between humans and robots, allowing the two to work together efficiently and effectively.

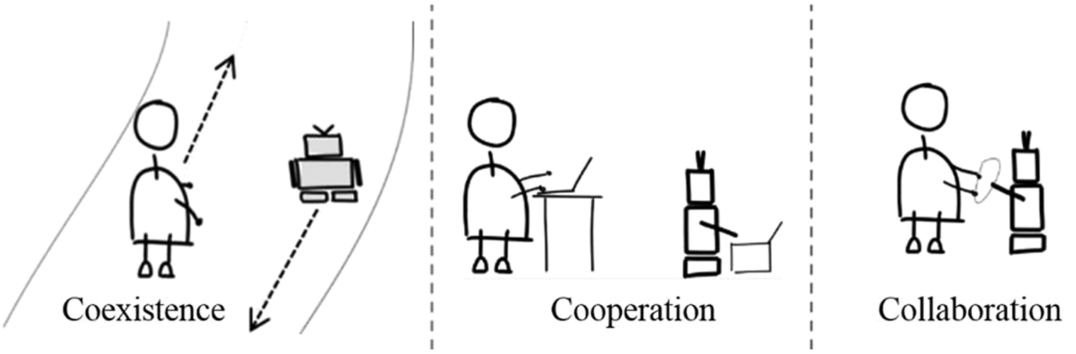


Figure 3.3.2 Types of human-robot interaction [26]

Even though collaborative robots are meant to work together with humans, interaction levels can differ depending on the application. Interaction between robots and humans is divided into the following classes: coexistence, cooperation and collaboration.

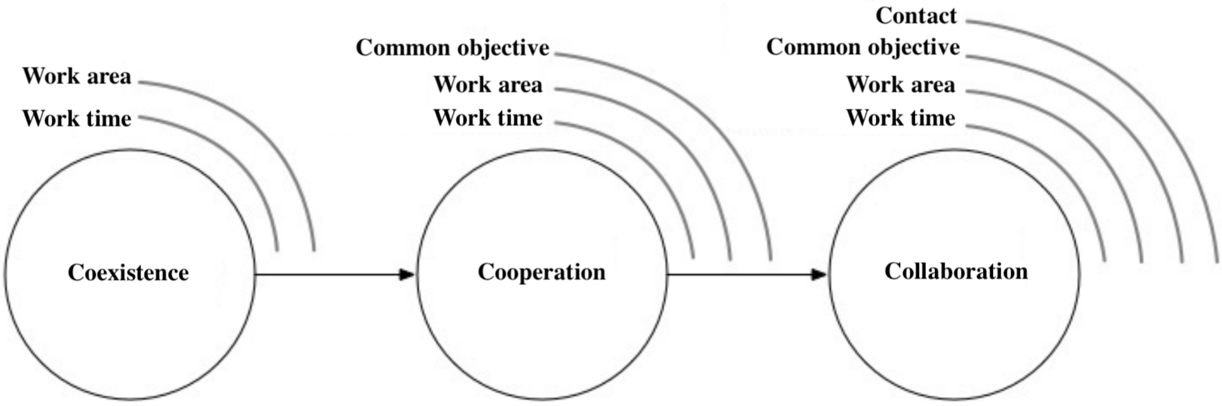


Figure 3.3.3 Characteristics of classes for human-robot interaction [27]

Classes are determined by specific characteristics: work time, work area, common objective, and contact. The time when humans and robots interact in the common work area is considered work time, representing coexistence. For defining cooperation, both person and robot should have a common objective of interaction and shared work time and work area. If during cooperation, direct contact between robot and human occurs, then this kind of interaction can be considered as collaboration [27].

In the gluing process, the interaction between human and person is determined as a collaboration due to the necessity of glue cartridge change, as described in the following chapters. Figure 3.3.4 describes more preciously the roles of human and robot within the process.

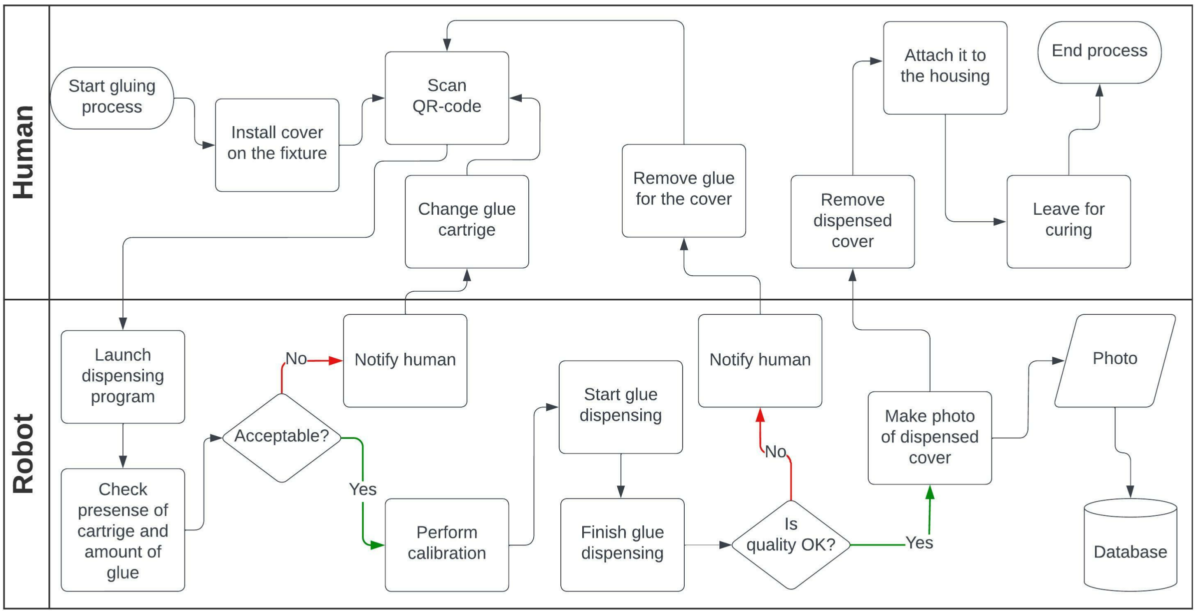


Figure 3.3.4 Distribution of tasks between human and robot during gluing process

Safety is a much relevant topic which should be considered for HRC. The theory describes three main concepts for securing safety in HRC:

- Controlled collision – if a collision between a human and a robot appears, it is controlled. In other words, it is safe for both humans and machines. The idea of this method is to limit forces which impact humans.
- Active safety – different sensors (proximity, force etc.) or surveillance systems are connected to the robot and detect collision before it happens. If the active safety system is triggered, the robot stops any movement.
- Adaptive safety – due to sensors, the robot gets the signal of a possible collision and applies corrective actions to avoid it without stopping the primary operation.

Risk assessment results are needed to define the necessity of additional safety equipment. Auspiciously, all cobots are supplied with a safety system that can control collision. Risk assessment is not in the scope of this particular work, so the author will move further, taking into account only the collision control system supplied by the cobot manufacturer.

4. ROBOTIZED WORKSPACE DESIGN

4.1 Best robot selection

Robots suitable for industrial applications can be classified by their mechanical structure. Each structure has its own technical capability and application area. The most common robot structures are:

- Linear – consists of three sliding joints, capable of moving only in a linear direction. Most suitable for loading, transporting, palletizing tasks.
- Cylindrical –a vertical pole relative to which the arm is moved in and out, up and down, around the pole—typically used for loading and unloading assignments.
- Articulated or joint armed – vertical column is connected to the rotatable base on one side and rotary joint on the other. The number of rotary joints can be different and each joint adds one extra degree of freedom. Robot recalls human arm and due to its flexibility, is the most widely used robot type in the manufacturing industry. Robots can be used for assembly, welding, painting etc. operations.
- Selective Compliance Assembly Robot Arm (SCARA) – consists of two arms connected together with vertical rotational joint and attached to the base. The robot has four-axis and freedom of movement along the X-Y-Z axes, rotating around the Z axis. Mainly used for assembly works [28].

For the glue dispensing process author chose a joint-armed robot because of its flexibility and suitability for different types of applications.

Before moving forward, the working concept of joint-armed robots should be explained. The system consists of three units: the robot itself, a robot controller and a teach pendant, which is not vital. The robot is the most visible part of the system and is responsible for making various mechanical movements. The robot controller is in charge of gathering data from the robot's sensors, processing that data, and then instructing the actuators to move and perform the tasks. A computer program or a human operator can also provide input to the controller, instructing it on what tasks and moves the robot should make [29]. The teach pendant is a hand-held device typically consisting of buttons and a display connected to the robot controller and used for manual programming of the robot. Additionally, the teach pendant is needed for manual control of the robot and troubleshooting the robot's problems [30]. Depending on the robot manufacturer, both the robot controller and the teach pendant can be included in the final price of the robot or sold separately.

Figure 4.1.1 Teach pendant, robot controller and robot [31]

The market of joint-armed robots is vast, different suppliers provide robots for various applications. Before choosing a particular robot supplier and model, it is essential to conduct research and evaluation of robot models. The evaluation phase should include a comparison of robots within specific technical parameters. If a comparison of technical parameters does not show the preferable option, other parameters, such as cost, previous experiences, and availability of auxiliary devices should be considered.
For comparison author has chosen the following parameters:

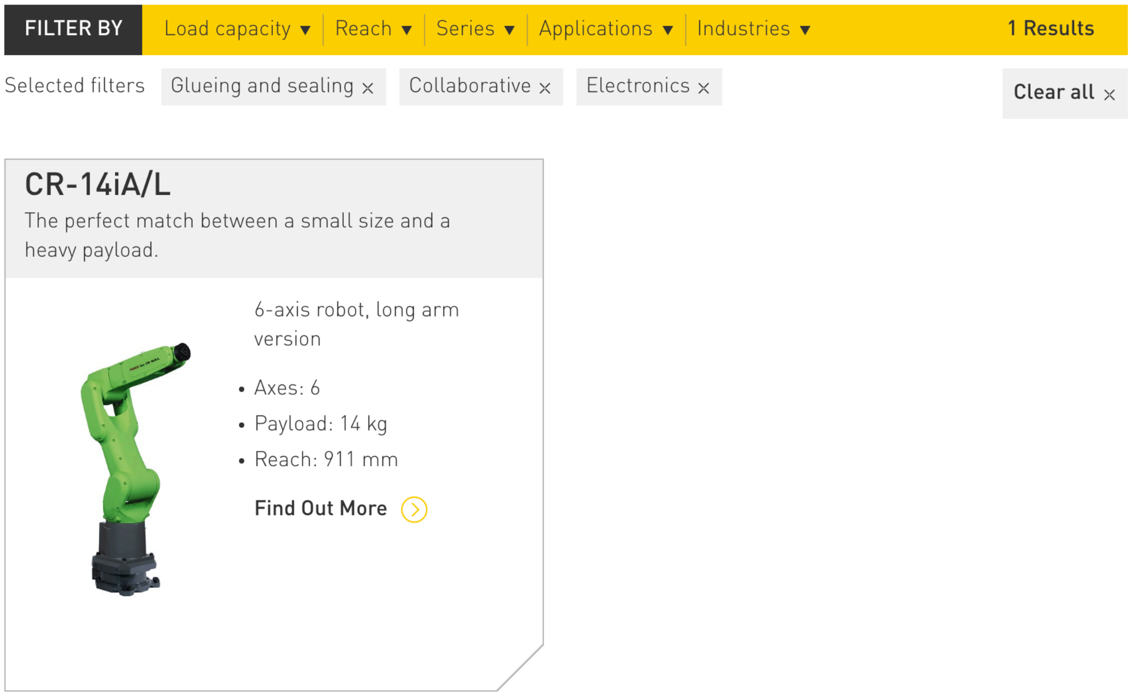
- Footprint on the production floor – the amount of production area that the robot will occupy
- Payload - maximum weight which the robot is capable of lifting up
- Working range - the area in which the robot can access
- Number of axes - increased number of axes enables the robot to access a more significant space area
- Movement speed - shows how quickly the robot can relocate the end of its arm
- Accuracy – shows how preciously a robot can reach a prescribed point
- Repeatability - shows how accurately a robot can revert to a predetermined location

Within the framework of this comparison the author decided to focus on the robots from 5 different suppliers:

- Fanuc Co. Ltd.

- ABB Ltd.
- Yaskawa Electric Corporation
- Universal Robots A/S
- KUKA AG

These suppliers have been chosen as they are the biggest robot manufacturers on the market and provide convenient robot selection options on their web pages.



FILTER BY
Load capacity ▾
Reach ▾
Series ▾
Applications ▾
Industries ▾
1 Results

Selected filters
Glueing and sealing ×
Collaborative ×
Electronics ×
Clear all ×

CR-14iA/L

The perfect match between a small size and a heavy payload.

6-axis robot, long arm version

- Axes: 6
- Payload: 14 kg
- Reach: 911 mm

Find Out More

Figure 4.1.2 Robot finder by Fanuc Co. Ltd. [32]

The selection was made using three main parameters:

- Application area: Dispensing/Gluing
- Industry: Electronics
- Robot should be collaborative

Table 4.1.1 Technical parameters of selected joint-armed robots [33] [34] [35] [36] [37]

	Fanuc CR-14iA/L	ABB GoFa™ CRB 15000	Yaskawa Motoman HC10DTP Classic	Universal Robots UR10e	KUKA LBR iiwa 14 R820
Footprint (mm)	297x235	165x165	215x215	190x190	310x310
Payload (kg)	14	5	10	12.5	14
Working range (mm)	911	950	1200	1300	820
Number of axis	6	6	6	6	7

Movement speed (mm/s)	500	2200	2000	1000	2500
Accuracy (mm)	No data	No data	No data	0.1	No data
Repeatability (mm)	±0.01	±0.05	±0.05	±0.05	±0.15

To find out the most suitable robot, the author rated each technical parameter within each category with a grade from 1 to 5, where 5 was the highest result and 1 was the lowest; after that, all grades were summed up to highlight the winner. To make the comparison more relevant category "accuracy' was not included as there needed to be more data about all the robots.

Table 4.1.2 Relative comparison of selected cobots

	Fanuc CR-14iA/L	ABB GoFa™ CRB 15000	Yaskawa Motoman HC10DTP Classic	Universal Robots UR10e	KUKA LBR iiwa 14 R820
Footprint	2	5	3	4	1
Payload	5	2	3	4	5
Working range (mm)	2	3	4	5	1
Number of axis	4	4	4	4	5
Movement speed	1	4	3	2	5
Repeatability	5	4	4	4	3
Sum	**19 (5th)**	**22 (2nd)**	**21 (3rd)**	**23 (1st)**	**20 (4th)**

The comparison showed that UR10e by Universal Robots is the most applicable cobot for the previously described task. Based on information from open sources, the price for UR10e starts from 35,500 EUR [38]. A robot controller together with a teach pendant are also included in the price. Additionally, the cobots manufactured by Universal Robots are current market leaders [39], so they recommended themselves as reliable and effective. Last but not least, a wide variety of standard end effector tools are available for Universal Robots [40].

4.2 End of Arm Tooling and axillary equipment selection

End of Arm Tooling (EOAT) is a crucial part of robot setup as it helps the robot to perform the needed task. There are 2 main types of EOATs for the gluing process. The first one consists of an EOAT, hose, container with glue and pump. The idea behind this concept is simple, the pump pumps glue from a container through the hose into EOAT and while moving, the robot dispenses the glue. This system has a lot of benefits but also it has one big downside. If for some reason air gets inside the hose and glue hardens, it starts to act as a cork for not hardened glue and the dispensing process becomes impossible. As a repair the whole system should be disassembled and cleaned, furthermore, it is not always possible to clean the hose from glue and as a result, a new hose should be purchased. Additionally, if a lengthy production stoppage occurs, glue inside the container can start losing its properties, leading to the scrapping of material and additional costs for the company.

Figure 4.2.1 UR10 with hose and EOAT for glue dispensing [41]

For this work, the author will proceed with the second type of EOAT for gluing process. The most significant difference from the previous type of EOAT is the elimination of the pump from the system and the presence of a glue cartridge in close proximity to the dispensing nozzle. This type of EOAT is ideal for high-mixed, low-volume production as it is available for quick changeover of gluing cartridges in case of glue hardening inside the cartridge.

A 310ml plastic cartridge is a widely used packaging solution for one-component glue. The manual dispensing gun mentioned previously is designed to work with these. From a supply chain perspective, it would be beneficial to keep the type of glue package for the robotized solution the same. It will keep the glue purchase price the same and the need to search for different suppliers will not be relevant.

Initially, the author selected to develop EOAT for gluing process by himself. Figure 4.2.2 shows the prototype designed by the author. Also, the author described the principles of work for this tool. After the dispensing program is launched, the robot sends a signal to the servomotor, which starts to rotate. Due to worm-gear rotary movement converting into linear movement and the piston starts moving towards the cartridge with glue. After touching the cartridge, the piston presses glue through the nozzle of the cartridge. As the servomotor constantly exchanges signals with the robot, the robot knows the amount of glue left in the cartridge. It can inform the operator if there is not enough glue for dispensing. Additionally, relying on a servomotor signals robot can adjust dispensing speed based on the resistance of piston movement. As described, this EOAT is not a standard solution for UR. Integrating it into the UR program environment could become very challenging, so the author considered giving up that idea.

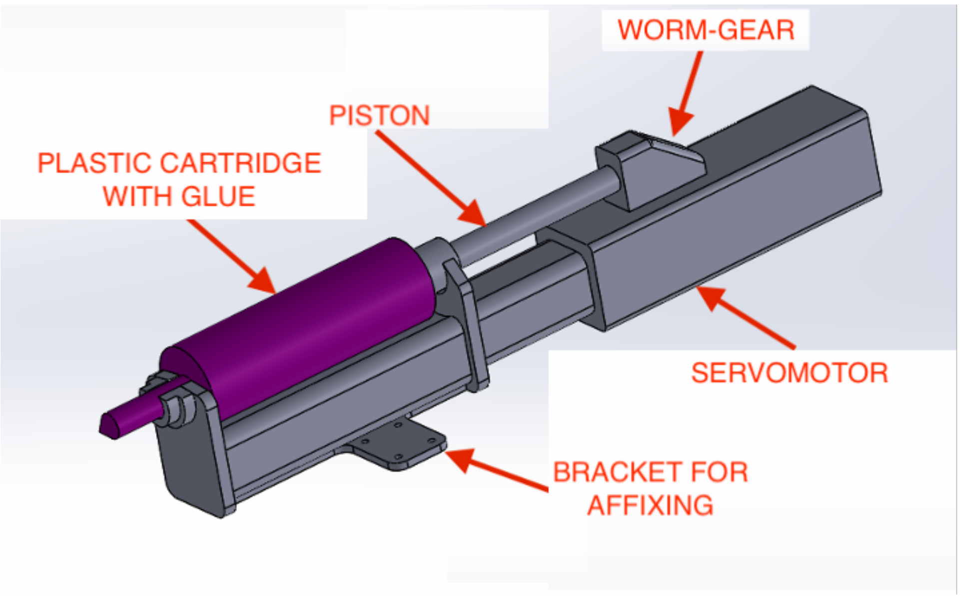


Figure 4.2.2 EOAT developed for glue dispensing

Nevertheless, later the author decided to check EOATs for the gluing process offered on the market and found EOATs designed especially for the UR series of robots and 310 ml glue cartridges.

Figure 4.2.3 FD 310 on the left and FD 400 on the right [42]

FD 310 and FD 400, manufactured by AIM Robotics, are material dispensing tools with the native support of Universal Robots [42]. Both tools are designed for 310 ml cartridges. The weight of the tools without cartridges is m = 0,8 kg and m = 1,7 kg [43], respectively. According to the manufacturer, no additional programming is needed to make tools visible for the robot. Tools are supplied with specially developed software for the UR programming environment, which will make programming less complex. The difference between FD 310 and FD 400 models lies in their precision and application area. Besides, FD 310 requires an external air supply for precise glue feeding. Due to that, materials such as adhesives and polymers are acceptable for dispensing using this particular model. As FD 400 does not require an additional air supply, it is primarily suitable for liquid materials such as grease, acrylic or silicone. The manufacturer claims that the precision of FD 310 is +/- 1% and the precision of FD 400 is +/-10%. The price for FD 310 starts from 6,000 EUR [44] and for FD 400 from 5,650 EUR [45]. Considering the above facts, the author chose FD 310 as the main EOAT for gluing dispensing.

Based on the initial description of a task for a robot, the robot should be able to make pictures of covers dispensed with glue. For this operation camera for the robot is needed. Also, the camera can be used for automatic adjustments of the robot’s movements during glue dispensing. For this reason, the author has chosen Cognex DataMan 370 [46], the weight of the camera is m = 0,2 kg. This camera is not only able to take a photo, but also it is capable of reading QR codes. In the future, scanning QR codes with a scanner from covers can also be automated, so operators will only have to press the button to launch the dispensing program and the robot will automatically detect the cover in front of it. Additionally, relying on machine vision technology, the camera can distinguish poorly dispensed covers. The price for Cognex DataMan 370 camera starts from 1250 EUR [47].

Figure 4.2.3 Cognex DataMan 370 camera [46]

An additional bracket should be developed to have the glue dispensing mechanism and camera attached to the robot. In order to minimize the total mass of the assembly bracket must be made from durable, lightweight material. To solve this problem, the author proposes to modify the bracket for attaching the dispensing tool to the robot. Figure 4.2.4 shows the solution developed by the author, weight of which is m = 0,7 kg.

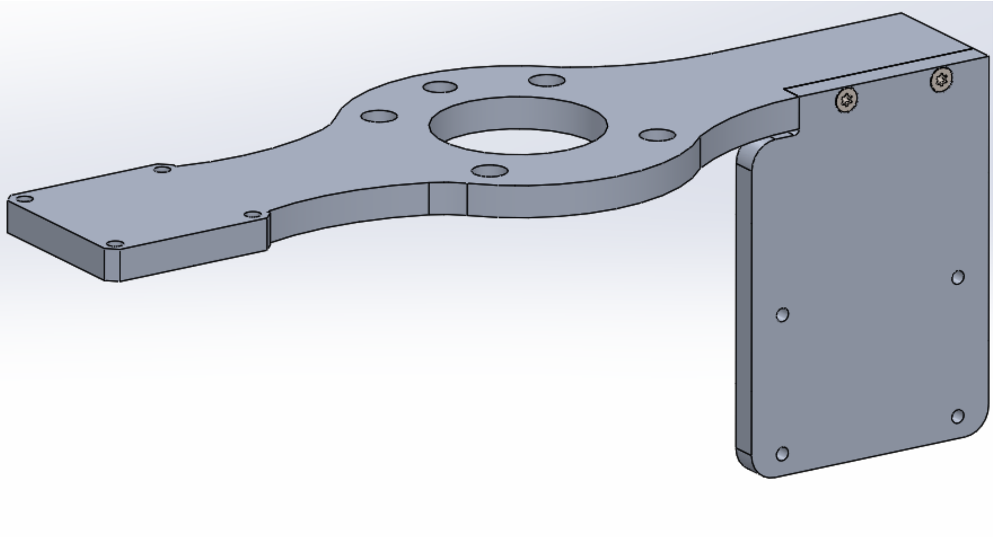


Figure 4.2.4 Bracket for camera and dispensing tool

Knowing the weights of EOAT components, it is possible to calculate the approximate total weight of the EOAT. The weights of fasteners and required cables are not included in this calculation.

$$m_{total} = m_{tool} + m_{bracket} + m_{camera} + m_{glue} = 0{,}8 + 0{,}7 + 0{,}2 + 0{,}5 = 2{,}2\ kg \qquad (4.1)$$

where m_{total} - total mass of EOAT, kg,

m_{tool}- mass of tool, kg,

$m_{bracket}$ - mass of bracket, kg,

m_{camera}- mass of camera, kg,

m_{glue}- mass of glue cartridge, kg.

Calculation showed that the total mass of EOAT is lower than the maximal payload of UR10e, which means that the robot is suitable for lifting for the given EOAT.

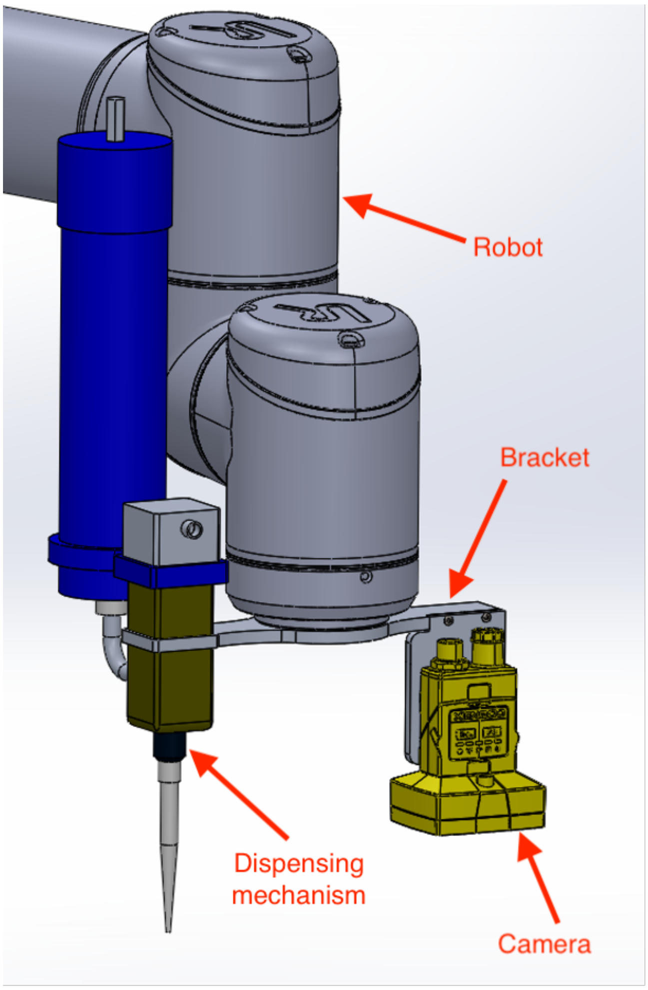


Figure 4.2.5 Concept of EOAT with camera

4.3 Workplace layout and production cycle design

Before making a workplace layout, it should be decided how the robot will be mounted to the floor. One of the reasonable solutions is to affix the robot not to the floor but to the unique pedestal. The pedestal can look like a box-shaped frame on top of which the robot will be mounted. Inside the pedestal, the robot controller will be located. Also, the pedestal should have wheels for transportation if there is a need to relocate the robot in the future. The pedestal will be supplied with stands on the threaded shafts, by screwing them - the length will be changed to provide horizontality to the robot and avoid the production floor curvature factor. Moreover, the pedestal has to have a place to keep the teach pendant when it is unused. Finally, the robot's emergency stop button is needed to provide the operator with an opportunity to emergency shutdown the robot in case of danger. The button needs to be located within reach of the operator.

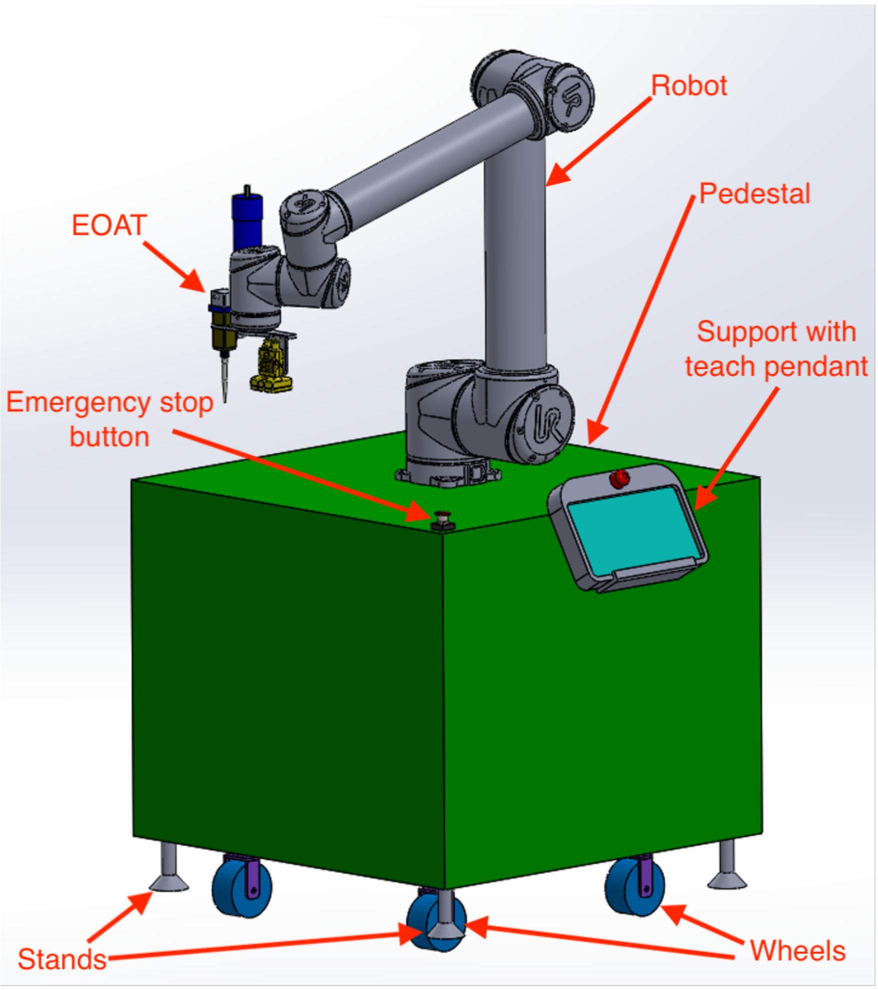


Figure 4.3.1 Isometric projection of the pedestal

The operation of the system described above requires an electricity supply, a compressed air supply is especially needed for EOAT and a network connection is needed to connect the robot to the database for photo storage. Figure 4.3.2 shows the schematic connection of all required devices for successful system functioning. Network, electricity and air cables should run from the ceiling to prevent accidental pull-out of them caused by the movement of operators. Also, this connection pattern will facilitate the process of robot reconnection after the location change, as only the connection of three cables is needed.

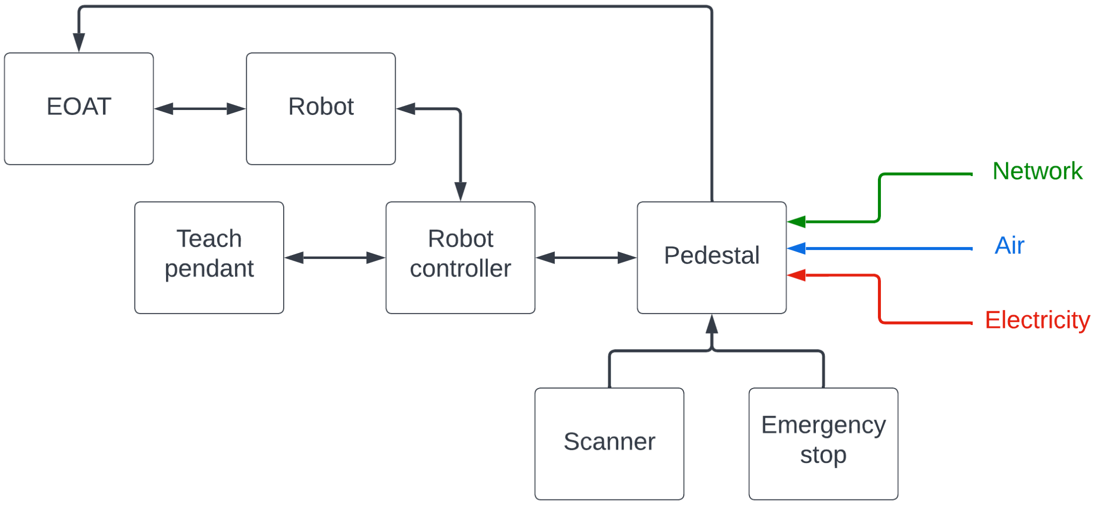


Figure 4.3.2 Connection diagram

All necessary connectors for cables should be located on the backside of the pedestal. Those include a 380V socket for the power supply, an air filter regulator for compressed air, Ethernet, USBs and an additional 220V socket, which can be used for laptop charge during the robot's programming.

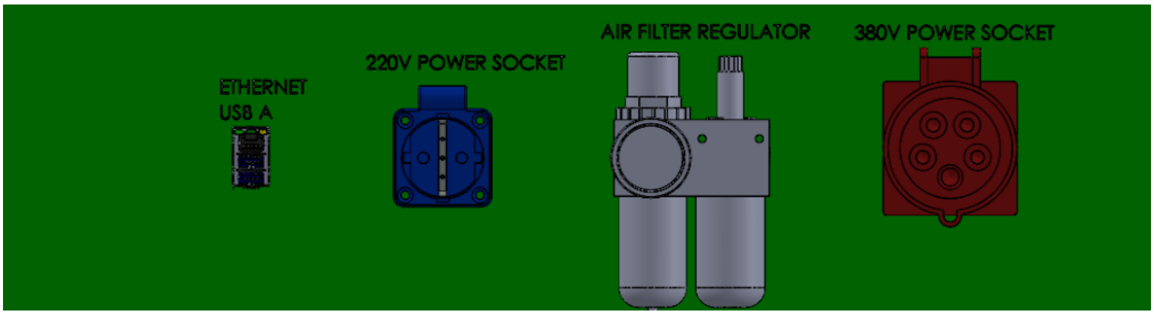


Figure 4.3.3 Connection interfaces on the backside of the pedestal

Next, for dispensing of covers, a table with a fixture must be placed in front of the robot. Affixing the table to the pedestal will not only avoid possible wobble of the table, but also it will make the top surfaces of the table and pedestal parallel to each other. Additionally, a barcode reader is required for the robot program launch based on the initial robot job description. The author decided to choose Voyager 1250g barcode reader by Honeywell, a price for which starts from 120 EUR [48]. On top of that, the author added the storage shelf to lower the risk of cover or glue cartridge shortage during production process. Spare covers and glue cartridges will be stored on the shelf nearby the robot, so an operator will save time searching for them.

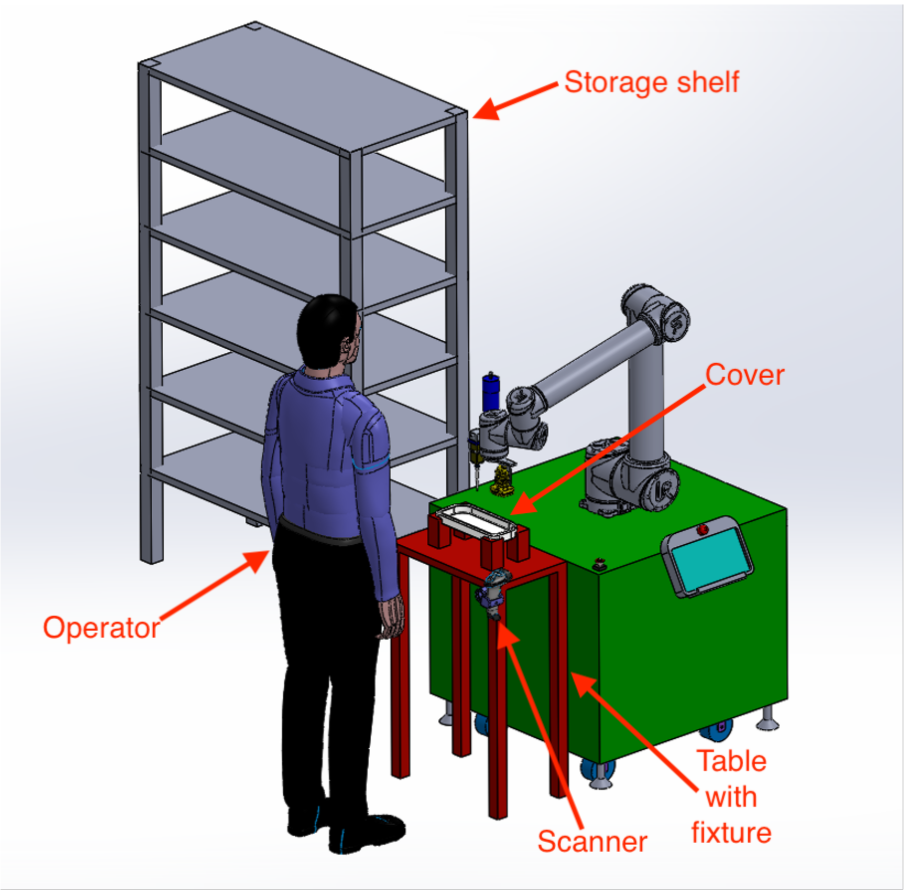


Figure 4.3.4 Isometric projection of robotized workspace

4,45 m2 of free production floor area is needed to implement the workspace designed by the author. The workspace design developed by the author is general and is not reflecting the production floor peculiarities of each company, thus some variances during actual implementation are acceptable.

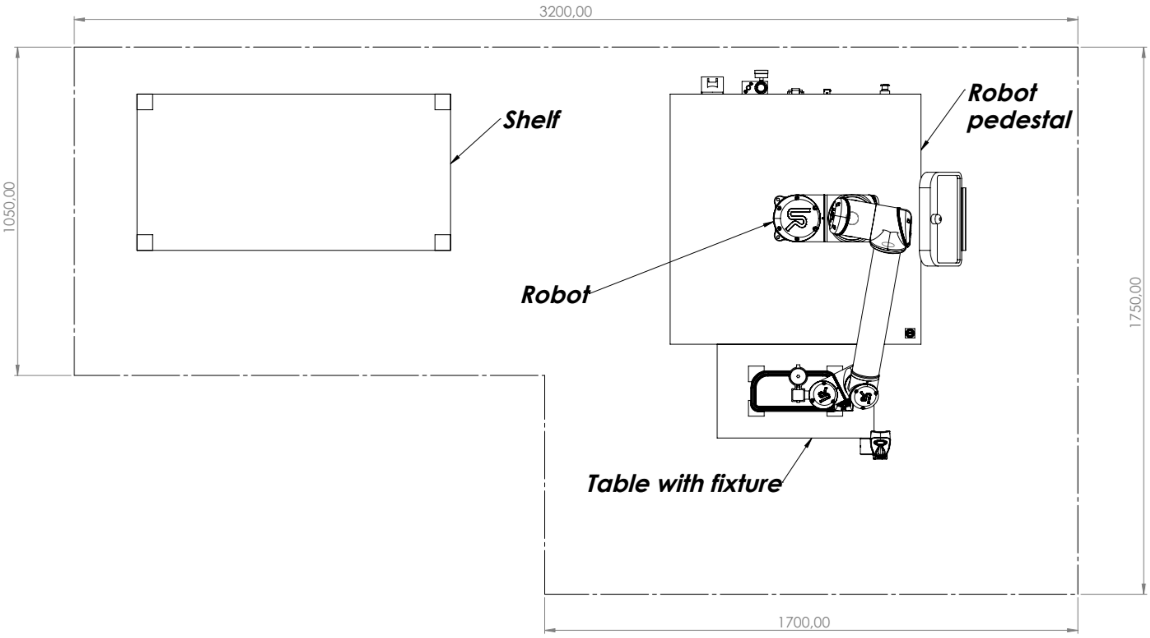


Figure 4.3.5 Top view of robotized workspace

The production cycle can be determined as a series of tasks that are involved in the production of a product. Good production cycle design is essential as it determines how efficiently the work is carried out. Task duration is one of the primary metrics for estimating the efficiency of the designed production cycle. A shorter task duration generally indicates that the process is running more efficiently and that more units can be produced in a given period of time.

The production cycle of the robotized gluing process designed by the author will include both manual and automated labour, and contain the following tasks:

- Operator places cover on the fixture.
- Operator takes a scanner, scans the QR code on the cover and puts the scanner back.
- Robot starts program execution from home position
- Robot checks the presence of glue cartridge and amount of glue. If the cartridge is installed and the amount of glue is acceptable for dispensing, the robot continues with the next step. If the cartridge is not installed or the amount of glue is insufficient, the robot notifies the operator and he or she changes the glue cartridge and relaunches the program.
- Based on the amount of glue in the cartridge, the robot makes calculations and adjusts the program's parameters.
- Robot moves towards cover and stops approximately 15 cm above it.
- Robot starts searching for reference points through a camera. After finding all the needed reference points, the robot adjusts the program.
- Robot moves to the start position of a glue dispensing operation.
- Robot starts to dispense glue while moving along the pre-defined path.
- After finishing dispensing, the robot moves up and visually analyzes the quality of the dispensed glue. If the robot accepts the dispensed cover, it takes a photo of the dispensed cover and saves it to the database. If the camera distinguishes a poorly dispensed cover, a relevant message will be shown on the teach pendant for the operator and he or she will troubleshoot the cover.
- Robot returns to the home position and stops execution of the program.
- Operator removes the cover from the fixture and attaches it to the housing.

It is possible to determine the amount of time needed for glue dispensing by knowing the robot's movement speed and the length of the groove.

$$T_{dis} = \frac{S_{cover}}{V_{robot}} = \frac{720}{20} = 36\ s \tag{4.2}$$

where T_{dis} - time consumed for dispensing, s,

S_{cover} – length of the groove, mm,

V_{robot} – movement speed of the robot, mm/s.

The total task duration of the mentioned process will be determined by following components:

$$T_{total} = T_m + T_{ch} + T_{cal} + T_{dis} + T_f + T_r = 25 + 4 + 6 + 36 + 6 + 5 = 82\ s \qquad (4.3)$$

where T_{total} – total task duration, s,

T_m – time consumed for manual labour, s,

T_{ch} - time consumed for checking the presence of cartridge, s,

T_{cal} - time consumed for calibration of program, s,

T_f - time consumed for taking a photo, s,

T_r - time consumed for returning to home position, s.

Unfortunately, it is only possible to preciously estimate task duration without a real working system as many parameters, such as fluidity of glue, operator skills, will affect overall task duration. Nevertheless, calculation showed that robotized solution is quicker than the manual dispensing of covers.

4.4 Performance criteria selection

Performance measurement is an essential part of any organization. Generally, the profits of the company are secured by efficient work. To evaluate performance, specific indicators should be specified for each process and their achievement should be observed. For a robotic workplace, performance indicators should be selected based on the nature of the application and goal. Table 4.4.1 reflects Key Performance Indicators (KPIs) selected by the author for the created workplace.

Table 4.4.1 KPIs for created workplace

KPI	**Explanation**	**Unit of measurement**	**Goal**
Idle time	Time spent between finishing program execution and starting a new one	Minute	Minimise
Unplanned stoppages	Duration of unplanned stoppages due to hardware or software issues	Minute	Minimise
Collisions	Duration of stoppages that we caused by collision of robot	Minute	Minimise
Cycle time	Time spent for program execution	Minute	Minimise
Yield	Relationship between approved dispensed covers and amount of performed programs	Percentage	Increase
Utilization	Relationship between total use time and total time including idle and stoppages	Percentage	Increase

5. IMPLEMENTATION PROCESS IN THE COMPANY

5.1 Robot-cell implementation

Integration and implementation are distinct processes, but they are closely related. Integration is the process of combining different elements into a single whole as intended to carry out predetermined duties. It may involve data integration, system integration, or process integration. Implementation is the process of carrying out a decision or plan. Implementation involves installing and deploying the new system or product, as well as training employees on how to use it—combining the individual subsystems into a single system and ensuring that the subsystems work as a unit is known as system integration in engineering [49].

Robot-cell implementation refers to the implementation of robots into production. A Robot-cell is a group of machines and equipment that are arranged and programmed to work together to perform a specific task. Frequently, robot cells are integrated into already existing manufacturing processes, increasing the difficulty of implementation. Also, challenges occur due to the complexity of linking and programming devices produced by different manufacturers.

Usually, implementation is performed by outsourced engineering companies whose task is to make all devices work for one target. In case of collaborative robots, straightforward implementation tasks can be done without an external service provider, modern robot manufacturers supply robots with user-friendly robotic software and pre-programmed teach pendants to simplify the implementation process. But the support of third parties is still needed for complex systems. Fortunately, implementation service prices are constantly decreasing, and SMEs can afford them.

Robot-cell described by the author previously includes multiple pieces of equipment which will not fulfil the desired task out of the box. The author considers the engagement of a specialized subcontracted company to be reasonable. Subcontracted company will be responsible for programming and hardware installation. Once the robot-cell is up and running, the company will test and calibrate it to ensure that the cell is operating correctly and meeting the required specifications. This may involve fine-tuning the robot's movements and settings and conducting quality control checks on the products being produced. Ongoing maintenance and troubleshooting may also be required to keep the robot-cell running smoothly. Additionally, the subcontracted company should provide training for personnel, to ensure that robot is operated safely [50].

5.2 Risk analysis

Design and implementation of a robotic workspace are always associated with significant investments for the company. Any sizable investment is considered a risk for the company due to the probability of exceeding the nominal payback period. Both technically wrong decisions and incorrect management of the implementation process can cause risks [51]. ISO defines risks as an effect of uncertainty on objectives [52]. Risks should be identified and eliminated as early as possible to secure a successful investment. However, during the early stages of the project, risk identification is challenging as not all risks are apparent.

Not always all risks are real risks for the project; it is necessary to recognize and eliminate the most critical ones, as resources are always limited. The table below gives an overview of the risks highlighted by the author, which can occur during robot cell implementation. Furthermore, the author subjectively estimates their occurrence and importance for the cell, meanwhile providing an action plan to minimize their influence.

Table 5.2.1 Risk analysis

Risk description	The probability of risk occurring	Importance of risk	Actions needed for minimizing risk
Robot will collide with operator	Medium	Low	If a collision occurs, robot will stop and operator will have to relaunch the program. The operator should be trained to cooperate with the robot to avoid collisions
Human errors during reprogramming	Medium	High	Create a procedure that explains how reprogramming should be done
Loss of network connection	Low	Low	An additional hard disk drive should be installed inside the robot system to prevent data loss
Mechanical breakage of robot	Low	High	Regular maintenance should be performed
Changed glue compound can become more toxic	Low	High	Install additional ventilation for robot cell
No knowledge about robot usage	Medium	High	Conduct training for employees and create written instructions

No knowledge about robot maintenance	Medium	High	Conduct maintenance training for employees
Failure of power or air systems	Low	High	Regular maintenance should be performed
Mechanical breakage of EOAT	Medium	High	Regular maintenance should be performed as well as critical spare parts should be always in stock
Cyber security	Medium	High	Implement cyber securing measures across the whole company
Glue dispensing will still be done manually	Low	Medium	Remove manual dispensing gun from the workplace

6. PERFORMANCE ANALYSIS

6.1 Performance measurement

Defining performance metrics for robot cell before implementing them into production is essential. Overall Equipment Effectiveness (OEE) is the most widely used metric for measuring equipment productivity. It can be described as a result of the multiplication between availability, performance and quality [53]. The formulas below show the fundamental approach to calculating OEE for the designed robot cell.

$$Availabilty = \frac{T_{Actual}}{T_{Planned}} \tag{6.1}$$

$$Performance = \frac{A_{Total} \cdot C_{Ideal}}{T_{Actual}} \tag{6.2}$$

$$Quality = \frac{A_{Success}}{A_{Total}} \tag{6.3}$$

$$OEE = Availability \cdot Performance \cdot Quality \tag{6.4}$$

where T_{Actual} – pure time spent on performing the task, s,

$T_{Planned}$ - time spent (including stoppages) on performing the task, s,

A_{Total} - total amount of dispensed covers including poorly dispensed, pieces,

C_{Ideal} - fastest time spent on dispensing one cover in ideal circumstances, s,

$A_{Success}$ - amount of successfully dispensed covers, pieces.

If the result equals 1, it means that the system is ideal and working without losses. Unfortunately, OEE does not always show an accurate picture as theoretical values are used for calculation, and only major wastes are considered.

As described previously, manual labour will be included in every working cycle of the cell, which means that the OEE of the cell will cover both manual and automated labour. The author focused only on measuring the robot's performance in this work.

A solution or process should be developed for gathering, recording, and analyzing data from the robot. There is a possibility to perform all mentioned operations manually, but this will require investments into human resources as an additional person should be hired to fulfil this task.

Also, it means that training for this person should be organized, and if this person gets ill or goes on vacation, a substitute should be able to carry out this job.

Fortunately, there is a possibility to install an already-developed software solution that will automatically store and inspect information from the robot. Robot monitoring software is an addition to the existing robot software and is usually sold separately. Insights by ROBOTIQ is a software that allows programming specific KPIs that should be tracked [54]. Data is gathered in real-time, meaning that there is always a possibility to monitor robot performance without being physically present near the robot. Insights is sold based on a subscription model, meaning the company must purchase a license extension each year. The exact subscription price depends upon each application and is not publicly available [55].

6.2 Payback period calculation

The payback period is known as the time required to reimburse the cost of an investment. Longer payback times are unfavorable, while shorter paybacks make investments more attractive. For the given work, the author could not precisely calculate the payback period of a robotized gluing solution, as the calculation should include data from a real-world production company. Thus, the author performed calculations counting figures based on his assumptions.

To start with, the total amount of investment should be calculated. Table 6.2.1 shows a list of items and services that should be purchased to implement the robotized gluing cell. Even though prices for all items and services were not available in open sources, the author estimates them based on personal experience.

Table 6.2.1 List of items and services needed for implementation of robot cell

Item or Service	**Price (EUR)**
UR10e + Robot Controller + Teach Pendant	35500
Dispensing mechanism FD 310	6000
Cognex DataMan 370 Camera	1250
Barcode reader Voyager 1250g	120
Bracket for EOAT	200
Pedestal for robot with all needed interfaces	7000
Table with fixture	600
Shelf	200
Installation and training	5000
Robot monitoring software Insights (subscription for 3 years)	6000
TOTAL:	**61870**

Secondly, the expenses of human and robot based workplaces should be compared. The human based workplace is operated by 2 operators and robot based workplace is operated by an operator and a robot. Dispensing task cycle time calculation has shown that robotized dispensing is twice time faster as manual dispensing performed by one operator. In other words, the productivity of two operators equals the productivity of the robot and an operator.

Also, for the comparison, the author used Estonian average employer total labour cost for the production operator position, which equals 2000 EUR per month or 24 000 EUR per year [56]. Also, the author included the possible growth of workforce costs.

Table 6.2.2 Comparison of expenses

Years **Expenses**	2023 (EUR)	2024 (EUR)	2025 (EUR)	2026 (EUR)
Human based workplace				
Yearly salary of 2 operators	48000	60000	60000	66000
Workplace operating cost	3000	4500	6000	8000
Total costs	51000	64500	66000	74000
Costs cumulatively	51000	115500	181500	255500
Robot based workplace				
Total investment	61870			
Yearly salary of operator	24000	30000	30000	33000
Maintenance	7000	9000	11000	11000
Total cost	92870	39000	41000	44000
Costs cumulatively	92870	131870	172870	216870
Profitability calculation				
Profitability difference by year	-41870	25500	25000	30000
Profitability cumulatively	-41870	-16370	8630	38630

Calculation results have shown that a payback period for robotized workplace is less than 3 years. Moreover, the implementation of robot-cell cut labour costs in half.

SUMMARY

The main objective of this work was to analyze the possibilities of robotizing a gluing process in the manufacturing procedure of the antenna assembly.

In order to achieve the goal, the passive antenna assembly procedure, including an adhesive bonding process, was inspected. Then robotization justification analysis was performed. Results of the analysis showed rationality for robotization, and then the roles of a human and robot were defined in the human-robot collaboration. Additionally, the need for a collaboration robot was identified.

After that, the development of robotized workspace was carried out. Development included a selection of the most suitable cobot, end of arm tooling and auxiliary equipment. Also, development covered a choice of metrics for performance evaluation. Based on development outcomes, the workplace layout was created.

Next, an implementation process of the designed solution and risk analysis were described. The performance measurement activity was explained. The thesis ended with a calculation of the payback period.

The main aim of the thesis was successfully reached. As a result, the author proposed a complete solution for the robotized gluing process. Moreover, with minor adjustments, the same workplace setup can become applicable for other gluing tasks.

Gluing as a production process is constantly becoming more relevant because of manufacturers' numerous intentions to improve their products' final appearance. Furthermore, gluing has a broad range of use cases, namely the bonding of dissimilar materials, sealing or better carriage of loads compared to mechanical connections.

To sum up, due to the unavailability of required data in open sources, the goal of the thesis was reached using the theoretical approach. However, the same framework can be used using real-world data.

KOKKUVÕTE

Käesoleva magistritöö põhieesmärk oli analüüsida liimimisprotsessi robotiseerimise võimalusi antenni koostu valmistamise protsessis.

Eesmärgi saavutamiseks kontrolliti passiivse antenni kokkupaneku protseduuri, sealhulgas liimimisprotsessi. Seejärel viidi läbi robotiseerimise põhjendatuse analüüs. Analüüsi tulemused näitasid robotiseerimise ratsionaalsust ning seejärel määratleti inimese ja roboti rollid inimese ja roboti koostöös. Lisaks tuvastati vajadus koostööroboti järele.

Pärast seda viidi läbi robotiseeritud tööruumi arendamine. Arendus hõlmas sobivaima koostööroboti mudeli, lõpplülli ja abiseadmete valikut. Samuti hõlmas arendus efektiivuse hindamise mõõdikute valikut. Arengutulemuste põhjal koostati töökoha planeetingut.

Järgnevalt kirjeldati kavandatud lahenduse juurutamise protsessi ja riskianalüüsi. Selgitati tulemuslikkuse mõõtmise tegevust. Lõputöö lõppes tasuvusaja arvutamisega.

Lõputöö põhieesmärk oli edukalt saavutatud. Tulemusena autor pakkus välja robotiseeritud liimimisprotsessi terviklahenduse. Veelgi enam, väiksemate muudatustega võib sama töökoha seadistus muutuda rakendatavaks ka muude liimimisülesannete jaoks.

Liimimine tootmisprotsessina muutub pidevalt aktuaalsemaks, kuna tootjatel on pidev kavatsus parandada oma toodete lõplikku välimust. Lisaks on liimimisel lai valik kasutusjuhtumeid, nimelt erinevate materjalide liimimine, veekindlamaks tegemine või koormuste parem kandmine võrreldes mehaaniliste ühendustega.

Kokkuvõtteks võib öelda, et seoses vajalike andmete puudumisega avatud allikates saavutati töö eesmärk teoreetilist lähenemist kasutades. Sama lähenemist saab aga kasutada ka reaalmaailma andmetega.

REFERENCES

[1] Ericsson, "Mobile data traffic outlook," November 2022. [Online]. Available: https://www.ericsson.com/en/reports-and-papers/mobility-report/dataforecasts/mobile-traffic-forecast#:~:text=It%20is%20projected%20to%20grow,a%20CAGR%20of%2019%20percent.. [Accessed 14 December 2022].

[2] A. S. Gillis and K. Gerwig, "What is 5G?," TechTarget, March 2022. [Online]. Available: https://www.techtarget.com/searchnetworking/definition/5G. [Accessed 14 December 2022].

[3] J.Donovan, "Fiber-To-The-Antenna," Commspoce, 1 January 2017. [Online]. Available: https://www.commscope.com/Blog/fiber-to-the-antenna. [Accessed 14 December 2022].

[4] S. Steers, "Ericsson unveils lightweight radio for mid-band 5G," Mobile Magazine, 22 September 2021. [Online]. Available: https://mobile-magazine.com/5g-and-iot/ericsson-unveils-lightweight-radio-mid-band-5g. [Accessed 14 December 2022].

[5] Strand Consult, "How mobile operators can reduce cost for mobile masts and improve mast regulation," [Online]. Available: https://strandconsult.dk/how-mobile-operators-can-reduce-cost-for-mobile-masts-and-improve-mast-regulation/. [Accessed 14 December 2022].

[6] P. von Butovitsch, D. Astely, A. Furuskär, B. Göransson, B. Hogan, J. Karlsson and E. Larsson, "Advanced antenna systems for 5G networks," Ericsson, 15 November 2018. [Online]. Available: https://www.ericsson.com/en/reports-and-papers/white-papers/advanced-antenna-systems-for-5g-networks. [Accessed 14 December 2022].

[7] S. Beuvelet, "Nokia 5G Airscale 64T64R Smallest Antenna on the market," 27 February 2019. [Online]. Available: https://twitter.com/stephbeuv/status/1100795401991532545. [Accessed 14 December 2022].

[8] Varius, "СЕКТОРНАЯ АНТЕННА SISO-700/2700-12/15 DBI ВНЕШНЯЯ," [Online]. Available: https://www.yota-shop.ru/sektornaya-antenna-siso-7002700-1215-dbi-vneshnyaya. [Accessed 14 December 2022].

[9] E. Радист, "Секторная антенна базовой станции сотовой связи на 5 диапазонов как устроена и что внутри," 21 October 2021. [Online]. Available: https://www.youtube.com/watch?v=Y5HSh09CBOA. [Accessed 15 December 2022].

[10] Б. Красильников, Х. Рахимянов and Э. Мартынов, in *Технология машиностроения: сборка и монтаж 2-е изд. Учебное пособие для СПО*, Moscow, Urait, 2017, pp. 13-16.

[11] K. Sampath, "Design for Joining," in *ASM Handbook: Materials Selection and Design, Volume XX*, ASM International, 1997.

[12] F. C. Campbell, "Adhesive Bonding," in *Joining: Understanding the Basics*, Ohio, ASM International, 2011, pp. 243-245.

[13] Atlas Copco, "Pocket guide on adhesive bonding," 2019. [Online]. Available: https://www.atlascopco.com/content/dam/atlas-copco/industrial-technique/general/documents/pocketguides/AC-Pocket-Guide-Adhesive-Bonding-EN-web.pdf. [Accessed 15 December 2022].

[14] Master Bond Inc., "Achieving Better Adhesion with Proper Surface Preparation," [Online]. Available: https://fpg.phys.virginia.edu/fpgweb/useful_info/Master_Bond-Proper_Surface_Preparation_Bonding.pdf. [Accessed 15 December 2022].

[15] ISO, "ISO 8373:2021 Robotics — Vocabulary," 11 2021. [Online]. Available: https://www.iso.org/standard/75539.html. [Accessed 15 December 2022].

[16] Association for Advancing Automation, "Association for Advancing Automation," [Online]. Available: https://www.automate.org/. [Accessed 15 December 2022].

[17] British Automation & Robot Association, "Introduction to Industrial Robots," [Online]. Available: https://www.ppma.co.uk/bara/expert-advice/robots.html. [Accessed 15 December 2022].

[18] Japan Robot Association, [Online]. Available: https://www.jara.jp/e/index.html. [Accessed 15 December 2022].

[19] Tajima, "Convoy® Super CNV-100SP," [Online]. Available: https://www.tajimatool.com/product/convoy-super/. [Accessed 15 December 2022].

[20] ISO, "ISO/TS 15066:2016 Robots and robotic devices — Collaborative robots," February 2016. [Online]. Available: https://www.iso.org/standard/62996.html. [Accessed 15 December 2022].

[21] Universal Robots, "TOP FIVE INDUSTRIAL APPLICATIONS OF COBOTS," 5 May 2022. [Online]. Available: https://www.universal-robots.com/blog/top-five-industrial-applications-of-cobots/. [Accessed 15 December 2022].

[22] Maakondlike Arenduskeskuste Võrgustik, "Digitaliseerimisega alustamise toetus," 2021. [Online]. Available: https://www.arenduskeskused.ee/digitaliseerimisega-alustamise-toetus/. [Accessed 15 December 2022].

[23] Next Move Strategy Consulting, "Collaborative Robot (COBOT) Market - Global Opportunity Analysis and Industry Forecast 2022-2030," Jule 2022. [Online]. Available: https://www.nextmsc.com/report/collaborative-robot-market. [Accessed 15 December 2022].

[24] A. A. Malik and A. Bilberg, "Collaborative robots in assembly: A practical approach for tasks distribution," *Procedia CIRP Volume 81,* pp. 665-670, 2019.

[25] T. Nomura, T. Kanda, T. Suzuki and K. Kato, "Prediction of human behavior in human - robot interaction using psychological scales for anxiety and negative attitudes toward robots," *IEEE Transactions on Robotics, Issue 24, Volume 2,* pp. 442-451, 2008.

[26] L. Onnasch, X. Maier and T. Jürgensohn, "Mensch-Roboter-Interaktion - Eine Taxonomie für alle Anwendungsfälle," Dortmund, 2016.

[27] R. Galin, V. Serebrennyj , G. Tevyashov and A. Shiroky , "Human-robot Interaction in Collaborative Robotic Systems," 9 February 2021. [Online]. Available: https://www.researchgate.net/publication/349041457_Human-robot_Interaction_in_Collaborative_Robotic_Systems. [Accessed 15 December 2022].

[28] J. Riives, "EMT 0120 Best Robot and EOAT Selection [PowerPoint Slides]," [Online]. Available: https://moodle.taltech.ee/pluginfile.php/619334/mod_resource/content/1/Best%20robot%20selection.pdf. [Accessed 15 December 2022].

[29] Robots Done Right, "Robotic Controller," 2022. [Online]. Available: https://robotsdoneright.com/Articles/robotic-controller.html. [Accessed 18 December 2022].

[30] Robots Done Righ, "What are Robotic Teach Pendants?," 2022. [Online]. Available: https://robotsdoneright.com/Articles/what-are-robotic-teach-pendants.html. [Accessed 18 December 2022].

[31] Robots Done Right, "FANUC LR Mate 200ic robot with R-30ia controller acquired," 14 August 2019. [Online]. Available: https://robotsdoneright.com/News/7-1-19-to-12-31-19/FANUC-LR-Mate-200ic-8-14-19.html. [Accessed 18 December 2022].

[32] Fanuc Co. Ltd., "Find the right industrial robot for your needs with the FANUC robot filter," [Online]. Available: https://www.fanuc.eu/se/en/robots/robot-filter-page#?t=955369676bb74bfaba0d20847798d9a9,030001b7b73a4d45ac7b6acfd2170c2d%7C3eb0765706e443cd9bb19d9b01905d17,d2f8ceaa82864554ae312b9beb052e7c%7C49373fb6290f48a9b32ddb95c4bc6340,9e2795151865472dae0ca5be4e0da91. [Accessed 15 December 2022].

[33] Fanuc Co., Ltd., "CR-14iA/L," [Online]. Available: https://www.fanuc.eu/ua/en/robots/robot-filter-page/collaborative-robots/collaborative-cr-14ial. [Accessed 15 December 2022].

[34] ABB Ltd., "GoFa™ CRB 15000," 2021. [Online]. Available: https://library.e.abb.com/public/561a06a8a1914ee7a2289bca01dcd329/GoFa_CRB15000-datasheet_edited.pdf?x-sign=FTFlqiLKnUVtmTakvXBk1GYsTPXlBkEIPSU2TVPPhYkklmNXtEjZ2tmNcnCGGwCT. [Accessed 15 December 2022].

[35] Yaskawa Electric Corporation, "MOTOMAN HC10DTP Classic," February 2022. [Online]. Available: https://www.yaskawa.eu.com/Global%20Assets/Downloads/Brochures_Catalogues/Robotics/MOTOMAN_Robots/HC-DTP-Series/Flyer_Cobot_HC10DTPClassic_E_02.2022.pdf. [Accessed 15 December 2022].

[36] Universal Robots A/S, "UR10e Technical Specifications," July 2021. [Online]. Available: https://www.universal-robots.com/media/1807466/ur10e-rgb-fact-sheet-landscape-a4-125-kg.pdf. [Accessed 15 December 2022].

[37] KUKA AG, "LBR iiwa 14 R820," 01 June 2022. [Online]. Available: https://www.kuka.com/-/media/kuka-downloads/imported/6b77eecacfe542d3b736af377562ecaa/0000246833_en.pdf?rev=1edbd610b7104ba5b0a930097178e2db&hash=4F808F2B36EE98DE7BEF354362482DBD. [Accessed 15 December 2022].

[38] WiredWorker, "UR10e Universal Robots," [Online]. Available: https://wiredworkers.io/product/ur10e/. [Accessed 15 December 2022].

[39] Statzon, "lobal Collaborative Robot Market is Forecasted to Reach $2.3bn by 2025," 22 March 2021. [Online]. Available: https://www.einnews.com/pr_news/537318200/global-collaborative-robot-market-is-forecasted-to-reach-2-3bn-by-2025. [Accessed 15 December 2022].

[40] Universal Robots A/S, "UR+ PRODUCTS," 2022. [Online]. Available: https://www.universal-robots.com/plus/products/. [Accessed 15 December 2022].

[41] Universal Robots A/S, "360° GLUING – INTEGRATION KIT," 2022. [Online]. Available: https://www.universal-robots.com/plus/products/robatech/360-gluing-integration-kit/. [Accessed 15 December 2022].

[42] AIM Robotics, "FD Series SteadyFlow™ Material Dispensers," 2022. [Online]. Available: https://aim-robotics.com/fd-series-material-dispensers-for-collaborative-robots/. [Accessed 19 December 2022].

[43] AIM Robotics, "FD SERIES USER MANUAL," 2021. [Online]. Available: https://manuals.plus/m/8831a57f55d8c1775631137045c502f5f32d1126ff5cae2bc0c49038cfef722c_optim.pdf. [Accessed 19 December 2022].

[44] WiredWorkers, "AIM Robotics FD310 Dispensing Unit," [Online]. Available: https://wiredworkers.io/product/aim-robotics-fd310-dispensing-unit/. [Accessed 19 December 2022].

[45] WiredWorkers, "FD400 Aim Robotics AirLess cartridge dispenser," [Online]. Available: https://wiredworkers.io/product/fd400-aim-robotics-airless-cartridge-dispenser/. [Accessed 19 December 2022].

[46] Cognex Corporation, "DATAMAN 370 SERIES FIXED-MOUNT BARCODE READERS," 2022. [Online]. Available: https://www.cognex.com/products/barcode-readers/fixed-mount-barcode-readers/dataman-370. [Accessed 15 December 2022].

[47] eBay Inc., "Cognex DataMan 370 Fixed Mount Barcode Scanner," 2022. [Online]. Available: https://www.ebay.com/p/1655335492. [Accessed 15 December 2022].

[48] Kaup24, "Triipkoodilugeja Honeywell Voyager 1250G Must," 2022. [Online]. Available: https://kaup24.ee/et/mobiiltelefonid-foto--videokaamerad/nutiseadmed-ja-aksessuaarid/triipkoodilugeja-honeywell-voyager-1250g-must?id=12263130&feat=search&keyword=honeywell. [Accessed 20 December 2022].

[49] J. Snoderly and A. Faisandier, "System Implementation," [Online]. Available: https://www.sebokwiki.org/wiki/System_Implementation. [Accessed 21 December 2022].

[50] IPG Photonics Corporation, "6 Steps to a Successful Industrial Robot Integration in Your Facility," [Online]. Available: https://www.genesis-systems.com/blog/6-steps-successful-robotic-integration. [Accessed 15 December 2022].

[51] P. Bromiley, M. McShane, A. Nair and E. Rustambekov, "Enterprise Risk Management: Review, Critique, and Research Directions," 2015. [Online]. Available: https://escholarship.org/uc/item/37872078. [Accessed 21 December 2022].

[52] "ISO 31000:2018(en) Risk management – Guidelines," 2018. [Online]. Available: https://www.iso.org/obp/ui#iso:std:iso:31000:ed-2:v1:en. [Accessed 21 December 2022].

[53] H. Tang, "A new method of bottleneck analysis for manufacturing systems," *Manufacturing Letters , vol. 19,* pp. 21-24, 2019.

[54] ROBOTIQ, "Take Universal Robots production to the next level," [Online]. Available: https://insights.robotiq.com/. [Accessed 21 December 2022].

[55] ROBOTIQ, "Insights Instruction Manual," 2021. [Online]. Available: https://blog.robotiq.com/hubfs/Support%20Documents/Instruction%20Manuals/Insights_Instruction_Manual_PDF.pdf?_ga=2.10016501.1597160955.1671750159-1808103887.1516022592. [Accessed 22 December 2022].

[56] "Tööline Tootmine," 2022. [Online]. Available: https://www.palgad.ee/palgainfo/tootmine/tooline. [Accessed 25 December 2022].