Bachelor Degree Project

UNIVERSITY OF SKÖVDE

PROTOTYPE AN INTEGRATED 3D CAMERA IN A GRIPPER

Bachelor Degree Project in Product Design Engineering
Level G2E 30 ECTS
Autumn/Spring term Year 2023

Julia Barón Suárez
Almudena Roldán Cobos

Supervisor: Peter Thorvald & Johanna Höög
Examiner: Ari Kolbeinsson

Assurance of own work

This project report has on (date) been submitted by Julia Barón Suárez and Almudena Roldán Cobos to the University of Skövde as a poft of obtaining credits on basic level G2E within Product Design Engineering.

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Julia Barón Suárez

Almudena Roldán Cobos

Abstract

In today's interconnected world, our lives are inextricably linked with technology, a trend set to continue. Robots, pivotal to global industry and commerce, have made a significant impact since their inception. This report proposes an approach to enhance robotic functionality by integrating a 3D camera into a gripper's case. This integration improves robotic functions and refines how robots perform tasks, mirroring human-like capabilities. This paper outlines the design and creation process of the prototype, including considerations for its development. Extensive research was conducted on current grippers, 3D vision systems, and available 3D cameras. Moreover, the design process using CAD tools is shown and explained in detail, followed by the creation of a physical prototype through 3D printing. The study underscores the significance of such advancements in shaping the future of robotics. It emphasizes that the innovative design of these products will play a crucial role in advancing automation technology.

Keywords: Gripper, 3D camera, integrated camera, prototype, vision systems, ABB.

Acknowledgments

We would like to express our heartfelt gratitude to everyone who has contributed to the successful completion of this project. First and foremost, we sincerely thank ABB for their invaluable collaboration, which was instrumental in making this project a reality.

We are deeply grateful to the University of Skövde for providing us with the enriching Erasmus experience, which broadened our horizons academically and culturally. The knowledge, connections, and memories gained during this period will be treasured for a lifetime.

We would also like to convey our gratitude to the University of Málaga for their many years of quality education, support, and guidance. The dedication and commitment of the faculty and staff have truly shaped our growth as students and prepared us for our future endeavours.

A special mention goes to Assar Industrial Innovation Arena for providing us with a conducive work environment and the opportunity to engage with cutting-edge technologies. The resources and networking opportunities available at Assar have significantly enriched our learning experience and enhanced our project outcomes.

Our heartfelt appreciation goes out to all those who have assisted and supported us throughout this journey. To our mentors, colleagues, and friends, your encouragement and assistance have been invaluable. We could not have achieved this milestone without you.

Lastly, but by no means least, we would like to extend our deepest gratitude to our families. Your unwavering love, support, and belief in our abilities have been the foundation upon which we have built our success. We are eternally grateful for your sacrifices and understanding that have made this accomplishment possible.

Thank you all for your contributions and for being a part of our academic journey.

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Cobot	Collaborative robot
ROI	Return on investment
DFA	Design for Assembly
DFE	Design for Environment
DFM	Design for Manufacture

1 Introduction

An industrial collaborative robotic arm usually consists of several links or segments connected by joints. The end of the arm may be equipped with an end effector, such as a gripper. The primary aim of every robotic gripper is consistent: to grasp and stabilize the position of an object relative to a robotic arm, thereby enabling the arm to relocate the object from one point to another, where it is subsequently let go (Huat, 2006; Birglen & Schlicht, 2017).

Figure 1: Robotic gripper

Regarding the project, is going to be prototyped the integration of a 3D camera into a gripper, which can be placed on a robotic arm of the GoFa collaborative robot. The idea of integrating a 3D camera is that the robot's precision and efficiency in manipulation tasks would be augmented, enabling real-time trajectory adjustment and collision avoidance. The project involves selecting a suitable gripper and a camera, designing the integration, and creating the prototype.

Engineers are held to high standards of honesty and integrity due to their significant impact on people's quality of life. Their services must be characterized by honesty, impartiality, fairness, and a commitment to safeguarding public health, safety, and welfare (Harry, Pritchard, Rabins, James, & Englehardt, 2013). The project will be carried out ethically, prioritizing integrity in all stages of development. The essential role of the product engineer in ensuring the safety, quality, and responsibility of the design is recognized. The commitment to general well-being is demonstrated by ensuring a product that is respectful to both society and the environment.

1.1 Mission Statement

The integration of 3D vision in the gripper of a robotic arm means more efficient and versatile performance in the different tasks performed by the robot. The following advantages can be highlighted: it improves perception, manipulation accuracy, object and shape recognition, path planning, and interaction with the environment, and allows the robot to be more flexible and adaptable in operations (these systems can work with objects of varying sizes and in a range of lighting conditions) and 3D cameras provide a dense depth map, meaning they can capture a high level of detail about the distances between the camera and different objects. This allows for a more nuanced understanding of the gripper's environment, enhancing its ability to interact with it effectively (Kaczmarek, 2020).

To carry out the integration, an existing gripper compatible with the GoFa robot will be chosen, therefore a study will be carried out on the different types of existing compatible grippers for the GoFa robot considering their characteristics. Moreover, research will also be carried out on 3D cameras to choose one and proceed with the integration. This selection will be made according to different important considerations, which will be explained throughout the project. In addition, environmental impact and 3D camera assembly systems will be considered among other criteria.

Once the selection part has finished, different methods will be used to develop possible solutions for the integration of the camera into the gripper's case. These ideas will be captured in the form of sketches. These sketches will be improved and optimized along the design part to reach a solution that will be CAD-modelled and prototyped by using 3D printing to analyse whether the solution is optimal and suitable.

It is imperative to highlight that there are no intentions to construct an entirely new gripper. Rather, a redesign will be implemented to the selected gripper's housing to facilitate the integration of a camera. As a result, the operational functionality of the gripper will be preserved.

1.1.1 Objectives of the project

When considering the objectives of this project, it is important to understand why this project was chosen and what the main interests are. As has been discussed before, integrating a 3D camera into a robotic gripper has many advantages when working with robots. The idea for this project was sparked by the desire to help improve and push forward the future of cutting-edge technologies.

The objectives of the project can be briefly summarized as follows:

- Selection of appropriate gripper: conduct a detailed study on different types of existing grippers that are compatible with the GoFa robot and select the most suitable one according to its functionality.
- Selection of suitable 3D camera: carry out not only a comprehensive study on the different 3D camera systems but also research on various types of 3D cameras, choosing the one that meets the project requirements for integration with the selected gripper.
- Integration design: by doing sketches is going to develop possible solutions for integrating the chosen gripper and 3D camera.
- Prototyping and evaluation: CAD software and 3D printing technologies will be used to create the prototype of the camera integrated into the gripper.
- Study the product: environmental impact and the camera assembly system are going to be studied to know how the camera is going to be integrated into the gripper and how the product's materials affect the environment.

1.2 Stakeholders

The stakeholders involved in this report are anyone interested in the outcome of the product it is going to be redesigned. However, the most important ones to consider in this report are:

- ABB: is the company with which we are collaborating on this project, and they have a significant interest in its outcome. The redesign of the gripper could influence how the GoFa robot interacts with its surroundings and carries out tasks while handling workpieces with this specific product.
- The users of the GoFa robot: the development of this product could potentially alter their working methods, specifically in terms of how they interact with the gripper.

1.3 Strategies for execution

A design method is a systematic approach for addressing specific types of problems, particularly those related to creating products that meet user needs and provide satisfaction. Although the concept of design has been around for a long time, the formal recognition and conscious application of design methods is relatively recent. The use of the design method distinguishes engineers from scientists, as they both solve problems but in different ways. Scientists aim to understand the natural world and discover new knowledge, whereas engineers use the design method to create new products, systems, and services that benefit society. Design is a constructive process that involves identifying user needs, exploring potential solutions, and selecting the best option to create something of value that did not exist before (Gregory, 2013).

For the development of the project, different methodologies have been investigated to carry out the design project. The Double Diamond Method is the strategy adopted for this project. This choice was made based on previous experience and the desire to guide the project's structure in that direction.

This method is iterative, collaborative, and data-driven. It helps designers create effective solutions that meet the needs of their target audience and provide a better user experience. (Fleury & Richir, 2022).

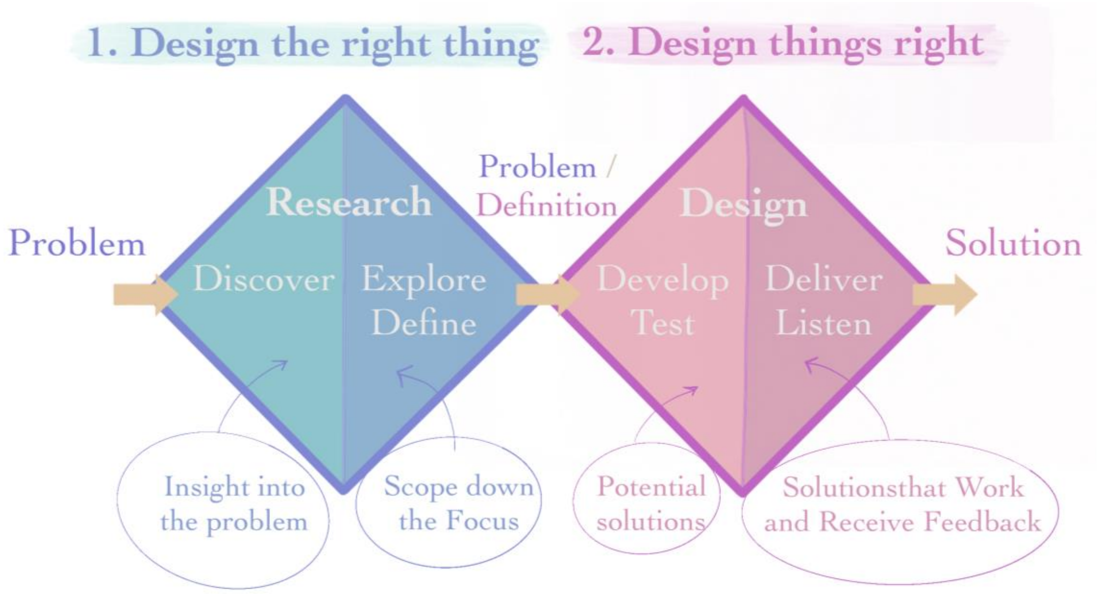

Figure 2: Double Diamond Method

The Double Diamond Method consists of four stages: discover, define, develop, and deliver (Dekker, 2020):

– Discover: the discover stage focuses on understanding the problem and needs of the company, the context, and the desired outcomes. This part relates to the introduction of the problem, mission statement, goals, and objectives.

– Define: during this stage, the collected insights are leveraged to progress the project. Simultaneously, user analysis is conducted to tailor the report toward a definitive toward

– Develop: in the develop stage, ideas, and prototypes will be created to explore potential solutions. This stage involves a lot of iteration and testing.

– Deliver: the project will end with the prototyping part and analysis of the result. It is not going to be production ready as we do not have the means to buy the camera and the gripper. Therefore, results are not going to be correctly checked.

1.3.1 Project organization

The purpose of integrating a built-in camera into the gripper is to facilitate the manipulation of objects. This camera-gripper system can be applied to various types of objects, not limited to a specific category.

Each step of the Double Diamond Method involves contents that are shown and explained below:

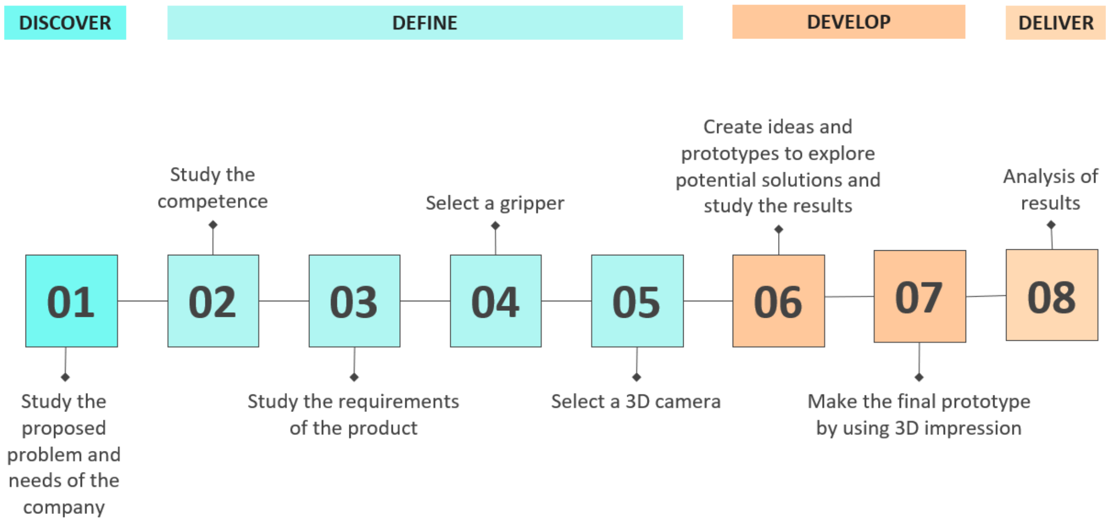

Figure 3: Guide of the project's structure

1. Discover stage.

Before starting the design process, it is important to understand the needs of the company and the reason why this project is needed to be developed.

Communication was initiated with ABB to establish the fundamental elements of the project, as delineated in User requirements. The Performance Specification Method.

2. Define stage.

After defining the project's purpose, the primary components, namely the gripper and camera, will be researched.

A market analysis will identify suitable grippers. Benchmarking will assess competitors and how cameras integrate with grippers or robots. Understanding product requirements is crucial; without this, appropriate equipment selection is challenging. To gather these insights, GoFa robot users will be surveyed, and ABB will be interviewed for their specific needs.

Researching equipment options before user engagement ensures a broad understanding of market offerings, facilitating informed selections based on user needs. A detailed requirement list will be formulated.

With clear requirements, the gripper and camera choices will be finalized.

3. Develop stage.

This part of the project will primarily concentrate on integrating the camera into the gripper. To accomplish this objective, sketches will be generated and analysed. Ultimately, the one that best meets the requirements will be selected.

The next step would be modelling the sketch selected in 3D by using CAD tools such as AutoCAD or Inventor. This stage involves a lot of iterative evaluation and improvements in the design.

Once the design is correctly done and has no mistakes, the physical prototype would be done by using 3D printing.

4. Deliver stage.

This last part of the project will be completed once the results have been studied and the physical prototype is created. Moreover, if there are any possible improvements, they will be also proposed.

1.4 Ending objectives of the project

Before achieving the end of the project, lots of prototypes of the integration of the camera into the gripper should be done in order not to miss any detail and to correct possible mistakes that could appear during the modelling part. Once the prototype is completely correct and the results analysed, the project would have finished. Due to the unavailability of the gripper and the camera, real integration cannot be achieved. As a result, the product will remain in its physical prototype stage.

Additionally, in the roles of design and product development engineers, there is no intention to delve into programming the automaton or any other aspect related to it.

1.5 Sustainability

Sustainable development prioritizes responsible resource use and conservation, aiming for economic growth without compromising quality of life. It bridges the link between economic advancement and environmental care, striving for prosperity while protecting the earth for future generations. Creating a sustainable product involves balancing economic, environmental, and social considerations. Socially, it should enhance well-being and promote a just, thriving society. Environmentally, it should minimize carbon emissions and be economically feasible (Heng, 2011).

Incorporating a camera in a robotic gripper bolsters sustainability by improving efficiency and judicious resource use. Prioritizing eco-friendly materials furthers these aims. For a sustainable future, integrating strategies like environment-conscious design and manufacturing is essential.

2 Discover

The discover part focuses on understanding the problem and includes all the information that has been searched in the first steps to develop this report.

2.1 Pre-study

A feasibility analysis will be carried out before the project's onset to collect crucial design information. This pre-study phase is essential for achieving project targets.

A gripper, resembling the human hand's function, is central to this project. It ensures the secure handling of objects, allowing gripping and releasing. Grippers can attach to robots or fixed automation systems. With various styles available, the right gripper can be chosen for specific tasks. The gripper jaws move in three main ways: parallel, angular, or toggle, indicating their relation to the gripper body (Applied Robotics Inc., 2023).

– A parallel gripper features jaws that move in a parallel direction relative to the gripper body.

Figure 4: Parallel gripper

– The jaws of an angular gripper operate around a central pivot point, performing a sweeping or arcing motion as they open and close.

Figure 5: Angular gripper

– A toggle gripper uses a pivot point jaw movement that acts as an over-center toggle lock, which yields a high grip force to weight ratio.

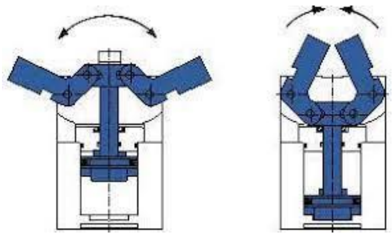

Figure 6: Toggle gripper

Secondly, the distinctions between 2D and 3D cameras will be elucidated to facilitate an informed decision on selecting the latter based on the project requirements. Moreover, the different types of 3D camera systems are analysed and explained to choose one that fits the interest of the project. To finish the pre-study of the project is going to be studied some existing integrating camera-gripper systems.

2.2 History

Carbone (2013) outlines the evolution of grippers in four stages: passive, mechanical, hydraulic/pneumatic, and electric. Passive grippers relied on basic shapes for holding, without actuators. Mechanical ones utilized springs and levers. Hydraulic and pneumatic versions employed pressurized fluids, suiting high-grip sectors like automotive. Electric grippers, known for precision and system integration, represent modern robotics advancements.

2.2.1 Cobots

Collaborative robots, or cobots, can execute a range of tasks from simple assembly to intricate operations, essential for the shift to smart factories and digitized industry (Sherwani, Asad, & Ibrahim, 2020). Designed to enhance human productivity and safety, some cobots incorporate advanced sensors, artificial intelligence, and machine learning, with applications in sectors such as automotive, electronics, healthcare, and logistics. Although initially complex to set up, these lightweight, flexible robots, once integrated, demand minimal human oversight and cater to a mix of repetitive and intricate tasks (Universal Robots, 2023).

2.2.2 ABB

As mentioned before, the project is going to be developed in collaboration with ABB. The robot used in the study is the GoFa Robot, technically known as the "GoFa CRB 15000 collaborative robot".

The reason why it is going to be used this robot is because ABB already has the YuMi Robot, which has an integrated 2D camera in the gripper. The company was searching for a similar system with a 3D camera for this automaton.

Figure 7: GoFa Robot

The GoFa Robot is a high-capacity collaborative robot designed for a variety of industrial applications. It is a lightweight robot, which is articulated on six axes, it is flexible, and agile (ABB.1, 2023). Some of its main characteristics include (ABB.1, 2023):

- The payload capacity of a robot is defined as the maximum weight a robotic arm can manipulate, excluding the gripper, as per Corke (2011). The GoFa robot is capable of handling up to 5 kg.
- In terms of reach, the robot can extend up to 1.5 meters. Its speed is rated at a maximum of 2.2 m/s, demonstrating its rapid movement capabilities.
- As for accuracy, the GoFa robot exhibits repeatability of ±0.03 mm, ensuring precision in its actions.

- One of its distinct characteristics is its collaborative operation design, ensuring safe and efficient cooperation with human operators.
- Its mounting flexibility allows it to be positioned in multiple ways, such as on the floor, ceiling, or wall, catering to various industrial process integrations.
- Moreover, the robot is designed with a user-friendly interface, including a touchscreen pendant, simplifying programming and operation tasks.

Safety has been considered as well in the design of this automaton. It has intelligent sensors in every joint that stops the robot within milliseconds if contact is detected (ABB.1, 2023).

The most important specifications are as follows (ABB.1, 2023):

Table 1: GoFa robot specifications

Robot version	Reach (mm)	Payload (kg)	Armload (kg)
CRB 15000	950	5	No armloads
Number of axes	6		
Protection	IP54		
Mounting	Any angle, including table mounting, wall mounting, and ceiling mounting		
Controller	OmniCore C30		
Customer power supply	24V/2A supply		
Customer signals	4 signals (for IO, Fieldbus, or Ethernet)		
Tool flange	Standard ISO 9409-1-50		
Functional safety	SafeMove Collaborative included all safety functions certified to category 3, PL d		

The GoFa robot uses flexible automation and can communicate with other systems. It is designed for repetitive tasks. The main objective of this automaton is to provide an efficient and effective solution for a wide range of industrial applications. Its high payload capacity, precision and accuracy, and collaborative operation make it ideal for tasks such as machine tending, pick and place, and material handling. The robot is designed to work safely alongside human operators, which can help to improve productivity and efficiency in industrial processes. (ABB.1, 2023).

2.3 Research about grippers

To select the most appropriate gripper for the GoFa robot, an investigation has been conducted to evaluate all the compatible gripper options and their key features. The purpose of this process is to identify the gripper that can best meet the specific needs and requirements of the company and its users.

To carry out this investigation, a review of all available gripper options has been undertaken, considering factors such as compatibility, functionality, reliability, and performance.

2.3.1 Introduction to robot grippers

Robotic grippers play a crucial role in modern automation as they serve as the end-of-arm tool for robotic manipulators, allowing direct contact with the workpiece. Grippers are designed to meet the demanding requirements of mass production, where grasping and manipulation of workpieces must be achieved according to established objectives while ensuring high efficiency and reducing cycle times. However, this need for speed can become challenging when the workpieces have unpredictable or inconsistent properties. Today, grippers face a wide range of variable objects, which has prompted the development of grippers with improved adaptability to accommodate this issue. As a result, there are now countless shapes and sizes of grippers available, with various designs of tool-changing mechanisms to accommodate different products (Birglen & Schlicht, 2017).

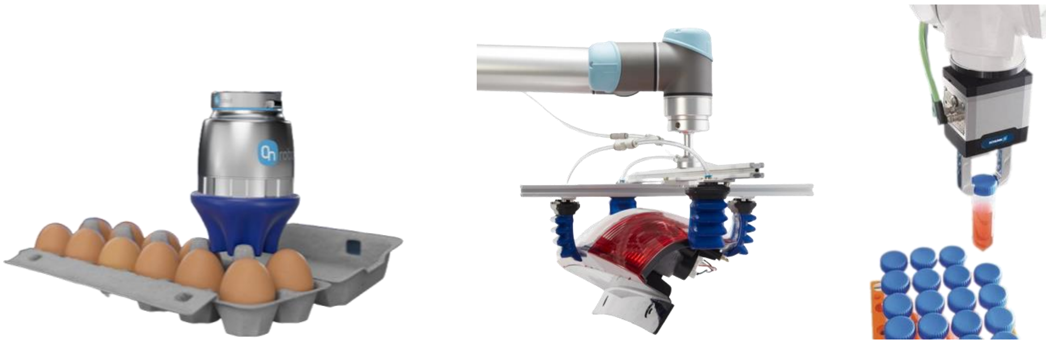

Figure 8: Applications of grippers

It is worth noting that each gripper is specifically designed to handle a limited set of objects. To ensure optimal performance, grippers are designed to be versatile and flexible, with the ability to operate under various conditions and handle a wide range of shapes and sizes of objects. This requires a high degree of precision, speed, and reliability to achieve the desired level of accuracy and consistency in production (Birglen & Schlicht, 2017).

2.3.2 Benchmarking

According to Ettorchi-Tardy, Levif, and Michel (2012), benchmarking is a systematic process of comparing an organization's performance against the performance of other organizations or industry standards with the aim of identifying best practices and improving the organization's performance. Several methods should be followed to create a good benchmarking process. These methods include:

- Identify the areas to be benchmarked: these areas should be aligned with the organization's strategic goals and objectives.
- Select appropriate benchmarking partners: the benchmarking partners should be selected based on their similarity to the organization in terms of size, complexity, and service offerings. The partners should also be willing to share information and collaborate in the benchmarking process.
- Determine the data collection methods: these methods should be determined based on the benchmarking partners and the areas to be benchmarked. The data can be collected through surveys, site visits, and document analysis.

- Collect and analyse the data: the data collected should be analysed to identify best practices and areas for improvement. The analysis should be conducted systematically and objectively.

To summarize, a good benchmarking process requires careful planning, collaboration with benchmarking partners, objective data analysis, and effective implementation and monitoring of action plans.

Benchmarking is appropriate for gripper selection because it allows for a comparative, standardized analysis of different grippers. It can help identify the most cost-effective option, determine performance under specific conditions, reveal strengths and weaknesses, and provide a framework for repeated testing and comparison.

The steps of the benchmarking method are going to be followed to develop this part of the project:

1. Identify the areas to be benchmarked and select appropriate benchmarking partners.

ABB does not design the grippers themselves; instead, they use grippers produced by other companies and integrate them into their robots.

To select the gripper used in the report, it has been studied all the different companies that produce grippers compatible with the GoFa Robot in order to select further on one to redesign. These are: OnRobot, Schmalz, Zimmer group, and Schunk.

2. Determine the data collection methods.

Two methods have been combined for this benchmarking step: categorization and best-in-class (BIC).

- Categorization involves grouping data based on shared characteristics. An article titled "A categorization method applied to the study of urban road traffic noise" (Barrigón Morillas et al., 2005) provides an example of how this method can be used. The process for developing the categorization of the grippers involved defining categories, classifying data, and analysing the data.

- Best-in-class selection is a strategy used to identify top performers within a specific category. An article titled "The use of multi-attribute utility theory to determine the overall best-in-class performer in a benchmarking study" (Collins, Rossetti, Nachtmann, & Oldham, 2006) demonstrates the application of this method. To select the final gripper for each group, the following steps were followed: defining criteria, evaluation, ranking, and selection.

3. Collect and analyse the data.

During research on compatible grippers, it was noted that grippers from various manufacturers designed for similar tasks shared comparable features. These grippers were categorized based on their intended function and the type of piece they could manipulate. From each category, a gripper was selected for in-depth study, primarily based on its attributes and data availability. Exclusion occurred in cases of incomplete data.

The selected grippers are characterized by:

– Versatility: handling of varied objects by shape, size, and material.

– Precision and control: ensuring high accuracy in handling with controlled grasp.

– Easy integration: compatibility with a range of robotic arms and systems.

– Durability: resistance to challenging industrial environments.

Criteria for gripper selection included:

– Reputation: production by reputable manufacturers and positive feedback.

– Application suitability: demonstrated efficacy in similar project applications.

– Cost-effectiveness: performance consistent with industry standards and a favourable cost-benefit ratio.

By focusing on these grippers, an exhaustive analysis was undertaken, increasing the chance of identifying the most appropriate gripper for integration with the 3D camera. The chosen grippers are listed below:

OnRobot 2FG7

Figure 9: OnRobot 2FG7

The electric parallel gripper shown in the previous figure is appreciated for its completeness and affordability. An additional feature of the 2FG7 is its adaptability, as it can be readily reassigned to any major collaborative or light industrial robot. As a result, it is often chosen for situations involving low-volume, varied production (OnRobot.1, 2023).

The most important characteristics to consider for this gripper include (OnRobot.1, 2023):

– It can be use in applications with limited manoeuvring space.

– It can carry a maximum payload of 11 kg.

– It has a gripping force from 20 N to 140 N.

– Gripping speed from 16 mm/s to 450 mm/s.

– Gripping time of 200 ms.

– This gripper can be programmed for precise force, speed, and stroke control settings through an intuitive software interface.

– The overall accuracy is improved due to intelligent feedback. This benefits grip detection and lost-grip detection, among others.

It is important to analyse the different ways the grippers pick up the workpieces. In this case, the object can be picked up in two ways: external and internal.

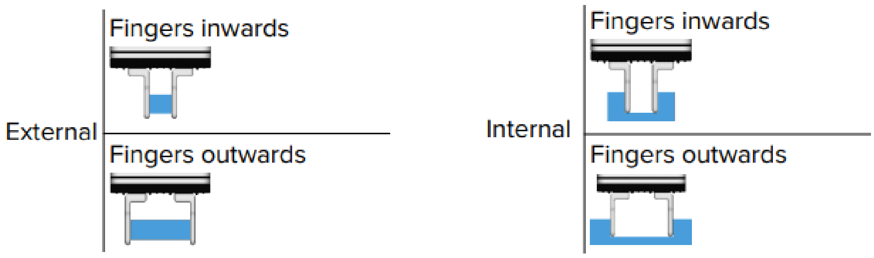

Figure 10: Pick up ways of the gripper 2FG7

Another interesting aspect of OnRobot's 2FG7 is that it includes a force sensor on the connector side.

Figure 11: Force sensor of the gripper 2FG7

The importance of having a force sensor resides on measure both tensile and pressure forces and elastic deformations that are applied to the workpieces.

OnRobot 3FG15

Figure 12: OnRobot 3FG15

This gripper is specifically designed for machine-tending applications where a wide range of cylindrical objects need to be gripped. One of its standout features is the pre-integrated software that comes with the OnRobot 3FG15, making it easy to install and program. (OnRobot.2, 2023).

The most important characteristics to consider for this gripper include (OnRobot.2, 2023):

– Swift deployment, combined with a robust, steady hold and accurate positioning.

– It can carry a maximum payload of 15 Kg.

– It has a gripping force of 10 N to 240 N.

– It has a large stroke, up to 150 mm.

– Its gripping speed is 125 mm/s.

– It has a gripping time of 500 ms.

As previously mentioned, this gripper is capable of picking up rounded workpieces. This operation can be conducted in two distinct manners: externally and internally.

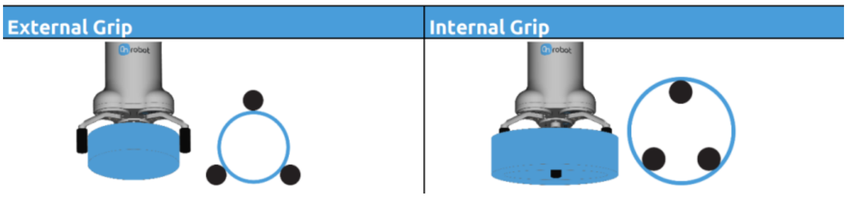

Figure 13: Pick up ways of the gripper 3FG15

Moreover, the supplied fingers can be mounted in 3 different positions to achieve different gripping forces and diameters, as can be seen in the figure below.

Figure 14: Ways of mounting the supplied fingers of the gripper 3FG15

OnRobot Soft Gripper

Figure 15: OnRobot Soft Gripper

The OnRobot Soft Gripper is designed to handle irregular shapes and delicate items. However, it is important to note that sharp edges on workpieces can cause damage to the silicone material and reduce the tool's lifespan. This gripper is available with three interchangeable silicon-moulded cups (OnRobot.3, 2023). These are shown below:

Figure 16: Interchangeable silicon-moulded cups

The most important characteristics to consider for this gripper include (OnRobot.3, 2023):

– Grip dimensions ranging from 11 mm to 118 mm.

– It can carry a maximum payload of 1,1 Kg.

– It has a spindle force of 380 N.

– It has a spindle speed of 37 mm/s.

– The gripping time of this gripper is 32 grip/min.

To properly handle the workpiece, some parameters should be taken into account, such as (OnRobot.3, 2023):

– Shape.

– Dimension.

– Weigh.

– Roughness.

– Fragility.

– Orientation of pick/placement.

Schmalz Vacuum Generator ECBPMi

Figure 17: Schmalz Vacuum Generator ECBPMi

The Schmalz Vacuum Generator ECBPMi can be universally adapted to lightweight robots or cobots using a flange adapter plate, making it easy to connect to the ABB GoFa Robot. Equipped with a suction cup, this gripper offers a complete vacuum gripping system and an electric vacuum generator for securely handling suction-tight workpieces. As well as the other gripper, it has an integrated interface for controlling, regulating, and monitoring the handling process (Schmalz.1, 2023).

The most important characteristics to consider for this gripper include (Schmalz.1, 2023):

– Intuitive operation via a user interface with capacitive keys and a rotating status display.

– It has small dimensions and low weight for robots with payloads less than 3 Kg.

– Flexible application in lightweight robotics, human-robot collaboration as well as in mobile robotics.

– It can carry a maximum payload of 3 kg.

– It has a suction rate of 1,6 l/min.

Schmalz Vacuum Generator ECBPi

Figure 18: Schmalz Vacuum Generator ECBPi

The Schmalz Vacuum Generator ECBPi is equipped with an advanced electrical vacuum generator, allowing it to handle both airtight and slightly porous workpieces. It was specifically designed for use in mobile robotics, fully automated small parts handling, and stationary handling tasks. Additionally, as the other grippers mentioned earlier, it features an integrated interface for controlling and monitoring the handling process (Schmalz.2, 2023).

The most important characteristics to consider for this gripper include (Schmalz.2, 2023):

– Integrated ventilation valve for fast and precise depositing.

– Targeted process monitoring and predictive maintenance through connection via IO-Link.

– Condition monitoring reduces errors and improves plant availability.

– NFC interface allows readout and parameterization via smartphone.

– Improved energy efficiency through automatic adjustment of the suction power.

– It can carry a maximum payload of 3 Kg.

– It has a suction rate of 12 l/min.

Schunk Co-act EGP-C 40-N-N-GoFa

Figure 19: Schunk Co-act EGP-C 40-N-N-GoFa

The Co-act EGP-C 40-N-N-GoFa is an electric gripper consisting of 2 parallel fingers, specifically designed for collaborative operations. This gripper comes equipped with important safety features, such as an integrated current limitation and a collision protective cover. The gripping force of this gripper is precisely controlled by the current limitation, which ensures that it does not exceed a defined value. To have an easy and fast integration, this gripper has a pre-assembled gripping unit with a robot interface (Schunk, 2023).

The most important characteristics to consider for this gripper include (Schunk, 2023):

– Maximum stroke of 20 mm.

– Gripping force of 30-150N

– Recommended payload of 0,7 Kg.

– Closing and opening time of 0,2 s.

This model comes with an accessory - various clamps that vary depending on the size of the pieces to be picked up. These accessories range from larger to smaller, as follows:

Figure 20: Top jaw AUB Co-act EGP-C

Grippers' overview

The data on the grippers are collected in the following chart:

Table 2: Data of the grippers

Product's name	OnRobot 2FG7	OnRobot 3FG15	OnRobot Soft Gripper	Schmalz Vacuum Generator ECBPMi	Schmalz Vacuum Generator ECBPi	Schunk Co-act EGP-C 40-N-N-GoFa
Type of workpieces gripped	Anytype	Rounded workpieces	Irregular and delicate items	Small dimensions workpieces	Porous workpieces	Anytype
Ways of picking up the workpiece	2 parallel fingers that can be placed in a external or internal way	3 fingers that can be placed in a external or internal way	Suction	Suction cup	2 suction cups	2 parallel external fingers
Maximum payload it can carry	11 Kg	15 Kg	1,1 Kg	3 Kg	3 Kg	0,7 Kg
Gripping force / Spindle force / Suction rate	[20 - 140] N	[10 - 240] N	380 N	1,6 l/min	12 l/min	[30 - 150] N
Gripping speed / Spindle speed	[16 - 450] mm/s	125 mm/s	37 mm/s	Unspecified	Unspecified	Unspecified
Gripping time	200 ms	500 ms	32 grip/min	Unspecified	Unspecified	Opening and closing time: 0,2 s
Integrated sensor	Yes	No	No	No	No	Yes
Aplications	Ideal for low volumen, high-mix production, and enabling fast ROI for many different aplications	Is ideal for gripping a wide range of cylindrical objects in machine-tending applications	Pick up food and beverage and another ''clean'' productions applica tions	Automated handling of small parts	For use in mobile robotics, fully automated small parts handlin and stationary handling tasks	Electric gripper for flexible handling of workpieces

2.4 Research about a camera for the gripper

Robots are traditionally programmed to perform repetitive tasks without the ability to "see". However, the industry is rapidly evolving, and there is now a growing demand for collaborative robots with vision systems. These systems enhance the precision and accuracy of tasks and allow robots to perform a variety of activities such as inspection, identification, counting, measuring, and barcode reading. Cameras are strategically placed on the robot arm or integrated into the gripper. The cobot's camera captures 2D or 3D scans of the object (TM-Robot, 2023). The robot vision system then follows a process that can be summarized as follows (TM-Robot, 2023):

- Image capture: cameras capture images of objects entering a cobot's workspace. Capture visual data from a calculated distance. The machine will then analyse the images or sequences and enhance them to produce a clear image.
- Image processing.

– Connectivity and response: the machine recognise that the object in the image matches the pre-programmed image. Further on the automaton will perform the corresponding action.

Two types of vision systems can be installed on robot arms: 2D and 3D.

A 2D camera equips a robot arm with data to interact with its environment and make decisions, benefiting manufacturing and sorting tasks. In contrast, 3D visions systems, employing multi-camera setups or single cameras with laser sensors, generate 3D models of objects for precise measurements and defect detection. Multi-camera setups use laser triangulation, creating highly reliable point clouds, while single-camera systems with laser sensors inspect surfaces and measure volumes, requiring either the object or camera to move. The laser reflection is measured, creating a height map (TM-Robot, 2023).

However, in this project, the 3D camera system will be used as it is the one required by our collaborating company, ABB. Therefore, there is no option to choose any other type.

2.4.1 Benchmarking

Research on the different types of 3D cameras available in the market has been done to choose the camera that best suits the task the robot needs to perform. Once this is clear, the best models of the type of 3D camera will be sought. Among the tasks the GoFa robot needs to perform, the main one is picking up a workpiece and moving it along the workspace to the following spot. The camera would help with this task by capturing the position and shape of the object and help by a communicator between the camera and the robot, giving information about its location and shape.

Following, the steps of the Benchmarking explained before, are going to be developed now for the cameras. One of the preferences of the ABB is having a 3D camera so 3D vision systems are the ones that are going to be studied.

1. Identify the areas to be benchmarked and select appropriate benchmarking partners.

Before making research on 3D cameras, it is important to know the different types of 3D systems that can be found nowadays. These are the following:

– Time-of-Flight camera, TOF: this type of camera can accurately measure distances with a single laser pulse. It uses infrared light to determine depth information. The sensor emits a light signal that is directed toward the subject and measures the time it takes for the signal to bounce back to the sensor. This information is used to create depth maps and provide the ability to capture three-dimensional information about the subject (Tillman, 2023).

– Stereo camera: it has two or more image sensors to simulate human binocular vision and give the ability to perceive depth (e-con Systems, 2023).

– Structured light system: a structured light pattern is projected onto an object. Subsequently, the deformation of the light pattern by the object is recorded using at least one camera, though typically two cameras are used.

By triangulating multiple images of the scan, it can be calculated the dimensions of the object in all its complexity (Emmrich, 2023).

– Laser scanning camera: this camera captures XYZ coordinates of myriads of points of an object's surface to calculate its dimensions. It also reconstructs its shape in a 3D environment and defines its position in space (Goluveba, 2023).

2. Determine the data collection methods.

To develop this benchmarking step, the investigation was conducted by gathering information through a search process. The first step involved familiarizing oneself with the various types of 3D camera systems currently available (Clearview, 2023). Subsequently, different types of systems were studied by referring to documentation found in books or articles.

3. Collect and analyse the data.

The different 3D camera systems are going to be analysed in this section.

Time-of-Flight Camera.

These cameras are specifically designed to capture depth information and can measure the distance to an object with high accuracy, typically within a few centimetres (Hansard, Lee, Choi, & Horaud, 2012). Some characteristics of these types of cameras are (Hansard, Lee, Choi, & Horaud, 2012):

– Non-contact sensing: ToF cameras can capture depth information without touching the object being measured, making them ideal for applications where physical contact is not possible or desirable.

– Depth resolution: it can achieve high depth resolution, usually in the range of a few millimetres to a few centimetres.

– Real-time performance: it can capture depth information in real-time, which makes them suitable for applications that require fast data capture and processing.

– Range: ToF cameras have a limited range, typically up to a few meters. However, some of these cameras can capture depth information up to tens of meters.

– High data capture speed: it can offer data capture speeds of up to hundreds of frames per second (fps), depending on the specific device and configuration.

– Sensitivity to ambient light: unfortunately, ToF cameras can be affected by ambient light, which can lead to errors in-depth measurement. However, modern ToF cameras use techniques such as modulated light sources and advanced filtering algorithms to mitigate these effects.

– Robustness: these cameras can be more robust than other depth sensing technologies such as stereo vision, as they are less affected by changes in lighting conditions or occlusions.

- Resolution: unfortunately, Time-of-Flight cameras generally offer lower resolution compared to traditional 2D cameras due to the nature of their technology and the requirement for rapid data processing. While ToF cameras can generate depth maps with accurate distance measurements, the resolution of these maps is usually lower than that of high-resolution 2D images.

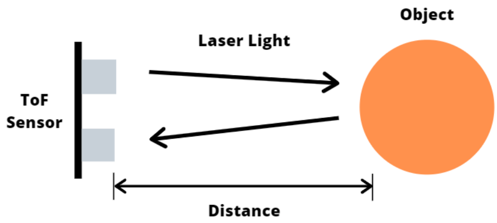

Figure 21: Time-of-Flight camera

Stereo camera

Stereo cameras are interesting tools for generating 3D representations of the environment. These cameras consist of two cameras positioned a known distance apart, which capture images of the same scene from slightly different angles. By analysing the differences between the images captured by the two cameras, stereo vision algorithms can determine the distance to objects in the scene and generate a 3D representation of the environment (Pears, Liu, & Bunting, 2012). The characteristics of the stereo cameras are (Pears, Liu, & Bunting, 2012):

- Non-contact sensing: these cameras capture two images from slightly different perspectives. This disparity between the images is used to compute depth information, thereby sensing objects in the scene without physical contact.
- Two cameras: as it is mentioned above, stereo cameras consist of two cameras that are positioned a known distance apart, which capture images of the same scene from slightly different angles.
- Depth perception: by analysing the differences between the images captured by the two cameras, stereo vision algorithms can determine the distance to objects in the scene and generate a 3D representation of the environment.
- Accuracy: stereo cameras can provide highly accurate depth information, making them ideal for applications such as robotics, autonomous vehicles, and augmented reality.
- Calibration: these cameras must be accurately calibrated to ensure that the relative positions and orientations of the two cameras are known precisely.
- Image rectification: to perform stereo matching accurately, the images captured by the two cameras must be rectified, which involves adjusting for differences in perspective and orientation between the two cameras.
- Stereo matching: it identifies corresponding points in the two images captured by the cameras and is essential for determining the depth of objects in the scene.

– Data capture speed: stereo cameras can have high data capture speeds, but the actual speed depends on the specific model and its technical specifications.

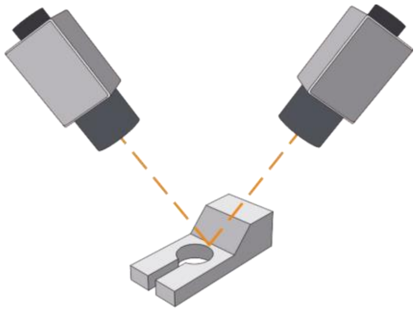

Figure 22: Stereo Camera

Structured light system

According to R.J. Valkenburg (1998), a 3D camera structured light system is a technology that uses projected patterns of light to capture information about the shape and contours of objects in a scene. Some features of this type of camera are:

– Non-contact sensing: by using a structured light system it provides a non-contact with the object measured. This means that there is no risk of damage to the object.

– High accuracy: this system can achieve high accuracy in 3D measurements, including sub-millimetre precision in some cases. The structured light system can capture many data points in a short amount of time.

– Fast data acquisition: it can capture 3D data quickly, with frame rates of up to several hundred frames per second possible. This makes them suitable for real-time applications such as robotics or quality control.

– Flexible setup: it is relatively flexible, and it can be also adapted to different scenarios.

– Limited range: the range of this type of camera is limited by the power of the projector and the sensitivity of the camera. Therefore, it may not be able to capture data from objects that are too far away or too small.

– Sensitive to ambient light: this system is sensitive to ambient light, which can interfere with the patterns projected by the system. This means that they are best used in controlled lighting environments.

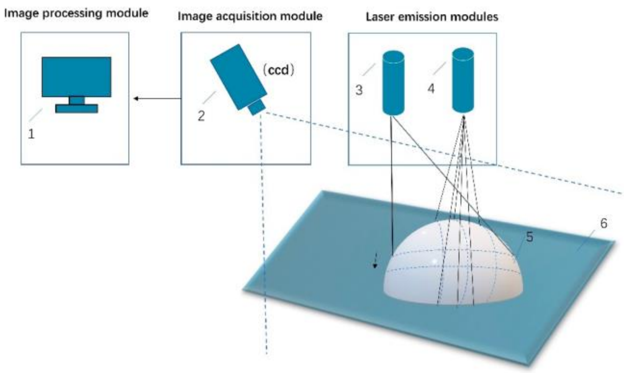

Figure 23: Structured light system

Laser scanning camera

According to Marshall and Stutz (2012), laser scanning cameras use laser beams to scan a surface and create a 3D representation of it. Moreover, laser scanning cameras use various techniques such as time-of-flight, triangulation, and confocal microscopy to measure distances and generate 3D data. Some characteristics that this camera has are:

- Non-contact sensing: these devices use laser beams to capture the properties of the object or scene they are examining, without ever needing to physically touch the object or scene.
- Laser source: laser scanning cameras use a laser source to generate a beam of light that is directed toward the object being scanned.
- Detector: a detector is used to measure the reflected or scattered light from the object and create a 2D or 3D image.
- Scanning mechanism: it is used to move the laser beam across the surface of the object being scanned.
- Resolution: laser scanning cameras can achieve high spatial resolution, allowing them to capture fine details and features of an object.
- Accuracy: these types of cameras can achieve high accuracy in measuring distances and capturing 3D data.
- Range: the range of laser scanning cameras can vary depending on the type of laser used and the sensitivity of the detector.
- Speed: it can operate at high speeds, allowing for rapid scanning of objects and surfaces.
- Applications: these cameras have a wide range of applications, such as industrial inspection, robotics, biomedical imaging, and cultural heritage preservation.

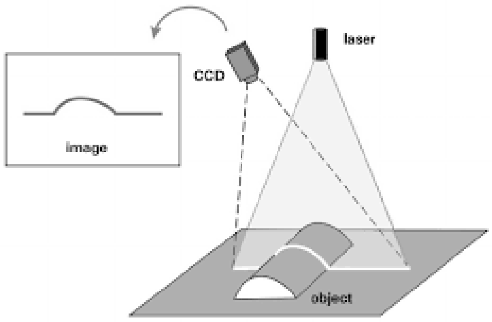

Figure 24: Laser scanning camera

2.5 Research about robots with an integrated camera

Integrating cameras directly into the gripper of a robot is currently not a widespread practice. As a result, other methods have been investigated to allow a camera to work in conjunction with a robot. The benchmarking method has been used again.

2.5.1 Benchmarking

A benchmarking study is going to be done to analyse the different ways a camera is working in collaboration with a gripper or a robotic arm.

1. Identify the areas to be benchmarked and select appropriate benchmarking partners.

To carry out this research, companies that have implemented cameras onto robots or robotic arms have been investigated, some of them are Robotiq and Omron. ABB also has a robotic arm with an integrated 2D camera. Currently, only a limited number of robotic arms or grippers in the market incorporate vision systems; a study has been conducted on these existing models.

2. Determine the data collection methods.

To collect the information, document analysis from the different datasheets of the robots with an integrated camera has been studied.

3. Collect and analyse the data.

The robots with integrated vision systems that have been studied are observed bellow:

YuMi Robot

A relevant example that can be found and fits with this report is the YuMi Robot from ABB, which features an integrated 2D camera in the gripper. This is a "Cognex AE3 Camera", which enables the robot to perform various tasks such as (ABB.2, 2023):

- Part location.
- Feature identification.

– Dimension measurement.

– Identifying numbers and text, and QR code reader.

In the following image, the integration of the camera into the gripper is demonstrated. The camera is located in the area where the circle is.

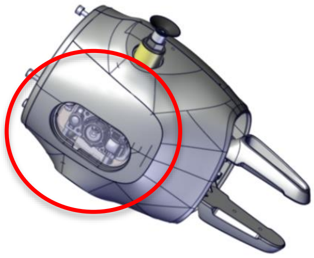

Figure 25: Gripper of the YuMi robot

The Cognex AE3 camera has the following features (ABB.3, 2023):

Table 3: Specifications of the Cognex AE3 camera

DESCRIPTION	DATA
Resolution	1.3 Megapixel
Lens	6.2 mm f/5
Illumination	Integrated LED with programmable intensity
Software engine	Powered by Cognex In-Sight
Application programming software	ABB Integrated vision or Cognex In-Sight Explorer

Omron TM Robot

Figure 26: Omrom TM Robot

The Omron TM is a collaborative robot that has an integrated 2D camera (Omron, 2023). Among the advantages of integrating this vision intelligence, the following can be found (Omron, 2023):

– Tasks such as stacking and handling a diverse range of products can be executed without much difficulty using this system.

– Different machines, parts, and work tasks can be automatically detected.

Moreover, smart vision is also used in other activities such as (Omron, 2023):

– It determines if machine doors are open or closed along with machine indicators to initiate the cobot tending process. This eliminates the control and communication integration.

– Provide quality inspections.

– Identify or read codes for new products and line changes.

The Omron TM Robot has an external camera for eye-to-hand robot applications. The one used is the “Basler GigE Camera” (Omron, 2023).

Figure 27: Basler GigE Camera

Furthermore, this robot can have two integrated cameras at maximum. Some important specifications of these cameras are explained below (Omron, 2023):

Table 4: Specifications of the Basler GigE Camera

DESCRIPTION	DATA
Monochrome / colour	Monochrome
Dimensions	640 x 480 mm 1600 x 1200 mm
Frame rate **Illumination**	Integrated LED with programmable intensity120 fps 60 fps
CCD / CMOS **Software engine**	Powered by Cognex In-Sight CCD CMOS
Application programming software	ABB Integrated vision or Cognex In-Sight Explorer

Robotiq Wrist Camera

The Robotiq Wrist Camera is integrated into *Universal Robots* between the gripper and the robot arm. The following image shows the structure:

Figure 28: Robotiq Wrist Camera

This camera consists of a slim, compact aluminium body with sealed hardware for industrial needs (Robotiq, 2023). Some features of this device are (Robotiq, 2023):

- It includes programming software that runs directly on the teach pendant. A teach pendant is a device used by robot operators to control a robot. It is a key interface between the human and the machine (Morley & Syan, 1995).
- It has three flexible multi-object teaching methods.
- It permits customizable colour validation.

3 Define

The defining part is going to focus on the customer requirements. This information has been obtained by conducting a questionnaire to users of the GoFa robot, who have extensive experience using it. In addition, ABB has also provided specific requirements based on the needs of its customers. Both requirements are going to be considered for the development of the project.

3.1 General use situation of the GoFa robot and possible clients

The combination of a robotic gripper and a 3D camera contributes significantly to advancements in automation and robotics. This integration goes beyond the functionality of a conventional robotic arm by offering a more sophisticated approach to tasks.

The primary function of this product is to provide precise and intelligent manipulation of small objects. According to Kaczmarek (2020), the integration of the 3D camera within the robotic gripper allows the system to perceive depth and dimensions, thus enabling it to adjust its actions based on the size, shape, and location of the object it interacts with.

The potential applications for this product are extensive and span various sectors (Tai, El-Sayed, Shahriari, Biglarbegian, & Mahmud, 2016):

- Manufacturing: this product can be used in assembly lines where it can handle delicate or minute components with precision, reducing human error and increasing productivity.
- Logistics: in warehouses, the device can be used for sorting and arranging objects based on their size and shape.
- Healthcare: in pharmaceutical production or laboratory settings, it can handle delicate biological samples or chemical substances with minimal risk of contamination.
- Research: in research institutions, it could prove useful in experiments requiring precise manipulation of objects.
- Agriculture: it can assist in selective harvesting, where the ripeness or size of a product determines its readiness for harvesting.

In conclusion, this product promises to bring significant improvements in precision, efficiency, and safety in various sectors.

3.2 User studies

The questionnaire method has been used to collect information about the user requirements to translate them into technical specifications. A questionnaire is a list of questions that are sent to users to find out their opinion or feeling about particular issues. This method has been employed due to its numerous advantages, such as the ability to obtain information on specific topics when no other information is available. However, questionnaire methods often struggle with obtaining in-depth information, lack personalization, and can result in misinterpretation of questions. Response bias, such as social desirability or acquiescence bias, can affect the accuracy of responses. Sometimes questionnaires suffer from low response rates, which can limit the statistical validity of the findings. Moreover, the lack of contextual data can also limit the interpretation of responses. (Høisæther , et al., 2018).

The questionnaire has been carried out with employees and researchers of Assar Industrial Innovation Arena, who frequently use the GoFa robot for different tasks. Since these questions have been made to researchers, this is the target audience it has been stablished for the product. However, anyone interested on the product could use it. Unfortunately, getting in contact with production personnel of any other company was much more difficult. Nevertheless, this should not be considered as a problem since this integration system would also provide advantages in various industries due to the increasingly necessity of vision systems integrated into robotics, as it is mentioned before.

The questionnaire made to the users and its answers can be found in Appendix I.

The conclusions drawn from the questionnaire are presented below:

- The main reason for the use of the GoFa robot by these users is research and manufacturing processes.
- The workpieces that the users use are usually plastic or metal parts.
- The shape of the workpieces used in the different tasks performed by the robot is cubic, irregular, and cylindrical.
- They often work with more than one type of workpiece.
- It is important that the gripper can pick up workpieces of different materials.
- The workpieces size used usually are small (0-10) mm and intermediate (10-100) mm.
- It would be useful to integrate a 3D camera into the gripper for the work it performs.
- It is important that the camera is positioned downwards.
- It is important that the material of the gripper housing is as environmentally friendly as possible.
- It is important that the camera has a high resolution.
- It is important that the style of integration matches the GoFa robot.

3.3 User requirements. The Performance Specification Method.

In addition to the questionnaire made to collect information about the users, ABB has also given information about more specific requirements. Both requirements from ABB and the users have been collected in a chart of desires and wishes.

It is important to establish a specific type of product that the gripper will be handling. ABB has kindly granted us the flexibility to select from a variety of small-sized products, as the intended use of this gripper extends beyond a singular product. According to the requirements ABB proposed, the workpiece should be small and lightweight. These requirements are in line with the information collected in the questionnaires; due to this, we propose focusing on hose connectors.

Hose connectors exhibit an irregular shape, lightweight construction, varying sizes (small and medium), and are made of metallic material. They fulfil both user's and ABB's requirements, therefore this workpiece is going to be considered as the handled one (DK-LOK MÉXICO, 2023).

Figure 29: Hose connectors

The different sizes this workpiece has can be found in Appendix II.

To set up the requirements, the Performance Specification Method has been used. This method is used in engineering and construction projects to ensure that the final product meets the required performance standards. This involves specifying the required level of performance for a particular system or component and then allowing the designers the flexibility to determine how to achieve that performance level. Moreover, this method is particularly useful in situations where there are multiple possible solutions to a problem or where there is a need for flexibility and innovation (Cross, 2021). The steps that should be followed (Cross, 2021):

- Levels of the generality of solution which might be applicable: it has an intermediate level because the gripper will pick up different small objects.
- level of generality at which to operate: it has a low level of generality, as in many aspects we do not have so much freedom. For example, the gripper cannot be modified as wanted; instead, one compatible with the automaton should be chosen. However, we can choose the most suitable one.
- Identify the required performance attributes: the attributes are independent of any particular solution. The attributes are separated into those relating to the gripper, the camera, and the gripper-camera system.

Regarding the gripper-camera system:

- It is important to consider the payload of the GoFa robot. This has a payload of 5kg (not including the weight of the gripper). Therefore, the sum of the weight of the gripper, the camera, and the workpiece that is going to be handled must not exceed 5kg.
- It would be better that in the final design of the product, the camera looks towards the workpiece, as the robot would then make fewer movements to watch the workpiece that is going to be handled.
- The gripper's case can be modified. However, the camera is not going to have a redesign.
- It is important to consider in the design part the aesthetic of the gripper when integrating the camera.
- Consider the potential environmental impact of developing the product.

Regarding the gripper:

- Compatibility with the GoFa Robot from ABB.
- The total gripping force is the sum of the forces exerted by each gripper jaw. This force must have a high range between the maximum and minimum values.
- The gripping speed should be as high as possible.
- Must be able to pick up cylindrical workpieces.
- Must be able to pick up stainless steel and brass workpieces.
- Must be able to pick up small workpieces.
- Must be able to pick up lightweight workpieces.
- The repeat accuracy is defined as a distribution of the end Position for 100 consecutive strokes. It should be as high as possible.
- The casing material for the gripper must be environmentally friendly, sustainable, and have a minimal environmental impact, such as those derived from renewable sources and being recyclable or biodegradable.

Regarding the camera:

- Intermediate measuring range: the measurement range required for the robotic arm application is a key factor. Some 3D cameras have a short measurement range, suitable for applications in small or close spaces, while others have a longer range, suitable for applications in large or remote spaces.
- High precision: for distance measurement, the camera must be quite accurate.

- High data capture speed.
- The amount of detail in the captured three-dimensional image: the resolution must be high.
- It would be better to set the camera at the bottom of the gripper.

State succinct and precise performance requirements for each attribute: in this section, the attributes are defined. For example, if the workpiece to be gripped is small, the dimensions of it must be stated.

3.3.1 Requirements table

Following, it can be observed the requirement list for both the gripper and the camera:

Table 5: Gripper-camera requirements table

Customer needs	Requirements	Demand	Wish	Source
Maximum payload of the camera-gripper assembly and the workpiece	Payload	<5 Kg		ABB
Direction to which the camera is pointing	Position of the camera		Towards the workpiece	User
Modification of the case	Case modification		No	ABB
Modification of the camera	Camera modification	No		ABB
Style of the ensemble	Style		According to the robot	User
Consider the potential environment impact	Environment impact	Yes		User

Regarding the gripper's requirement, the information is collected in the following chart:

Table 6: Gripper requirements table

Customer needs	Requirements	Demand	Wish	Source
Intermediate measuring range	Measuring range	(0-1) m	(0-2) m	User
Intermediate precision	Precision	Pinpoint accuracy	Sub-millimetre accuracy	ABB
High data capture speed	Capture speed	50 fps	60 fps	ABB
High resolution	Resolution	160x120 pixels	640x480 pixels	User
The camera must go at the bottom of the gripper	Location	Bottom of the gripper		ABB
Environmentally friendly material	Sustainable material	Yes	Yes	User/ABB

Following, it is going to be studied the requirement of the camera:

Table 7: Cameras' requirement table

Customer needs	Requirements	Demand	Wish	Source
Intermediate measuring range	Measuring range	(0-1) m	(0-2) m	User
Intermediate precision	Precision	Pinpoint accuracy	Sub-millimetre accuracy	ABB
High data capture speed	Capture speed	50 fps	60 fps	ABB
High resolution	Resolution	160x120 pixels	640x480 pixels	User
The camera must go at the bottom of the gripper	Location	Bottom of the gripper		ABB

In the process of product design, two essential elements must be considered: the environmental impact of the materials used and the assembly procedures for the product's components. Even though these aspects may not be explicitly stated in the requirements, they carry equivalent significance. The assembly process should be designed for easy assembly and disassembly. Additionally, the product should be developed in a manner that minimizes environmental harm to the greatest extent possible.

3.4 Weighted Decision Matrix (WDM)

Once the users' requirements have been established, a method to select one gripper had to be decided. After making an investigation on the different types of methods that can be used, the Weighted Decision Matrix has been selected since it provides a structured approach to decision-making by evaluating and comparing different options based on multiple criteria or factors (Gransberg, et al., 2009).

The Weighted Decision Matrix is a decision-making method when dealing with multiple options and criteria. It's particularly beneficial when the problem is simple, the criteria are independent, there's low uncertainty, and data variability is minimal. This aligns well with the decision to be made and its criteria. The method provides a systematic and objective approach, reducing bias and subjectivity, and allowing simultaneous consideration of multiple factors. This leads to comprehensive decisions, while also improving communication and transparency by providing a structured framework for stakeholder discussions (Triantaphyllou, 2000; Gransberg, et al., 2009).

The steps that must be followed while working with this method are (Gransberg, et al., 2009):

- Define the decision criteria: identify the different criteria that will be used to evaluate project delivery methods. In this case, it is going to be selected the requirements of ABB and the users' needs as the criteria.
- Assign weights to the criteria: allocate each criterion a weight according to its respective significance. It is important to underline that the weight should be above 1.0 to ensure that the overall evaluation is properly balanced.
- Establish a rating scale: it should be defined as a rating scale for each criterion. This scale can be numerical (1-5) or descriptive (poor, fair, good, very good, excellent).

– Calculate the weighted score: it consists of multiplying each criterion rating by its assigned weight and summing all the results. In the end, it is obtained a score for each project delivery method.

– Analyse the results: once obtained the result, it is important to compare them and use the results to inform the selection of the most appropriate delivery method for the project.

3.5 Selection of the gripper and the type of camera

Once the different types of grippers and 3D camera systems have been analysed and, considering the requirements of ABB and the users, choosing the final products is the following step.

The importance of each criterion has been established based on the list of users and ABB requirements. Therefore, all requirements have high importance. However, those requirements that are not a demand, but a desire have been given reduced importance.

Below is the weighted decision matrix for the gripper and the camera. Regarding the grippers:

Table 8: Grippers' Weighted Decision Matrix Interpretation

Name of the gripper	Score	Importance:
A = OnRobot 2FG7	1 = fulfils criteria from 0% a 20%	1 = not important
B = OnRobot 3FG16	2 = fulfils criteria from 20% a 40%	2 = important
C = OnRobot Soft Gripper	3 = fulfils criteria from 40% a 60%	3 = very important
D = Schmalz Vacuum Generator ECBPMi	4 = fulfils criteria from 60% a 80%	
E = Schmalz Vacuum Generator ECBPi	5 = fulfils criteria from 80% a 100%	
F = Schunk Co-act EGP-C 40-N-N-GoFa		

Table 9: Grippers' Weighted Decision Matrix

Criteria	Importance	Score						Weighted score					
		A	B	C	D	E	F	A	B	C	D	E	F
Compatibility with the GoFa Robot	3	5	5	5	5	5	5	15	15	15	15	15	15
The gripping force must have a high range between the maximum and minimum value.	2	3	5	5			4	6	10	10	0	0	8
It is interesting that it has force sensors	1	5	0	0	0	0	5	5	0	0	0	0	5
The gripping speed should be as high as possible	1	5	3	2			4	5	3	2	0	0	4
Must be able to pick up cylindrical workpieces	3	5	4	4	2	2	5	15	12	12	6	6	15
Must be able to pick up stainless steel and brass workpieces	3	5	5	5	5	5	5	15	15	15	15	15	15
Must be able to pick up small workpieces	3	4	3	3	4	3	5	12	9	9	12	9	15
Must be able to pick up lightweight workpieces	3	4	4	1	5	5	5	12	12	3	15	15	15
High repeat accuracy	2		5				4	0	10	0	0	0	8
Total score								85	86	66	63	60	100

According to the specifications of the gripper and analysing the list of requirements, the gripper that fits better is the Co-act EGP-C 40-N-N-GoFa.

Following, it is explained why this gripper aligns with the specific requirements and constraints of the project.

– Weight and payload: when considering the weight and payload, it is important to note the differences between the models. Both the Schmalz Vacuum Generator ECBPMi and ECBPi have a maximum payload of 3 kg, whereas the Onrobot Soft Gripper can carry up to 1.1 kg. The Schunk gripper has a recommended payload of 0.7 kg, which provides less carrying capacity compared to the other models.

– Gripping force: there are notable variations in gripping force among the different models. The Onrobot 2FG7 ranges from 20 to 140 N, while the gripping force of the Schunk Co-act EGP-C 40-N-N-GoFa reaches up to 150 N.

– Opening/Closing speed: the speed at which the grippers open and close varies significantly. The Schunk gripper has an opening/closing time of 0.2 seconds, while the Onrobot 3FG15 and Onrobot Soft Gripper have gripping times of 500 ms and 32 grip/min respectively.

– Design adaptability: in terms of adaptability, there are also differences. The Onrobot 3FG15 has a large stroke of up to 150 mm, while the Onrobot Soft Gripper requires consideration of several factors like shape, dimensions, weight, roughness, fragility, and pick/placement orientation. On the other hand, the Schunk gripper has a maximum stroke of 20 mm.

– Safety features: the safety features also differ among the models. The Schmalz vacuum generators offer process monitoring and predictive maintenance, while the Schunk gripper incorporates a current limitation and a collision protective cover.

The material with which the grippers are manufactured has not been taken into account, despite being a requirement from the customer and ABB. However, this does not imply that this criterion will not be considered; rather, the material selection will be made subsequently by analysing whether the current material of the gripper is suitable, and if not, it will be replaced with a more sustainable one with similar characteristics.

In conclusion, each gripper has unique characteristics that make it suitable for different applications. The Schunk Co-act EGP-C 40-N-N-GoFa was selected based on the specific requirements of this project.

Next, the Weighted Decision Matrix of the camera will be studied:

Table 10: 3D Systems' Weighted Decision Matrix Interpretation

Name of 3D vision system type	Score	Importance:
A = Time-of-Flight Camera	1 = fulfils criteria from 0% a 20%	1 = not important
B = Stereo camera	2 = fulfils criteria from 20% a 40%	2 = important
C = Structured light system	3 = fulfils criteria from 40% a 60%	3 = very important
D = Laser scanning camera	4 = fulfils criteria from 60% a 80%	
	5 = fulfils criteria from 80% a 100%	

Table 11: 3D Systems' Weighted Decision Matrix

Criteria	Importance	Score				Weighted score			
		A	B	C	D	A	B	C	D
Intermediate measuring range	3	5	4	5	4	15	12	15	12
High precision	3	5	5	4	5	15	15	12	15
High data capture speed	2	5	4	5	5	10	8	10	10
High resolution	2	4	4	4	5	8	8	8	10
Total score						48	43	45	47

Based on the characteristics of each camera type provided, it is clear that each has its advantages and disadvantages and can be optimal in specific applications. However, focusing on the needs of a robotics application, a Time-of-Flight (ToF) camera stands out due to several reasons:

- Real-time Performance: unlike stereo cameras that require substantial computation for stereo matching and image rectification, or structured light and laser scanning systems that rely on time-consuming scanning processes, ToF cameras can provide depth information instantly. This characteristic makes ToF cameras more suitable for real-time robotic applications.
- Ease of Use: ToF cameras do not require complex calibration as stereo cameras do, making them easier to implement and maintain in a robotic system. Moreover, unlike structured light systems that require precise alignment between the projector and the camera, ToF cameras are standalone devices, simplifying their installation and operation.
- Robustness: while all systems are impacted by lighting conditions, modern ToF cameras have advanced significantly in mitigating these effects. This feature gives them an edge over both structured light systems and stereo cameras, which can struggle with variations in lighting or textures in the scene.
- Range and Resolution: although laser scanning cameras can offer high accuracy and resolution over a long range, they are typically slower and more expensive. In contrast, ToF cameras offer a balanced combination of range, resolution, speed, and cost, making them a more practical choice for many robotic applications.

However, this step is not complete, as now it has to be selected by the camera.

3.5.1 Study of ToF cameras

Before studying the cameras, it is important to consider the dimensions of the gripper where the camera is going to be integrated. According to the specifications of the users and ABB's requirements, it would be better to integrate the camera at the bottom of the gripper. Below, it can be observed the dimensions expressed in mm.

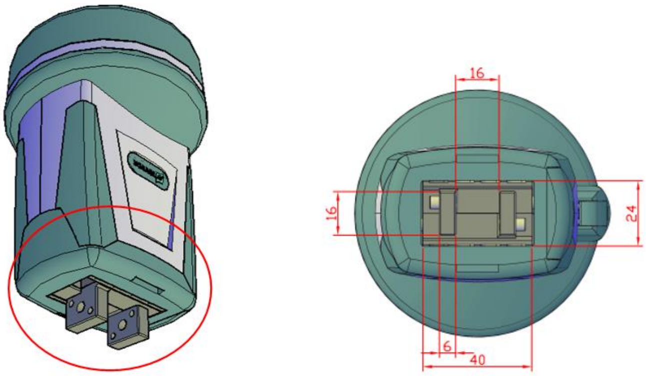

Figure 30: Dimensions of the gripper bottom

Next, several Time of Flight (ToF) cameras will be examined using the benchmarking method:

1. **Identify the areas to be benchmarked and select appropriate benchmarking partners.**

This process has been very limited as it has been decided beforehand to focus the study on Time-of-Flight (ToF) cameras. Moreover, as the camera's case cannot be modified, the study is going to focus on selecting cameras which size is the smallest possible. Therefore, the integration would not be so complicated, and the aesthetic of the gripper's casing will not be affected by the size of the camera.

2. **Determine the data collection methods.**

In developing this benchmarking step, a descriptive and comparative research approach was utilized along with documentary research. The selection process among the different 3D Time-of-Flight cameras considered the requirements and prioritized the smallest size due to its importance in achieving seamless integration. This information was taken from their datasheet.

3. **Collect and analyse the data.**

The cameras selected for the study are all highly sophisticated devices with distinct features that make them suitable for this project. These shared special features:

– 3D Imaging: all these cameras can produce three-dimensional images. This is crucial for the application in question, as the ability to perceive depth is vital for a robotic gripper to handle objects accurately and safely.

– Compact design: each of these cameras features a compact and lightweight design, which is a critical factor when integrating with a robotic gripper.

– High precision: these cameras have been selected for their high precision and accuracy in depth sensing and object recognition. This precision is necessary to ensure the gripper can accurately pick and place objects.

– Robustness and durability: these cameras are built to last, with high-quality components and construction. This is especially important in industrial or manufacturing environments, where the camera may be subject to harsh conditions.

The decision to study these cameras more closely, as opposed to others on the market, could be justified by several factors:

- Reputation and reviews: each of these cameras comes from a reputable manufacturer and has received positive reviews for its performance, reliability, and durability.
- Technical specifications: the technical specifications of these cameras, such as resolution, frame rate, field of view, and depth range, are suitable for the requirements of this project.
- Cost-effectiveness: while offering high-quality performance, these cameras also provide good value for money, making them a cost-effective choice for integration into a robotic system.
- Availability and support: they are widely available on the market, and the manufacturers offer good technical support, which can be crucial for the success of the project.

By focusing on these specific cameras, a comprehensive and in-depth analysis that is more likely to lead to successful integration with the robotic gripper can be ensured. The cameras that have been studied are the followings:

Terabee 3Dcam 80x60

Figure 31: Terabee 3Dcam 80x60

The given camera is equipped with an 80x60 resolution, which utilizes Time-of-Flight technology to produce vivid 3D images in real-time. It can be employed in diverse domains, such as robotics, autonomous systems, and security and surveillance sectors. It is compact size and high-performing nature when it comes to 3D imaging (Terabee, 2023).

Some important features of this camera can be seen in the following table:

Table 12: Characteristics of the Terabee 3Dcam 80x60

Resolution	80 x 60 px
Range	Close range mode: 0.2m to 1.2m Standard mode: 1m to 4m
Field-of-View (H x V)	74º x 57º
Frame Rate	30 fps
Dimensions	54 x 53 x 24 mm

Mounting Mechanism	The Terabee 3Dcam 80×60 aluminium housing offers an easy back panel mounting option for a more discreet integrated look.

Helios 2+

Figure 32: Helios 2+ camera

The Helios 2+ utilizes advanced Time-of-Flight (ToF) technology, enabling it to record high-resolution 3D images. Its design is compact and sturdy,. Its proficiency spans a variety of fields, from robotics and automation to surveillance and augmented reality (Helios2, 2023). Some important features of this camera are described in the following table:

Table 13: Characteristics of the Helios 2+ camera

Resolution	640 x 480 px
Range	0.3 – 8.3 m (Normal, HDR) 0.3 – 2.5 m (High-speed)
Field-of-View (H x V)	69º x 51º
Frame Rate	30 fps (normal) 10 fps (HDR) 103 fps (High-speed)
Precision	0.6 mm
Dimensions	60 x 60 x 77,5 mm
Mounting Mechanism	The camera has an adapter for use with a tripod

Intel RealSense D455

Table 14: Intel RealSense D455

The Intel RealSense D455 camera is a device engineered for accurate depth sensing. It has been used in various sectors, including robotics, autonomous systems, and security. It operates with an extended range and uses stereo vision combined with Global Shutter technology, which allows it to produce high-quality 3D images in real-time. (Intel RealSense, 2023).

Some characteristics of this camera are described in the following table:

Table 15: Characteristics of the Intel RealSense D455 Camera

Resolution	1280 x 800 px
Range	0.6m to 6m
Field-of-View (H x V)	90º x 65º
Frame Rate	30 fps
Dimensions	124 x 26 x 29 mm
Mounting Mechanism	– One 1/4-20 UNC thread mounting point – Two M4 thread mounting points – Tripod

Basler blaze (Blaze-101 model)

Figure 33: Basler blaze (Blaze-101 model)

The Basler blaze camera, featuring the Blaze-101 model, is a high-performance 3D ToF imaging solution. It is used in applications in robotics, automation, and inspection. It offers depth sensing, capturing 3D point clouds in real time. This model boasts a compact design (Basler, 2023).

Some of its main characteristics are described in the table below:

Table 16: Characteristics of the Basler blaze (Blaze-101 model)

Resolution	640 x 480 px
Range	0 – 10 m
Field-of-View (H x V)	67º x 51º
Frame Rate	30 fps
Dimensions	100 x 81 x 64 mm
Mounting Mechanism	Not specified

3.6 Selection of the camera

Even though one of the requirements is that it would be better to integrate the camera into the bottom of the gripper, this is not going to be possible due to the dimensions of the cameras. As well as in the other choosing steps, the Weighted Decision Matrix is going to be used. The importance of each of the criteria has been established based on the following aspects:

– Measuring range: this is the field of view in which a 3D camera can recognize an object. All objects within this range will be recognized by the camera. It is considered of utmost importance that the measuring range has an intermediate value to recognize parts that are close and far away from the robot's working area.

– Resolution: determines the quality and sharpness of the image. High quality is not of utmost importance, as the image captured by the camera will be used to know where the part to be worked on is located.

– Dimensions: the camera must have small dimensions so that integration is as simple as possible.

– Mounting mechanism: the camera must have a simple assembly system so that the robotic gripper can be integrated more simply.

Because of this, an intermediate measuring range, small dimensions, and an easy mounting mechanism are considered more important than the camera's resolution.

Moreover, the score has been established by making a comparison between the different cameras studied and their data.

Table 17: Cameras' Weighted Decision Matrix Interpretation

Name of the cameras	Score	Importance:
A = Terabee 3Dcam 80x60	1 = fulfils criteria from 0% a 20%	1 = not important
B = Helios 2+	2 = fulfils criteria from 20% a 40%	2 = important
C = Intel RealSense D455	3 = fulfils criteria from 40% a 60%	3 = very important
D = Basler blaze (Blaze-101 model)	4 = fulfils criteria from 60% a 80%	
	5 = fulfils criteria from 80% a 100%	

Table 18: Cameras' Weighted Decision Matrix

Criteria	Importance	Score				Weighted score			
		A	B	C	D	A	B	C	D
Intermediate measuring range	3	3	5	4	5	9	15	12	15
High resolution	2	2	4	5	4	4	8	10	8
Small dimensions	3	4	2	2	1	12	6	6	3
Easy mounting mechanism	3	5	1	4	1	15	3	12	3
Total score						40	32	40	29

It is important to notice that two of the requirements (capture data speed and precision) have been removed from the chart as there was no numerical information in the datasheet of the cameras and it has been already considered when the TOF system camera was selected.

Moreover, as can be observed in the chart above, two cameras tied in the results. However, for selecting one of them, the dimensions have been considered. The smallest one has been selected (Terabee 3Dcam 80x60). This way, there would be fewer issues during the integration.

Upon comparing the given cameras in relation to the outlined user requirements and the scope of the work, the following observations can be made:

- Comparison of Terabee 3Dcam 80x60 and Helios 2+: while both devices are capable of real-time performance, it is found that the smaller dimensions of the Terabee 3Dcam potentially offer a distinct advantage in terms of integration into the robot design. The size reduction may allow for increased flexibility in positioning and potentially contribute to a decrease in the overall system weight.
- Comparison of Terabee 3Dcam 80x60 and Intel RealSense D455: both of these cameras offer valuable attributes, yet the compactness of the Terabee camera could prove beneficial. The Intel RealSense D455 might provide an extended range. However, the range offered by the Terabee camera is likely sufficient for the task the GoFa robot is thought to make. Furthermore, when considering the emphasis on compactness, the Terabee 3Dcam aligns more closely with the user's specifications.
- Comparison of Terabee 3Dcam 80x60 and Basler blaze camera: both cameras demonstrate robustness in varying lighting conditions. However, given the necessity for collision avoidance and navigation within confined spaces, the compactness of the Terabee camera offers a significant advantage. Even though the Basler blaze camera can capture 3D point clouds in real time, the smaller footprint of the Terabee device could make it more appropriate for integration into a compact gripper design.

3.7 Environmental impact

According to Ulrich, Eppinger, and Yang (2008), every product has an impact on the environment. Design For Environment (DFE) represents a practical method for companies to reduce such impacts to create a more sustainable society. It conserves or improves product quality while reducing costs. Moreover, it considers materials, production, distribution, use, and recovery.

To study the environmental impact, the gripper's material is going to be analysed to know how environmentally friendly it is.

The Schunk Co-act EGP-C 40-N-N-GoFa gripper's case material is Polyamide with glass fibre additive. This material is a type of composite made by combining polyamide with glass fibres. It is a thermoplastic material, which means that it can be melted and moulded into different shapes. This material has the following characteristics (Correira, 2019):

- High strength and durability: this composite material can stand high levels of stress and strain. It is resistant to impact, abrasion, and fatigue.
- Lightweight: this characteristic is important as with any other material the gripper would be much heavier, therefore the GoFa Robot may not be able to carry it.
- Resistance to chemicals and UV radiation.
- Thermal stability: suitable for use in high-temperature applications
- Design flexibility: this material can be moulded into complex shapes and designs.

Subsequently, the environmental impacts of Polyamide with glass fibre additive will be analysed (Correira, 2019):

- The production of the composite requires the extraction of raw materials such as crude oil and natural gas. The manufacturing process involves the use of energy and water, resulting in greenhouse emissions and water pollution.
- It is not a readily biodegradable material. However, it can be recycled, meaning that it can be melted down and used to create new products, which reduces the environmental impact.
- As mentioned above, this compound has a high chemical resistance. This makes it easy to transport with little risk of spillage and contamination.
- As a durable material, the possibility of the material ending up in a landfill is reduced. The amount of waste generated is reduced.

Even though the material has some negative impacts on the environment, there are more benefits to the functionality of the gripper.

4 Develop

This part of the project is going to focus on developing ideas for the product design by brainstorming, SCAMPER, and sketches. Moreover, 3D CAD is going to be used for prototyping. Finally, it is also going to be made a physical prototype by using the 3D print.

During this point, it is also going to be considering the Design for Manufacturability. O'Driscoll (2002) defines manufacturability, also known as Design for Manufacture (DFM), as the common engineering approach of creating products to be easily manufactured. The goal of DFM is to minimize complexity and cost in the manufacturing process while maximizing the efficiency and reliability of the final product.

4.1 Idea Generation

For developing the idea generation, sketches are going to be done considering the dimensions of the gripper. In Appendix III can be observed both dimensions of the camera and the gripper.

4.1.1 3-12-3 Brainstorming

According to Gray, Brown, and Macanufo (2010), the 3-12-3 brainstorming technique is used to generate ideas. This technique is divided into three activities: 3 minutes of observation, 12 minutes to generate concepts approximating to the ideas that emerged from the observation, and 3 minutes to show the ideas to the partner. Firstly, the brainstorming topic is written on a piece of paper. In this case: integrate a camera into a gripper.

In a three-minute observation period, the observer documents all salient features of the subject matter, recording them on separate index cards within the time constraint (Gray, Brown, & Macanufo, 2010).

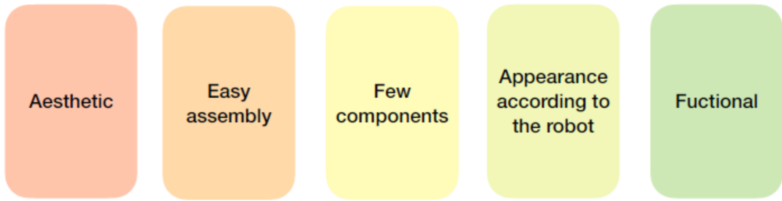

Figure 34: Characteristics of the topic

During the 12 minutes of generating concepts, 3 cards are randomly chosen. Concepts are developed according to their characteristics for the 3 words. Activities such as sketches and prototypes can be made (Gray, Brown, & Macanufo, 2010). The three cards selected are aesthetic, easy assembly, and appearance according to the robot.

Finally, there is a presentation of 3 minutes where the participants reflect on the different concepts that have been developed to try to choose one (Gray, Brown, & Macanufo, 2010). The results are as follows:

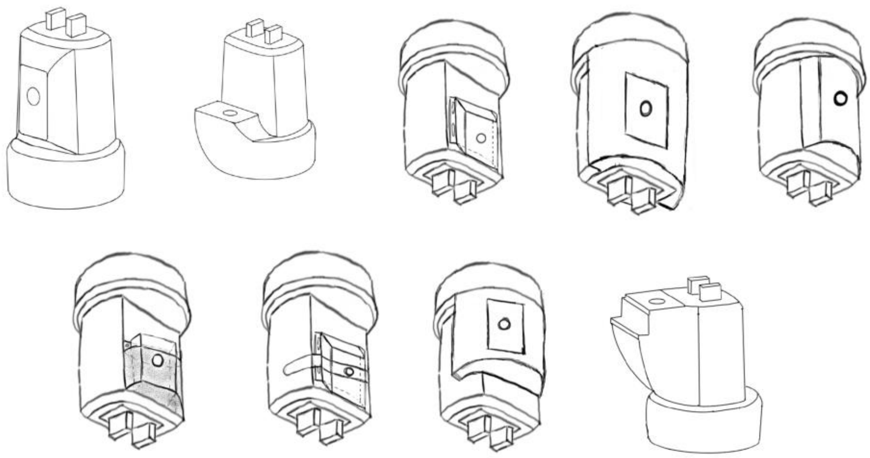

Figure 35: Sketches I

4.1.2 SCAMPER technique for creative thinking

According to Curedale (2013), SCAMPER is a brainstorming technique and creativity method that uses seven techniques. The name SCAMPER is an acronym for these seven techniques: (S) substitute, (C) combine, (A) adapt, (M) modify, (P) put to another use, (E) eliminate, and (R) reverse.

According to Eberle (2017), the SCAMPER technique is based on the idea of "what is new is a modification of existing old things around us". This method can be done in a group or individually to come up with innovative ideas that are more difficult to obtain by using other methods. There are two aspects to keep in mind when using this technique:

– The seven techniques can be done without following a specific order.

– Illogical ideas are considered.

This technique will be applied to the project to find a solution for integrating a camera into a gripper. In each of the 7 techniques of the method, new ideas or solutions will be generated from the reflections and conclusions reached in each section.

In the following points, each technique will be explained. Moreover, a series of questions will be answered to help generate ideas. Many of the questions have been adapted to the project's product.

1. Substitute.

The substitute technique focuses on the product's parts that can be replaced with another (Karina, 2017).

– Can the gripper case be replaced?

– Can the internal geometry of the gripper be replaced?

2. Combine.

Analyse the possibility of combining two ideas to achieve a new product with new features. Different questions can be included to help clarifying the ideas (Karina, 2017).

– Are there grippers with built-in cameras?

– Can the company combine resources with another partner in the market?

– Can two or more components be mixed?

3. Adapt.

Adjust or tweak a product for a better output. This adjustment can range from minor changes to radical changes in the whole project (Karina, 2017).

– What would be needed to change to reach better results?

– What else could be done in this specific task?

– How can be adjusted the existing product?

4. Modify, minify, or magnify.

According to Eberle (2017), changing the process in a way that unleashes more innovative capabilities or solves problems.

– How will the results improve by modifying the process?

– If the market were different, what would the process look like?

– Could the process be changed to work more efficiently?

– What if the product is double the current size?

5. Put to another use.

This technique refers to how to put the current product or process to another purpose (Karina, 2017).

– What if another market segmentation is targeted for the current product?

6. Eliminate or elaborate.

In this section, it will be analysed if there is anything in the product that could be removed to improve it (Karina, 2017).

– What would happen if we removed a part of the gripper?

– Can the gripper housing be modified by adding more material?

7. Reverse.

According to Eberle (2017), this technique tries to detect if a better result could be achieved by modifying the order of the process.

– What would happen if we modify the camera casing and leave the robotic gripper casing as it is?

This method facilitates the generation of new ideas for design integration and the exclusion of certain options due to project rigidity. Furthermore, sketching serves as an effective tool for the communication of various ideas. There are several established considerations for sketching, including the need for the camera to face downwards, the unchangeability of the camera housing contrasted with the modifiable nature of the robotic gripper case, and the necessity for the mounting bracket to be attached to the gripper case.

The sketches that have been generated are the followings:

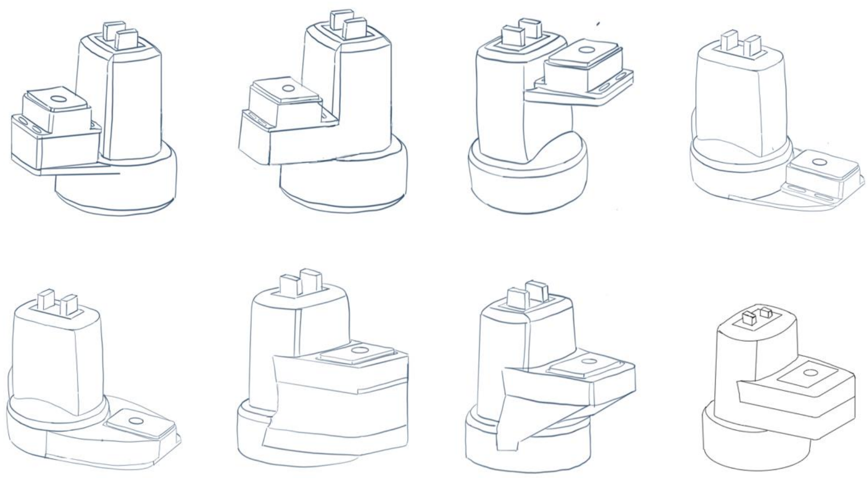

Figure 36: Sketches II

These recent sketches appear very similar, primarily because camera position is a key consideration in the redesign. The next step involves choosing a design that best fulfils the requirements, while also accounting for the environment and manufacturability.

The main difference between the two methods of idea generation, 3-12-3 Brainstorming, and SCAMPER, is that the latter, by considering multiple factors, leads to solutions that are closer to feasibility.

4.2 Concept selection

Three design sketches have been shortlisted based on several criteria. These criteria include the stability of the gripper, the structure of the case, minimal material usage for integration, the simplicity of the assembly process, and the aesthetics, with an emphasis on harmonizing with the original gripper's design. Furthermore, a thorough analysis of the requirements was undertaken to identify the most suitable grippers. In all three concept sketches, the camera is oriented downwards, the housing is modified, and only a minimal amount of material is added. Moreover, these sketches were favoured by several individuals due to their aesthetic appeal. In all three concepts, the camera faces downwards, the case is modified, and little material is added. Furthermore, these sketches were presented to a diverse audience to include the perspectives of potential users in the evaluation process.

The selected concepts are the following:

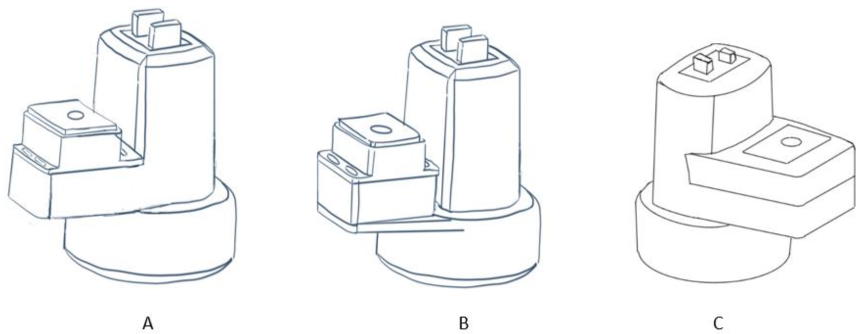

Figure 37: Concept selection

Once the potential solutions have been selected, we will focus on one. Therefore, the Weighted Decision Matrix method has been applied to see which is the most promising solution.

Table 19: Sketches' Weighted Decision Matrix Interpretation

Score	Importance:
1 = fulfils criteria from 0% a 20%	1 = not important
2 = fulfils criteria from 20% a 40%	2 = important
3 = fulfils criteria from 40% a 60%	3 = very important
4 = fulfils criteria from 60% a 80%	
5 = fulfils criteria from 80% a 100%	

The importance of each criterion has been established based on the list of users and ABB requirements. Therefore, all requirements have high importance. However, those requirements that are not a demand, but a desire have been given reduced importance.

Table 20: Sketches' Weighted Decision Matrix

Criteria	Importance	Score			Weighted score		
		A	B	C	A	B	C
Style according to the robot	2	3	2	4	6	4	8
Good visibility of the camera	3	4	4	4	12	12	12
Camera pointing down	3	5	5	5	15	15	15
Few Parts	2	5	3	5	10	6	10
Simple assembly	2	5	5	5	10	10	10
Total score					53	47	55

The one that fits better with the requirements established in concept C.

The final concept consists of modifying the casing of the gripper so that everything is mounted in a single piece. The assembly of the camera would be done by using M4 screws. Therefore, the assembly operation is not going to be complicated. Moreover, the design of the case includes another piece, its function is covering the camera, so the screws are not visible, and the aesthetic of the gripper is not damaged as it is thought to continue with the style of the gripper's case.

4.3 CAD concept

To model the integration of the camera into the gripper, it was necessary having access to the CAD model of the selected gripper. This was easily downloadable, as the company provided the CAD model on their sales page. Subsequently, the CAD model of the camera was created based on its dimensions. With both models in hand, the integration process could commence. The following can be observed in the process:

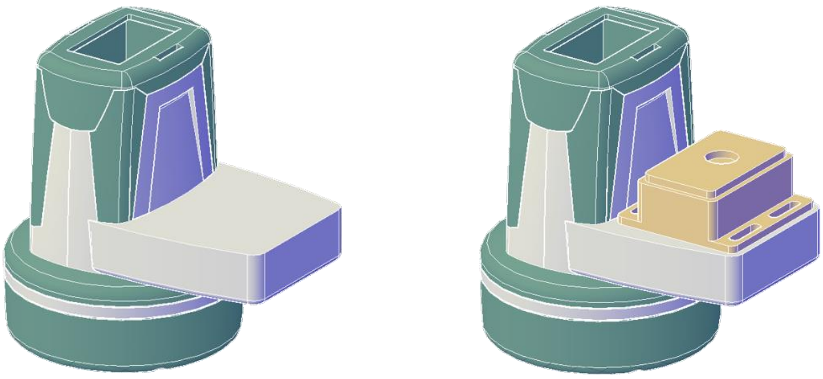

Figure 38: CAD model of the gripper's case

Before starting the design process, it was important deciding how the case of the gripper is going to be produced and mounted. In order not to use too much material it was thought to modify the case by adding a piece where assembly the camera, this will be part of the original case, not being able to separate it.

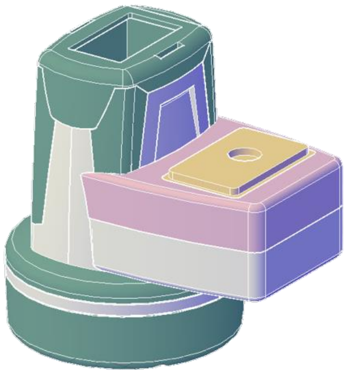

Figure 39: CAD model of the gripper's case and trim

Subsequently, it was realized that the camera disrupted the gripper's aesthetic appeal. To address this, a decorative trim was designed to conceal both the camera and the assembly screws. This component is not an integral part of the gripper's casing, its design purpose is to be easily removable to facilitate the installation and removal of the camera from the gripper as necessary.

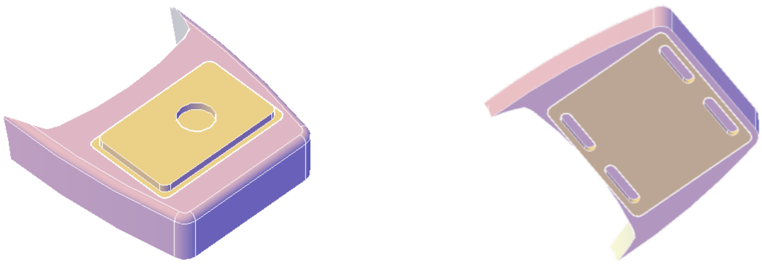

Figure 40:Basic CAD model of the trim

Above can be observed the way this trim is placed into the camera.

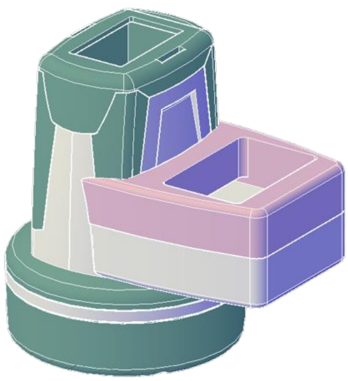

Figure 41: Basic CAD model of the case

The figure represents the final concept of the design process. The dimensions of the product can be found in Appendix IV. In this prototype, the assembly has not been considered. It is important not to pay attention to the colours used in the CAD model as it corresponds to the different layers used during the process.

4.3.1 Camera operations

The Terabee 3Dcam 80x60 transfers information using a USB interface. The camera has a USB 2.0 connector that allows bi-directional communication between the camera and the host device, which can be a computer or a microcontroller.

In the design, the camera has been positioned in such a way that it is easy to connect the cable without disturbing the other elements of the robot. To connect the USB cable to the camera is only necessary to remove the trim. In the following image it can be seen where the USB port is located in the camera:

Figure 42: USB connector of the camera

4.3.2 Aesthetics

For the colour selection of the design, the aesthetics of the GoFa robot and the Schunck gripper have been considered. Moreover, it was also taken into account the users' opinion of the GoFa robot, who claimed that keeping the aesthetic of the Schunk gripper was better than designing a different one since the customers are already familiarized with this product and it would be easier to recognise it in the market.

The robotic arm of the GoFa robot is characterized by a compact design and a slim profile. White and grey colours are one of the attractiveness of this automaton, which allows for easy visual integration in different working environments. Regarding the gripper, Schunk Co-act EGP-C 40-n-n-GoFa, it has a compact design and a dark blue colour finish with a textured surface. It has ergonomic details such as smooth contours and rounded edges. With these considerations in mind, it has been decided to be faithful to the aesthetics of the gripper by respecting as much as possible the colours of the gripper's case: dark blue and white. Moreover, the rounded and smooth edges have been respected in the new design. To match perfectly with the aesthetic of the GoFa's robotic arm, white and grey colours have been used in the gripper. The following pictures show the final prototype of the product regarding materials and textures:

Figure 43: Aesthetic of the product

4.4 Manufacturability

According to O'Driscoll (2002), manufacturability, also known as Design for Manufacture (DFM), is a methodology that focuses on designing products in such a way that they are easy and cost-effective to produce. It aims to lessen the manufacturing expenses and enhance the product's manufacturability. Following is going to be explained how the product will be developed according to this methodology.

4.4.1 Design For Environment

Regarding the Design for Environment (DFE), it has been considered the following aspects for doing the CAD model:

– The minimum amount of material should be used.

– The components of the product should have easy assembly.

– The minimum number of pieces of different materials should be used.

– It should be easy to produce.

This point will be explained more in detail in the following sections.

4.4.2 Design For Assembly

According to Ulrich, Eppinger, and Yang (2008), Design for Assembly (DFA) focuses on reducing manufacturing costs and improving product quality, development time, and development costs. Assembly costs can be reduced by redesigning components, to simplify assembly operations, or eliminating components by integrating their functions into other elements. DFA starts in the concept development phase and continues in the design phase.

For the integration of the camera and the gripper, the camera's mechanism for fixing it to a wall is going to be used. This bracket consists of four holes through which four screws are screwed to the wall. It can be seen the system in the following picture:

Figure 44: Camera mounting bracket for wall installation

The integration design idea is modifying the gripper's case so the camera would not only be integrated inside but also by using the camera mounting system. To modify the case, a base where to screw on the camera bracket will be created. Therefore, the gripper is going to be larger, the shape is going to be modified, and more material is going to be used. Although modifying the original case to integrate the camera requires an increase in material, efforts will be made to use as little material as possible.

To place the camera into the case, four screws will be used, which will be hidden with a trim. The camera has a mounting system, this mounting system includes screws for fixing the camera. The screws are M4. This is specified in Appendix III.

Figure 45: M4 screws

Several points have been considered for the design for assembly:

- To take advantage of the assembly system that the gripper has to save costs.
- Reduce the number of parts as much as possible. It has only two main parts, which are the outer casing of the gripper and a trim.
- Modularity has been considered, it can be easily assembled and disassembled. The trim can be easily attached to the gripper case.
- The connection of the individual parts is very simple. The gripper case and the trim are easy to connect.

The assembly is as follows:

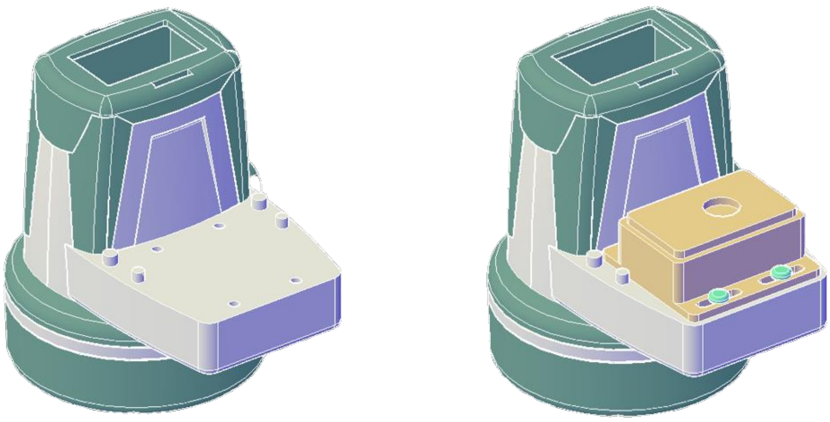

Figure 46: Assembly Process I

In the image on the left, it can be observed a hollow case is designed with four designated slots for screws and four holders intended for trim attachment.

In the image on the right, it can be observed the assembly of the camera. The four screws are placed in their respective holes.

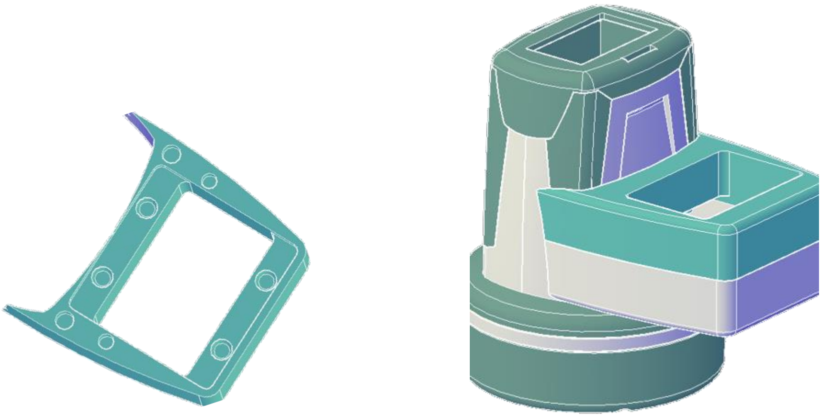

Figure 47: Assembly Process II

Above, one can observe the trim where the fasteners also fit. Furthermore, on the right side, one can see how the trim is positioned on the brackets using an interlocking connection.

4.4.3 Simplicity

Mollerup (2016) distinguishes design simplicity through three pivotal pillars:

- Functionality (simplicity for comfort): this dimension concerns the reduction or elimination of redundant elements to foster a more intuitive design. A functionally driven design aims to enhance user comfort by presenting a product or system that's readily comprehensible and user-friendly, minimizing unnecessary intricacies.
- Aesthetics (simplicity for pleasure): within the bounds of simplicity, aesthetics revolves around a minimalist design ethos that offers visual appeal. A harmoniously balanced aesthetic design judiciously utilizes space, colour, and form to convey a visually pleasing yet uncluttered appearance.

– Ethics (simplicity for conscience): this facet zeroes in on sustainability, emphasizing the incorporation of only quintessential features and ardently sidestepping resource wastage. Ethical design deliberates the environmental footprint and the broader social responsibility tethered to the product or system.

For the gripper's design, two primary determinants were spotlighted: the precise positioning and orientation of the camera. A nuanced redesign of the gripper was undertaken to seamlessly embed the camera, ensuring its downward orientation and smooth integration.

When appraising the product in light of Mollerup's criteria:

– For comfort: the product exudes simplicity, comprising two distinctly defined components, eschewing any extraneous complexity that doesn't proffer tangible value.

– For pleasure: the camera's size was judiciously selected to sustain an apt design proportionality. Furthermore, colour selection was pivotal in upholding the gripper's intrinsic aesthetic allure.

– For conscience: while the inclusion of an aesthetic trim might ostensibly seem like a superfluous use of material, this embellishment amplifies the product's perceived worth, thereby vindicating its inclusion.

The culminating product manifests as a primary gripper embedded with a camera and a supplemental, optional trim designed to bolster its aesthetic appeal.

4.4.4 Material selection and sustainability

The material of the product is going to be polyamide with glass fibre additive, the same one the original case has. However, why is this material good for grippers?

When comparing Polyamide with a glass fibre additive to other materials, several characteristics potentially render it superior for use in grippers. These include the distinct properties of the material, which have been already explained in 3.7 Environmental impact.

Regarding the product's end-of-life disposal, several options can be followed (Hedlund-Åström, 2005):

– Reuse and repurpose: where possible, consider repurposing the material for secondary applications. This not only reduces waste but also extends the utility of the material.

– Recycling: polyamide with glass fibre additive can be recycled. It is crucial to ensure the material is clean and free of any contaminants before recycling.

– Mechanical recycling: this is the most common method of recycling this material. The process involves grinding the material into small particles, which can then be remelted and reshaped into new products.

– Chemical recycling: this process involves breaking down the polyamide back into its monomer components. While this method is not as widely available, it holds the potential for recovering high-quality materials.

– Incineration: if recycling is not feasible, incineration is an option. However, this should be done in a controlled environment and with proper filtration systems to capture any potentially harmful emissions.

– Landfill disposal: as a last resort, if no other options are available, the material can be disposed of in a landfill. However, this is the least preferred method due to the long degradation period and potential environmental impact.

4.4.5 Manufacturing process

Despite the current high demand for vision systems integrated into robotics, the journey of a product to market necessitates not only time but also a strategy to captivate customers, while also considering competitive factors. Consequently, it is anticipated that the product will secure sales. However, due to its specialized nature, the production volume will likely be lower than the one of a standard gripper, leading to a more modest manufacturing process.

As it was specified before, the material thought for the product is Polyamide with glass fibre additive, also known as glass-filled nylon. Fortunately, this material can be used in 3D printers, which involves producing the piece rapidly. Moreover, it would be cheaper than traditional methods. Furthermore, using glass-filled nylon for 3D printing the product could provide the right balance of strength, durability, heat resistance, and design flexibility (Protolabs, 2023).

4.4.6 Cost

As mentioned before, 3D printing can be used to produce this product. To calculate the product's cost, it is necessary to consider the following aspects: the weight of the product, the cost of the material, and the production hours. It is important to note that the costs of electrification, printer maintenance, and the electronics of the gripper and the camera are not considered, as this project focuses on prototyping a redesign of a gripper's case.

Even though the impression of the prototype has been made in PLA (Polylactic acid), it is going to be studied the cost of the polyamide with glass fibre additive material, the one suggested for producing this product.

It is going to be considered that the polyamide with glass fibre additive that weighs 500g, costs 70,5$ (3DPrima, 2023).

Following is going to express the data needed for calculating the cost of the product.

Table 21: Data to calculate costs

Weight of the product	0,16 Kg
Time to produce the product	10 h
Cost of the material	141 $/Kg

Considering these data, the cost of producing this product would be:

$$141\ \$/Kg \times 0{,}16\ Kg = 22{,}56\ \$$$

The time of producing the product is important when knowing the cost of electricity.

In conclusion, the case of the gripper with a place for the integrating camera would cost around 22,56$ each. It is important to notice that the camera and the electronic part of the gripper are not considered for this estimation since the project's aim is only to focus on the case of the gripper. However, the camera costs 271$, and the original gripper 2.700$ (Terabee, 2023; Schunk, 2023).

Nevertheless, it is important to consider that the complexity of the product's interior couldn't be considered when printing the prototype. Consequently, the weight and price of the final product could vary.

5 Prototype

To produce a physical prototype of the product, a 3D print has been made.

The principles and benefits discussed in the article "Impresiones 3D, Nueva Tecnología que Apoya la Docencia Anatómica" can be applied to a broader range of fields, including the design and development of a robotic gripper integrated with a 3D camera. Some reasons why 3D printing is beneficial for the project are (Inzunza, et al., 2015):

– Precision and complexity: one of the main strengths of 3D printing is its ability to replicate intricate designs with notable accuracy. This is important when trying to integrate a camera into the gripper, where exact fits and placements are essential.

– Customization and iteration: the technology permits easy modifications to the design. This flexibility is especially crucial during the prototyping phases, where a design might undergo various changes based on testing and feedback.

– Tangible visualization: a salient benefit of 3D printing is that it transforms digital designs into physical models. Having a tangible model helps in assessing the ergonomics and understanding how the design will function in real-world scenarios, which is crucial for devices like our gripper that physically interact with objects.

– Efficiency in time and cost: in comparison to traditional manufacturing, 3D printing offers a faster and more economical way to prototype. This speed is vital when rapid iterations are necessary for the design process.

– Diverse material options: modern 3D printers can accommodate a range of materials, offering the flexibility to select one that matches the desired properties of the final product.

– Validation through testing: with a physical prototype at hand, it becomes feasible to conduct hands-on tests, which is instrumental in recognizing potential design improvements.

The printer used for prototyping the product has been the Original Prusa i3 since we had access to it in Assar. The following pictures show the result:

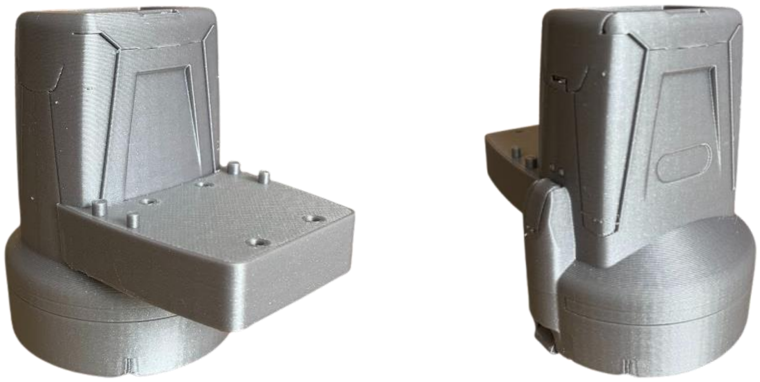

Figure 48: Physical prototype of the product I

Firstly, the case of the gripper was printed all in one piece.

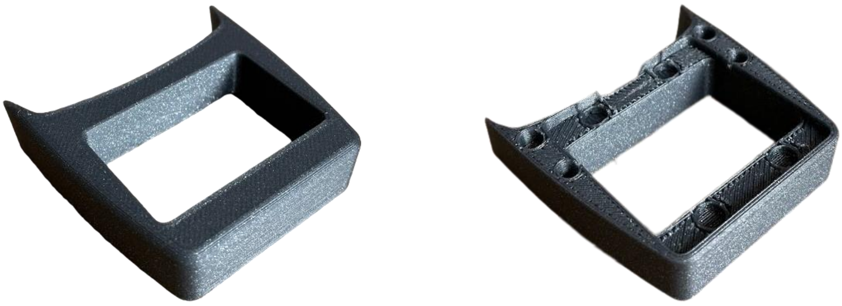

Figure 49: Physical prototype of the trim

Secondly, the trim for the gripper was printed.

Figure 50: Physical prototype of the product II

Finally, both parts were joined together.

The dimensions of the physical prototype are the same as the original one made in the CAD software. This means that the scale used for prototyping the physical product has been 1:1.

6 Sustainable development goals

In the modern era, where technology and sustainability intersect, it's imperative that technological advancements are weighed against their environmental and broader societal impact. The United Nations' Sustainable Development Goals

(SDGs) offer a framework that allows innovators and developers to assess how their contributions align with a more sustainable and equitable future. By exploring the relationship between the chosen material for the robotic gripper, specifically polyamide with a glass fibre additive, and the SDGs, we aim to understand how this material choice intertwines with broader sustainability goals and its potential impact on the world. This connection not only underscores the inherent responsibility in material and technology choices but also highlights opportunities for technological innovation to positively contribute to global challenges (United Nations, 2023):

– Goal 9 (Innovation and Infrastructure): the use of polyamide with glass fibre, a composite that allows for significant design flexibility, is a clear indication of innovation in the field of robotics. The strength, durability, and lightweight nature of the material can facilitate the construction of more sustainable and resilient infrastructures, especially in industries requiring precise object manipulation with robotic tools.

– Goal 12 (Sustainable Consumption and Production): choosing a recyclable material, like polyamide with glass fibre, reflects a commitment to sustainable production. By promoting its recycling and minimizing its end-of-life in landfills, it aligns with reducing environmental impact and promoting sustainable consumption and production patterns.

– Goal 13 (Climate Action): although indirectly, by opting for materials with a longer lifespan that can be recycled, emissions related to the production of new materials are reduced. By decreasing the need to extract and process raw materials repeatedly, it contributes to the mitigation of climate change.

– Goal 11 (Sustainable Cities and Communities): a robotic gripper made from durable materials can be essential in industrial processes in urban areas, reducing the need for frequent repairs and replacements, thereby minimizing waste and contributing to the sustainable management of resources in cities.

– Goal 6 (Clean Water and Sanitation): while there isn't a direct evident relationship, the material's chemical resistance means it can be used in environments where other materials might become contaminated or degrade, including watery environments. Its durability might contribute to the reduction of resource wastage in systems that require interaction with water.

– Goal 17 (Partnerships for the Goals): in the pursuit of improving and optimizing the use of polyamide with glass fibre, it's essential to form partnerships with academic entities, recycling companies, and other organizations to ensure sustainable practices and knowledge sharing.

7 Deliver

7.1 Renders of the result

In Appendix V , the renders depicting the ultimate outcome of the Computer-Aided Design (CAD) can be observed. This process has been accomplished through the transfer of the AutoCAD file into Inventor, followed by the meticulous selection of appropriate materials and colours.

7.2 Future improvements

Regarding the improvements in the development of the project, two sections could have improvements: CAD, and manufacturing process.

7.2.1 CAD

During the CAD prototyping process, issues have been continually appearing. The main difficulty was respecting the shape of the gripper due to this one has so many different shapes in its design.

As an improvement in the design of the product, it would be better to have a round edge between the platform where the camera is placed and the rest of the gripper. In the following figure, this detail can be observed:

Figure 51: Improvement of the CAD

Another way of joining the gripper and the trim could have been creating lips instead of using the attachment method used.

Moreover, a draft analysis would have indicated how producible the product is.

7.2.2 Manufacturing process

The proposed manufacturing process for the development of the product has been identified as 3D printing. However, injection moulding might also serve as a viable solution. Due to time constraints, a comprehensive analysis to evaluate the viability of this method could not be conducted. Therefore, injection moulding, potentially offering higher precision than 3D printing, was not suggested as an alternative. Injection moulding's ability to create a wide array of complex products, often requiring intricate shapes and precise dimensions, is noteworthy (Kryachek, 2004).

7.3 Analysis of the prototype

The analysis and evaluation of the prototype are identified as critical processes in the assessment of the executed product design. This process is detailed further by addressing key elements (Kirchner & Eugenio, 2010):

- Functionality of the prototype: due to the unavailability of the camera, the assembly efficiency of the two components could not be directly verified. Nonetheless, with precise dimensional adjustments, it is presumed that there should not be any major issues. This presumption is based on the notion that the accurate dimensions of the prototype should ensure seamless assembly, even without the direct verification provided by the camera.
- Usability: upon completion of the prototype, feedback was sought from the same respondents who participated in the initial product survey. They were requested to handle the prototype and articulate their understanding of the product's assembly process. This process was essential in gauging the perceived ease-of-use of this design from the users' perspective. No difficulties were reported in understanding the assembly mechanism, which suggests an intuitive design.
- Limitations: the main challenge encountered during the product's prototyping phase was related to the printer. It struggled with the first layer, which did not adhere properly, necessitating several process iterations. However, this issue did not significantly impact the overall timeframe to achieve a satisfactory product print. Concerning the physical prototype, the diameters of the joining part of the casing and trim, as designed in the CAD software, were not factored into the initial printing process. This resulted in an assembly challenge as both parts had identical diameters. To address this, a second prototype was produced, aiming to improve upon this identified weakness.

8 Discussion and conclusions

In this stage, the obtained results will be analysed, and the design process will be reflected upon, taking into consideration the challenges faced and the materialization of the product. Additionally, the highlighted aspects and opportunities for improvement in future developments will be discussed.

Throughout the project, we have applied the double diamond methodology, an iterative design process. Following this methodology, we have repeatedly returned to previous stages whenever an error or improvement opportunity was identified, as the method itself suggests. This has allowed us to refine and optimize the product at each stage of the process.

Moreover, numerous methods were examined and utilised. To ensure a coherent structure in the report, analogous methods were applied to similar circumstances. This approach allows the reader to concentrate on a single type of development at a time, thereby enhancing the report's readability and comprehension. Subjective methods such as SCAMPER and the 3-12-3 brainstorming method were selected for idea generation due to their capacity to offer flexibility, stimulate creativity, and foster the development of various solutions tailored to the specific design requirements of the client and ABB. However, it is noteworthy to mention that more objective methods such as functional analysis could have also been implemented, an aspect that will be considered in future projects.

At the outset of the project, visualising the final outcome was challenging. Early discussions with ABB to specify the project's requirements revealed an unexpected focus on programming rather than design. We negotiated to strike a balance between meeting ABB's needs and satisfying the requirements of our end-of-degree work in Industrial Design and Product Development Engineering. Once the project's competencies were agreed upon, numerous details arose that we were unfamiliar with and necessitated intensive research. Key questions centered on the utility of integrating a camera into a robotic gripper, the benefits this might confer on users, and the reasons for choosing a 3D camera over a 2D one for product development.

Further complicating matters, researching cameras and gripping systems proved to be the most complex aspect of the project, due to their critical importance and the exhaustive investigation they required. Although time-consuming, the selection of the camera and gripping system was relatively straightforward, facilitated by well-defined requirements from both users and ABB.

However, our inability to modify the camera's design, combined with rigid specifications for the robotic gripper's design and structure, constrained the flexibility of our sketches during the development stage. Furthermore, we lacked detailed information about the internal structure of the robotic gripper, adding another layer of complexity to the design process.

Once the sketches were completed, we moved to the CAD design stage, a time-intensive process due to the product's complexity, but somewhat more familiar due to our previous experience with CAD tools. This phase was repeated numerous times to improve aesthetics and correct design errors. The prototyping phase revealed several design flaws, necessitating a return to the computer-aided design phase. This underscored the importance of prototyping. In the final phase of prototyping, user feedback was solicited to refine the product further.

The sustainability of the product has been a paramount factor throughout the development process. From a social perspective, efforts have been made to create a more efficient product with new functionalities, such as incorporating 3D vision, enabling the robot to perform collaborative tasks more effectively. This translates into greater usefulness and benefits for users, fostering a more positive interaction with the work and social environment.

In terms of environmental considerations, special attention has been given to reducing the carbon footprint. The selection of materials has been carried out consciously, opting for those with a lower environmental impact and greater durability. Additionally, a focus on recycling and component reutilization has been implemented to minimize waste and reduce the product's environmental impact throughout its lifecycle.

From an economic standpoint, cost optimization has been pursued without compromising product quality. The number of required parts has been minimized to the greatest extent possible, not only contributing to cost reduction during production but also facilitating maintenance and repairs of the robot, thus diminishing its long-term economic impact.

Looking ahead, this project could be extended to allow control of the camera from the GoFa robot's screen. However, this would require expertise we currently lack. The opportunity to collaborate with robotics engineers for concurrent development of the gripper and this feature would have been highly beneficial.

In conclusion, this project has been an engaging and intricate endeavour, touching upon various facets of product design. It has provided us with a rich learning experience, offering insights into a completely new subject. Despite encountering numerous challenges throughout the process, we have managed to hone our skills and effectively navigate through various obstacles.

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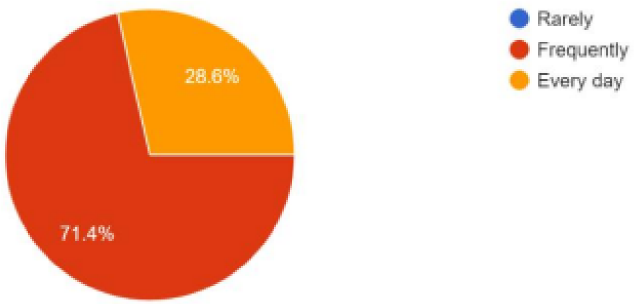
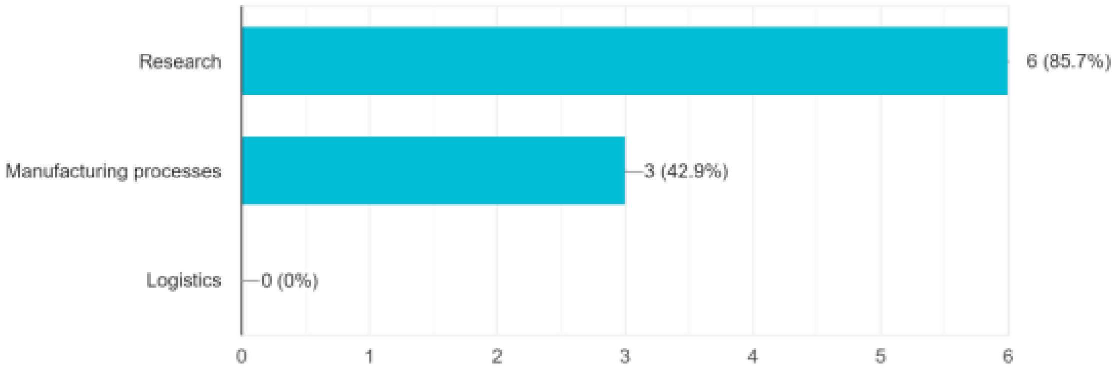
Appendix I

Questionnaires

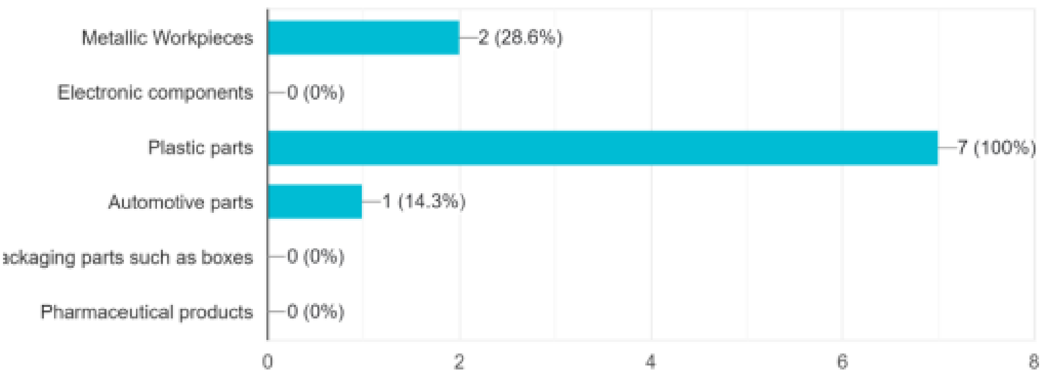
How frequently do you use the GoFa robot?
7 responses



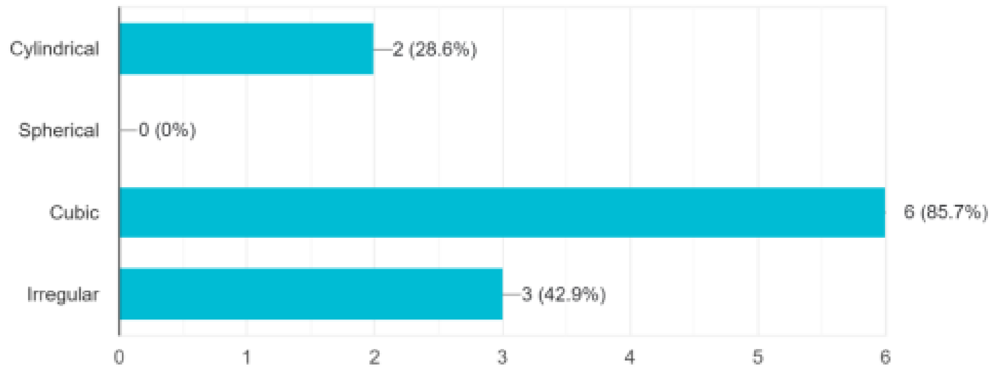
For what purpose do you use the GoFa robot in your operations?
7 responses



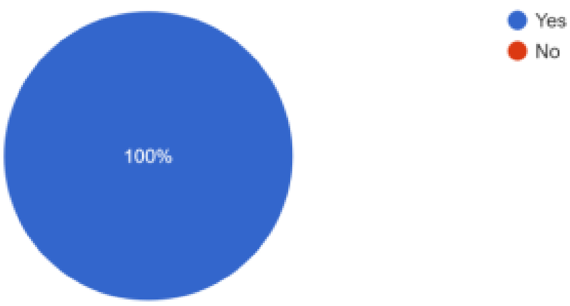
What kind of objects do you usually handle with the robot?
7 responses



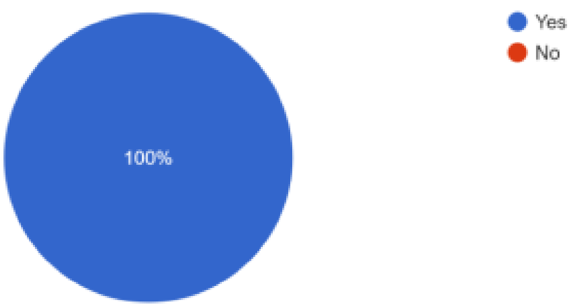
What is the shape of the objects usually handled by the robot?
7 responses



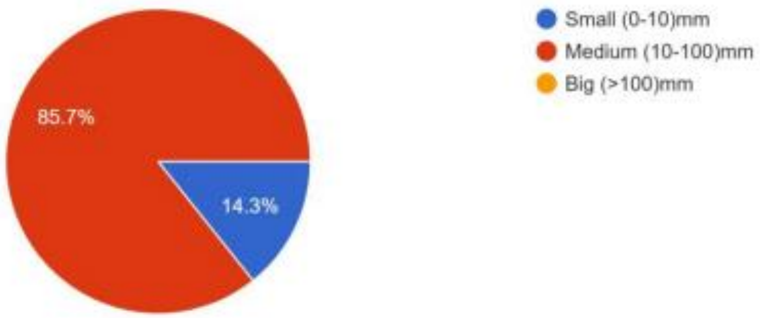
Do you use the GoFa robot to handle more than one type of product?
7 responses



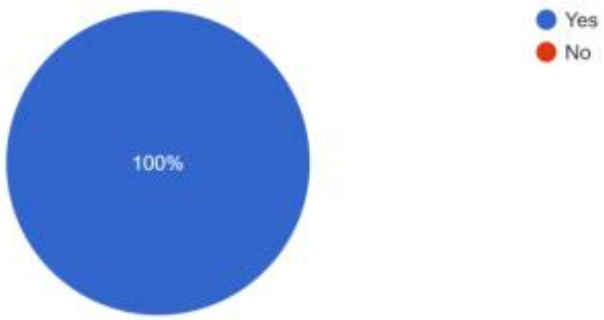
Do you consider essential to be able to pick up different workpieces made of different materials such as stainless steel or brass?
7 responses



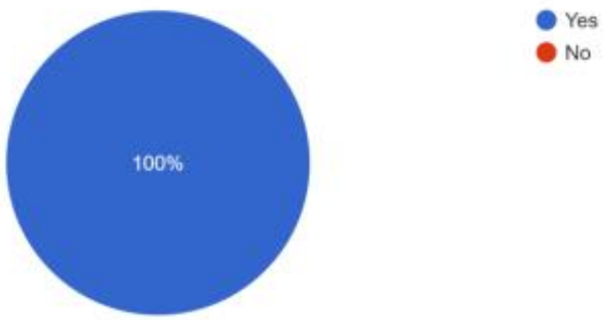
What is the size range of the objects you handle with the robot?
7 responses



Would you consider useful if the gripper of the GoFa robot was equipped with an integrated 3D camera?
7 responses

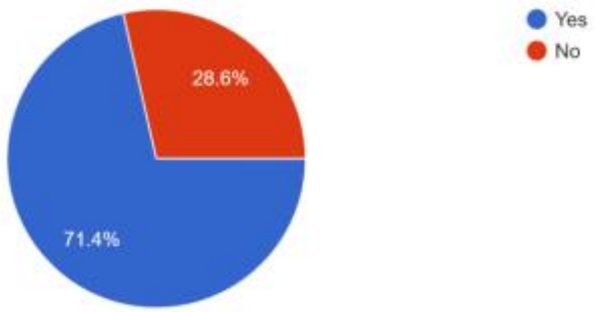


If so, do you consider important that the camera is oriented downwards to optimise the robot's movements and to observe the workpiece easily?
7 responses

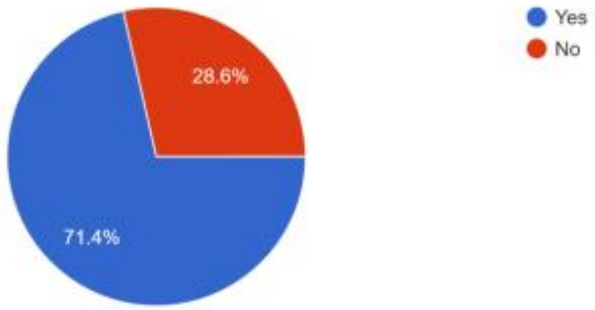


Do you think it is important that the material used in the gripper's case should be as environmentally friendly as possible?
7 responses

Is it important that the camera integrated in the gripper of the GoFa robot has a high resolution?
7 responses



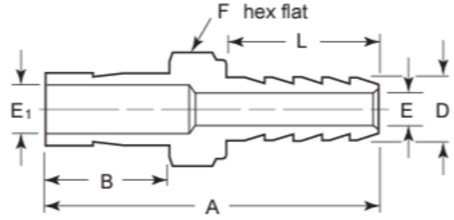
Regarding the aesthetic of the product, do you think it is important to follow the style of the gripper and the robot in the integration?
7 responses



Appendix II

Sizes of the workpiece

Tube Adapter

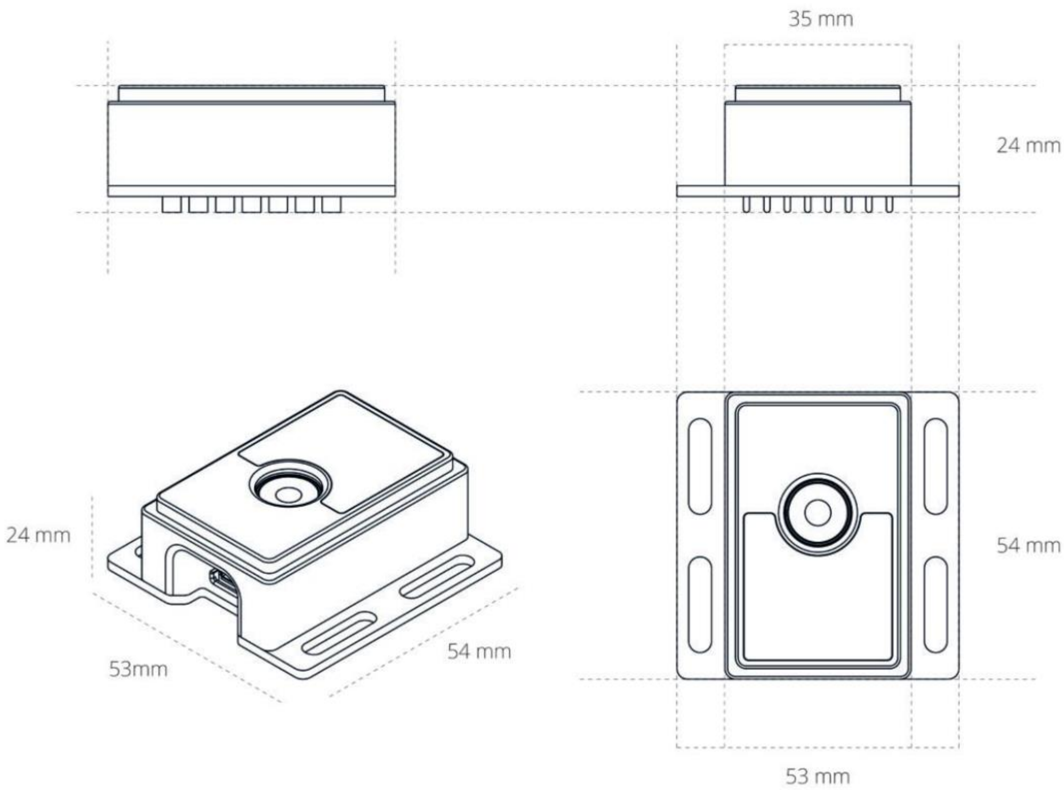


Part No.	End Connections		Dimensions, in.						
	Hose ID	Tube Size	A	B	D	E	E1	F	L
DHAT 2-2T	1/8	1/8	1.36	0.54	0.15	0.08	0.09	5/16	0.40
DHAT 2-4T	1/8	1/4	1.46	0.64	0.15	0.08	0.19	3/8	0.40
DHAT 4-4T	1/4	1/4	1.85	0.64	0.30	0.19	0.19	7/16	0.79
DHAT4-6T	1/4	3/8	1.91	0.70	0.30	0.19	0.28	7/16	0.79
DHAT 4-6MT	1/4	6mm	1.88	0.64	0.30	0.19	0.18	7/16	0.79
DHAT 5-4T	5/16	1/4	1.93	0.64	0.37	0.19	0.19	7/16	0.87
DHAT 6-4T	3/8	1/4	1.93	0.64	0.45	0.30	0.17	9/16	0.87
DHAT 6-6T	3/8	3/8	1.99	0.70	0.45	0.30	0.28	9/16	0.87
DHAT 6-8T	3/8	1/2	2.25	0.96	0.45	0.30	0.39	5/8	0.87
DHAT 8-6T	1/2	3/8	2.06	0.70	0.60	0.38	0.28	11/16	0.94
DHAT 8-8T	1/2	1/2	2.32	0.96	0.60	0.38	0.39	11/16	0.94
DHAT 12-12T	3/4	3/4	2.49	1.02	0.90	0.63	0.59	1 3/16	1.05
DHAT 16-16T	1	1	3.02	1.30	1.20	0.88	0.80	1 3/8	1.19

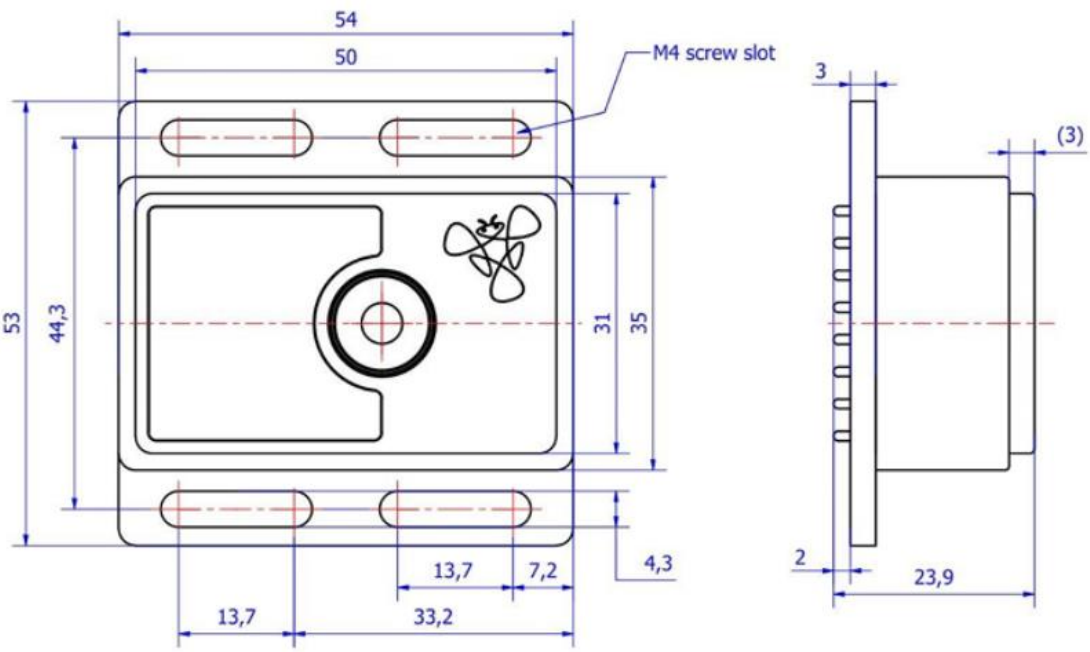
Appendix III

Camera and gripper's dimensions

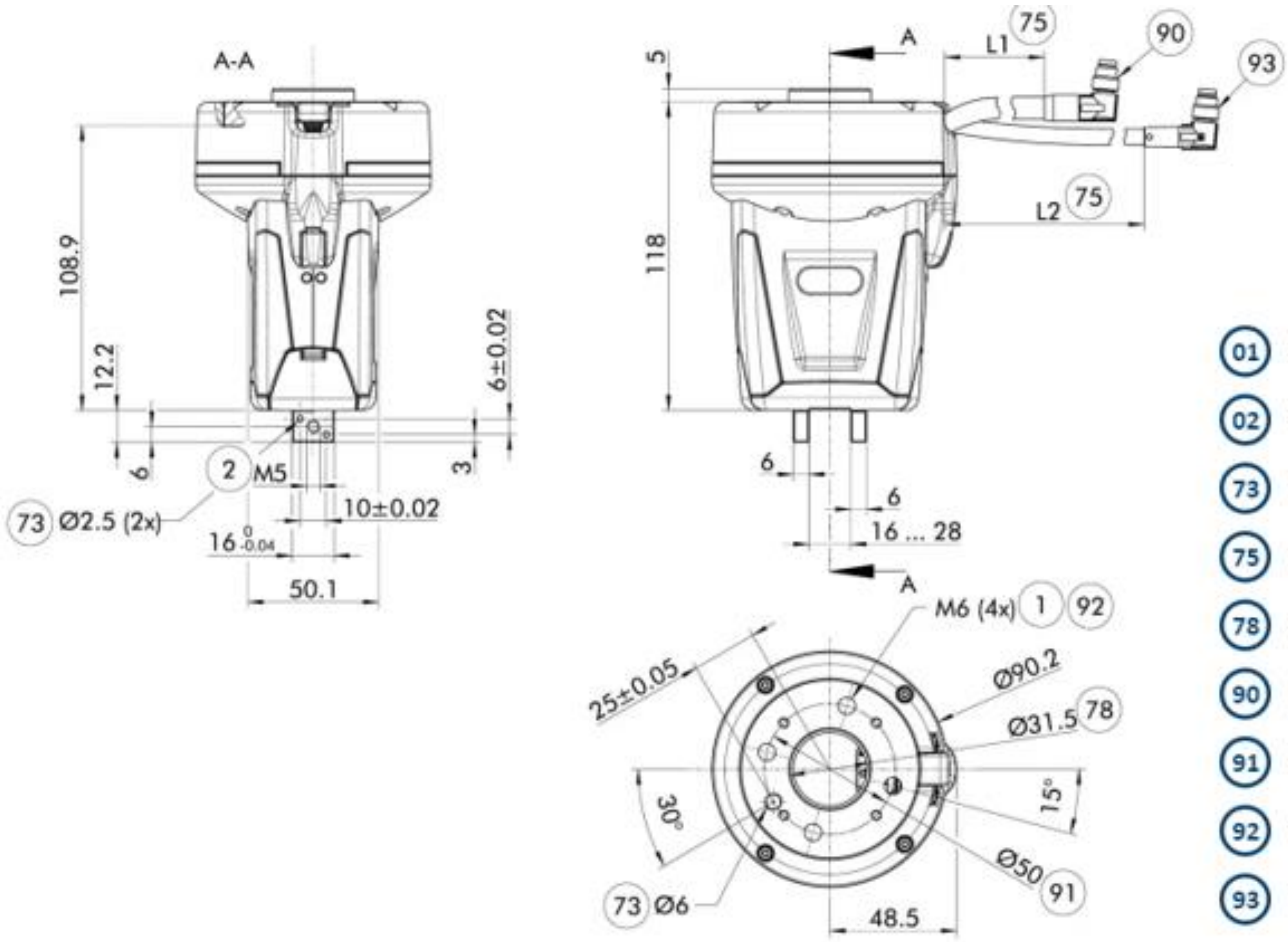
Camera's dimensions:



Following, it can be observed more dimensions that do not appear above:



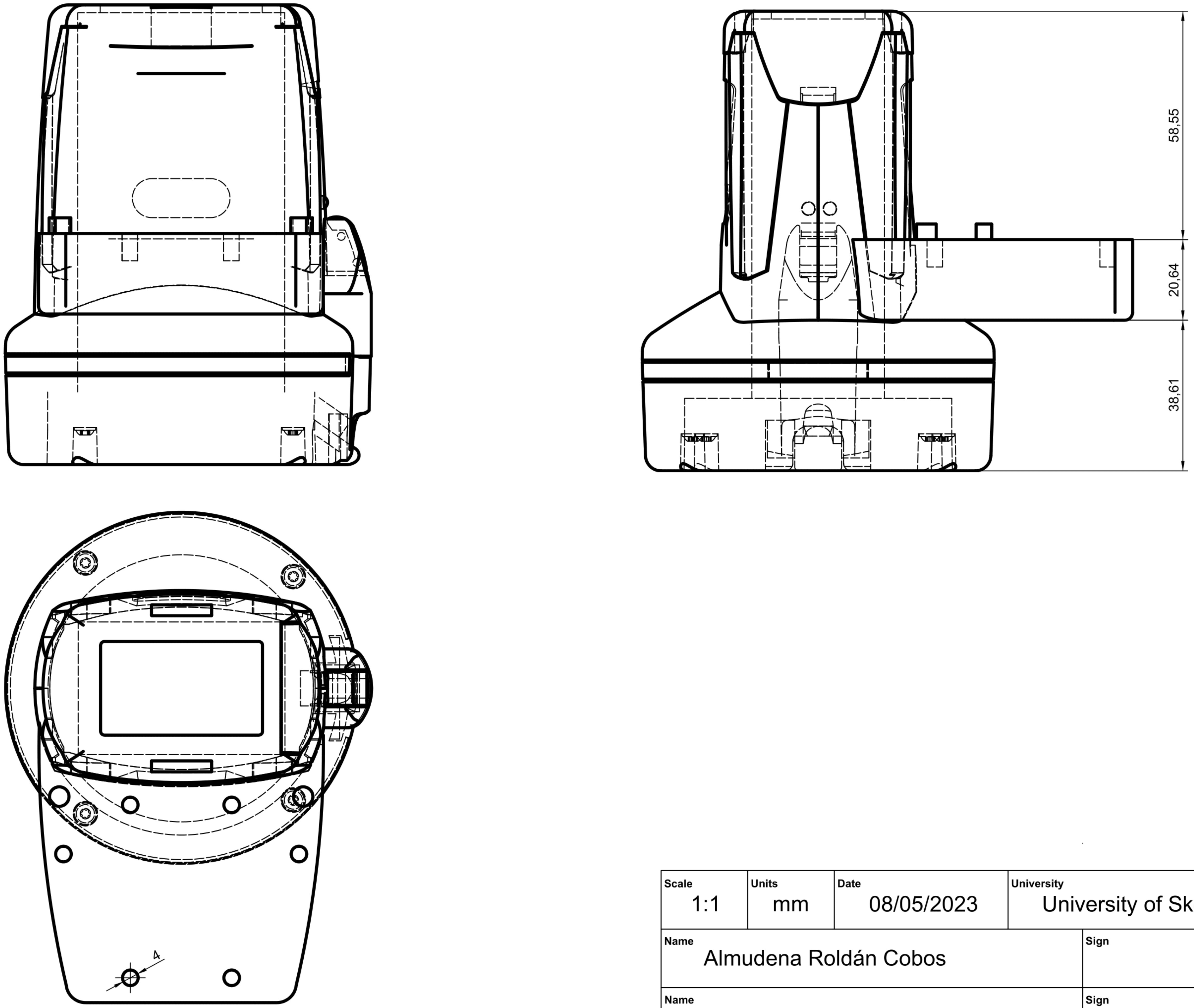
Gripper’s dimensions:



- (01) Gripper connection
- (02) Finger connection
- (73) Fit for centering pins
- (75) Cable length
- (78) Fit for centering
- (90) M8 connector, 3-pin
- (91) DIN ISO-9409 bolt circle
- (92) Through holes for screw connections
- (93) M8, 4-pin Male Connector

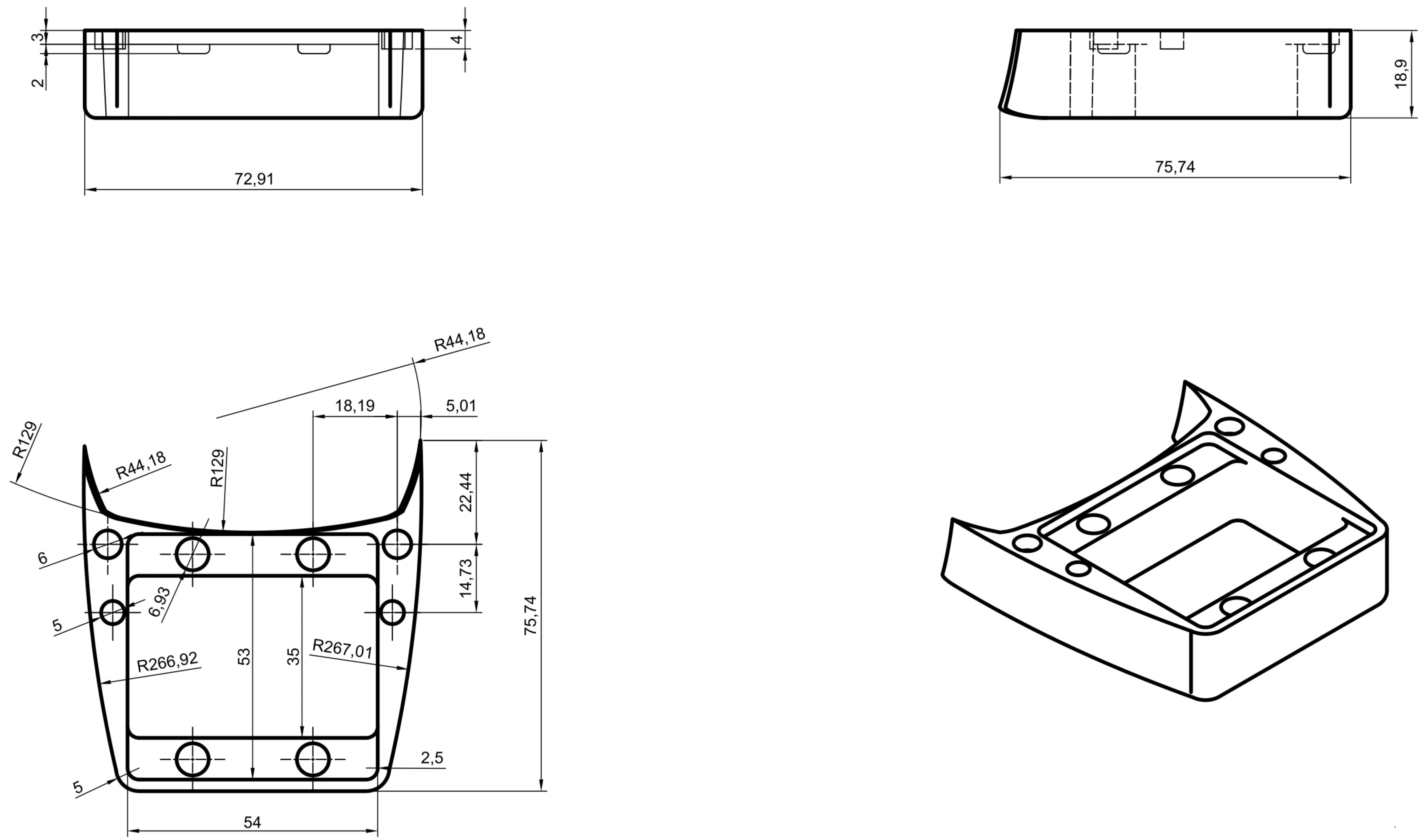
Appendix IV

CAD modelling



Scale	Units	Date	University
1:1	mm	08/05/2023	University of Skövde

Name	Sign
Almudena Roldán Cobos	
Julia Barón Suárez	



Scale	Units	Date	University
1:1	mm	08/05/2023	University of Skövde
Name: Almudena Roldán Cobos			Sign
Name: Julia Barón Suárez			Sign

Appendix V

Renders of the result

For rendering the CAD prototype, it has been used, Inventor. Following it can be observed the final product:

Figure 52: Front and lateral view of the product

The perspective view of the product is as follows:

Figure 53: Perspective view of the product

Assembly of the camera:

Figure 54: Assembly view of the product

Render of the trim:

Figure 55: Perspective view of the trim