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DESIGN OF A SMART GRIPPER FOR INDUSTRIAL APPLICATIONS

Master of Science thesis

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ABSTRACT

ALBERT APARISI I ESCRIVÀ: Design of a Smart Gripper for Industrial Applications
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The gripper is the most important part from an industrial robot. This one interacts with the environment that surrounds the robot. Nowadays, the industrial robot grippers have to be tuned and custom made for each application by engineers, searching to get the desired repeatability and behaviour.

This thesis discusses the design of a smart and flexible gripper for industrial activities. This means that the gripper has to be able to sense the environment that surrounds it. For this will be need to choose different sensors for improving its flexibility and function ability. Furthermore, a power tool finger will be added for make the gripper able to use power tools. With all of these the aim is to choose a design that can be able to be more independent than the other grippers that already exist in the industry. Also tries to keep it easy and the low costs.

This thesis also will 3D print a prototype of the results from the design discussions. This prototype would not be functional, it will be for represent the results.

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LIST OF SYMBOLS AND ABBREVIATIONS

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DoF	Degrees of freedom
CCD	Charge Coupled Device
FPS	Frames Per Second
N	Newton
CPU	Central Processing Unit

1. INTRODUCTION

Robot grippers are attached at the end of an industrial robot. Those are connected as end effector to realize and develop a task in an industrial work floor. They are normally designed as jaws for grasping objects and to move them. The grippers are mostly constructed for opening and closing the jaw. But the evolution of the technology provides the opportunity to bring the grippers to a next level. Smart grippers that not only open, close and bringing objects to another position. Grippers that are capable of sense different factors around them and react to this. For this interaction different sensors and actuators have been added to grippers and can be directed by microcontrollers.

The device that is going to be designed in this project is an improved smart gripper that includes different sensors. The gripper, unlike the other smart grippers, tries to reach a widely amount of tasks using multiple sensors. The aim of the gripper is to reach a high flexibility using the feedback of these sensors. Being able to develop different industrial activities without the need of someone that change the gripper for another one or change the station.

Designing a flexible smart gripper is a nowadays necessity, due to its advantages for developing multiple tasks without the need of a human interaction or changing places to save production time.

1.1 Definitions

Robotics is the branch of science that involves designing, construction, provision, manufacturing and applies to the robots. The robotics combines different disciplines such as: mechanics, electronics, informatics, artificial intelligence, engineering of control and physics. Other important fields are the algebra, animatronics, PLCs, and machine status. [2]

Oxford defines a “Robot” as a machine capable of carrying out a complex series of actions automatically, especially one programmable by a computer. ("Robot - Definition of Robot in English from the Oxford Dictionary")

Here is a definition of a gripper from the book “Robot Grippers” by Monkman. "Grippers are subsystems of handling mechanisms which provide temporary contact with the object to be grasped. They ensure the position and orientation when carrying and mating the object to the handling equipment. Prehension is achieved by force producing and form matching elements. The term “gripper” is also used in cases where no actual grasping, but rather holding of the object as e.g. in vacuum suction where the retention force can act on a point, line or surface." (Monkman)

After these definitions there is just the one left that that is interesting for the project, Smart gripper. A smart gripper is an end effector that can adapt itself to the physical properties and environmental changes (force, position, grasping mode, etc.) in presence of a particular stimulus. [27]

Before continuing, it is interesting to know the different generations that have been in robotics, to understand in which one the smart gripper situated and what involves this generation. The robots can be classified in the following generations:

1. **Manipulators:** are multifunctional robots with a basic mechanical system, they can be used for easy and repetitive tasks. They can be controlled by a person using a remote control, and they have four degrees of freedom. [1]
2. **Computerized precision programmable logic controller (PLCs):** are adjustable manipulators that use sensors for regulating itself Thanks to this they have more precision and force. They are adjusted by PLCs and have four degrees of freedom. [1]
3. **Computerized by CNC:** are programmable robots with continue trajectory, they are more advanced devices programmed by CNC. They have higher force and perform more demanding tasks. They have six degrees of freedom. [1]
4. **Sensory:** are robots that with sensors can acquire information about the environment that surround them and they are able to adapt to it. They have six degrees of freedom with a precision of ±0,04mm. [1]

The elements that conform the robots are

1. *Manipulator:* mechanical element, formed by different links connected with joints that allow it to move.
2. *Controller:* in charge of the manipulator's movements, actions, operations and information processing.
3. *Inputs and Outputs data device*: allow to send and receive the information between the controller and the manipulator.

At the end of the manipulators it can be found and end effector in charge of the interaction between the environments. It is sometimes known as a gripper. This is going to be the part of the robot which represents the main focus of the project. A smart gripper that is able to sense the environment around the manipulator and improve its performance. This kind of gripper makes it able to pass from an easy manipulator to a sensory robot.

1.2 Scope

The scope of this project is to design a smart gripper for industrial applications. The project will be focused on selecting different features that gives more functionality and flexibility to the gripper. Choosing them throw the main ones used in the industry.

Also it is needed to find out which is the best configuration for being flexible but to keep the system simple and cheap.

Selecting these features and the design is quite important, for introducing a new idea of smart grippers, which can be more independent than the ones already used in industry.

Design as parts of robotics is going to be the main challenge of the thesis. Afterwards, a 3D prototype of the smart gripper will be printed.

Although it is desired to have a possible solution of a smart gripper, but building one in reality is a really tough challenge for the master thesis. Each sensor and the different mechanism that the gripper needs can become complex problems that could become a new thesis. Therefore, this master thesis will focus on designing the hand, choose the sensors that would make it flexible and functional in a wide range of tasks and 3D print a prototype of the design.

2. ROBOT GRIPPERS

2.1 History

The first steps of the grippers started in 1969 at the Stanford University by the hand of Victor Scheinman. This mechanical engineer developed the Stanford arm with the first readily controllable gripper. His predecessors, Hydraulic Stanford arm was faster and more effective, but dangerous and uncontrollable. In contrast, Stanford arm was steerable in six full degrees of freedom; gears, harmonic drives and dc motors generated its motion. [5]

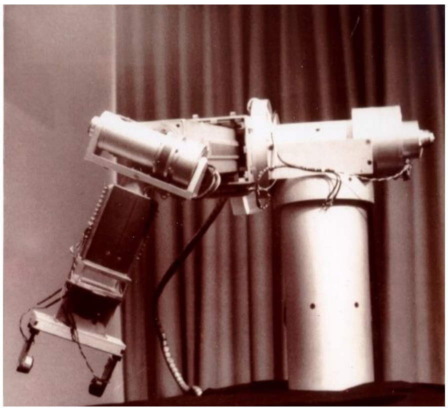


Figure 1. Stanford arm

In the decade of 1980s more powerful microchips permitted designing rougher grippers based on the Stanford arm for using them in the heavy industry. Even if some feedback and control elements were copied from the Stanford arm the industrial arms started to introduce arms powered by air and used in automotive manufacturing. Nowadays the majority of grippers are still pneumatic. [5]

2.1.1 Gripper evolution

The Stanford arm included a parallel gripper. This configuration is still common nowadays, consisting of two straight fingers (bars) that slide apart or move together to release and grip objects. This is thanks to their stroke versatility. [5]

In the late 1970s a two fingered angle gripper was invented. The fingers are designed for closing like a lobster claw on targeting objects. The difference between these and the parallel fingers is that parallel jaw simplifying the design, and the force stays the same in whole stroke. Parallel fingers have two design options: Direct-acting piston and wedge that give a high grip force (to 44482.22N) and shorter stroke. The other option is straight direct piston which has less force but generates a longer stroke (to 24 in.) [5]

A new gripper innovation was invented in the 1980s. A three fingers gripper, designed at the Massachusetts Institute of Technology licensed by Barrett Technology. The configuration, Barrett hand, build with servo controllers, communication, four brushless motors and software. Although the three fingers were created in 80s, they are beginning to be used widely now. [5]

2.1.2 Grip and Rotate

Pneumatic powered grippers with traditional cylinders require multiple air supplies. For dual motion units that grip and rotate this is certainly true. In other cases, after establish the initial grip, a mechanical retainer holds the object. The Stanford arm design is still giving inspiration here, in the old breakthrough configuration, slide jaws and electromechanical brakes held joints in position and prevented collision damages. [5]

Schunk Inc. miniaturized rotating grippers. They produce and assemble thiny components. A parallel gripper is combined with Schunk RM rotary module, which can be equipped with different gripping forces and safety devices for designing semiconductors. Combining rotation with griping requires some modifications. The design adds longer pistons rods for the grip drivers to operate on rotary modules. [5]

In addition, finger grippers use a third mounting option in Cartesian gantries as set up. For an easier construction, Schunk's rotator have standardized patterns to adapt and connect plates. [5]

2.1.3 Last Evolutions

Till nowadays, robot grippers have been restricted to two and three fingers. But in today's companies as Fest Corp are introducing new technologies combining mechatronics and bionics, more than 30 pneumatic muscles, metacarpal and finger bones, radius and ulna polyamide sintered by laser. [5]

Using compressed air with this elastic tubes variates the diameters and length and making them able to develop tasks. An advantage from the human is that muscles don't need energy supply after moving or holding weight in a place. Tensile and contraction forces are monetarized by length and pressure sensors. A regulator distributes pressure in the model giving force, refinement and rapidity. [5]

Other ideas are being developed, such as robotic hands with dexterity and strength of a human one. New microcontrollers bring the possibility of new complex hands with more actuators and adding more strength to the fingers, which makes it possible to create new configurations which are more flexible and efficient for a widely sort of tasks. [5]

2.2 Type of Grippers

The End-of-arm has to be in contact with the objects and interact with them. Adapting these ones to the different objects and industrial activities ended with different kinds of grippers. There are four main types of robot grippers: vacuum grippers, hydraulic grippers, pneumatic grippers and servo-electric grippers.

2.2.1 Vacuum Grippers

The vacuum gripper has been a standard tool for robots in manufacturing due to its high level of flexibility. The tool is made of polyurethane or rubber suction cup to catch the objects. There are some vacuum grippers that use closed-cells foam rubber layer, instead of the suction cups. [28]

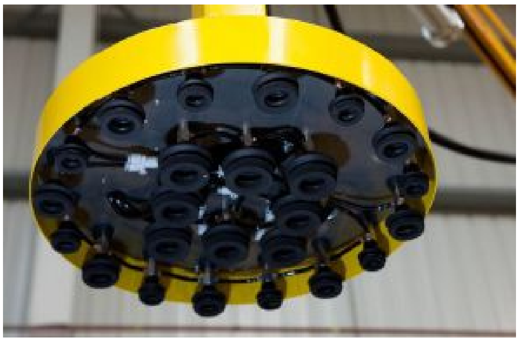


Figure 2. Suction Cups [12]

2.2.2 Hydraulic Grippers

Hydraulic Grippers are the ones that can apply the most strength and often are used in applications that require a huge amount of force. The force is provided from pumps that can generate up to 13789.51 kPa. Although their strength, they are messier than any other gripper due to the oil that the pumps are using. Also they need more maintenance because of the huge amount of force that they can apply. [28]

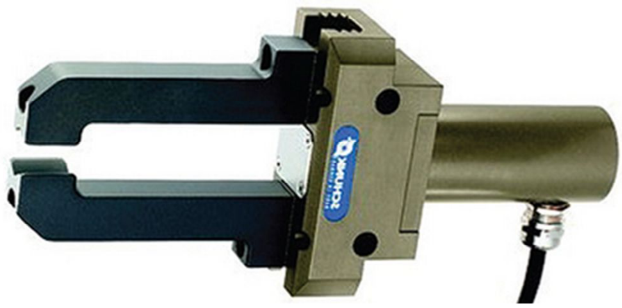


Figure 3. Hydraulic Gripper [29]

2.2.3 Pneumatic Grippers

Pneumatic grippers are popular due to their light weight and compact size. They can be design for tight spaces, which can be helpful in manufacturing industry. This kind of gripper can be open and close; because of this their nickname is “bang bang” actuators, given by the sound they do when the metal-on-metal is operating. [28]

Figure 4. Pneumatic Grippers [12]

2.2.4 Servo-electric Grippers

The servo-electric grippers are becoming more used in the industry; thanks to their easy control. The gripper jaw movements are controlled by electronic motors. These grippers are highly flexible and good for handling different material tolerances. Also they are cost effective because they don’t have air lines and are clean. [28]

Figure 5. Electric Gripper [12]

2.2.5 Magnetic grippers

Magnetic grippers can be configured by permanent magnets or electromagnets. Permanent magnets, don't need of an external supply for grasping, once an object is grasped there is an additional device called stripper push which separate the object from the gripper. In the other hand, there are the electromagnets, including a controller unit and a DC power which can grasp magnetic objects. [8]

Figure 6. Electromagnetic Gripper [12]

2.3 Energy Supply

The smart gripper, end effector of a robot, can't accomplish any job without a power source. Moving the fingers, use the sensors, receive feedback and new orders needs energy. The main power supplies are electricity, hydraulic power and compressed air.

Grippers use this sources for work, having this on mind it is possible to classify the grippers in four kinds: electric, pneumatics, suction cups and magnetic grippers.

2.3.1 Electric Grippers

In robots there are three main electric driven. *Stepper Motors* which are used for easy pick and place. *Dc servos* where the most used thanks to the output power given and the high degree of control in position and velocity. But *Ac servos* are taken Dc servos place due to are more reliable than this one, more silent, also having a high power output and don't need almost maintenance.

The main advantages of using electric gripers are:

- **Position Control:** Electric grippers allow to control easily the range that is need to open for pick up objects.
- **Detect grip:** Motor's encoders allow to determinate when the object is grasp.
- **Force Control:** Controlling the current it is possible to control the torque thanks to the proportionality between them.
- **No air lines:** reduce the operation cost on maintenance and power.
- **Cleaner grippers:** Doesn't need any fluid to work, they are cleaner for any kind of activity that requires clean environment. [12]

2.3.2 Pneumatic Grippers

These have a simple design; they use compressed air for moving a piston in a parallel or angular movement. The costs of these grippers are very low.

The main characteristics are:

- **Full stroke:** Either it's on or off, closed or open. This can require more time for grasping objects.
- **Limited force control:** Controlling the pressure of the fluid is hard to programme.
- **Limited speed control:** most of this grippers will hit the object at maximum speed.
- **Compressed air problems:** The used fluid has guarantee some quality for not affecting the system. Also the fluid needs a compressor and cost of maintenance. [12]
- **No grip detection.**

2.3.3 Suction caps

These grippers use vacuum to grasp objects. They are good for handleling materials and low cost.

The main characteristics are:

- **Varied surface problems:** not flat areas present contact problems with the cups. Furthermore, the surface has to be clean, not bee corrugated or have porous.
- **Marks:** In some surfaces the cup can leave some marks that add more steps for cleaning.
- **End-of-arm:** the vacuum grippers need an end-of-arm tooling to support them
- **Compressed air problems.** [12]

2.3.4 Magnetic grippers

Those are similar to the previous but can be use just with metal materials. There are two types: electromagnets that use a Dc power to handle the material and Permanent Magnets that always are working.

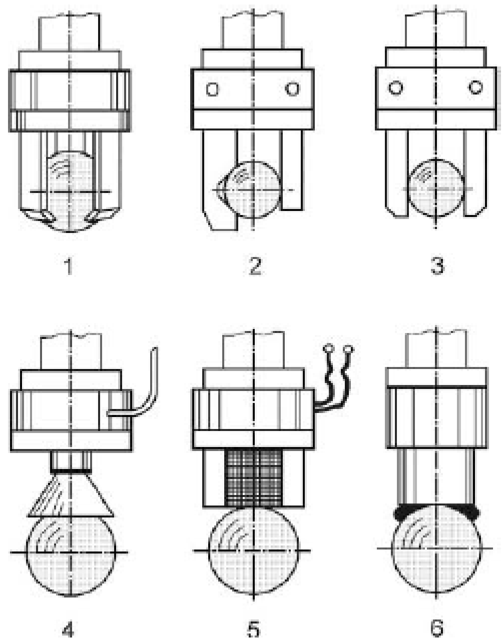
The main characteristics are:

- Only need one surface
- Fast grasping
- Requires minimal maintenance
- Fast movements can move the part
- Liquids between the magnet and the part can reduce the force.
- Parts can stay magnetized afterwards [12]

3. THEORETICAL BACKGROUND

Grippers are the end of the kinematic chain in an industrial robot system and interact with the environment. Universal grippers that can clap a wide range of objects with different shapes, but in some cases the grippers have to be adapted to the working piece to improve the efficiency.

It's possible to depict in six examples the three most usual configurations (astrictive, impactive and contigutive).



1. Pure enclosing without clamping
2. Combination of partial from fit with clamping force
3. Pure force grasping
4. Vacuum air
5. Magnetic grasping
6. Adhesive media retention

Figure 7. Different grippers for spherical object [10]

The difference between holding (retention) and grasping (prehension) forces need to be pointed out. Grasping applies force at the initial point of prehension and the holding forces keeps the object gripped. In some cases, the retention forces can be weaker than the prehension one. The energy required for moving the mechanical parts to a static prehension force determinates the grasping force. But the kinematics chin drive, kinematics, holding system are just present for mechanical grippers, not for vacuum grippers. [10]

In the following, its going to be defined the three most usual gripper configurations and shown the subsystems of a mechanical gripper.

Astrictive gripper: when a field produces a binding force which is astrictive. They can have the form of magnetism, electrostatic charge displacement or air movement.

Contigutive gripper: contigutive is a synonym of touching. These grippers make direct surface contact with the objects surface to apply prehension.

Impactive grippers: these mechanical grippers achieve the prehension by impactive forces. Forces that impact against the object that wants to be acquired.

Example of a mechanical gripper and its principal subsystems:

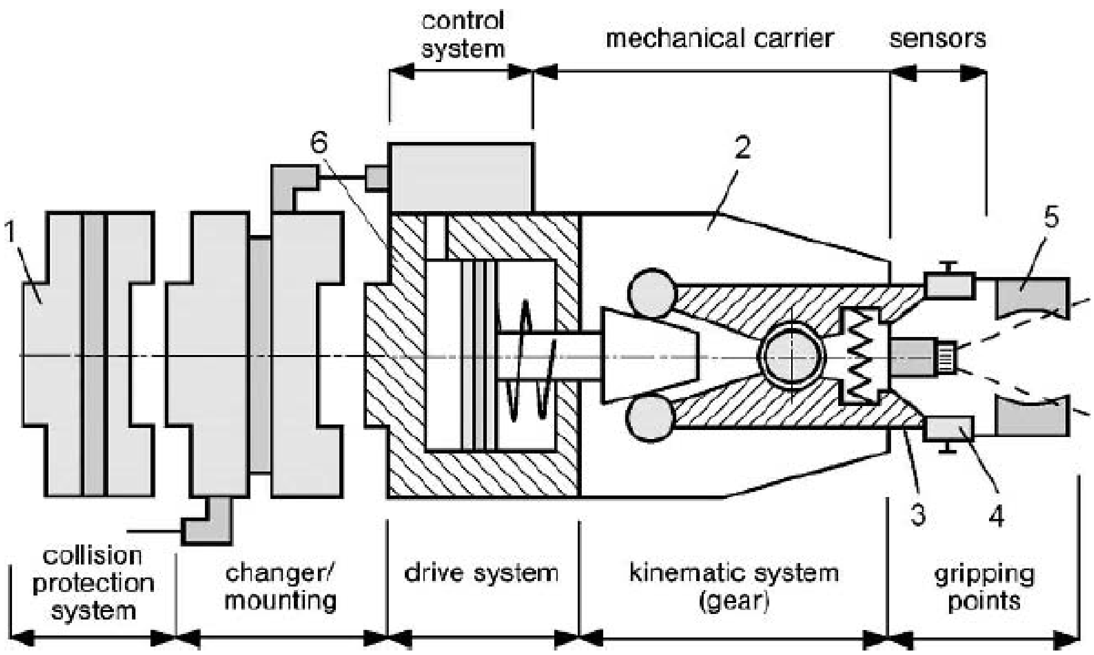


Figure 8. Mechanical Gripper's subsystems. 1 remote centre compliance, 2 carrier, 3 gripper finger, 4 basic jaw, 5 extended jaw, 6 flange.

Control system: is in charge of analysing and processing the sensors information for regulating the motion and grasping.

Drive system: transform the supply energy (pneumatic, electrical, hydraulic) in translational or rotary motion

Jaw: is the part in which normally the fingers are attached.

Extended jaw: Optional part that is added to the jaw for fitting with the objects profile.

Changer system: module easily the gripper.

Gripping area: points where the prehension is transmitted to the object for grasping it.

Kinematic system: mechanical part in charge of convert drive motion into velocity and force.

Sensors system: group of sensors installed on the gripper for improving the performance, giving feedback to the control system and makes it able to correct the motion and force application

[10]

3.1 Design Challenges

The gripper is the part of the robot that physically interacts with the objects and the area around it. A good design can improve the efficacy, improving robot inaccuracy, and gives more flexibility to the robot for developing different tasks. Due to the importance of the gripper created Causey and Quinn (1998) two guidelines for design robot grippers efficiently. These guidelines focus in increasing the reliability of the system and the other one on increasing the throughput of the system. Although they are two different categories, they are partly overlapped. [9]

3.1.1 Increase the reliability of the system

Grasp parts Securely: the part has to be well working for grasping and do not fell or change the position during robot movements.

Fully encompass parts with the gripper: this helps to hold the part securely and align the part in the gripper hand.

Chamfer finger's approach surface: this will decrease the possibility of colliding with the part to grasp.

Fingers should align grasped parts: centre parts on the gripper jaw when this is closed decrease collisions.

Proper Gripper-Part interaction: if the surface of the gripper and the part can align, it improves the grasping reliability.

Not deform the part during grasping: If the part is deformed during the process can become useless.

Provide and ample approach visualization: when the system becomes complex a clear vision of the system can simplify the process.

Minimize fingers length: it gives security, because the longer and bigger are the fingers going to be the deflection of this.

Incorporate functionality into gripper fingers: when the gripper grasps an object there is the possibility of error. Designing the fingers to perform extra tasks, because it reduces the chance of release from the gripper.

[9]

3.1.2 Increase Throughput of the system

Minimize gripper footprint: is the space that must be free for a successfully grasping.

Chamfer gripper fingers' exterior part: it will displace neighbour parts as the target part wants to be approached.

Minimize grippers weight: this allow the robot to perform better movements and reduce the overshooting.

Grasp parts securely: Secure grasps allows the robot to move at high speed and reduce cycle time.

Avoid tool changes: changing a gripper needs time and reduce the throughput.

Grip multiple parts with a single gripper: gives more flexibility to a gripper, avoids tool changing and reduces time and cost.

Install multiple grippers on a single wrist: when multiple grippers are ready for using they may decrease the cycle time.

Include functionality t in the fingers: improves the systems flexibility.

[9]

3.2 Dynamic and Kinematics Theory

A correct sizing of the actuators and other essential parts of the gripper is important for the functionality of it, this can be realized through calculations. The dynamical and kinematical design of the gripper depends on the weight, size, process cycle times and accelerations. This chapter tries to clarify and show briefly the formulas and theories behind the gripper's kinematics and dynamics.

The grasping force is a significant factor in the gripper design. It is important for the gripper to keep the object grasped while moving in whole positions. The object's position can be affected by inertia forces while the gripper is in movement. [11]

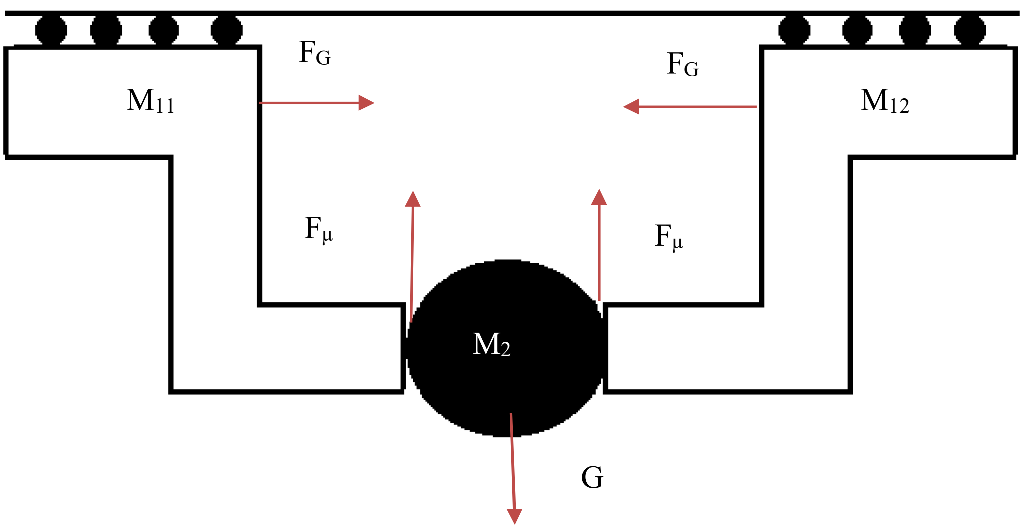


Figure 9. Gripper Force equilibrium system

The grasping forces are almost directly using direct driver actuators, like linear motors, to the output of this ones. In these cases, the force is calculated using the suitable method for the actuators in question. All the methods consider a safety factor for considering all the unknown or impermissible factors during the task, such as friction. There are also international safety standards to keep the system safe in the whole situation; this is defined to make sure that the robot can avoid any danger or for example lose the object. [11]

The following formulas also consider the rotary actuators. Using these actuators, the primary approach is to convert the grasping force in a rotational moment (screw torque). The torque plus the safety factor will indicate the force that the rotatory motor have to execute. [11]

3.2.1 Dynamics of the grippers

In dynamic calculations is only exanimated pure friction-locking for keeping the gripper's versatility; this is achieved considering the finger's contact surfaces planar, and the force for maintaining the object upward is provided by the friction generated between the contact surface and the object. [11]

Normally fingertips are not planar surfaces because this limits the grasping options and the versatility of the gripper. This not planar forms design almost always adds more friction to the surface due to the form. But anyway the equation considers a safety factor S. [11]

The following equation describes the gripping force in vertical motion:

$$F_G = \frac{m(g + a)S}{\mu \times n}$$

F_G =Minimum gripping force required (N)
n= number of fingers
μ= Friction coefficient between surfaces
g= gravity constant 9,81 m/s^2
m= total mass; object plus gripper (Kg)
a= acceleration of the gripper (m/s^2)
S=Safety factor
[11]

If the actuator used are linear motors, some lateral movements add load to the motors. The previous equation modified for lateral movement in actuator's axis direction becomes:

$$F_G = \frac{m \times g}{(\mu \times n + m \times a)}$$

F_G= Minimum gripping force required (N)
n= number of fingers
μ= Friction coefficient between surfaces
g= gravity constant 9,81 m/s^2
m= total mass; object plus gripper (Kg)
a= acceleration of the gripper (m/s^2)
[11]

In the case of rotational actuators, first the motion forms have to be converted from rotational to lineal. This can be achieved by connecting roller- or ball- screw on the actuator and a linear guide. The following equation shows how to calculate it for this case, adding also a safety factor:

$$M = \frac{F_G \times l \times S}{2\pi \times \eta}$$

F_G= Force/Load applied (N)
M= Moment (Nm)
η= Coefficiency
S= safety factor
l= screw lead (m)
[11]

3.2.2 Kinematics of the grippers

As mentioned before, for rotational actuators, the motion has to be converted from lineal to rotatory. For calculate the velocity of the motor the linear speed from the finger can be converted to rotatory using the next equation:

$$r = \frac{60 \times v}{l}$$

r= Rotational speed (revolutions per minute)
v= linear speed (m/s^2)
l= Screw lead (m)
[11]

4. STATE OF THE ARTS

In order to find out what is already done and is being used at the moment related with Industrial and smart grippers which are able to manipulate a wide variety of objects, it is necessary to review the related work. Due to the diversity of grippers they will be categorized in three groups: industrials and others.

4.1 Industrial Grippers

4.1.1 Adaptive Robots

These grippers are used in industrial applications due to their ability of grasping objects. They normally have two and sometimes three fingers with two degrees of freedom. Their configuration enables them to grasp a wide amount of different objects and they are powerful tools for industrial applications.

Power gripper

Figure 10. Power gripper [13]

This model from Festo is a new mechanism based on a bird's beak. This gripper reproduces this complex kinematic biological mechanism using bionic technologies.

It’s made of titanium alloy, produced by metal laser sintering. Its maximum opening is 56mm. It has a really good force-to-weight ratio and weight 482 grams. [13]

2-Fingers Adaptive Robot Gripper – 200

Figure 11. 2-Fingers Adaptive Robot Gripper-200 [14]

Robotiq has developed different adaptive grippers. These 2-fingers grippers integrate the main features for working in social and industrial areas.

This gripper has a simple design and moves by electric servos and has really good characteristics; stroke of 200mm durability, precision, flexibility, and a high payload (23Kg). It is also able to detect the grasping and give a feedback. [14]

3-Fingers Adaptive Robot Gripper

Figure 12. 3-Fingers Adaptive Gripper [15]

From the same company, Robotiq, there is this 3-fingers model also moved by electrical servos. This gripper is an evolution of the 2-fingers one, it can sense almost everything it has grasped and control the finger's position, speed and force. The stroke is 155mm and the only drawback of this gripper for industrial activities is the gripping force that it's maximum is 60N and it limits the gripper for heavy duties. [15]

Schunk SDH

Figure 13. Schunk SDH [15]

This gripper from the German company Schunk is a robot gripper with 3-fingers and two joints each finger with seven degrees of freedom. It has tactile sensors that permit to know when the object has been grasped. It also has a high movement resolution and control. It is able to develop one of the best performance with a wide variety of objects. The drawback that present are the high cost. [15]

Schunk SVH

Figure 14. Schunk SVH [16]

The SVH model is a really good representation of a human hand. This electrical gripper has 1:1 ratio to human hand, it has almost the same amount of degrees of freedom as the human hand (20 from 27). It can be produced as a right or left hand. The performance with objects, speed and force control it is at the high stage. It is one of the best human hand representation in robotics. Its only drawback are the really high cost. [16]

4.2 Others

Versaball

Figure 15. Versaball [17]

Versaball is a gripper conformed by a pumped air ball with a granular material. The fingers are replaced by this mass. The ball presses the object while a vacuum blows air inside and ones it is surrounded, the air is sucked and the object is catched by the ball. It is able to grasp any kind of object. The problem is that for a high amount of weight the size of the ball increases

4.2.1 Analyse

As it was shown it is possible to find different grippers for industrial applications with a widely variety of strokes and gripping forces. There are grippers that can grip a huge amount of objects, like the adaptive ones or the Versaball. Others that can handle high payloads; the pneumatics and some electrics. But talking about sensors and smart grippers, just a few of them have force sense which is used for feedback and improves the robot performance.

The gripper wished to be developed in this project aims to have the main characteristics: being able to grasp different objects combined with a high payload. It also has to have force sensors, and add different ones such as temperature, 6 axis force, torque sensor and artificial vision. With those configurations the gripper is characterized by multiple sensor feedbacks and tries to as much dependent as possible for developing tasks. These inventions are looking forward to be an industrial smart gripper.

5. GRIPPER DESIGN

This chapter defines the objective of the gripper and its specifications. Besides there are the discussions which will lead the gripper from all the possibilities to the best one that is able to achieve the objective for which one it will be created.

5.1 Smart gripper description

This project pretends to design a smart and flexible gripper for industrial activities. This means that the device has to be able to recollect information about the environment that surrounds it and send it to the control system to be able to process it and react to the data received, correct the movements and interact with the environment. By flexible it means that it has to be able to develop a wide amount of tasks without the need to change the gripper. Also it will have to be able to use a power tool, like a drill or electric wrench. For this it is necessary to be able to push a trigger. Apart of all of this the gripper has to be simple and try to keep low costs.

For achieving this aim the gripper needs a control system. A computer based control is needed for the application development, an easy implementation and to create flexibility. The control system needs a control software that will be the user interface which is used easily and in a logical way. The most important part is to define the different sensors for that project:

<u>Force sensor at the fingers:</u> this will help the gripper to know when it has to grasp the objects and if its grasping it correctly.

<u>Artificial vision:</u> with this the robot will be able to see and locate the objects and also avoid collisions.

<u>6 axis torque and force sensor:</u> this sensor situated normally in the wrist and they are an add on that can detect the forces and torques in 6 axes. It lets the robot to know in which direction it is applying the force and the torques that are applied to the gripper.

<u>Temperature sensors:</u> this can be useful in case there is an overheat in the gripper because of too much use or of power application. It also can be added to the finger tips for checking if the temperature of the objects can damage the gripper.

The finger will need a finger or add on which is able to push a power tool, giving the possibility of using a manual tool.

5.2 Gripping Method

One of the main parts for developing a gripper is to decide how this one will be. There are multiple choices for configuring robot grippers, such as a magnet or electromagnet, vacuum, balls (Versaball) and fingers.

The first step is to decide one of this gripping method. The magnet and vacuum are not interesting for this project due to the limitations about materials (magnets) and surfaces(vacuum) they can grasp.

A good option for keeping the hand flexible are the fingers. There is the possibility of two, three, four, five or even more. The ideal would be to use the same amount as the human hand due to all the tools and objects are created for being used by humans and it is easier to copy the human hand than create objects on purpose that can be just manipulated by one gripper.

"*According to an investigation by H.Muldau, Androiden a four finger gripper can handle 99% of the parts that a five finger gripper can handle, a three fingers can handle 90% and two fingers 40%." [Industrial Robots-Gripper Review G.Lundstrom, B. Glemme, Bw.Rooks -page 77 6.1 Construction for Versatility]*

As mentioned above the three fingers can handle 90% of the parts than a five finger gripper can handle. This is the best option for the project because it is more simple and easier than five and four fingers and still has a high percentage of parts that can handle more compared to five fingers.

As soon as the decision for designing a three finger gripper has been made, the main difficulty is which configuration is the most suitable for the project

To make this decision, it is necessary to analyse different types of three finger grippers and their functions. Those will be compared in an objective way with the specifications and requirements needed by our design.

The three hand configurations are:

- Three straight fingers: the fingers are designed in one piece, the three of them can rotate to open and close the jaw and two of them can rotate or move from the original positon of the base for changing from cylindrical to punctual grasping.

Figure 16. Three straight fingers gripper [31]

- Three adaptive fingers: the fingers can adapt to the object. It is possible to grasp with the tip or surround the object with the fingers.

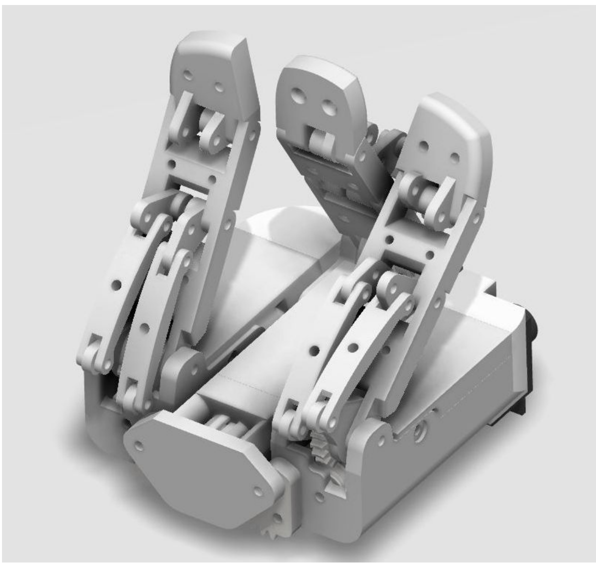


Figure 2. Adaptive fingers[32]

- Three fingers with joints: in this configuration the fingers have multiple joints apart the ones at the base of the fingers that allow to close and open the hand. Having more of them along the fingers makes them more similar to the human hand. Two of the fingers can rotate over his base.

Figure 17. Schunk 3 fingers gripper[15]

5.3 Decision Matrix

Choosing the best possibility for the project will be done by using a Decision matrix. [30] This matrix is fulfilled with the valued High, Medium and Low. Since all the values in this matrix do not have the same importance, the specifications and requirements have different weight given by how important is each one to the project. The values of High, Medium and Low have been translated to 5, 3 and 1 respectively. With this multiplying the percentages and summing all for the same gripper it is possible to get a value for deciding which configuration is the most valuable for the project.

For the discussion here are presented the specifications that the gripper will need to have:

- Multi-sensing: Force fingers and base, 6 axis Force and torque at the wrist, temperature and robot vision.
- Manipulate mass of 15 Kg (between 10-20Kg)
- Cylindrical and punctual grasping
- Possibility to push a trigger
- Low cost

- Simplicity, low number of mechanical parts to design

The percentages have been given to each specification following criteria.

Multi-sensing was written because it is important for the smart gripper but finally the weigh is 0% because it does not affect the configuration. The sensors can be added to all of them without problems.

The Payload is really important because in industrial applications it is possible to find heavy objects, the percentage given is 30%.

Grasping is another of the main characteristics of the gripper due to grasp objects is basically what the hand has to achieve, consequently the weigh is 35%. Punctual and cylindrical grasping have been considered equally important (35%) and it is divided half for each.

Pushing a trigger is a function added to this project to make it able to use tools with trigger. It has not been considered important because it can be an add on, another part can be added for work just as a trigger and keep the configuration simple. For this the weigh is 5%

The costs are always important and for the project it is a challenge to keep the price low while adding lots of different sensors and abilities to the robot hand. The percentage given is 20%

Finally, it is important to keep the design simple, this makes it easy not just to design and construct, moreover easy to repair it in case it is needed. The percentage for keep the mechanism simple is 10%.

With all these information, the configuration and the different percentages now is just needed to complete the decision matrix and calculate the values for which one is the ideal configuration.

Specifications / Grippers	Multi-Sensing 0%	Payload 30%	Grasping 35%		Push a trigger 5%	Low cost 20%	Simplicity 10%	Total
			Cylindrical	Punctual				
Straight Fingers	**High**	**High**	**Medium**	**High**	Low	**High**	**High**	4.45
Adaptive Fingers	**High**	Low	**High**	**High**	Low	**Medium**	Low	2.8
Fingers with multiple joints	**High**	Medium	**High**	**High**	**High**	Low	Low	3.2

Table 1. Hand configurations' Decision Matrix

5.3.1 Table values explanation

Above there is the table with all the values given and the final calculation for all the three configurations. The values in each characteristic has been given to each configuration with the following criteria.

Multi-sensing as mentioned before is important for the project but not for the configuration and for this the percentage given was 0%, also add them does not need to affect the configurations. Besides, all these ones can be added without design problems, so all of them have high value.

The payload, the amount of weight that can be handled, is related with the gripping force. This one, the gripping force, is related to gripping friction, number of fingers, gravity, linear acceleration and the total mass of the gripper. For this three configurations the difference can be just at the mass being the finger with multiple joints the heaviest one due to it has more motors for moving each join. But at the same time each motor can apply force independently from the other. Because of that this point has medium value. The straight fingers option has high value because the force is applied directly to the finger without need of too much or almost any mechanism from the motor to the fingers. However, the adaptive fingers configuration has low value because it needs lots of mechanism for transmitting the force from the motor to the finger and tip, this makes the fingers lose a lot of force compared to the other possibilities.

Grasping as it is shown in the matrix has been divided in cylindrical and punctual and they have the half of the weight of this part. The straight fingers option have two fingers that rotates or move (different mechanism already existing can be applied). This allow to change from cylindrical to punctual grasping. At the punctual all the fingers are pointing at the centre or this two facing to each other. For doing this it has a high ability of punctuality. Having the fingers in parallel position they can grasp in cylindrical mode, but this grasping is not the best one due to the fingers are straight so the value given is medium.

The second configuration, adaptive fingers, can grasp perfectly in cylindrical mode because the fingers can surround the object. Punctual grasping can be also good, but it needs a complex mechanism to face the fingers, anyway if this mechanism is achieved it will grasp in punctual mode so it has high value.

Fingers with multiple joints have high value in both grasping modes. Because it has also two fingers that can rotate so it can grasp punctual as the first configuration and because of the multiple joints it can surround the objects as the second.

The only option that can achieve to push a trigger without any additional corrections is the finger with multiple joints because any part if it can apply force. This is the only one that has high value, others can use an add on but they have low value because they need for this an optional part.

The cost estimated by the number of mechanism and actuators goes like this: the straight fingers does not need multiple mechanism or motors being the cheapest. The adaptive fingers need from multiple mechanism for applying the movement and more mechanism to be able to grasp punctually so the value given is medium. The finger with multiple joints need lots of force. So this one is the most expensive one.

Simplicity talks about the minimum number of mechanism and an easy configuration of the hand. In this specification the only one that keep the model simple is the straight fingers' configuration, for this it has high value. While the other two are more complex to design and create, both of them have low value because they need lot of mechanism.

5.3.2 Matrix Final Values

Straight Fingers

$$Total = 0.0 \times 5 + 0.3 \times 5 + 0.35 \times \left(\frac{3+5}{2}\right) + 0.05 \times 1 + 0.2 \times 5 + 0.1 \times 5 = 4.45$$

Adaptive Fingers

$$Total = 0.0 \times 5 + 0.3 \times 1 + 0.35 \times \left(\frac{5+5}{2}\right) + 0.05 \times 1 + 0.2 \times 3 + 0.1 \times 1 = 2.8$$

Fingers with Multiple Joints

$$Total = 0.0 \times 5 + 0.3 \times 3 + 0.35 \times \left(\frac{5+5}{2}\right) + 0.05 \times 5 + 0.2 \times 1 + 0.1 \times 1 = 3.2$$

Analysing the results, the configuration with more punctuation for our project is Straight Fingers with a punctuation of 4.45. Following this one there are fingers with multiple joints and finally the Adaptive fingers. But why do we get those results? Well the straight fingers, even if they cannot grasp in the best way in cylindrical mode and doesn't have a trigger. They need an add on. It has good values in the other characteristics and can handle a high payload, also the mechanism is easy and cheap compared with the others.

The adaptive is a great configuration that is getting popular nowadays thanks to the great grasping but it still needs to improve the payload. For normal activities it can work perfectly but for some industrial activities it is insufficient. Also the mechanisms are quite complex and if we want also to have punctual grasping it is necessary to add more complex components to this one.

Fingers with multiple joints would be a perfect configuration because they have a perfect grasping, can push triggers and use easily any kind of tool on the other handwhich are really complex and even more expensive. The payload of this one could be improved but this would add more costs and it would get also more complex.

Concluding, after making a decision which kind of hand is the best for the project, present three possible configurations to develop and realize a decision matrix with the important specifications and give weight to them according to the importance of the project. The configuration that better fits to the project is a robotic gripper with three straight fingers. Now the challenge is to design it and find the best characteristics to improve the specifications in which ones it is weaker compared with the other configurations.

5.4 Power Tool Finger

In the configuration discussion with best punctuation, was straight fingers. As a power tool finger, for pushing power tool triggers, for the gripper it will need to introduce an extra finger or mechanism.

First of all is to clarify the function of the power tool finger. It is easy to know that the main function is to push a trigger. But since it is an add on to the gripper, while it is not pushing a trigger, the finger or mechanism cannot disturb the normal function of the gripper. For this, the finger or mechanism has to be able to retract or stay apart.

Talking about a mechanism which would need to move in two axes, up and down for opening, closing and pushing and for pressing the trigger. Then, rotate or move left and right for locating itself in front of the trigger.

If it would be a finger this would need to stay apart till it is needed. This should also be a finger able to perform and adaptive grasping to be able to push trigger that can have different sizes.

With this characteristic explained before, it has been decided to use a predesigned finger. This election has been done easily thanks to the Yale Model T. A robotic hand from Yale university that it is open sources and the models are accessible for everyone (At Yale web page). Adding this to the fact that this model is an adaptive finger and it just need one actuator for moving is a cheap and easy option compared with a mechanism. The mechanism would use two actuators unless its developed one that can do it easily like this finger. Reducing the number of actuators and the time of creating a new model, finger or mechanism. This is a great option.

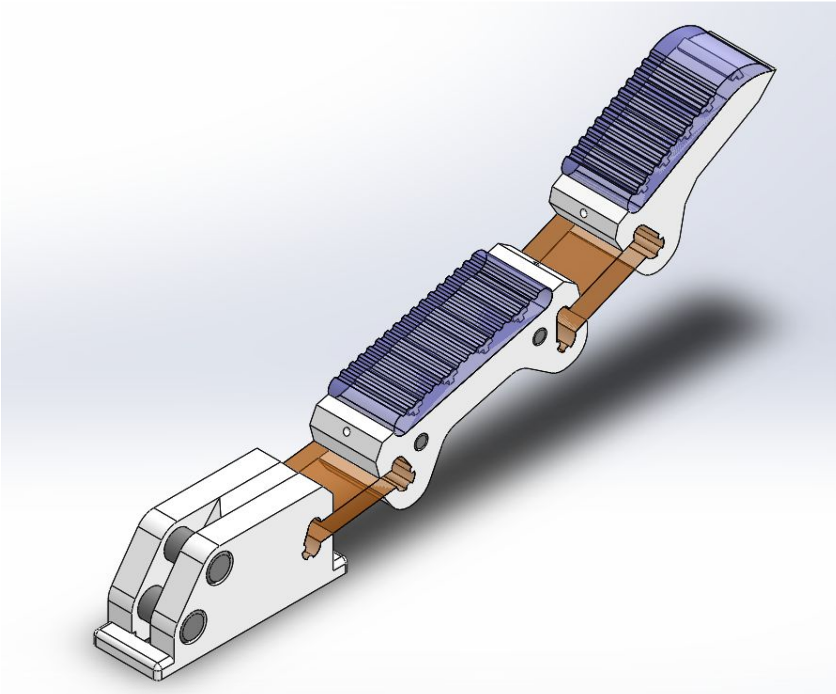


Figure 18. Yale's Model T ff Finger [19]

This finger extracted from Yale’s Model T, is a clever configuration that works with a rope attached to an actuator. This rope closes the finger and when this one is released, the silicone connections make the finger come back to its original position (open) and it doesn’t disturb the other fingers. The holding force is between 10-13N (with the normal actuator, another can improve this), enough for pushing a trigger. The mechanism of the rope is moved by one actuator throwing some pulleys, as it is shown in the following picture. [19]

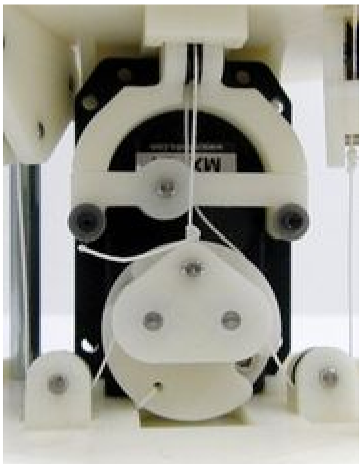


Figure 19. Model T actuator [19]

This mechanism is for four fingers. It is simplified for one to a wheel on the actuator that pulls the rope, and the pulleys that conduct the rope till the finger making direction changes when it is need.

As shown this finger presents a really good option as a trigger finger. It avoids designing a new mechanism. It just needs one actuator and some small pulleys and since it has a dedicated actuator for it, it has enough force for pushing a trigger and the move the finger away from the working area of the gripper and not being disturbed.

5.5 Sensors

Smart grippers are not just robot grippers with a really good control of the speed and position. They are equipped with different sensors that allow them to collect information and send feedbacks for improving the performances of the task in that environment.

The sensors that are interesting to add at the smart gripper are force sensor, temperature sensor, and artificial vision. All these sensors have to be connected to a microcontroller or CPU that works as a station; collects, process and send new orders to the gripper. This station can be outside of the gripper.

In the next chapters a description of different sensors is following.

5.5.1 Force Senor

A force sensor as its name suggests, detects the force applied on its base and the sensing plate. [20]

For the gripper there are going to be two different sensors, one that is for contacting forces; knowing when to grasp an object, and a 6-axis force-torque sensor; that detects if the gripper is applying correctly the forces and the torques that this forces (internal or external) generates on it.

Grasping sensor

As mentioned there it is necessary to know when an object is grasped, and that the fingers are applying the correspondent force. There are two main kind of sensors: the basic one, simple pressure sensor, and a more common used one strain gauge force sensors. [20]

Figure 20. Simple Pressure Sensor [20]

The simple pressure sensor is a simple sensitive force resistor. They are mainly used in hobby robotics. They can just detect the force in one axis; that for the application required can be enough. This is a really cheap sensor and it can be found for the low price of 5€. Their main drawback is that the error can be as high as 25%.

In the other hand, there is the strain gauge force sensor, which uses conduct foils that change the resistance under strain; using Wheatstone bridge that produce analogical voltage proportional to the resistance applied. The sensor can be single or multi axis sensing.

A strain gauge force sensor will be used for the gripper fingers, applied to each tip and the middle of the finger for knowing when the object is grasped. The strain gauge has better resolution than the simple pressure sensor, an also it is the most common used in robotics. In the following pictures it is shown its working concept for a better understanding.

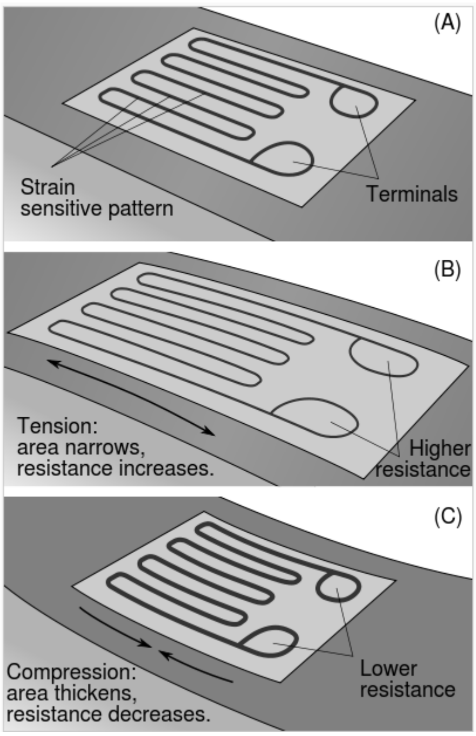


Figure 21. Strain gauge's working concept [21]

6-Axis Force Torque Sensor

This sensor can sense forces in the three Cartesian axis, and their rotational axis. This data allows the gripper to know all the forces that are applied to it and how much force is it applies to the environment. [22]

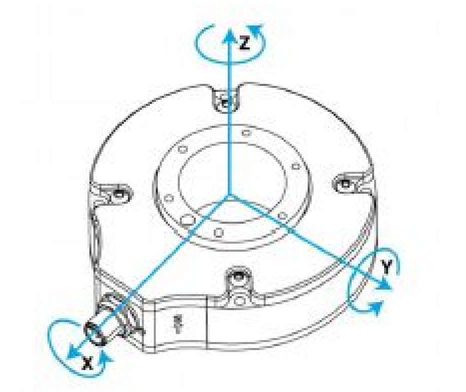


Figure 22. 6-Axis Force and Torque Sensor [22]

A good option from this sensor is the 6-Axis Force-Torque sensor from RobotiIQ, this company developed a high precision sensor, that is attached to the wrist, at the beginning of the gripper, between it and the robot arm.

It is an essential sensor if for example the gripper tries to fit a part into another knowing that is not having a collision and if it is correct it reads the different torques. Or if it is using an electric wrench and the torque from which could be too big and moves the gripper. It can make corrections easily because the direction it has to apply the force.

5.5.2 Temperature Sensor

It is interesting to measure the temperature of the motors, actuators inside the gripper and the electronics. An elevated temperature due to the excess of work, can affect to the components and the performances of it, affecting also to the data send by the other sensors. Besides, a temperature sensor in at least one of the finger's tip can be useful for knowing the temperature of the grasped material.

For inside the gripper any temperature sensor that has a range of positive degrees and medium accuracy is good enough. Because inside the gripper the interesting is to read overheats from the batteries and actuators, and this does not require special specifications.

LM35DZ is a really good choice for the inside of the gripper, it has a range from 0ºC to 100ºC and an accuracy of ±0,6ºC. It is a simple sensor and it has the low cost of $1,57. [23]

Figure 23. LM35Dz temperature sensor

For the fingers the characteristics needs to be different. This is because in the industry it is possible to find easily objects with negative temperatures or with high temperatures, that can be also dangerous for human manipulation. The needed characteristics are a temperature range from -20 to 100ºC and a medium/good accuracy.

The best options with these characteristics are: TMP100, LM75 and DS18B20.

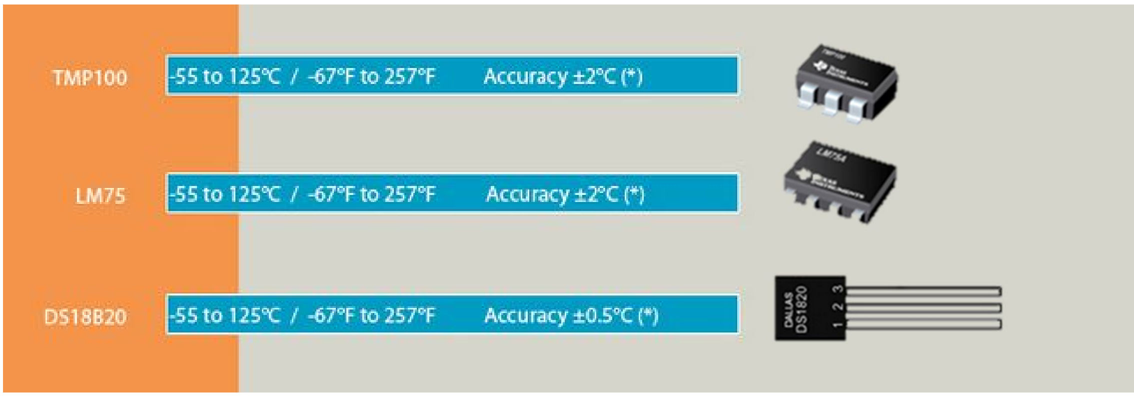


Figure 24. TMP100, LM75 and DS18B20 Temperature sensors characteristics [23]

All three options are good and have low costs less than 10€. So they are good options to give to the project what it needs and keep a low price. Between them the best option is the DS18B20, due its accuracy and that it is used for a large variety of applications and waterproofness.

5.5.3 Artificial Vision

This is a really important sensor in the group smart sensors. it gives the possibility of watching the surroundings, locating objects and interaction with the environment without the need of using designed points of picking up parts to the sensors. Furthermore, it gives independence to it, there is no need to prepare everything for the gripper, it can find things alone, such as bin picking.

For this it has been found a good camera from Point Grey, a company that works with cameras for industrial activities and it has lot of experience in this field. This camera has to be connected to a computer, that shows the image at the same time, and also process it for the gripper.

The camera Dragonfly 2 fits perfect in this project, designed for 3D operations, using stereovision and can be connected at high-speed from a computer. The camera is capable to transfer data at 400 megabytes. It is a cost-effective and reliable way to connect with the computer. It comes with software, where it is possible to control the camera’s parameters. Also it comes with an extendible head which is good to locate the camera wherever it is necessary without the need of a lot of space for it. [24]

Figure 25. Dragonfly 2 camera with extended head [24]

Parameter			Unit
Imaging Sensor	Size	4.65	µm
	Resolution	1032x766	pixels
Camera	Frame rate	30	fps
	Colour/B&W	Colour	
	Shutter	0.031 – 66.63	ms
Size	Board	30x20x1.57	mm
	Lens board	16.6x15x9.94	mm

Table 2. Dragonfly 2 DR2-08S2C-EX-CS parameters [24]

As shown in the parameters' table the camera has a high resolution in colours, good fps and it is really small. This model can be added without problems to the gripper and allows it to visualize the environment that surrounds it.

5.6 Power Source

The smart gripper that is the aim of this project also needs an energy supply for working most efficient. After researching and analysing the different types of sources with their characteristics for grippers, it is possible to choose the best energy supply for developing the smart gripper.

As the flexibility is one of the main characteristics of this gripper, the control of speed and force are really important. The best option for being as most flexible as possible goes through a good control. This variable allows the gripper to accomplish a great variety of jobs. With this the electric gripper starts to be the most interesting compared with the others. Although that the gripper will have force sensors, the electric gripper has the advantage that it can detect the gripping so that it gives the opportunity of saving sensors in some parts of the gripper. Furthermore, this one can be used at any kind of environment.

The magnetics and vacuums aren't interesting because they are just useful for some specific kind of material or surfaces that allows to grasp, also they have limited velocities of work or can leave some marks on the objects.

Finally, the pneumatics have lots of force but the control for this and the speed isn't that good and the work with a fluid adds more maintenance and costs, plus it isn't good for working in all the environments.

For conclude, the best source for a smart gripper with main point is to be a flexible electric gripper. Choosing this one, the Ac servos seem to be the most interesting because they have a good power output, are silent and don't need too much maintenance once they are installed.

5.6.1 Actuators

Once the energy supply is chosen, it is time to choose the actuators for each part of the gripper.
An Actuator is a mechanical device which function is to proportionate force for moving another mechanical device. As mentioned before it can be moved electrically, pneumatically or hydraulically. [25]

There are different kinds of actuators. Two main actuator types are linear and rotatory. Rotatory for example is an electrical motor, an actuator that transforms electrical energy into a rotation motion. On the other hand, Linear actuators produce no rotatory motion, such as sliding or piston motion. The difference is a bit abstract, but a linear actuator can be constructed using a rotatory motor and vice versa. [26]

The actuators necessary for each part need to move the different mechanism and has to be as small as possible and strong enough for each part. For the main fingers' actuators have to be able to move at least 100N, and the one for pushing the trigger doesn't need to have that much force. Since there are no big differences from linear or rotary actuators, both options can be used.

There was found a really good linear actuator for the straight fingers. The miniature linear motion series P16 with stroke of 50mm from Firgelli. The gearing option 256:1 gives us the wanted force for the gripper, with 300N. The datasheet with all the information graphics and drawings is added in the annex part.

Figure 26. Linear Actuator

For the power tool finger it is going to be use a rotary actuator, because it needs to roll the cable. It has been found the RCP2CR-RTBS/RTBSL, a small electric actuator with 360º of rotation range and 35N. Its datasheet is attached in the annex.

Figure 27. Rotary actuator+

5.7 Cover Material

Gripping objects is the main function of a robotic gripper. As better it can grasp an object better is this one. Grasp an object has to be achieved correctly and safe and has to be avoid to slide from the jaw. Apart of the fingers configuration, griping force is the main parameter that ensure a good grasping. This parameter has been presented in the theoretical background. It is directly related with the friction coefficient. As higher the friction coefficient is the higher is also the gripping force.

For improving the coefficient friction of the gripper the best option is to add a cover material that improves the grip and increases the coefficient friction.

The coefficient friction is the resistance to slide between two surface in contact.

For choosing a cover material it is necessary to know, apart from the friction coefficient, some material resistances and characteristics such as:

- Thermal resistance: this is the range of temperatures that the material can work without being damaged
- Oil Resistance: how easily it is damaged or lose characteristics in an interaction with oil
- Abrasion Resistance: resistance to chemical products.

Setting a value for this characteristics makes it easy to choose a cover material for the project.

The coefficient of friction should be equal or higher than 0,65, the thermal resistance has to be able to resist temperatures from -20 to +50ºC. The oil resistance and abrasion resistance has to be really good due to the environment of the gripper which is going to be the industry and these products are common there.

In the Annex number: Cover types, there is a selection of different covers and its properties. Here is going to be analysed some of the interesting ones.

The Polyurethane has two good options, AVAFC 60 and AVAFC 70, these two transparent polymers made by extrusion have a working temperature range from -20 to 80ºCm a friction coefficient of 0,65 and a very good resistance to water, oil and abrasion.

The APL a mixture of polyurethane and PVC made by extrusion has a working temperature range from -20 to +60ºC a friction coefficient of 0,70 and a good resistance in water, abrasion and oil.

The three first options are really good and all of them can serve as cover material to the gripper; increase the gripping force and they have good resistance properties that can also protect the gripper. There are also some from natural rubber, which have a really high friction coefficient but the resistance to the oil is low. Unless it is known from advance that the gripper is not going to be in contact with oil, these ones cannot be useful. Finally, one of the three options presented fits with the project, but it also can be another kind of material that has the characteristics described above.

6. SMART GRIPPER

All the main decisions for configuring the gripper have been done; fingers' configuration, trigger finger, different sensors, energy supply, actuators and cover material. The final part is to present the result of all of these elections and how they will be configured for this project.

The project was looking to choose different characteristics to create a cheap, easy, flexible and functional smart gripper for industrial applications. As shown in the previous chapter many sensors have been chosen. Also with a decision matrix has been possible to choose a design for the gripper. Also the power tool finger has been added. All this features can have different configurations or designs. This chapter show the design and all its main features.

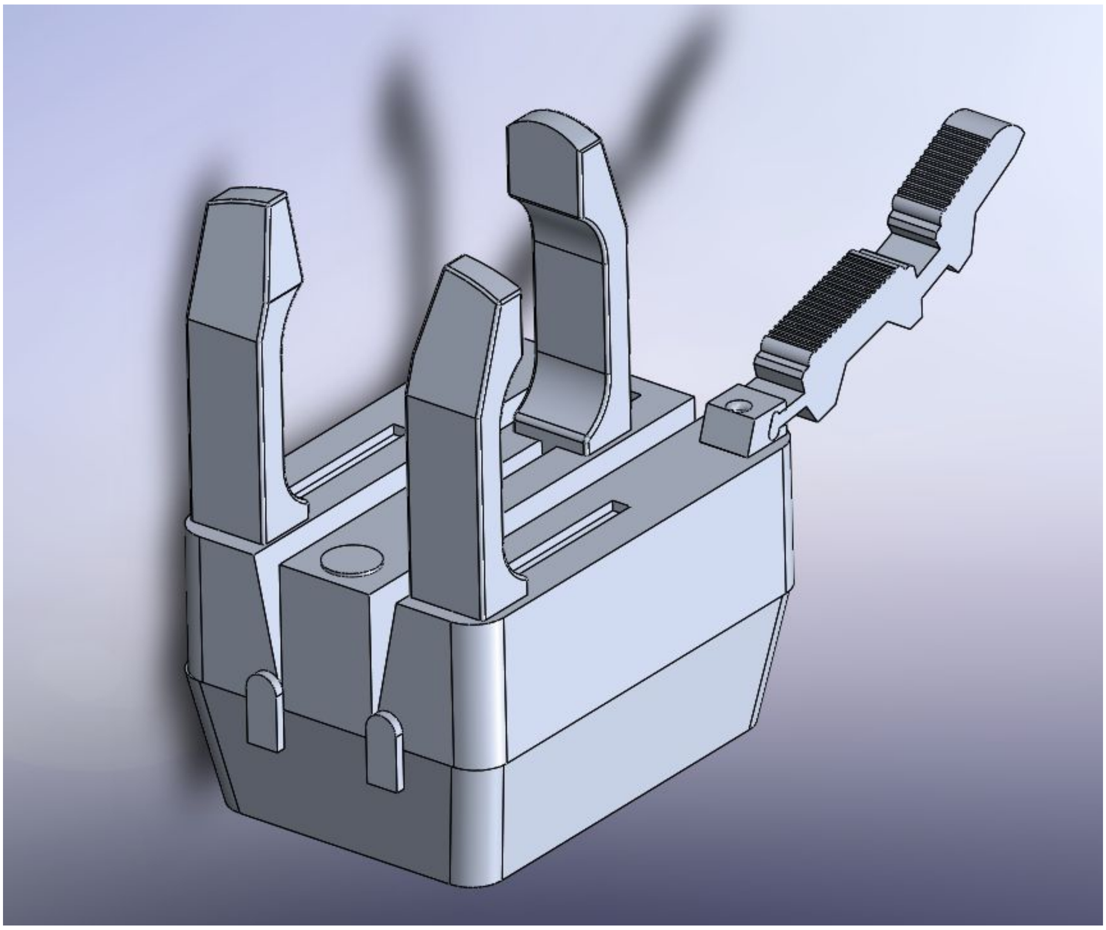


Figure 28. Final configuration

What is shown in the picture is the configuration as a result of the different elections. Because of the linear actuators the gripper has a simple opening and closing system, which is also really powerful. To this one it has been added a lifting system that allows the side fingers to get closer and perform scissor grasping and punctual grasping. All these aspects and where the sensors are allocated is explained in the following subchapters.

6.1 Grasping Modes

The configuration of the finger plus the mechanism added to it allows the gripper to perform different kinds of grasping. These types are inside grasping, tips grasping, punctual grasping and scissor grasping.

6.1.1 Inside grasping

These kind of grasping is performed with the inside part of the fingers. Designed for grasping cylindrical objects, tools and unknown shapes. Thanks to the shape, the beginning of the tips works as a top and can keep the objects inside.

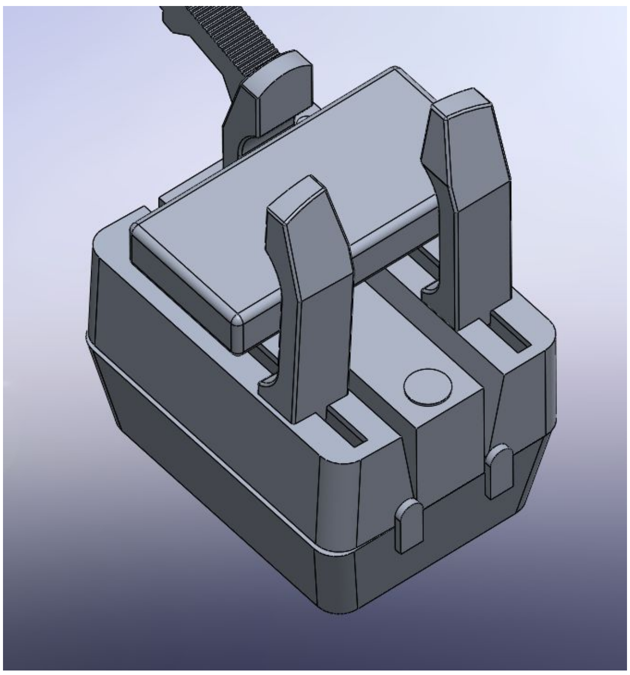


Figure 29. Inside grasping

6.1.2 Tip grasping

Tip grasping is for catching long or big objects with the tips. The ideal would be objects with parallel faces to the fingers' tips. Since the force of the actuators is high and there is the cover material that improves the friction it can also grasp no parallel faces, but sometimes it is necessary to have a safe grasping mode.

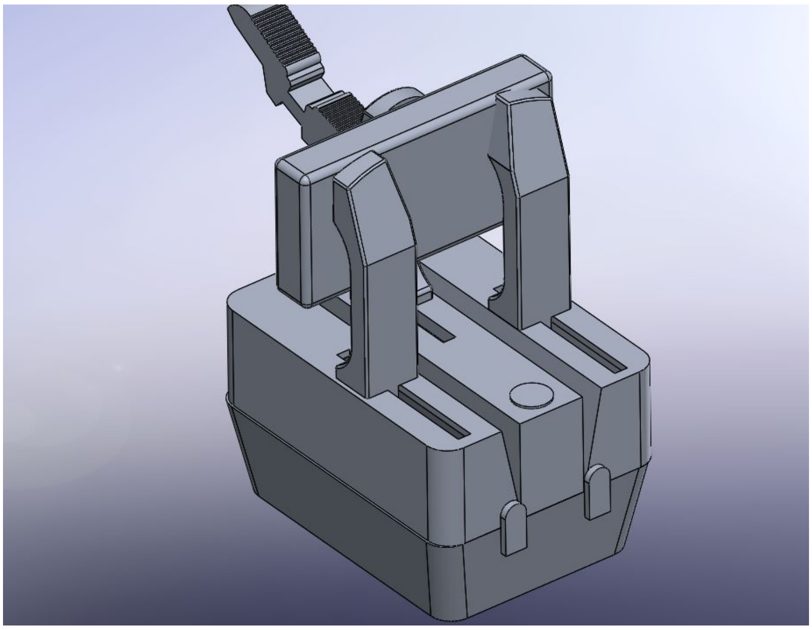


Figure 30. Tips Grasping

6.1.3 Punctual Grasping

The side parts can move with some angle. This is enough to put the side fingers together and in front of the middle one. This position emulates the two fingers grippers which is valuable for small objects.

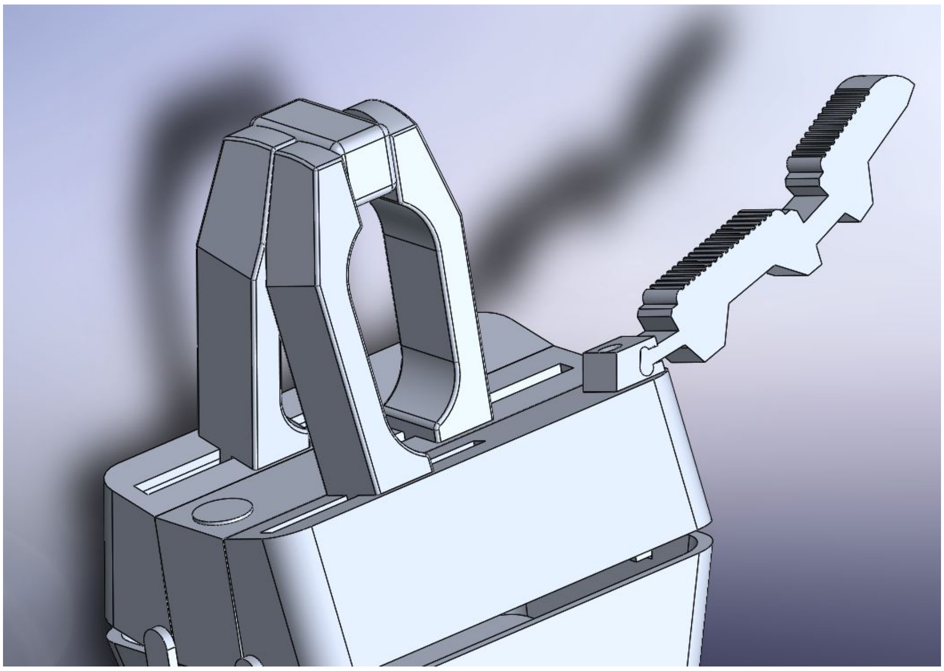


Figure 31. Punctual Grasping

6.1.4 Scissor Grasping

Thanks to the lifting mechanism used for the punctual grasping the side fingers realize a movement like a scissors. This can be used for grasping small objects with just two fingers.

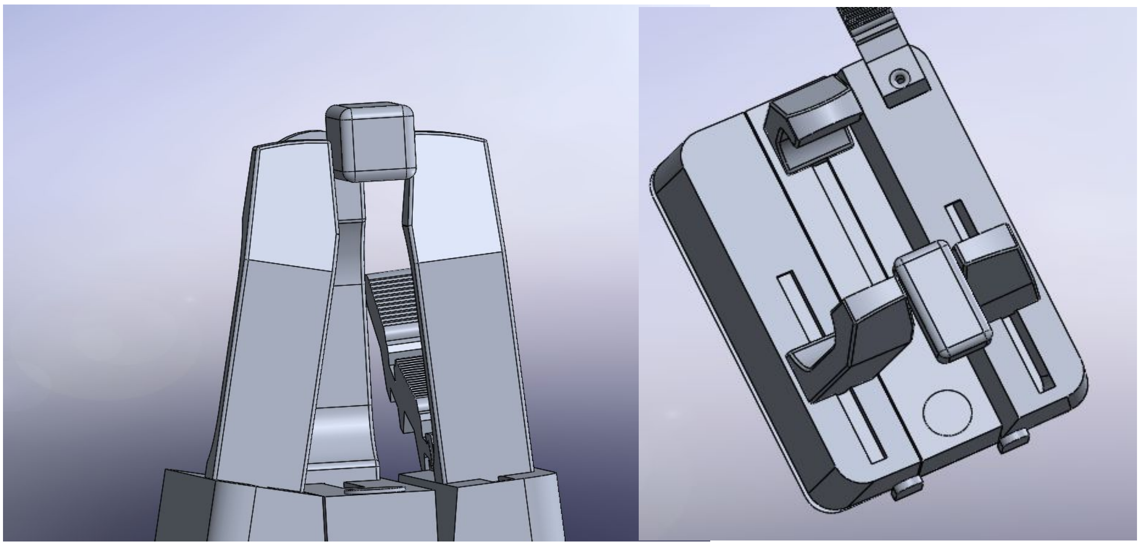


Figure 32. Scissor Grasping

6.2 Sensors

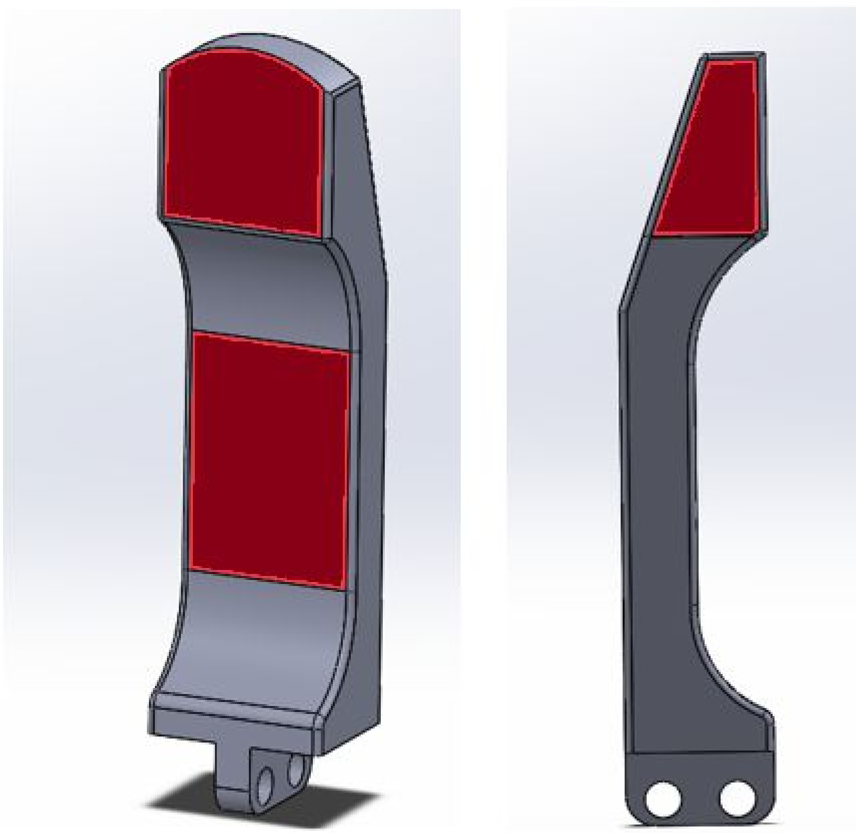
There are many sensors added in the gripper for improving the functionality and flexibility. These ones have been chosen in the previous main chapter. This part shows where the different sensors are allocated. Some of them do not need much explanation because they can be just added in some parts and others will be shown where.

6.2.1 Force Sensor

This kind of sensor had two different contact force and the 6-axis Force-Torque sensor.

The 6-Axis Force-Torque sensor can be added just on the wrist, so this one will be allocated on the wrist as a connection between the gripper and the robot arm. On the other hand, there is the contact force sensor for the fingers. This force sensor has to be placed on the main parts of the fingers according to the grasping techniques for sensing the grasped objects. In the following it is shown where it would be on the fingers.

The red area represents where the sensing parts are. All fingers have the front parts equal and the side fingers also have sensors on the sides for the scissor mode.



The power tool finger also will have this kind of sensor and it will be located on the front part of the finger for knowing how if it touches the trigger and how many force is applying to it.

6.2.2 Temperature Sensor

This one is located on the tip of the middle finger next to the force sensor for sensing the temperature of objects in case it is needed. And also there will be another one inside the hand at the middle part for sense the temperature of the actuators and electronics allocated there. In case that these ones overheat to much due to long work or high and dangerous voltages.

6.2.3 Machine Vision

This sensor has to be located where it can see the fingers working, where the gripper is going and what are the objects in front of it. For this reason, it has been situated on the palm of the gripper in the opposite side of the middle finger.

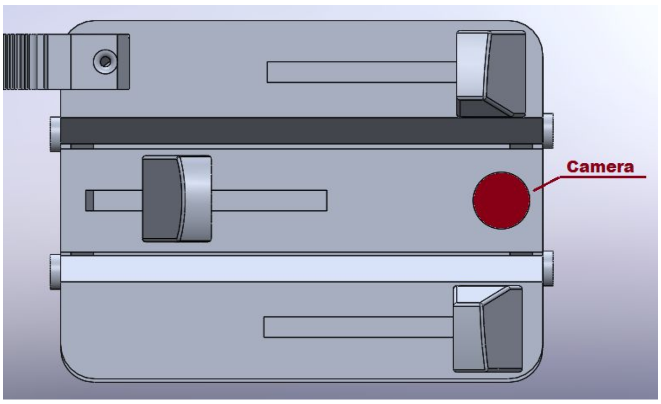


Figure 34. Camera sensor location

The area marque red has the size needed for passing through it the lent from the camera with extensible head.

6.3 Mechanism

The gripper uses different mechanism for being able to moving as explained before. The different mechanisms are the fingers movement, triggers movement and the one that lift the side parts of the gripper.

The linear actuators are attached indirectly to the fingers using a connection part. But the movement is transmitted directly.

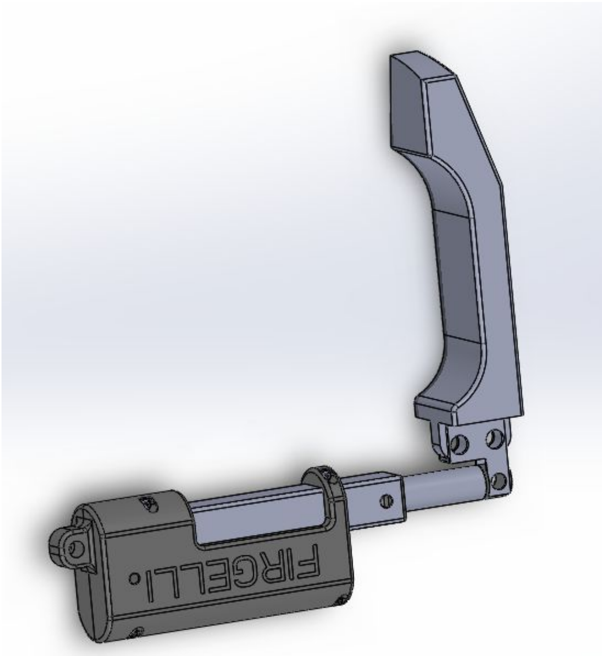


Figure 35. Finger connected to the actuator

The Trigger finger as mentioned before for move uses a rotary actuator. The rotary actuator is located at the base inside the gripper. Using a pulley for rolling and unroll the cable and three small pulleys more, the cable goes from the actuator to the finger. The cable goes out from inside through a hole which was designed at the base of the finger on purpose.

For the mechanism of lifting two more rotatory actuators are used like the ones used for the trigger finger. This one has a simple crank rod mechanism connected to the base of the side parts allowing it to go up and down.

The three parts under the fingers are thought and designed to locate the linear actuators without the external shield from factory that it is just used for attaching the actuator with a screw to a bar. And the under part of this three cabins is big enough to locate the other actuators.

6.4 Example Task

The smart robot gripper that is the aim of this project has to be able to develop lots of different tasks. The next task is going to be an example for showing the different functions that the gripper will be able to enforce. The example is good for checking how the gripper works and it shows the idea of how it would develop distinct tasks. Also the development of the activity will be compared with a human and a common industrial gripper. The aim of this analyse is to show the advantages and the drawbacks of the gripper designed compared with the grippers that are already running in the industry and a human worker.

The task chosen is to change a car tire, which introduces a variety of interesting activities for which is the aim of our gripper. The activities that conform this task are explained below.

Changing a tire is divided in different main tasks: screw/unscrew hub nuts, place the hub nuts and take out and place the tire. The first task is interesting because the hand will need to use a tool, placing the hub nuts, has to be precise, grasping small objects and places a heavy object

Objects

The objects needed for this task are:

- Industrial Electric Impact Wrench: Great Neck/1/2 in. 120 Volt, 134,4 m / kg. heavy duty corded impact wrench with a weight of 4.75 Kg
- Nuts: M22-1.5 X 6mm, 33mm socket
- Wheel: 15Kg

Task

Changing a tire is not that complicated for a human. In the following list it is described how it will need to be performed by our smart gripper:

- The gripper needs to locate the wheel and the nuts, for achieving this it will use the robot vision.
- With the nuts located, now needs to grasp the electric Impact Wrench in the correct position and use it with the extra finger to push the trigger.
- With the position and the tool, it has to unscrew the nuts, and leave them in a prepared box to continue with the next one.
- Once all the nuts are out of the gripper it
- has to catch the tire and take it out, get the new tire and place it to the position.

- After the well is placed the gripper will need to grasp the nuts and situate them at the screws and let them there for use the tool.
- Finally, with the nuts situated at their positions its need to grasp the electric Impact Wrench and screw the nuts.

6.4.1 Development of the task

Now that the necessary different objects are presented and the development of the activity is explained, it is time to explain how it will be performed by the different systems. With this it is possible to analyse which are the advantages and the drawbacks of each system; human worker, common industrial gripper and our smart gripper. This analyse is especially interesting for our gripper.

Human Worker

A human can perform the steps described previously without problems for changing the tire. The only drawbacks are that it consumes human expending time for the activity. Also that it can be efficient changing one, two or three but its productivity will decrease with the time. It has to be pointed out that it can be dangerous for a human working next to a heavy machine. For avoiding the danger, it is necessary to add more material and prepare a safe working area.

Industrial Gripper

In this system it is used the most common gripper in industrial activities, the two fingers parallel jaw. The source does not affect; it will be supposed that it can lift the wheel.

The process of this gripper differs from the one explained before. This gripper by itself can't use a tool, so it needs to change the end effector to a one that works as electric wrench. For this it needs a human to change it or if it can be change easily it needs from a human to screw out the nuts.

The gripper can take out the wheel easily with grasping it, since it has enough strength for it and leave it away. The needed wheel has to be prepared in some station programmed before, because the robot doesn't count with a vision sensor and can't find it by itself. Ones it grasps the new wheel it can put it back to the device, as a simple assembly task.

The nuts have to be also prepared in some station and if the position of the screws is known the gripper can screw a bit the nuts. Ones arrived to this point there is the same problem as at the beginning. There is the need from a human or change tool for using the tool and screw it.

The advantages of this system from the human is that the human is just replaced to basic task, it is out of danger and it is less exhausting for the human. There are two options in this system.

If the tool can be changed easily: to another tool. In this case the task is automatized an it reduces time, money and effort compared with the human. But it needs a gripper that can change easily and different tools that can be attached to its place. This option is faster than the human but it need a really high investment for buying the devices and create the station.

The other option is that the robot cannot change the tool. This is a useless system because the robot will need from a human that helps it to realise the task, it will be better for the human that just need to do some easy task like use the electric wrench. But the time will be increased and the robot is not used efficiently.

Smart Gripper from the project

The main quality that it was wanted to give to the gripper was flexibility and functionality. Because if these different sensors have been added

The gripper can use the machine vision sensor for locating the wheel, nuts and tools. This helps to give the needed flexibility and makes it easy to develop the work in a non-prepared station.

The Gripper locate the nuts, and the tool with the vision sensor. Using the trigger finger it can use the tool alone without changing parts or human help parts or need human help. Once it unscrewed the nuts it can grasp the wheel lift it and replaced with a new one. After using the punctual grasping, the gripper can grasp the nuts and put them on the place combining the punctual grasping with the machine vision. And again it can use the tool for screwing.

The different sensors are responsible for giving enough independency to the gripper and allow to perform the given tasks. The efficiency depends on the control system. But it can perform them using the different sensors without human help, change tools or have a prepared station.

In conclusion, the smart gripper is the best option for realizing a multitasking activity. First of all, it replaces the human of doing a burden task and makes the working environment safer. Then it is a cheaper option than a common industrial gripper. By adding different sensors, it earns more flexibility and needs lees features for being able to performed. It also does not need not need from a predefined working station. And finally it reduces time and cost.

6.5 Prototype

The different discussions and component selection brought the project to a possible result. This result has been drawn in 3D using Solidworks. Some pictures have been shown during this chapter, but the aim of this 3D model was to print it and see physically the results. A virtual prototype is good to visualize it but since there are 3D printers available at the university, a plastic prototype is better to see the results.

At the Tampere University of Technology there are available two Prenta 3D Printers for everyone. With the 3D model designed, was just need to reserve the printers.

The software use apart from Solidworks, was just the available at the computers for use the 3D printers, the Replicator. This program loads the files created in Solidworks and prepares it for the Printer.

Figure 36. 3D printed parts

Figure 37. Smart gripper 3D printed picture 1

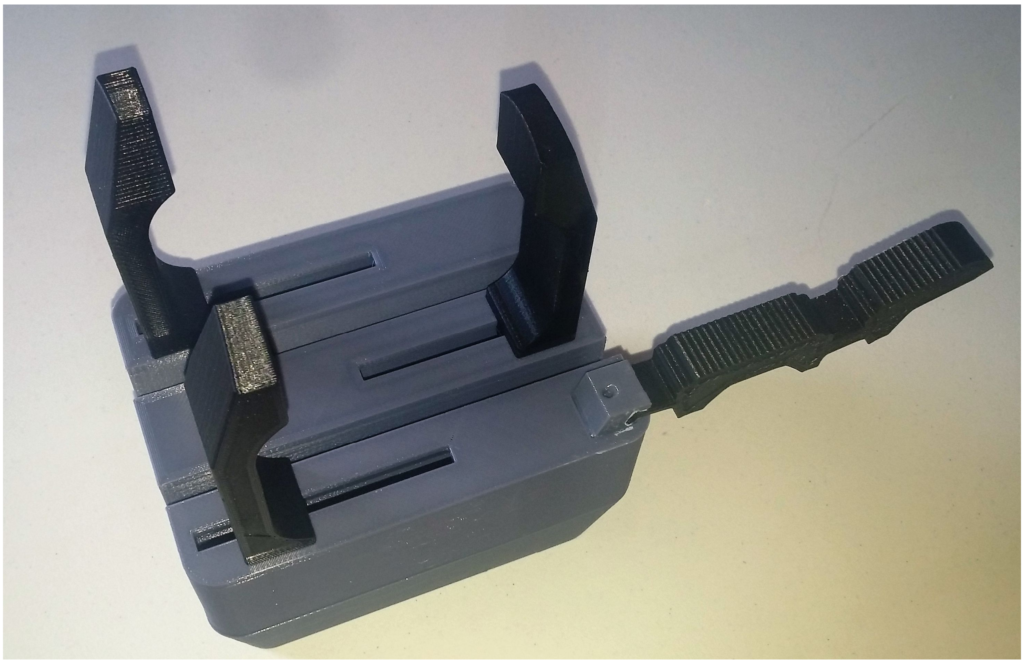


Figure 38. Smart Gripper 3D printed picture 2

This prototype as mentioned is not functional. But is possible to move the fingers and the base for performing the different types of grasping. It was go for see how it is the final result and also to see de different movements that the fingers can do.

7. CONCLUSIONS

The smart gripper designed is the result of different discussions. These discussions have been done for improving the flexibility and functionality of the smart gripper. The idea of the smart gripper for industrial applications was to design a gripper that is able to develop different tasks with a high autonomy and keeping it cheap and easy.

First of all, has been need to choose the gripping method of the gripper. After analyse the different methods has been decided that fingers are the best method for a smart gripper thanks to their flexibility. Once this was chosen, was need to select the better configuration of the fingers for grasping. This has been done with a decision matrix, which had all the important parameters for the gripper and each one had a weight depending on their importance. With this selection method we arrived to the straight finger configuration as the best for our smart gripper. Giving the possibility to achieve the different grasping methods: cylindrical and punctual, also to keep low costs and an easy configuration.

After this was needed to design the finger that is able to use power tools. This finger is added with the aim of giving more flexibility to the gripper and make it able to use power tools. The finger added is a finger designed by Yale university, that is open source and easy to get. This finger has been added to the design.

The next step for make sure that the gripper becomes a smart gripper and is able to use the power tool finger was to add different sensors. First there is the force sensors on the fingers for make the gripper able to have force and contact feedbacks. Also it has been added a 6-axis force-torque sensor to the wrist that allows to the gripper to sense forces and torques in 6 axes. Apart of this ones it has been added also temperature sensors for controlling the gripper temperatures in case of overheat of the electronics and to sense the temperature of some materials. The last sensors added has been a camera, this allows the gripper to see what there is around it.

All these sensors have been added for make the smart gripper more flexible and functional. The sensors added give to the gripper feedbacks about the environment that surrounds it. This data well analysed by the system makes the gripper able to adapt to the different necessities.

The different energy supplies have been analysed and the electrical ones is the best for our smart gripper due to its control of the speed and position. Also thanks to the possibility of sense force and because it does not have the drawbacks of working with fluids. These give to our gripper the flexibility that it needs. After this selection the next step was to choose the actuators. For the fingers has been chosen linear actuators and for the rest of mechanism rotatory. The actuators chosen are enough strong for the industrial activity.

For improving the gripping, a cover material has been added. Which gives to it more frictions and also cover and protect the fingers from the direct contact with the different objects.

Finally, after all of these discussions a 3D model has been created as a possible result. With the model has been possible to see the different grasping modes that the gripper has: punctual, cylindrical, with the tips and scissor. Also using the university's 3d printer I printed a prototype for seen physically the project.

The next step would be to make a real prototype and add the different sensors and make the proves needed to check if it works as designed. Also add a control system in a CPU that receives the sensors feedback and send new orders to the gripper.

The project introduces the idea of a smart gripper for industrial applications which is flexible and is able to perform a wide range of activities. All the sensors added show the potential that a gripper could have. Add sensors to the grippers is becoming more and more usual in the industry. More flexibility reduces costs and the space needed for the different stations.

The sensors combined with the new technologies that are appearing will give to the grippers the flexibility need to develop any kind of task. Not only in the industry.

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ANNEX 1 – COVER MATERIAL

ANNEX 2 LINEAR ACTUATOR FIRGELLI L16

ANNEX 3 – ROTATORY ACTUATOR RCP2CR-RTBS/RTBSL

ANNEX 4- GRIPPER DRAWING