WP3 – Dexterous gripping devices for flexible material handling

D3.2 - Gripper and skin demonstrator

Initial due date: M42 - 30/04/2023

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Version number: V1

Responsible partner

OMNIGRASP : V. Cacucciolo, D. Grasso, F. Gargano

Contributing partners

None

Summary

This document summarizes the demonstrators of novel grippers built enclosing Electroadhesive skins.

Two grippers have been developed. The first one was designed to handle flat sheets of fabric for the Selmark use-case. The Electroadhesive skin, fully clamped to a deformable support, is used to lift one corner of the fabric, while a motorized finger is used to clamp firmly the fabric corner after it is lifted, making it possible a safe handling of the sheet. The second gripper was designed to handle nearly flat pouches for the Thimonnier use-case. The Electroadhesive skins are connected to the body of the gripper by means of a soft interface only at the center of each skin. This way, the skins are free to zip onto the flexible pouches, conforming to their shape and increasing the area of contact.

Each design is the result of a large number of iterations. The forces generated by the Electroadhesive skins strongly depend on the grasping posture, which in turn depends on (1) object geometry, (2) object materials, and (3) grasping strategy. We based our designs on the models available in the scientific literature, some of which we authored, and on our internal expertise. While the knowledge of the science of grasping by Electroadhesion is essential to design efficient grippers, the complex coupling between all

the parameters involved requires design iterations followed by experimental evaluation, to create such gripper for a given class of objects.

We realized that the electroadhesive skins previously developed in the project by EPFL, while working on single fabric sheets, did not provide sufficient adhesion forces to reliably pick-up pouches and stitched multilayers of fabrics. For this reason, with the help of EPFL, we redesigned the Electroadhesive skins to increase the adhesion forces. The new skins have been developed only very recently. Therefore, we report here only limited results for these new skins. Detailed will be described in deliverable D3.5 ‘Report on gripping technologies - Part 2’.

We demonstrated, for the two grippers we designed with the new skins, the ability to successfully pick-up plastic pouches and fabrics (as single sheets or stitched multilayers).

Executive summary

This deliverable is constituted by the enhanced gripper prototypes made of the new low-cost gripper designs integrated with the new electro-adhesive skins. It illustrates the integration of the separate developments described in deliverables D3.1 and D3.5 (‘Report on gripping technologies’ Parts 1 and 2) and in milestone MS3 document (‘Skin Ready for Integration on Gripper’). Considering necessary adjustments (mechanical, electronic, sensing and control integration, and also the skin behaviour impact on the other characteristics of the hardware design), the final enhanced prototype grippers have been manufactured. This deliverable will be used in the work packages WP7 and WP8. Let’s remind here that, as the EA skins technology has been demonstrated previously to be not efficient for fibre glass fabrics, no such gripper has been developed for the VDL use-case which then will make use of a more classical technology.

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1. Gripper and EA skins for pick-up of fabric sheets (Selmark use-case)

1.1. Functional design and grasping strategy for fabric sheets

Due to the low adhesion forces generally obtained with Electro-adhesion on fabric, as reported in Deliverable 3.1, it becomes necessary to use a grasping strategy that prevents the peeling of the fabric from the EA skin. The solution demonstrated by EPFL, and already published[1] in the frame of this project, is to use the rotation of the EA skin rather than its lifting, to separate one corner of fabric from a fabrics stack, hence providing a grasping point for pinching the fabric with a motorized opposite finger. The preliminary embodiment developed by EPFL demonstrated this concept very effectively, yet it has two main problems that might hinder its use in an industrial scenario.

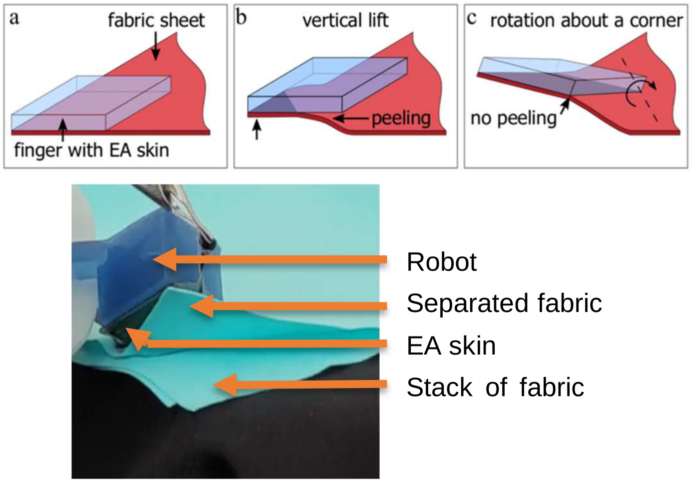

Figure 1 Concept of grasping fabric sheets using EA reported in D3.1

The first problem is that the finger that pinches the fabric corner was designed as a four-bar mechanism. This mechanism works very well, yet it cannot grasp the fabric from any point on the table, but only on the edge, since otherwise the finger would collide with the table.

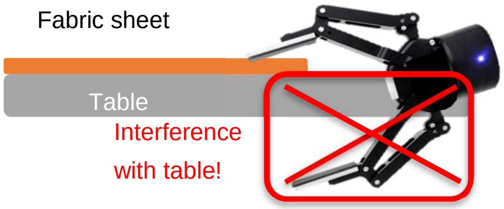

Figure 2 First concept interference problem

The second problem is that the EA skin was directly bonded to a rigid structure. This configuration is acceptable to grasp fabric with EA skins since textiles are very flexible and can adhere to the EA skin. However, having a rigid substrate requires a very high precision in the grasping posture, which is practically hard to realize, especially dealing with a stack of fabric sheets, where thickness uncertainty can be large.

In order to solve the first problem, we designed a new kinematics for the closing finger. This kinematics is a hybrid between a four-bar linkage and a pure rotation. The finger will rotate when close to its rest

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[1] Digumarti, K.M., Cacucciolo, V., Shea, H., Dexterous textile manipulation using Electro-Adhesive (EA) fingers (presented at the 2021 IEEE/RSJ International Conference on Intelligent Robots and Systems - IROS)

position, reducing the gripper size and allowing getting into contact with the corner of the fabric at any point on a table. When the finger closes down to pinch the fabric, it will behave similarly to a four-bar-linkage, approaching the EA skin with almost zero rotation, providing a clean pinching with very limited sliding between the facing surfaces. This is beneficial to reduce the wearing of the EA skins.

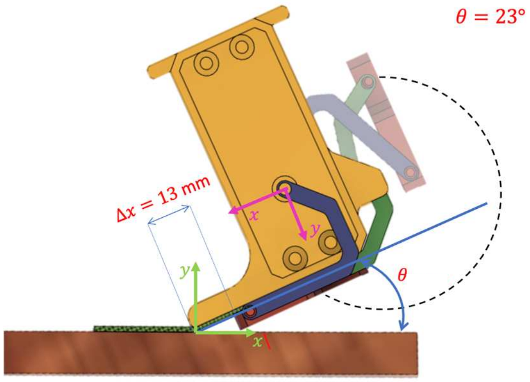


Figure 3 Example of the proposed kinematics for the closing finger

1.2. Gripper mechanical design and fabrication

The functional design has been translated into a series of CAD designs taking into account the interfaces with the robot arm, the size of the EA skins and the need to fit the EA electronics and the servomotor to actuate the finger.

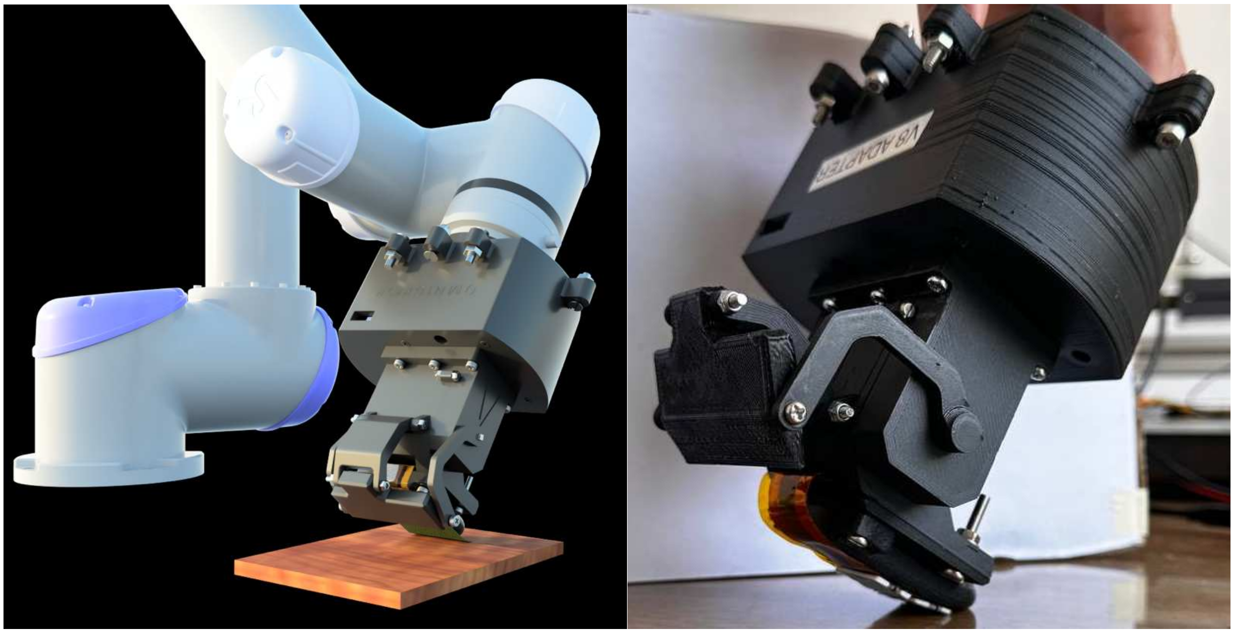


Figure 4 Gripper for fabric. Whole design. CAD (left) and prototype (right)

The moving finger has been implemented as a flat plate connected to the still body by three moving elements. The two elements on the front are curved linkages. On the back, one single large curved plate has been preferred to two smaller linkages to obtain enough rigidity during the finger movement. The motion is transmitted on both the small front linkages by a custom-made shaft with a built-in gear, which is itself put in motion by another gear connected to a servomotor. Connecting both linkages to one shaft proven to produce much smoother motion compared to connecting only one linkage leaving the other one fool. The shaft of the servomotor is aligned with the rotation axes of the finger.

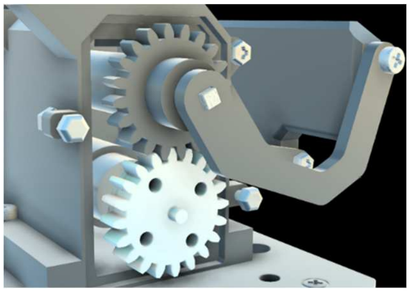


Figure 5. Gears that actuate the moving finger

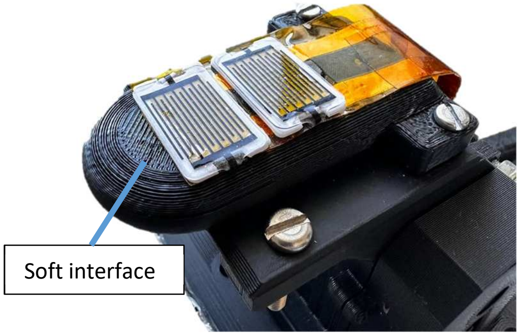


Figure 6. Soft interface between the EA skins and the body of the gripper.

The fabrication of the custom parts was done with 3D printing at Omnigrasp facilities, to both reduce the delays between each iteration and control closely each portion of the process. We developed 8 different versions of this gripper. The final version to date (shown in the figures), includes 15 components, made with different materials: 1 metal shaft, 2 PLA shaft supports, 3 PLA arms linkages (2 front arms, longer, and 1 back arm, smaller and wider), 1 PLA closing finger, 1 TPE soft pillow, 1 PLA support plate for the pillow, 1 PLA case, 1 PLA case closing, 1 PLA electronics case, 1 PLA electronics case closing and 1 PLA robot adapter. The total height of the gripper, including the robot adapter, is 154 mm.

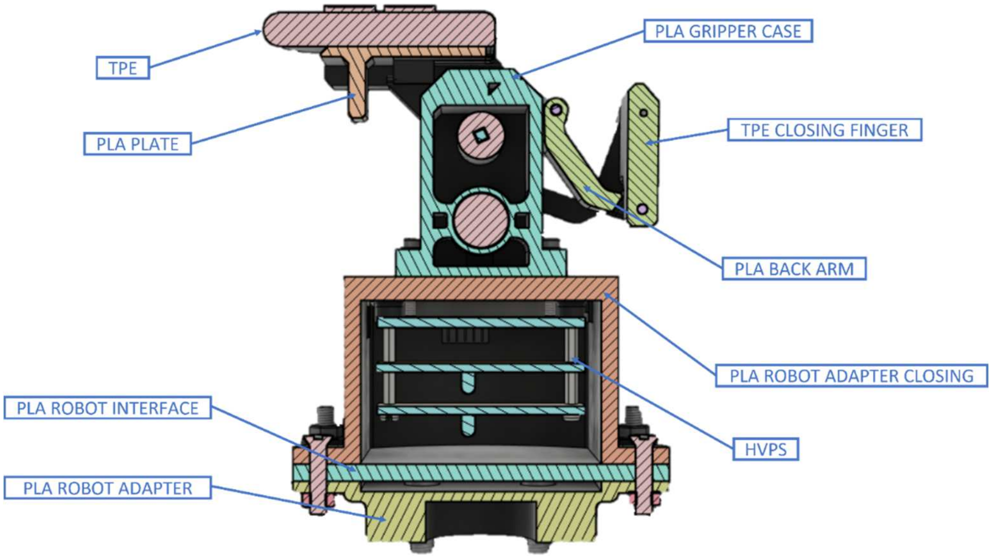


Figure 7. Cross section showing the gripper components

This gripper also features a case to hold the control and high voltage electronics. The case is especially designed to act also as connection with the wrist of the robot arm.

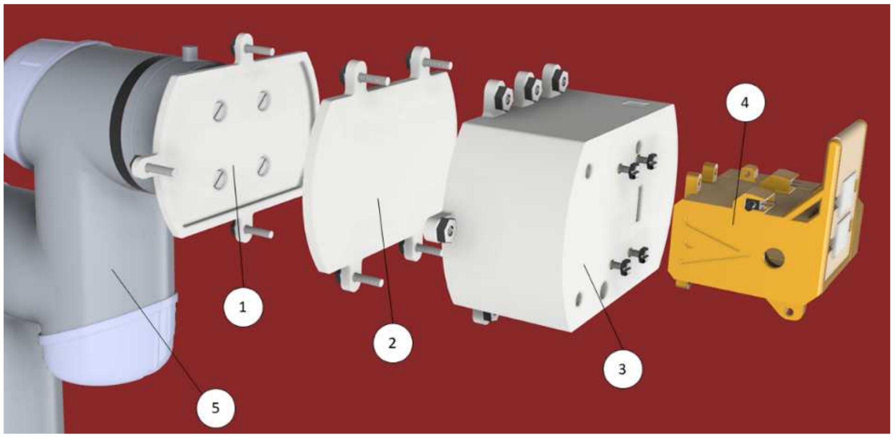
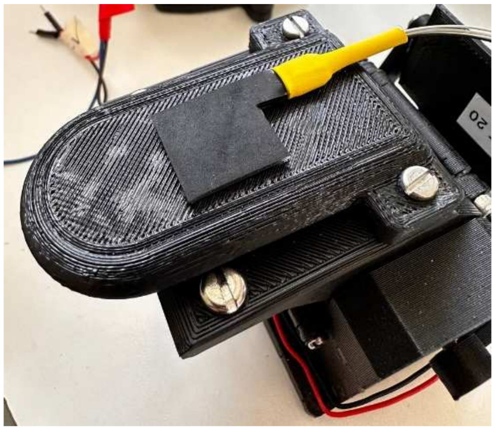


Figure 8. Exploded view of the gripper, the electronic case and the connection to the robot arm. (1) base, (3) case, and (2) case cover. The Gripper Assembly is shown mounted on a UR5 robot arm (5).

1.3. Soft sensor integration

The soft sensor is implemented between the soft interface and one of the EA skins. We tested the sensor individually. We are still implementing the sensor together with the EA skins and preliminary tests of the sensor with the EA skins will be soon realized. The results will be presented in deliverable D3.5.



1.4. Electrical connections

Very important and sensitive for these grippers is the design of the electrical connections to the EA pads. There are several reasons for this. The first one is that the EA pads consist of very thin and soft silicone pads (200 to 300 µm thick) with internal even thinner (20 to 30 µm) stretchable electrodes. The electrical connections need to be done between the thin stretchable electrodes and electrical wires that will then be connected to the High Voltage electronics. The electrical connections to the EA skin need to be reliable, robust, while not being too stiff to risk damaging or deforming the silicone skin. As any rigid – soft interface, these connections need very accurate engineering. The complexity is further increased by the need to guarantee reliable electrical and not only mechanical connection. We designed custom flexible electrodes with a Polyimide support as intermediate electrical connection between the EA skin and the high voltage wires used to connect to the High Voltage electronics. The electrical connection between the flexible electrodes and the EA skin was performed using special conductive silicone paste. All the connections were finally isolated to avoid electrical arcing.

1.5. Gripper validation

We tested this last version gripper in its ability to handle fabric sheets. It worked very well on single sheets. As planned by design, the gripper could grasp the items at any point on the table. The soft interface also proved to be very effective in reducing the requirement for highly accurate positioning. Thanks to its wide compliance over a range of 4 to 5 mm, it made it ensure the contact between the EA skin and the fabric sheet, while dramatically reducing the risk of overloading the EA skins and the whole gripper.

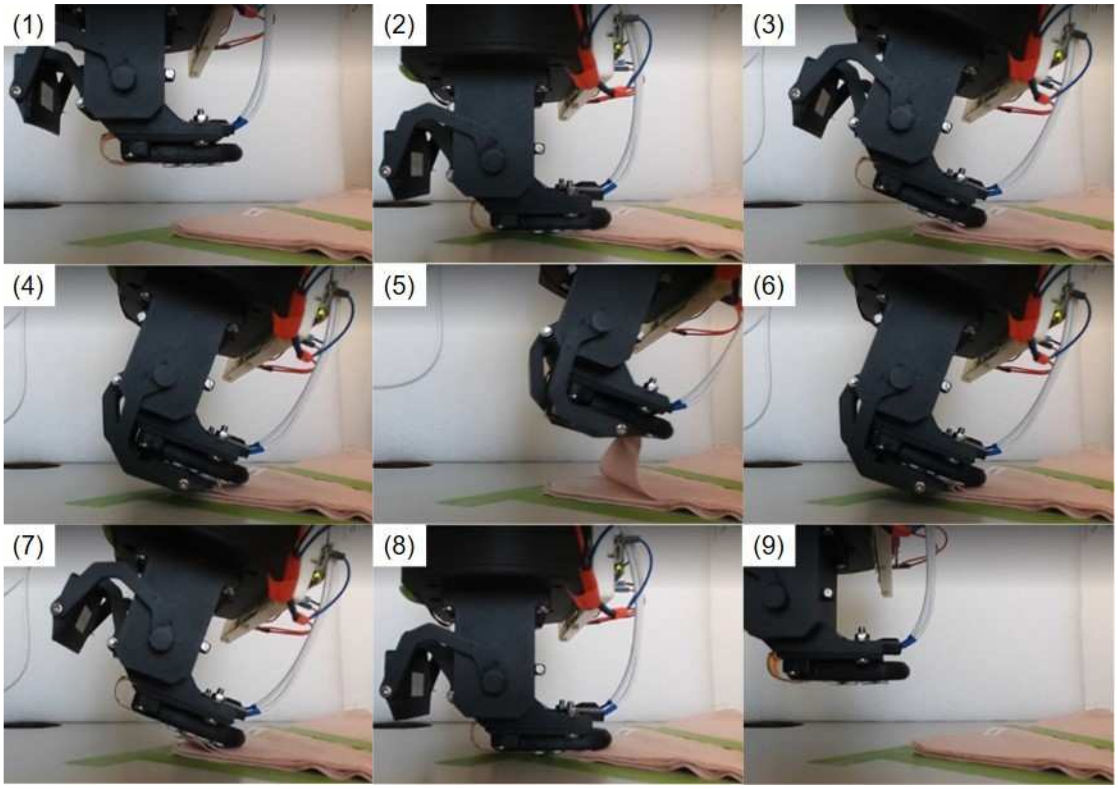


Figure 9. Grasping sequence with the last iteration of the textile gripper design. 1) approach, 2) contact, 3) adhesion and pivot, 4) pinching, 5) lifting, 6) placing, 7) release, 8-9) return.

2. Gripper and EA skins for the pick-up of flexible pouches (Thimonnier use-case)

2.1. Functional design and grasping strategy for flexible pouches

While being both flexible, plastic pouches and fabric sheets have very different mechanical properties. Fabric sheets are so flexible that they just bend down under their own weight. Depending on the fabric material and thickness, they can arguably be more flexible than the EA silicone skins themselves.

The same is not true for flexible plastic pouches, which are generally much more rigid than the EA skins. This difference in mechanical behavior changes drastically the approach required to grasp them using an EA gripper.

One fundamental mechanism to obtain effective electrical adhesion is the electrostatic zipping, i.e., the mutual attraction between the EA skin and the object surface, resulting in a large contact area with no apparent air gap. The physics of this mechanism and the fundamental parameters involved have been published during the project[2]: An effective electrostatic zipping depends on the balance between Electroadhesion forces, Bending stiffness and Weight.

Fabric low bending stiffness makes it possible to adhere the EA skin to a more rigid surface, since it will be the fabric to zip onto the EA skin, which can even not deform at all for zipping purposes. The same is not true for the plastic pouches. In this case, the bending stiffness of the pouches is too large to enable zipping with the EA forces that we normally can achieve before reaching electrical breakdown.

Therefore, we designed the EA gripper for the flexible pouches by leaving the EA skin free to deform and zip onto the pouches. The skin is connected at its center to a compliant pillar. The pillar is then mechanically connected to a more rigid column, which is itself connected to the rigid body of the gripper.

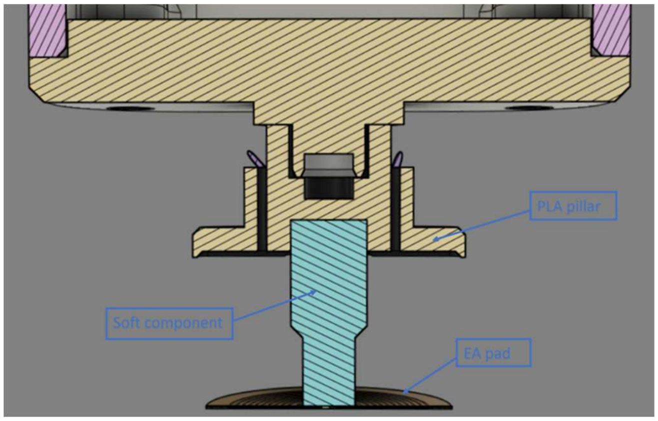


Figure 10 Cross section of one EA pad for the flexible-pouches gripper

By connecting an EA skin only at its center with a small flexible pillar, it is not possible for one EA skin to transmit torques at the gripping point (high compliance and the ability to transmit torque cannot be achieved at the same time). By using 3 EA skins placed at 120° one from the other, the whole gripper becomes able to transmit torques, and therefore rotate the plastic pouches. So, we designed each gripper with 3 pillars and 3 EA skins.

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[2] Mastrangelo, M., Caruso, F., Carbone, G., Cacucciolo, V., 2023. Electroadhesion zipping with soft grippers on curved objects. Extreme Mechanics Letters.

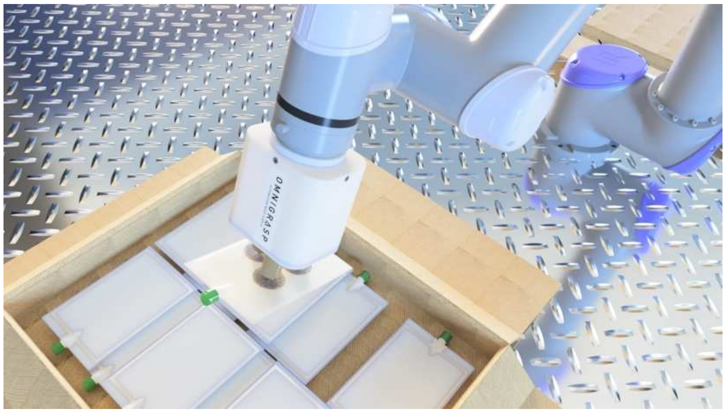


Figure 11 Rendering of the EA gripper on the Thimonnier use-case

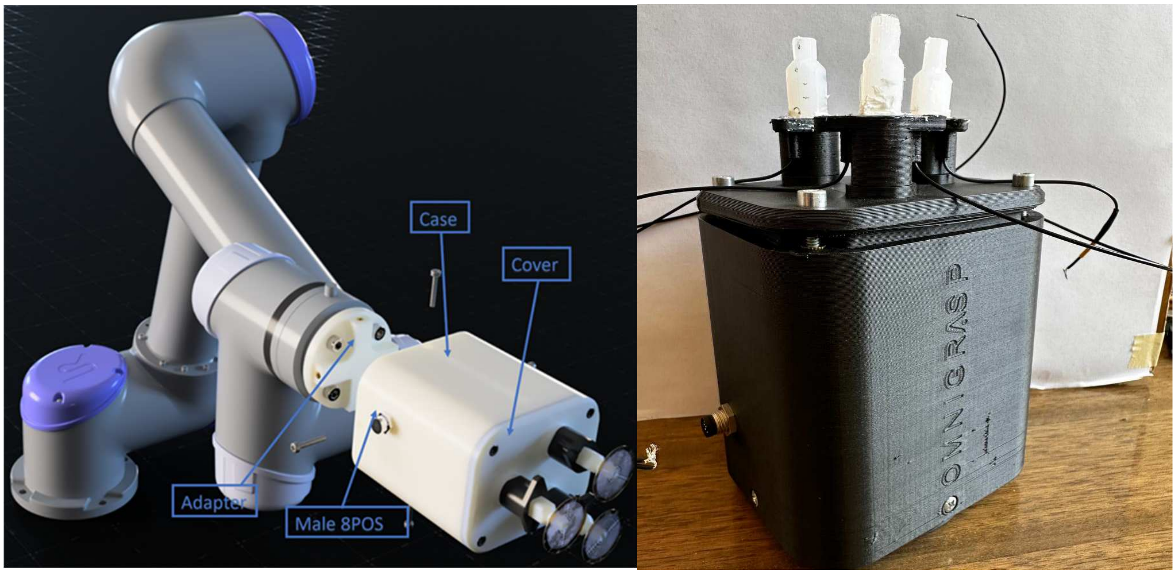


Figure 12. Assembly of the EA gripper with the 3 EA skins, the case, the connector and the adapter. CAD (left) and prototype (right)

2.2. Gripper mechanical design and fabrication

This gripper has no moving parts. The EA skins are positioned on the top of the flexible pouches by the 6DOF robot arm. This makes the design relatively simpler than the one of the fabric gripper.

However, having 3 EA skins increases by 3 times the likelihood of failure of one of them. Since these are still research samples and not industrial products, their lifetime and reliability can be a limiting factor. With the goal of minimizing the down time for these grippers, we designed each EA skins to be easily replaceable in case one of them gets damaged. Each rigid pillar is connected to the body of the gripper by a magnet, to facilitate the attachment and detachment.

A soft interface connects on a small area (3 to 4 mm diameter) the EA skin and the rigid pillar. We fabricated the soft interfaces using silicone molding. On the one hand, silicone is compliant, reducing the risk of damaging the skin when contacting the object; on the other hand, silicone can be easily glued to the EA pads, also made with silicone, simplifying the connection. We tried different silicone materials and silicone glues (e.g. Smooht on Ecoflex 0030, Dragon Skin NV10, Sil-poxy). The rigid removable pads where made of 3D-printed PLA.

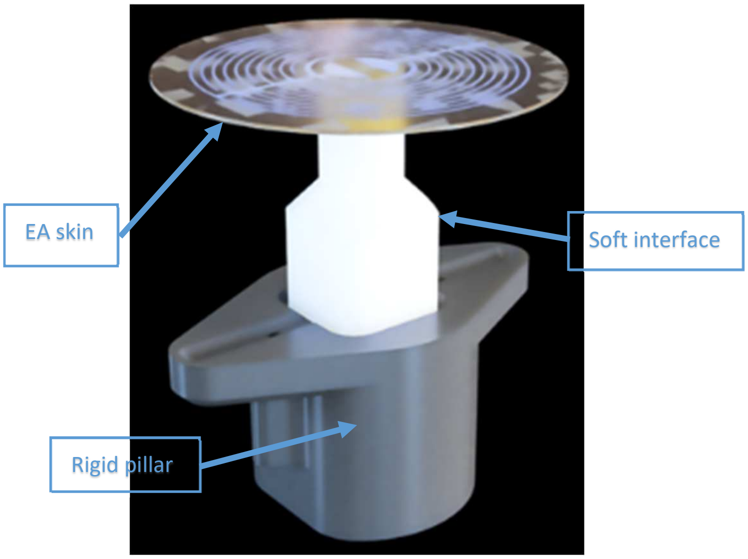


Figure 13. Rendering of the EA skin mounted on the rigid removable pillar through a soft pillar interface

2.3. Electrical connections

The electrical connections for this gripper replicate the same general challenges and strategies than for the fabric gripper. This case results though more complicated by the fact that the EA pad flexibility is an essential requirement for a successful grasping. Therefore, it is not acceptable to connect components that are more rigid and heavy to the EA skin perimeter. We produced two different strategies, one for the old EA skins and one for new ones.

The old EA pads had external strips made with the same material of the pad itself that hold the connection points. Here, we carefully included a rigid holder on the top of the pad, at a few mm distance from its surface, where the connection point could be glued. The position of this holder is such that the bent strip does not deform the EA skin in any noticeable way. We noticed though that the assembly process for the electrical connections was long and tedious, plus these bent strips are somehow fragile.

For the new EA pads, we designed the electrical connections at the center, at the same position where the mechanical connection is. This design has the advantage to keep the electrical connection points in the most stiff part of the EA pad. However, the fabrication of the electrical connections proved quite involved.

Our plan was to realise the connections by means of thin enamelled copper wires, which would be included in the soft silicone pillar that connects the EA pad to the rigid pillar. We succeded to fabricate such connections only on a few samples, and are still iterating the fabrication method. At the moment we are using the same thin copper wires but are leaving them external, which is easier to implement but is not robust enough for the implementation in the pilots.

2.4. Gripper validation

We tested the new gripper with the old and with the new EA skins on different pouches. Preliminary results showed that the gripper with the old EA skins could only effectively lift one kind of pouch (small one, category food).

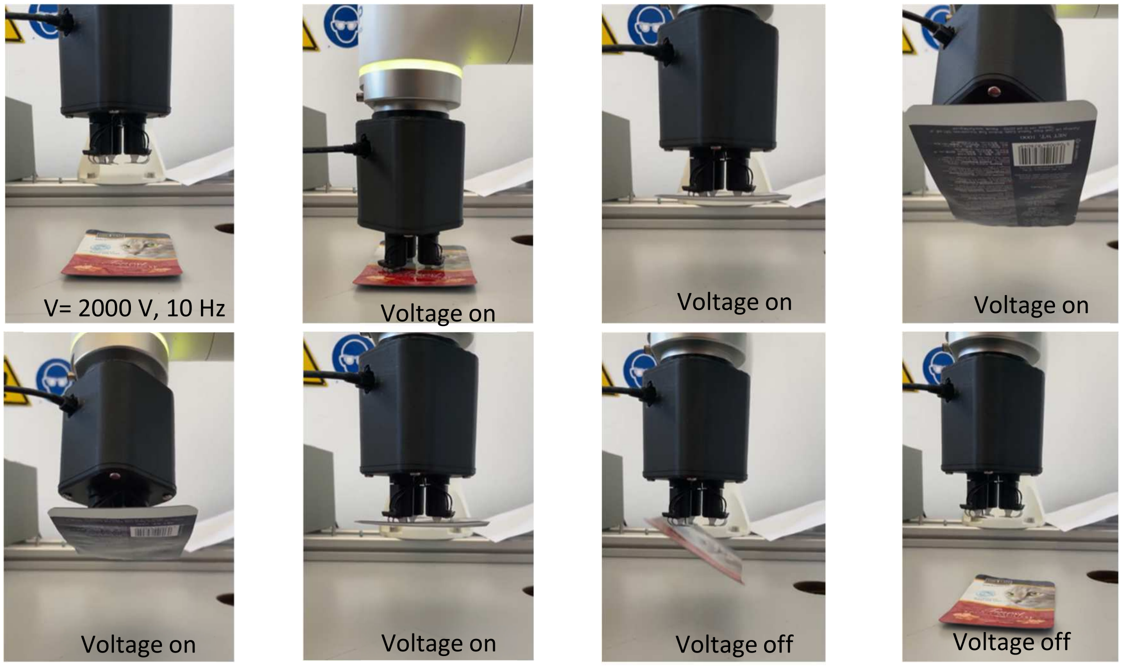


Figure 14. Two successful grasping of a flexible pouch with the Omnigrasp EA soft gripper

We are currently in the process of finalizing and testing the integrated gripper with the new EA skins.

Thanks to the higher actuation voltage, the new EA skins promise to achieve a much more effective zipping and therefore much higher adhesion forces. We also tested them manually on much heavier objects than the pouches such as a coffee mug, which they could grasp successfully.

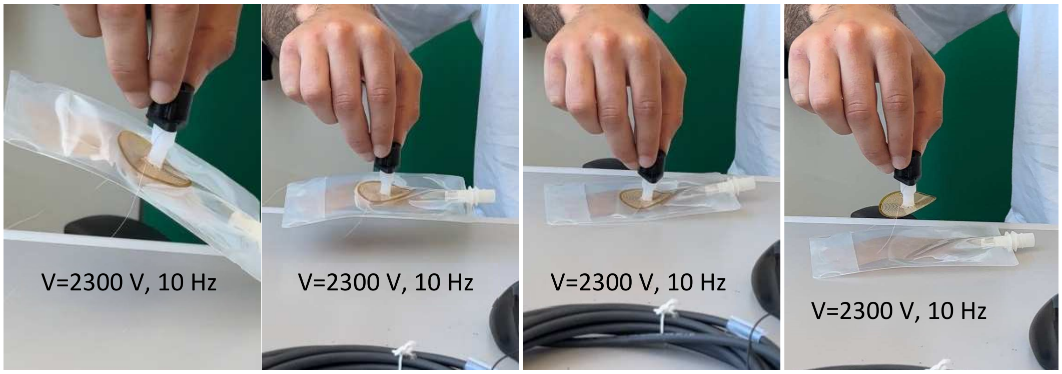


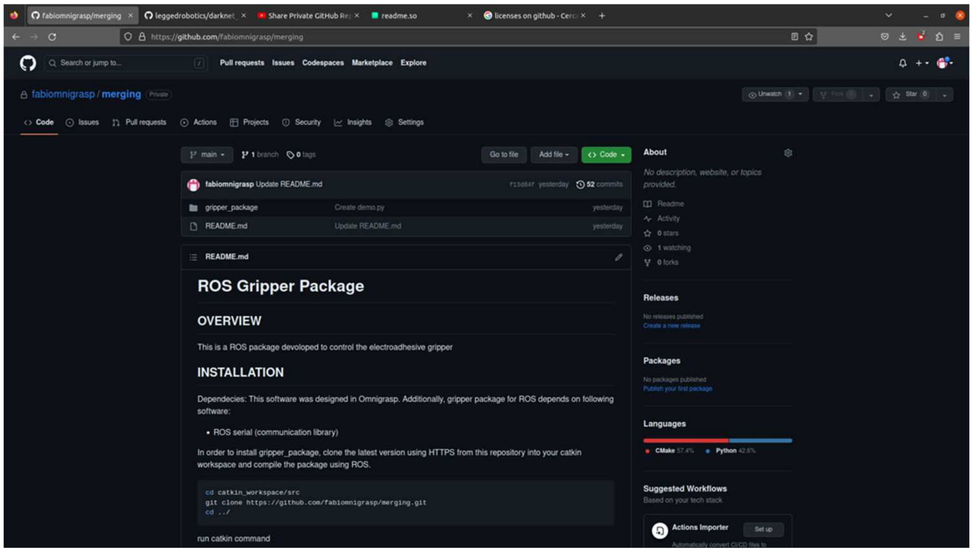
Figure 15. Preliminary successful attempt to grasp a flexible pouch with the new EA skins

Figure 16. New EA skins grasping a coffee mug from the top

3. Software, control and user interface

We developed all the components required to drive both grippers, including electronic boards, a firmware and a ROS-node software.

We used the version of ROS, Noetic. The guide and drivers required to install the gripper package are on GitHub: https://github.com/fabiomnigrasp/merging



fabiomnigrasp Update README.md — f13d84f yesterday — 52 commits

gripper_package	Create demo.py	yesterday
README.md	Update README.md	yesterday

README.md

ROS Gripper Package

OVERVIEW

This is a ROS package devoloped to control the electroadhesive gripper

INSTALLATION

Dependecies: This software was designed in Omnigrasp. Additionally, gripper package for ROS depends on following software:

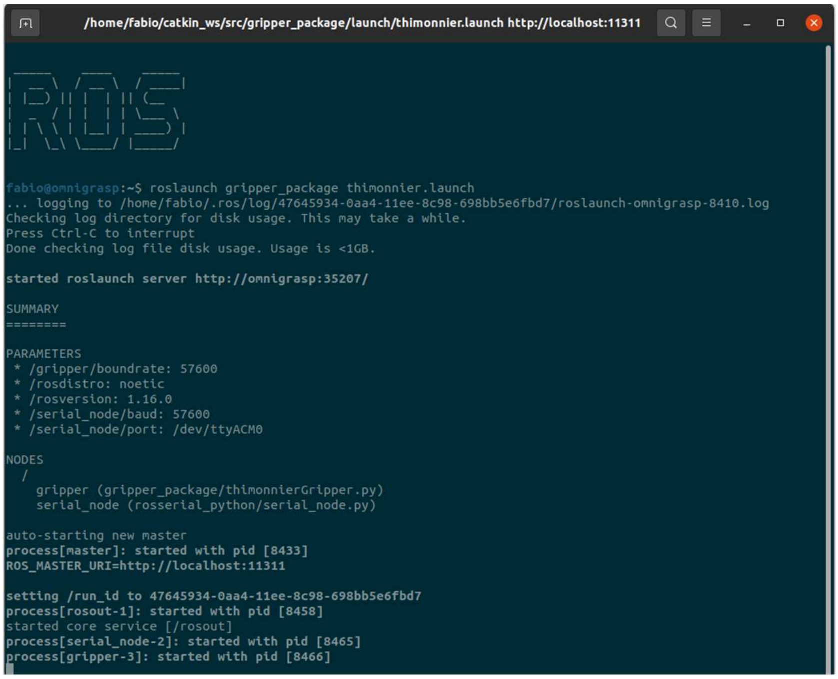
- ROS serial (communication library)

In order to install gripper_package, clone the latest version using HTTPS from this repository into your catkin workspace and compile the package using ROS.

```
cd catkin_workspace/src
git clone https://github.com/fabiomnigrasp/merging.git
cd ../
```

run catkin command

Figure 17. Screenshot of the GitHub page of the Ros Gripper Package.



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fabio@omnigrasp:~$ roslaunch gripper_package thimonnier.launch
... logging to /home/fabio/.ros/log/47645934-0aa4-11ee-8c98-698bb5e6fbd7/roslaunch-omnigrasp-8410.log
Checking log directory for disk usage. This may take a while.
Press Ctrl-C to interrupt
Done checking log file disk usage. Usage is <1GB.

started roslaunch server http://omnigrasp:35207/

SUMMARY
========

PARAMETERS
 * /gripper/boundrate: 57600
 * /rosdistro: noetic
 * /rosversion: 1.16.0
 * /serial_node/baud: 57600
 * /serial_node/port: /dev/ttyACM0

NODES
  /
    gripper (gripper_package/thimonnierGripper.py)
    serial_node (rosserial_python/serial_node.py)

auto-starting new master
process[master]: started with pid [8433]
ROS_MASTER_URI=http://localhost:11311

setting /run_id to 47645934-0aa4-11ee-8c98-698bb5e6fbd7
process[rosout-1]: started with pid [8458]
started core service [/rosout]
process[serial_node-2]: started with pid [8465]
process[gripper-3]: started with pid [8466]
```

Figure 18. Screenshot of the ROS program

The command to control the gripper through ROS is `roslaunch gripper_package thimonnier.launch`

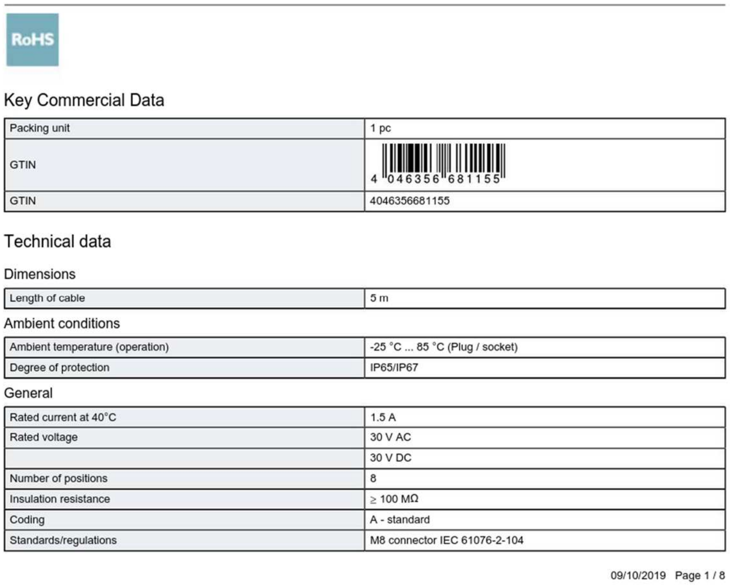
The EA skins can be activated / deactivated using the cmd_vel message:

angular.z = 2.0 EA on

angular.z = -2.0 EA off

The connection between the gripper and the robot arm is realised through an electrical cable (M8 8 pos female to XH-4Y (custom)) that carries both power and signal. One end of the cable is directly plugged into the gripper. The other end is plugged into a custom electronic box that we realised, which switches signal and power over two standard lines (a USB-B and a 2x5 jack, respectively).

Figure 19. M8 cable datasheet



RoHS

Key Commercial Data

Packing unit	1 pc
GTIN	4 046356 681155
GTIN	4046356681155

Technical data

Dimensions

Length of cable	5 m

Ambient conditions

Ambient temperature (operation)	-25 °C ... 85 °C (Plug / socket)
Degree of protection	IP65/IP67

General

Rated current at 40°C	1.5 A
Rated voltage	30 V AC
	30 V DC
Number of positions	8
Insulation resistance	≥ 100 MΩ
Coding	A - standard
Standards/regulations	M8 connector IEC 61076-2-104

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Figure 20. M8 cable carrying both power and data

The electrical box has one power plug (jack 3.5 mm, 12 V, 1 A) and one USB-B for serial communication with the orchestrator PC.

Figure 21. Custom electrical box that provides a standard interface to power the gripper and communicate with it