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Executive Summary

This deliverable demonstrates the integration of the family of Soft-End Effectors developed for the ReconCycle Project. To showcase their use and integration, a dismantling sequence for one of the Smoke Detectors considered in the project has been implemented. The Demonstrator integrates the Soft Claw, the SoftHand 2 and the SoftClamp. The programming of the system was performed adopting a single-shot teaching method, developed with the contribution of the ReconCycle Project. The attached video, reproduce the first step of the disassembly process and how the different components interact and work together in a single framework. The following document describes the integration work and explain the video sequence.

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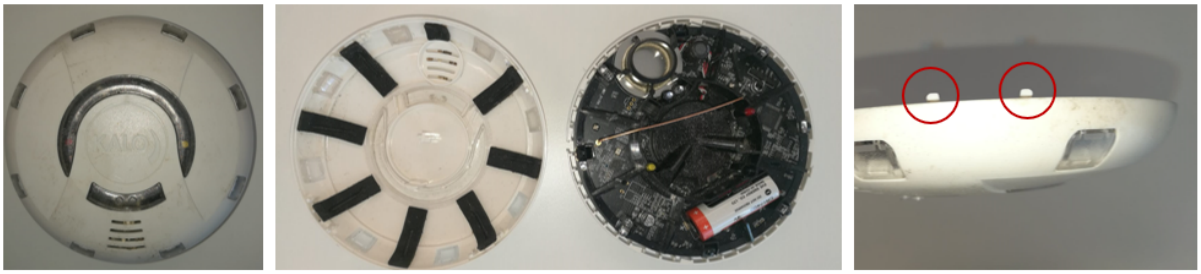
1 Introduction

To showcase the integration of the family of Soft End-Effectors developed within the ReconCycle project, an experimental setup has been established. The setup implements the disassembly sequence of a Smoke Detector, depicted in Figure 1. From the following link, it is possible to download the video.

https://www.dropbox.com/scl/fi/ahsen0xjyg1e86j2x6l52/d4.4_video.mov?rlkey=vc8fh7n4q3e3pnsmszxxdfwvt&dl=0

A detailed description of the setup and different actions performed are reported in the next sections.



a) b) c)

Figure 1 a) Kalo Smoke Detector); b) after removing the external lid (on the left), the internal components are accessible (on the right); c) a detailed view of the deformable tabs (in the red circles) that make up the snap-fitting system

2 The Smoke Detector Scenario

The Smoke Detector disassembly is one of the use cases of the ReconCycle project (Figure 1 a)). It consists of two external covers that protect the internal components, including LEDs, electronic boards, speakers, and batteries. The devices inside are therefore components that must be separated and properly disposed of at the time of dismantling (Figure 1 b)).

To do this, it is necessary to have access to the internal spaces of the device, which is only possible after opening the external covers.

The two external shells of the Smoke Detector are snap-fitted together. They have deformable tabs (Figure 1 c)) that allow for easy assembly but are challenging to disassemble, a process currently carried out manually by skilled personnel.

Through observation of humans at work during the disassembly of the Smoke Detector we noticed that they utilize a technique of levering the lid out while applying pressure to the device against a rigid surface (such as a worktable), with their hand that constitutes a second yielding opposing surface. Doing so they rely on an opposing rigid surface to counteract brutal forces, allowing the operator to insert a tool inside the narrow gap on the device while their hand does not hinder the lid from deforming and eventually sticking out.

The evident complexity of the procedure used by human personnel makes it extremely difficult to automate the device opening phase, and it is equally clear that traditional robotics is not well suited to perform this task.

The fact that the manual technique, as previously mentioned, relies on both rigid surfaces and a flexible grip suggests that soft robotics and the ability to switch from more rigid to more flexible grips may have a better chance of accomplishing the task compared to traditional rigid robotics.

Indeed, in this document, we aim to show how utilizing softness, variable stiffness, and the reconfigurability of the end effector grip can make the procedure of opening the external shells of the device automatable. This step is considered the most challenging subtask of the overall disassembly process: once the lid is removed, the battery and the internal components can be easily accessed.

3 System Setup and Components

The experimental setup (Figure 2) is composed of two collaborative robotic arms, one Franka Emika robot and one ABB GOFA robot and two bins for collecting the disassembled parts. The end-effectors of the robots and the clamping systems of the Smoke Alarm are the:

- the SoftClamp, fixed on the support table, that functions as a bench vise featuring a fixed finger and a specially designed template for the Smoke Alarm (Figure 3 a))
- the SoftClaw (VS Gripper) mounted on the ABB CRB15000 robot with a customized sharp tool attached to the fixed finger (Figure 3 b))
- a SoftHand2 Research mounted on the Franka Emika robot (Figure 3 c))

The programming of the working cell has been implemented utilizing the single-shot teaching algorithm described in Stefanini et al.[1], developed with the contribution of the ReconCycle Project.

It is worth to be noted that the demonstrator was created without the aid of a vision system, which could certainly be integrated to support the entire sequence, increasing its precision, robustness, and reliability, as well as managing anomalies such as missing parts to be disassembled, failures in various grips, etc. Such integration is not part of this deliverable but is exploited in the Final Demonstrator Deliverable of the project.

[1] Stefanini, Elisa & Lentini, Gianluca & Grioli, Giorgio & Catalano, Manuel & Bicchi, Antonio (2024). Exploring Saliency for Learning Sensory-Motor Contingencies in Loco-Manipulation Tasks, Robotics, 13:58, doi: 10.3390/robotics13040058.

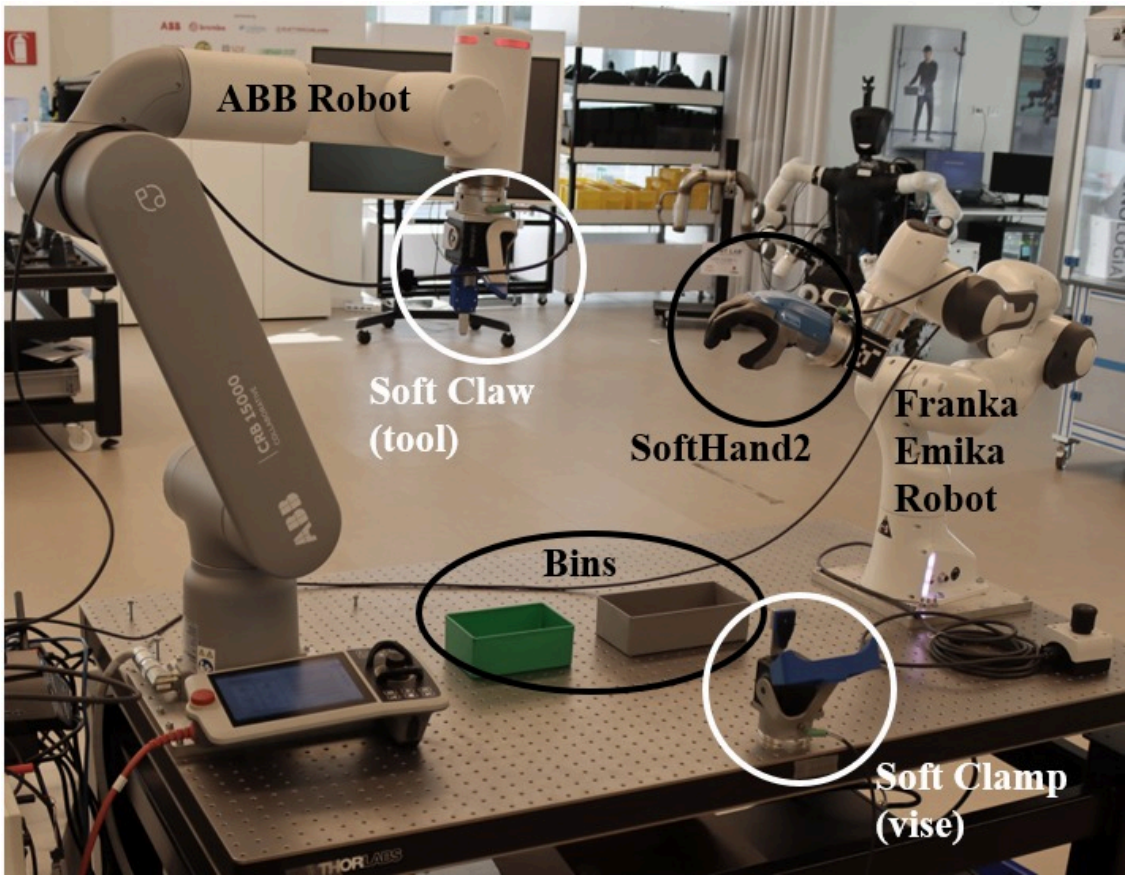


Figure 2: Picture shows the experimental setup composed of two robotic arms, two soft end-effectors and the SoftClamp fixture.

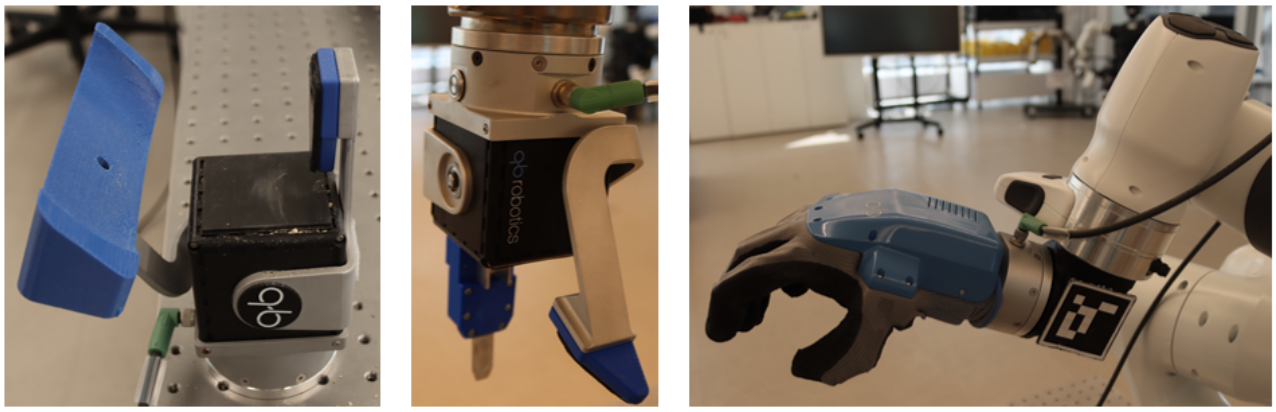


Figure 3: Detailed view of the equipment used; a) the SoftClamp (based on the VS Gripper) with a specially designed template for the Smoke Detector on its movable finger fixed on the worktable; b) the SoftClaw (VS Gripper) on the wrist of the ABB robotic arm with a sharp tool on its fixed finger; c) the SoftHand2 Research on the wrist of the Franka Emika robot.

4 Soft End-Effectors Demonstrator

The next pictures illustrate the sequence we followed to perform the removal of the lid:

a) The device is manually positioned onto the open soft vise which is initially set to maximum stiffness. As the vise closes, the special shape of the template securely clamps the Smoke Detector into a precise position.

b) A custom-made tool attached to the fixed finger of the SoftClaw is forced into the narrow gap between the device's external covers. By applying a controlled twisting motion to the tool within the gap, the small tabs holding the lid to the rest of the device are disengaged.

c) The Franka Emika robot brings the SoftHand2 close to the Smoke Detector. The SoftHand2 is configured to close by pointing and intervenes at this stage of the disassembly process to hold the rear cover in place with the index finger while the front cover is being disengaged. The compliance of the SoftHand2 allows its index finger to slide between the two covers as the gap between them gradually widens until it becomes large enough to allow the finger to pass through. This prevents the rear cover from following the front cover in the subsequent stages.

d) The ABB robot pushes the tool onto the VS Gripper against the front cover of the Smoke Detector and downward, while the SoftHand2 helps keeping the device to be disassembled open by holding the rear cover in place with its index finger. Additionally, at this stage, the SoftClamp fixed to the workbench reconfigures its stiffness to allow the covers to open under the action of the SoftClaw's push.

e) At this stage, two actions and one reconfiguration occur: the SoftClaw closes its jaws to grasp the front cover, the hand reconfigures its closure from pointing to pinch grasp to hold the rear cover, and the SoftClamp opens its jaws to hand over the two parts of the Smoke Detector to the two robotic arms.

f) The two robotic arms place the two parts of the smoke alarm into separate containers. The part containing the battery, electronic board, LED, and speakers subsequently requires further stages of separation and disassembly of the most critical components.

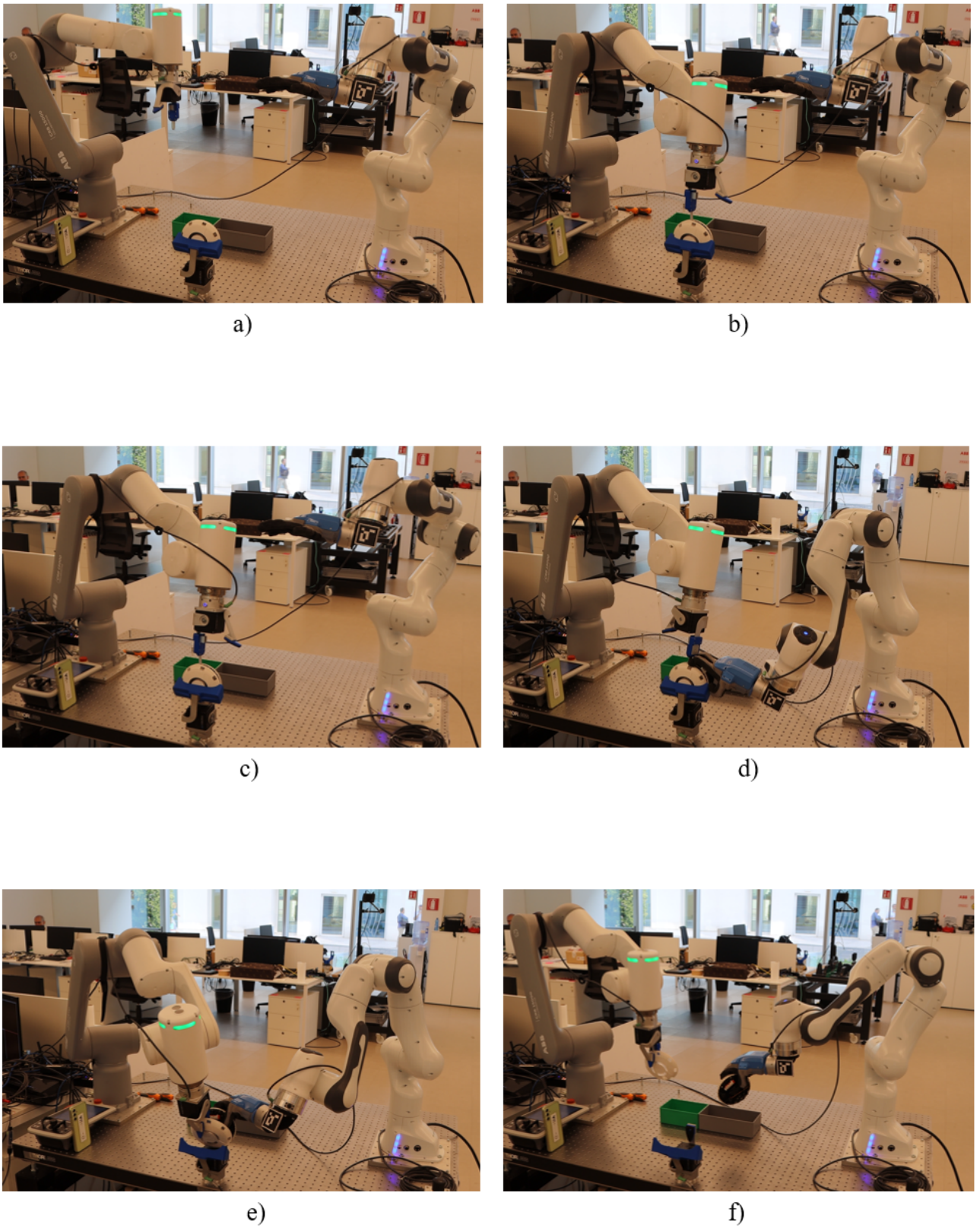


Figure 4: The sequence showcases the disassembly sequence of the Smoke Detector, based on the use of the soft end-effectors developed within the ReconCycle project