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Contents

1 Executive summary

In this deliverable we describe the skill library designed for ReconCycle to perform actions to disassemble devices. The skill library specifies for every action the general constraints and permissive ranges. The devices considered for disassembly are heat cost allocators (HCAs) and smoke detectors. These two types of devices have different sizes and shapes, and require different techniques for disassembly. Due to the constraints of the hardware underlying the skills, some skills work for smoke detectors and not for HCAs, and vice-versa.

2 The Skill Library

The skill library contains all the skills that the ReconCycle system can use to perform actions. The skills concern actions that can be performed by the robot arm, using a specific end-effector, or actions that are performed by a specific piece of hardware.

Each skill is performed by specific hardware and requires specific parameters to be performed. Skills are performed successfully if the parameters match the object the skill is performed on well. Skills are robust at performing the action if they can handle a range of parameters and still successfully perform an action.

2.1 Object Grasping

A set of skills was developed to enable grasping various objects of different shapes with the available grippers integrated within the workcell. The choice of grippers is such that different object shapes, including cylindrical and cuboid-shaped objects, can be grasped reliably.

2.1.1 Using qbRobotics SoftHand2: Grasping from Above

The qbRobotics SoftHand2 is a soft/compliant gripper resembling a human hand. Although it has 19 Degrees of Freedom (DOFs), the control software enables using Synergistic Control, so that the control input signal is two DOFs. See Figure 2 and Figure 3. While closing, the SoftHand2 fingers adapt to the grasped object shape. This relaxes the constraints on object pose determination accuracy and enables grasping a wider array of object than two-finger robot grippers. The SoftHand2 is used for grasping objects from above, i. e. in a top-down fashion.

Figure 1: qbrobotics SoftHand2 [8].

To perform this action, in the case of the object lying on a plane, the following parameters are required:

- 6D transform of the plane
- 6D transform of the object center w.r.t. the plane
- Bounding box of the object (width, height)
- 6D transform of the end-effector w.r.t. the object center, that specifies the grasp pose

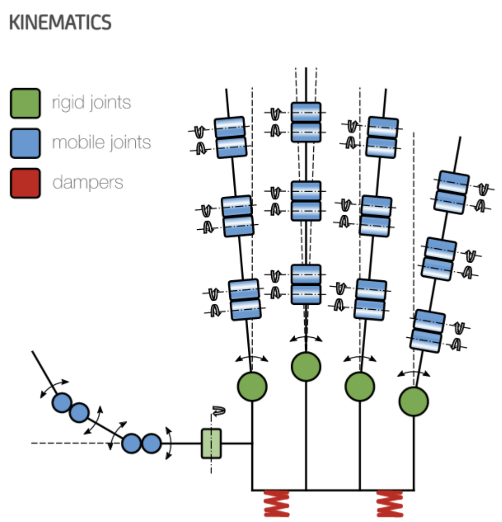

Figure 2: qbrobotics SoftHand2 kinematics. Image from [5].

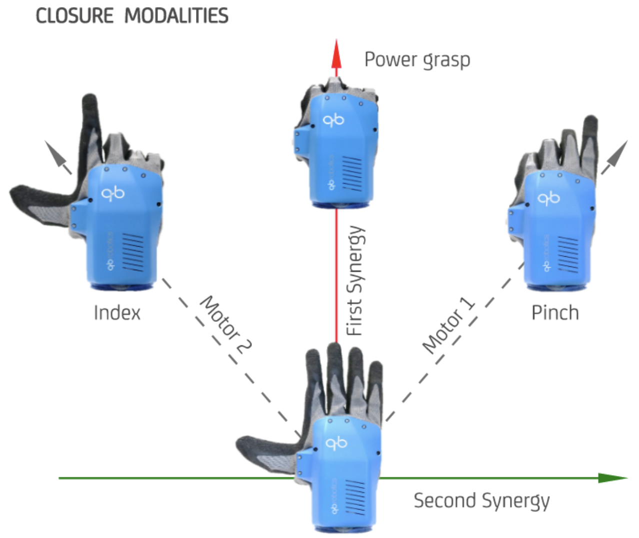

Figure 3: qbrobotics SoftHand2 closure modalities. Image from [5].

2.1.2 Using qbRobotics SoftClaw: Grasping from Above

The qbRobotics SoftClaw seems like a traditional claw but smarter and with the intrinsic ability to adapt the applied strength to whatever object it is gripping, as shown in Figure 5. The SoftClaw is used to grasp objects from above, but it can also be used for levering using the rigid finger.

Figure 4: qbRobotics SoftClaw. Image from [8].

To perform this action, the following parameters are required, in the case of the object lying on a plane:

- 6D transform of the plane
- 6D transform of the object w.r.t. the plane
- Bounding box of the object (width, height)
- 6D transform of the end-effector w.r.t. the object center

2.1.3 Using centric Schunk Three-Fingered Gripper: Grasping from Above

Centric grippers are most effective for objects that are cylindrical, such as smoke detectors. A key advantage of centric grippers is self-centering of circular objects within the gripper, which relaxes the constraints on the vision system as well as on robot positioning accuracy relative to the grasped object. The three fingers are positioned at 120° to each other. The fingers move linearly towards the center of the tool. Such tools are often (including in our case) powered by pneumatics, which provides the advantages of high gripping strength/closing force (when compared to electric motors), up to $350N$ in case of Schunk PZH-20. The second advantage is that gripping/closing times are very fast ($0.25s$ for Schunk PZH-20). In our use-case, the fingers are 3D printed out of carbon fibre reinforced PA12 (Nylon 12) filament. This allows for on-site production of replacement fingers or fingers with varying diameters.

The key parameter of a centric gripper is its **travel/stroke per jaw**, since this affects the maximal and minimal diameter of an object that can be grasped with a set of particular fingers installed.

In the ReconCycle workcell, centric grippers are used both as a robot tool to enable grasping smoke detectors, and as chucks, mounted within the CNC Mill (described later), where they enable reliably clamping the smoke detectors in place during the milling operation.

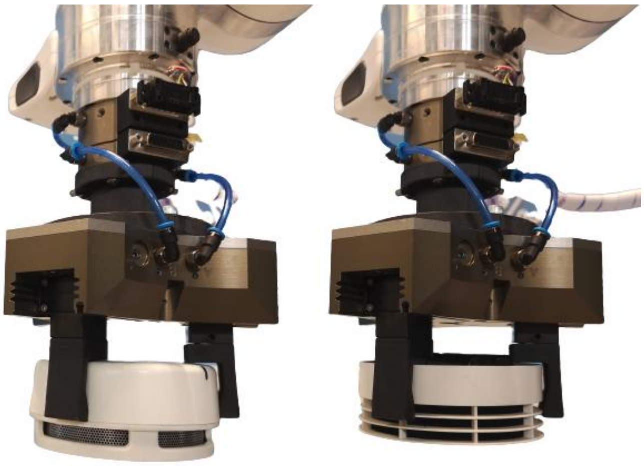

Figure 5: 3-finger centric Schunk gripper PZH-20 [7].

To perform this action, the following parameters are required, in the case of the object lying on a plane:

- 6D transform of the plane
- 6D transform of the object w.r.t. the plane
- Bounding box of the object (width, height)
- 6D transform of the end-effector w.r.t. the object center

2.2 Object Placing

To perform subsequent disassembly actions, it is necessary to place grasped objects within particular devices/modules (CNC mill, vise, cutter) in a specific configuration. To this extent, skills have been developed to enable placing objects in various configurations.

2.2.1 Using SoftHand2: Placing

In principle, the object can be placed anywhere, but to avoid it falling, it should be placed on a plane. The SoftHand2 is used for placing objects within the Vise, or for placing disassembled parts into specific end-component boxes.

Parameters:

- 6D transform of the plane
- 6D transform of the object drop pose w.r.t. the plane

2.2.2 Using Schunk: Placing

In principle, the object can be placed anywhere, but to avoid it falling, it should be placed on a planar surface.

Parameters:

- 6D transform of the plane
- 6D transform of the object drop pose w.r.t. the plane

2.3 Levering

Devices are often put together using a friction fit, or tabs, such that the device can be disassembled by providing enough force between these components to separate them. This can be achieved by inserting a tool, such as a robot-mounted screwdriver or qbRobotics SoftClaw, and levering out the components of the device.

2.3.1 Levering: Using QBRobotics Variable Stiffness Gripper

The qbRobotics SoftClaw has one movable and one rigid finger. The rigid finger can be inserted into a gap and used as a lever. By levering on the edge/case of the device, sufficient force can be generated so that a particular component (in the case of Heat Cost Allocators, the Printed Circuit Board - PCB) can be removed. An example of this is shown in Figure 6.

Parameters:

- 6D transform of the gap, levering plane and levering direction
- The maximum allowed force and torque to be exerted
- The torque drop-off value (in the levering plane) to consider a component dislodged

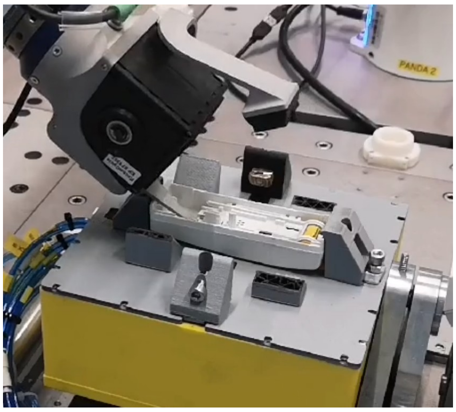

Figure 6: SoftClaw levering.

2.4 CNC Milling

In some cases, it may be extremely difficult for a human to disassemble a device, and even more difficult for a robot. For example, there might be small, hard to push clips securing the device together, or a large number of screws with differing screw head types. While these problems can be solved, they may increase the time required to perform the robotic disassembly cycle substantially, resulting in poor economic efficiency of the robotic workcell. In this case, a more destructive method can be used to achieve the result faster, with a smaller amount of steps, and more reliably. One such solution is using an industrial off-the-shelf CNC Milling machine, integrated within the workcell's ROS infrastructure. We note that other approaches, such as a robot in-hand cutting tool, could also be used, however the dedicated CNC Mill approach allows faster cutting times, increased precision, and lowers the wear on the robots, as well as relaxes the payload requirements on the robots. The CNC Mill takes as input G-code, a sequence of textual instruction on linear or circular moves to be performed.

During milling, high forces are exerted on the milled object, as well as the CNC end-mill. Any play in the clamped object can result in breakage of the end-mill. By using pneumatic centric grippers as chucks, objects can be reliably clamped within the machine.

We distinguish two cutting approaches. The first approach deals with devices (usually smoke detectors) where only a circular cut-out is required. In this case, the parameters are:

- 3D transform of the bottom center point of the device (or the chuck holding the device)
- Height of the device along the contour
- Radius of the cutting circle

The second approach deals with devices where a more specific cutting contour is required. This may be due to some components (most often capacitors) that are positioned just below the device shell and which should not be cut. Here, the parameters are:

- 3D transform of the bottom center point of the device (or the chuck holding the device)
- Height of the device along the contour
- Contour specified by n-points which should be cut out

The contour of the batteries can be detected by the vision system, more specifically, the rotation of the batteries within the smoke detector. With this information, G-code for the CNC machine is dynamically generated based on the detected rotation of the device (smoke detector) within the CNC chuck.

2.5 Cutter

In some cases, separating batteries from other device parts (separating batteries from the PCB of a Heat Cost Allocator) would be difficult using our current CNC machine due to the large thickness of the cut that would be required, as well as materials tough to cut, so a pneumatic cutting machine was devised for this purpose. Here we note that by using a larger and stronger industrial CNC machine, these issues could be avoided, however the large size and weight (upwards of 1t) of such machines makes them unsuitable within the ReconCycle project. A device can be positioned under the cutter, and the cutter can cut the device in two pieces. The position of the device under the cutter defines where the device is cut. This skill is used in combination with subsubsection 2.1.1 or subsubsection 2.1.2. The position at which the device is grasped determines how it can be put in the cutter. The parameters are:

- 6D transform of cutter plane.
- 6D transform of object to be placed in the cutter, w.r.t the cutter plane.

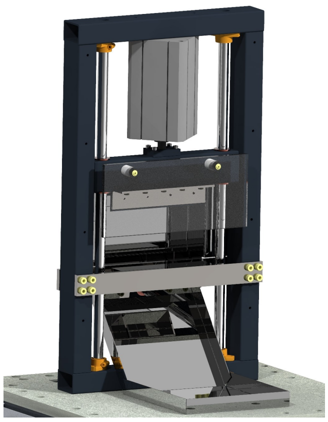

Figure 7: Reconcycle cutter module [6].

2.6 Unscrewing

The unscrewing action has been researched by TUM and JSI, however it has not yet been applied in practice in the ReconCycle Workcell.

2.7 Rotatary Vise

Some operations, such as levering, require that the candidate device be firmly clamped. To enable clamping of object of various dimensions, a modular vise was implemented. Additonally, the vise can rotate 180°, enabling removal of loose parts from the device while clamped, and removal of the entire device when not clamped. This can speed up the disassembly cycle times. For example, when disassembling HCAs, the PCB is removed by the robot, while the (plastic) frame stays within the vise. In an industrial setting, a chute might be implemented underneath the vise, so that after the part containing the battery is removed, other components can be quickly discarded.

Parameters:

- 6D transform of the vise plane
- 6D transform of object to be placed w.r.t. the vise

3 Permissive Ranges

Each skill can be performed by one or more end-effectors, using a robot arm, or a specific machine. For each of these we provide the permissive range.

The maximum robot payload is 3kg. The force ranges are given in Figure 8.

Force

Sensing [3]

Force resolution		<0.05 N
Relative force accuracy		0.8 N
Force repeatability		0.15 N
Force noise (RMS)		0.035 N
Torque resolution		0.02 Nm
Relative torque accuracy		0.15 Nm
Torque repeatability		0.05 Nm
Torque noise (RMS)		0.005 Nm

1 kHz Control [3]

Minimum controllable force (Fz)		0.05 N
Force controller bandwidth (-3 dB)		10 Hz
Force range [N]	Nominal case	Local best case
Fx	-125 – 95	-150 – 115
Fy	-100 – 100	-275 – 275
Fz	-50 – 150	-115 – 155
Torque range [Nm]	Nominal case	Local best case
Mx	-10 – 10	-70 – 70
My	-10 – 10	-16 – 12
Mz	-10 – 10	-12 – 12

Figure 8: Franka Emika force ranges. Image from [1].

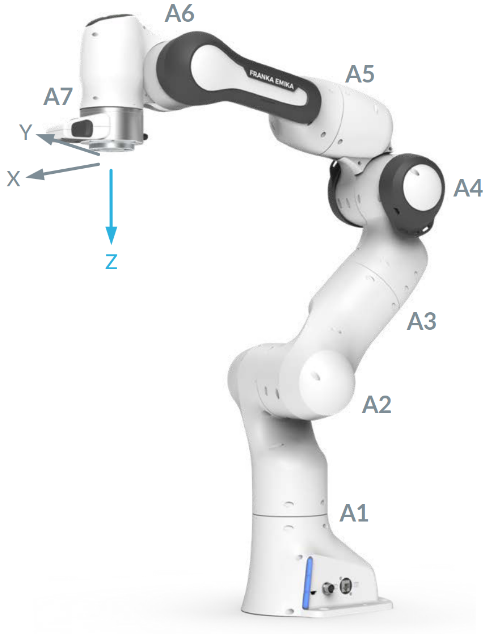

Figure 9: Franka Emika robot diagram. Image from [1].

3.1 Grasping skill

We find the parameters for the pick and place skills via experimentation and from the properties of the end-effectors. The HCAs and smoke detectors have sizes shown in Table 1 and Table 2.

HCA	width (mm)	length (mm)	height (mm)
min. size	35	70	25
max. size	40	125	30

Table 1: HCA minimum and maximum size.

Smoke Detector	diameter (mm)	height (mm)
min. size	95	30
max. size	130	60

Table 2: Smoke detector minimum and maximum size.

3.1.1 SoftHand2: Grasping

The SoftHand2 has two synergies, see Figure 3. This allows for different types of grasps, as shown in Figure 10. We are using the power grasp and the pinch grasp in the project. The hanging grasp is not used because it is not easy to pick up an object and use this grasp. The open pinch grasp is not used because the pinch grasp is stronger and we do not need the open fingers for anything.

From Figure 11 the pinch grasp can be used for cylinders with diameter 15-45mm and the power grasp can be used for cylinders with diameter 45-90mm.

From this range, and the sizes of the HCA shown in Table 1, the HCA can only be picked up by the hand using the pinch grip, where the device is grasped over the width. The SoftHand2 cannot pick up smoke detectors if they are lying on a plane, because the diameter of the smoke detectors is too large. If the smoke detector is on its side then it would be possible, but this is not a stable position of the smoke detectors.

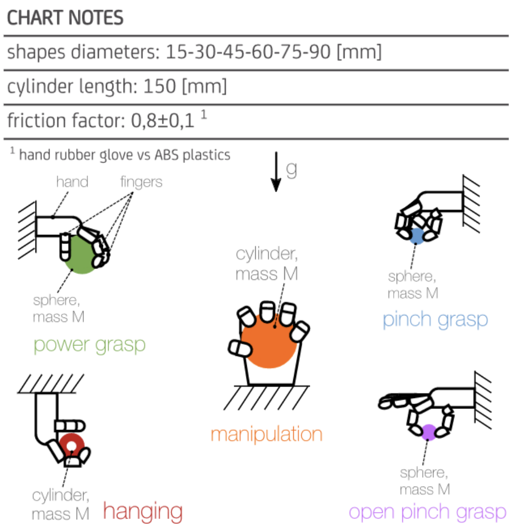

Figure 10: SoftHand2 grasps. Image from [5].

We carried out an experiment to determine the position of a tube relative to the hand to successfully grasp it. The tube has a diameter of 45mm and length 450mm. The tube has aruco markers on each end such that data collection can be automated. In Figure 13, the crosses denote the centers of the tube. The robot moves the hand SoftHand2 to the center of the tube and attempts to grasp the tube. Light green denotes successful grasps (grasped, lifted, waited, lowered and released without incident), red denote failures (the tube was not lifted at all), dark green were cases when the tube still touched the table with one end during lift, as shown in Figure 12. We find there is a circle of diameter 70mm where the grasps are successful. Moving

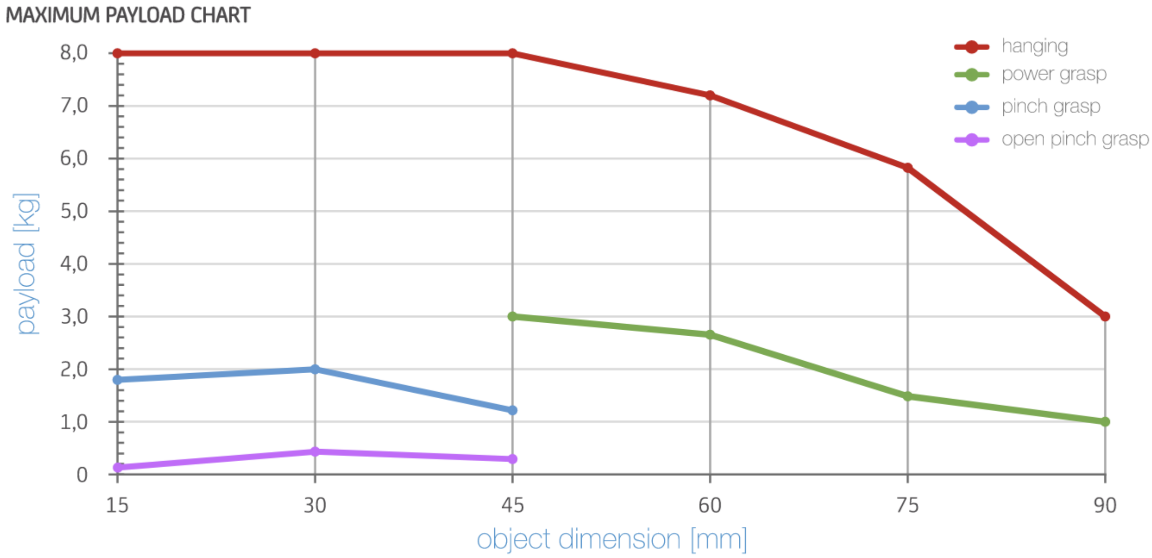

Figure 11: SoftHand2 payload. Image from [5]. The cylinder has length 150mm, and diameter in $\{15, 30, 45, 60, 75, 90\}$mm.

outside of this circle in one direction leads to partially successful grasps, and in other directions it leads to failed grasps.

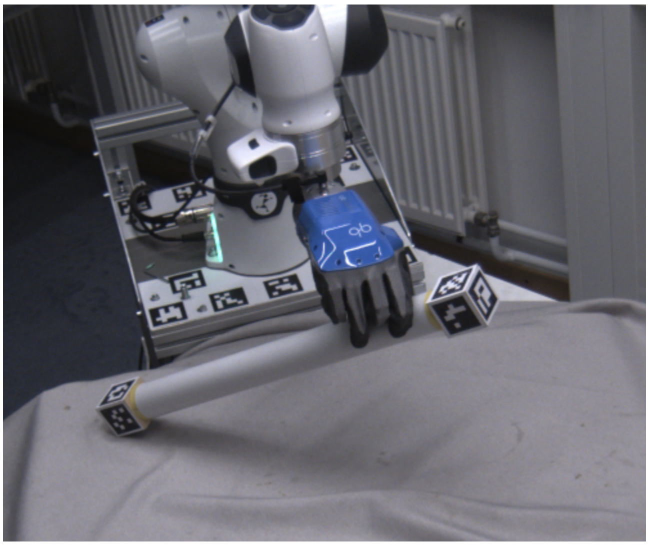

Figure 12: Grasping experiment by UGOE. Grasp is defined as partially successful in this example.

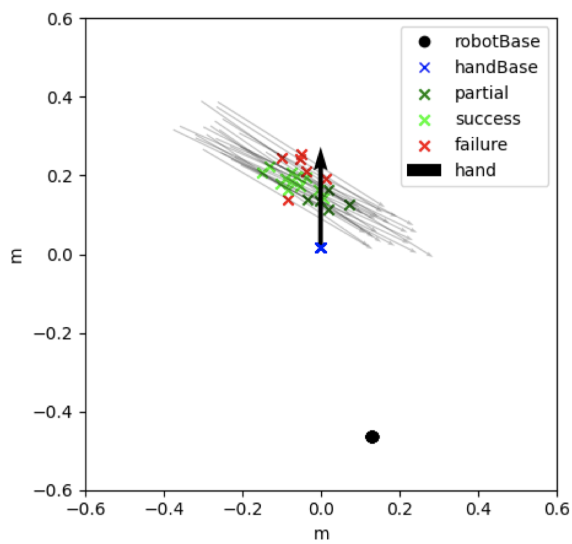

Figure 13: Repeatability results of grasping cylinder.

3.1.2 qb SoftClaw: Grasping

Let us define a cuboid object of length l, width w, and height h. The SoftClaw can grasp objects which have at least 2 vertical planar parallel sides (therefore this includes cuboid objects) with maximum distance (width w) between the two planes $w_{\max} = 45$mm, although the grasp is more effective if $w_{\max}$ is smaller. This means the SoftClaw is most suited to reliably grasping cuboid objects, such as Heat Cost Allocators, while grasping smoke detectors is difficult. The length l of the object to be grasped is limited only by the gripping strength (i.e. too long and heavy objects may fall out). The maximal height h of the grasped object is limited by the length of the SoftClaw finger, which extends for $h_{\text{finger}} = 50\text{mm}$ [3] [4]. This limits the maximum object height to $h_{\max} = 50\text{mm}$, although in practice, most relevant object (such as Heat Cost Allocators) have a maximal height $h_{\max\_\text{HCA}} \leq 30\text{mm}$.

Due to using electric motors, the SoftClaw has a maximum grasping force $F_{\max} = 75\text{N}$ [4]. In Figure 14 the object dimension vs. maximum grasping force, for different stiffness presets, is shown. This is sufficient for grasping and pick-and-place applications, however for some other use-cases, such as removing/pulling off the battery often soldered to the smoke detector PCB, this may be insufficient, and a pneumatic gripper may be preferred, as they can reach grasping forces of $F_{\max\_\text{pneumatic}} = 350\text{N}$.

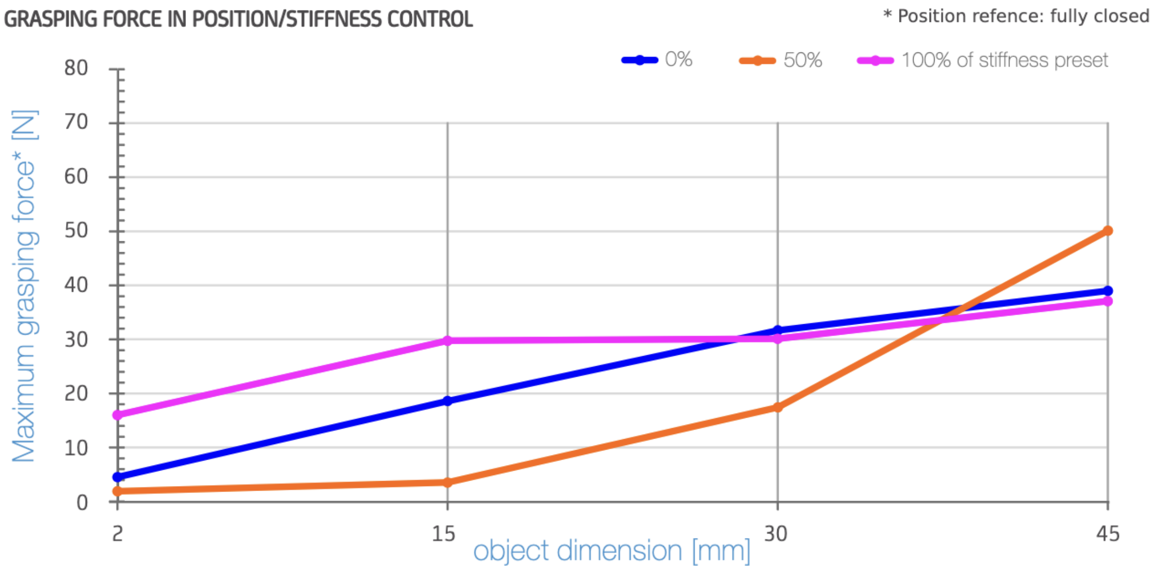

Figure 14: SoftClaw grasping force. Image from [4].

3.1.3 Centric Schunk Gripper: Grasping

A centric gripper with a particular finger design can grasp objects with a diameter between $D_{\max}$ and $D_{\min}$, and a height between $h_{\max}$ and $h_{\min}$.

The key parameter of centric grippers is their **travel length/stroke per jaw**, s. Custom fingers for the centric gripper can be 3D printed/designed. The inner diameter of fingers as the gripper is open, $D_{\max}$, is a variable of the finger design, and can be altered. The minimal diameter of objects that can then be grasped is a funcion of $D_{\max}$ and s, such that

$$D_{\min} = D_{\max} - 2s \tag{1}$$

The $D_{\max}$ of currently mounted finger on the robot-mounted gripper Schunk PZH-20 is $D_{\max} = 140\text{mm}$. The travel length of the gripper is $s = 20\text{mm}$, therefore $D_{\min} = 100\text{mm}$. The height h of fingers is $h = 30\text{mm}$.

3.2 Placing skill

The placing skill is the reverse of the grasping skill. If a device can be grasped, then it can also be placed.

3.3 Levering Skill

The levering operation is one of the main steps in the disassembly pipeline. For instance, when removing the PCB from a heat-cost-allocator (HCA), levering lets us apply moments using the levering support at the edge of the HCA. One approach to levering is to use periodic motions while maintaining contact perpendicular to the tooltip, essentially when the desired force is complicated to define to lever an object. Levering is likely successful when the locking mechanism is broken or fully opened, thereby stuck. In other words, it is difficult to define a goal for a successful execution.

During our experiments for constraint and permissive range calculations, in the levering scenario, the expected behavior for the robot is to move to the contact and maintain the contact force of 12 N with the lid in the z-direction while moving along the x-direction in the end-effector frame, see Figure 16. In contrast, the lid is levered about the y-direction. In particular, the levering process starts with no-contact 0 N. The initial back and forth motion around 60 mm/s and −20 mm/s with around 15 N is the initial contact. After the initial contact with the lid, the force decreases to 12 N while it moves together with the lid with 40 mm/s. Later, the contact force is maintained around 7 N at 0 mm/s, where the lid is fully opened and cannot move anymore.

In general, the focus in levering relies on contact/tool alignment and compliant behavior, in other words, force, and displacement tolerance, such that after a specific tool alignment error the robot should stop applying force or if the compliant behavior is activated due to the motion error and external forces occurred. Specifically, the levering process is analyzed and based on the results in Figure 16, the contact/tool alignment during sinusoidal motion or force-displacement tolerance is crucial to achieving a robust levering process as the lid moves primarily, and the robot should maintain contact between the tool and the lid during the motion.

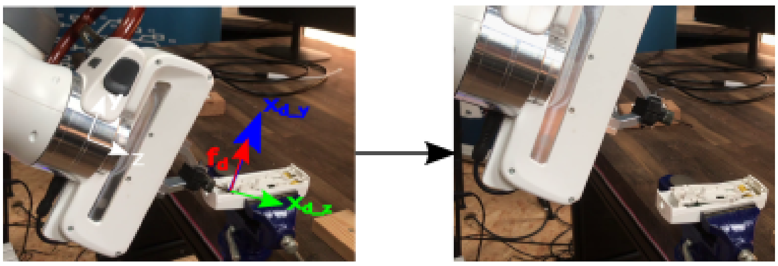

Figure 15: Configuration for levering the inner component out of an HCA [2].

The maximum force that Franka can apply in the y direction is ±100N, see Figure 8. The force of levering depends on the length of the fulcrum, see Figure 17.

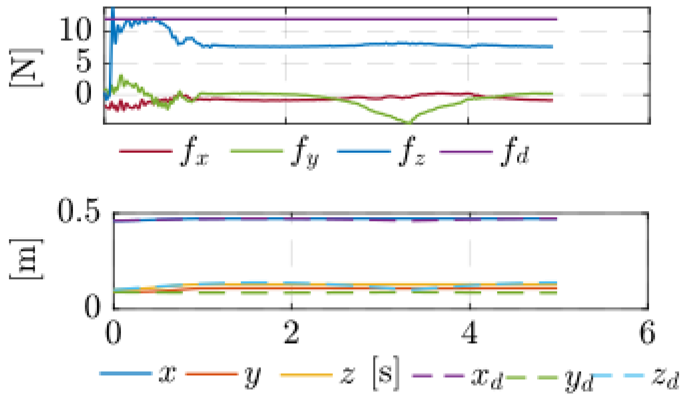

Figure 16: Performance metrics results for levering. Top: desired vs. measured force in the end effector frame, Bottom: desired vs. actual motion in the base frame.

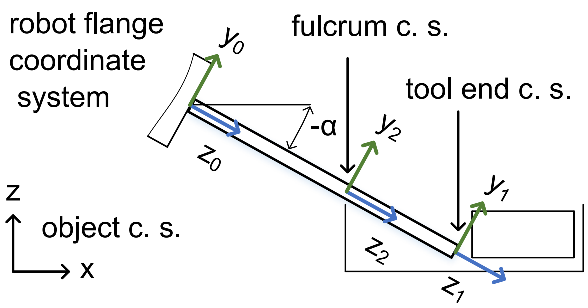

Figure 17: Levering diagram.

3.4 Vise clamping

The vise can clamp differently shaped objects. The vise is shown in Figure 18. It is most effective at clamping cuboid objects, such as HCAs. Such objects are defined by a length l, width w and height h. Due to the vise and vise finger design, only objects with length between l_{min} and l_{max} and width between w_{min} and w_{max} can be clamped.

Constraints and permissive ranges:

- Device length: $l_{\text{min}} = 50\text{mm}$, $l_{\text{max}} = 130\text{mm}$,
- Device width: $w_{\text{min}} = 30\text{mm}$, $w_{\text{max}} = 130\text{mm}$.

From Table 1, the vise can fit the range of HCA sizes, and also from Table 2, the vise fits the smoke detector sizes.

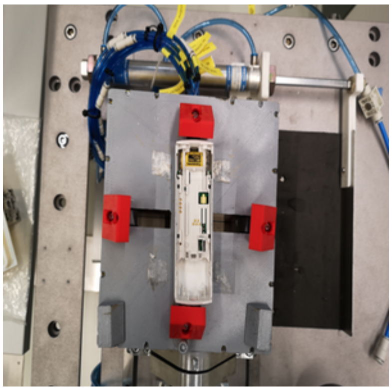

Figure 18: An unclamped HCA within the vise.

3.5 Cutting

Key variables of the cutter are the maximum applicable cutting force, the width of the cutting blade, the size of the cutting base surface, and the distance between the back panel and the cutting surface. The distance between the back panel and the cutting base surface, $d_{\text{panel}} =$ 60mm.

The key constraints on the devices being cut is the distance between the outmost device edge (on the battery side) and the innermost battery edge. If this distance is greater than d_{panel}, then it would not be possible to cut the battery. In practice, this is not a problem since the battery width of HCAs is often $w_{\text{battery}} < 25\text{mm}$, while $d_{\text{panel}} = 50\text{mm}$. The second constraint is that the line at which the cut has to be must be in front of the center of gravity (COG). The COG must overlap the cutting base surface, otherwise the device would tip over before cutting. Secondly, the orientation of the device matters, because the maximum possible cut is determined by the back panel (d_{panel}), since a device cannot be put further into the cutter than this. The range of cutting for the devices shown in Figure 19 are between 23-50mm and 18-34mm.

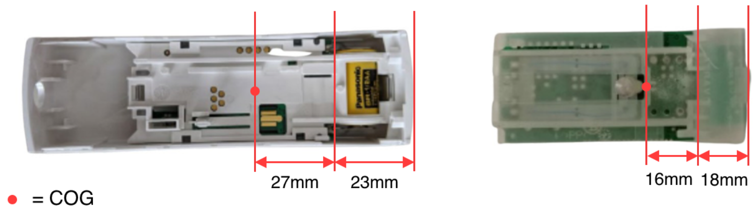

Figure 19: Key dimensions of HCAs for cutting for the KALO 1.5 and Siemens HCA.

The cutting force of the cutter depends on the inner radius of the cylinder used, $r_{\text{cylinder}} =$ 50mm, and the (air) pressure inside the chamber, P_{cylinder}. We use a pneumatic setup, where the standard pressures are between 5 and 8bar, in our case, $P_{\text{cylinder}} = 6\text{bar} = 6 \cdot 10^5\text{N/m}^2$. The cutting force is calculated as seen in Eq. 2.

$$\begin{aligned} A_{\text{cylinder}} &= \pi \cdot r^2 = 0.007854\text{m}^2 \\ F_{\text{cut}} &= P_{\text{cylinder}} \cdot A_{\text{cylinder}} \\ F_{\text{cut}} &= 4712.4\text{N} \end{aligned} \tag{2}$$

The achieved cutting force F_{cut} could be increased either by using a larger cylinder, increasing the air (pneumatic) pressure, or switching to a hydraulic setup, however in our use-case, this cutting force is sufficient. We note that by far the largest increase could be provided by switching to a hydraulic setup, where pressures of up to $P_{\text{hydraulic}} = 200\text{bar}$ or more can be used. This, however, requires increasing the security precautions and increases equipment cost.

The capability of cutting apart a device depends on the **pressure** applied on it, which is force spread over an area. Therefore the relevant parameter is the width of the device cut w_{device}, which is often in the range of $w_{\text{device}} = 20\text{mm}$ for HCAs, and the sharpness of the cutting blade, more precisely, the surface area of the blade. Let us assume the blade width is $w_{\text{blade}} = 0.5\text{mm}$. As the blade dulls, this width increases, and the pressure exerted upon devices decreases. The cut area, A_{cut}, depends on the blade width and the device width, and can be calculated as shown in Eq. 3

$$A_{\text{cut}} = w_{\text{device}} \cdot w_{\text{blade}} \tag{3}$$

The cutting force F_{cut} is spread over the cut area A_{cut} and results in a particular cutting pressure, P_{cut}, as seen in Eq. 4.

$$P_{\text{cut}} = F_{\text{cut}} / A_{\text{cut}} \tag{4}$$

The cutting pressure applied on the device is therefore highly dependent on its width. The relation between the device width w_{device} and cutting pressure P_{cut} is shown in Fig. 20.

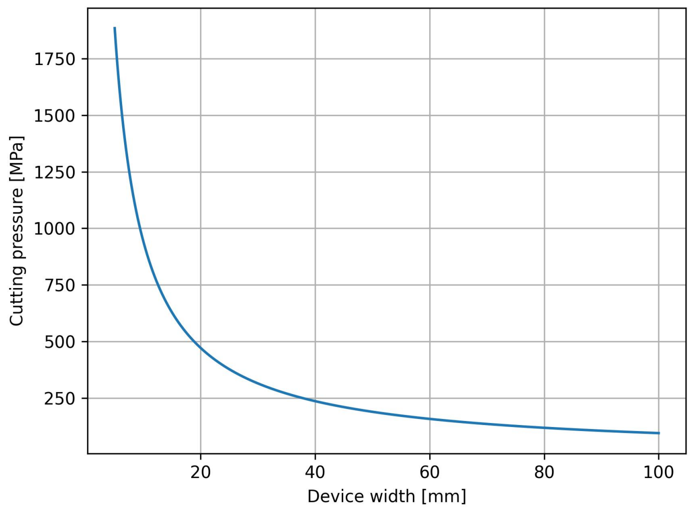

Figure 20: Relation between device width and cutting pressure exerted upon it.

3.6 CNC Milling

The CNC Mill can cut away the plastic covering the batteries such that the batteries can be reliably detected and then removed. The permissive range of the cut depend on the device. Each device has the batteries located in a different position.

Figure 21: Permissive range of the CNC Mill is between the batteries and the edge of the plastic securing the batteries.

Key limitations of the cutting skill and the CNC Mill are the working area of the machine, depth of cut, the hardness of the material being cut, and the limitations of the object fixation system within the CNC - in our case, the 3-finger centric chucks which grip the smoke detectors during cutting.

The working volume of the CNC Mill used is $V_{\text{work}} = 400 \times 300 \times 110\text{mm}$, which is sufficient for disassembling smoke detectors, where the maximal diameter and height are $D_{\text{max}} < 150\text{mm}$, $h_{\text{max}} \leq 50\text{mm}$.

The maximum depth of cut d_{cut} depends on the hardness of the material being cut. In the case of plastics, we estimate $d_{\text{cut\_max}} \geq 4\text{mm}$. This is sufficient, since for most smoke detectors, the shell thickness t_{shell} is relatively small, i.e. $t_{\text{shell}} \leq 3\text{mm}$.

In regards to the maximum hardness of material being cut, this is hard to determine since it depends on a variety of factors, including rigidity of the machine itself, spindle used, cutting tool diameter, cutting speed, etc. Nevertheless, plastics are relatively easy to cut compared to metal, and all considered devices have shells made of plastic.

Grasping smoke detectors within the CNC Mill is accomplished using centric Schunk grippers (SCHUNK JGZ 80-1 with travel length $s = 8mm$), as shown in Fig. 22. As with the robot in-hand centric gripper, the travel depends on the gripper itself and the design of the gripper's fingers. More specifically, the grippers/chucks within the CNC can grasp smoke detectors with a diameter between $D_{min} = 100mm$ and $D_{max} = 116mm$. Here we note that several chucks can be mounted within the workspace of the CNC mill, thereby increasing the range of smoke detector diameters which can be gripped.

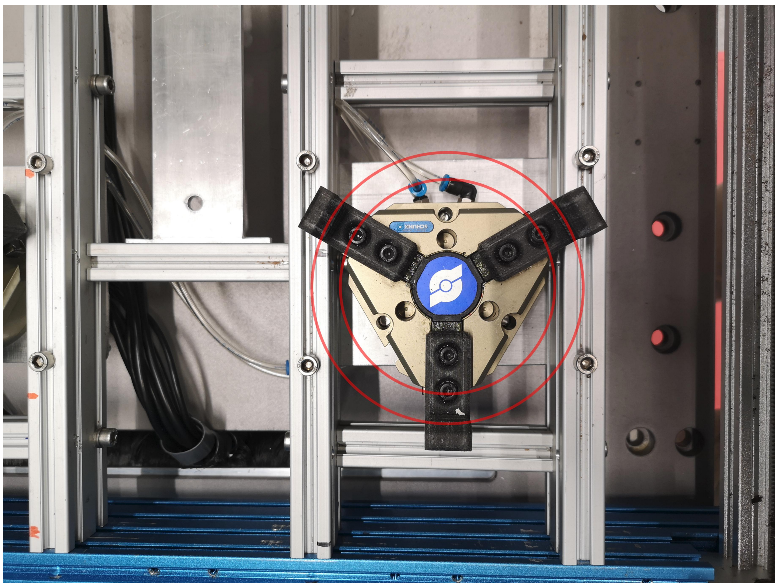

Figure 22: Permissive range of the chucks within the CNC Mill for grasping smoke detectors.

3.7 Battery removal with rocking

After removing the top shell using the CNC mill, the batteries are visible. Depending on the particular device, the batteries which must be removed are usually connected to the PCB using solder joints. If the solder joints are horizontally positioned, they can be milled away by the CNC mill. If the solder joints are vertical, they can't be milled away since the CNC mill would also damage the battery. In this case, the batteries can be removed by first gripping them using the qbRobotics SoftClaw, or a specifically-designed pneumatic gripper (which allows for a higher gripping force). In any case, a rocking motion can be performed to dislodge the battery from the solder joints by breaking them. The permissive range for gripping the battery follows similarly to in subsubsection 3.1.2. The second limitation is the force required to break the solder joints. As per Figs. (8, 9), the force which can be applied by the robot varies based on exact end-effector position (and weight of used gripper), however the nominal force that can be applied is at least 100N, if the battery removal is performed in the y axis of the robot end-effector, as shown in Fig. 8. Therefore, batteries can be removed if the required force to break the solder joints is $F_{\text{battery\_removal}} \leq 100N$.

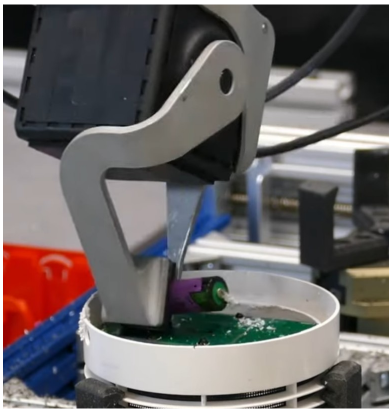

Figure 23: Removal of a battery using a rocking motion.

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