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Authors:	Rok Pahič, Primož Radanovič, Matej Štefanič, Aleš Ude, Manuel Catalano, Sebastian Ruiz
Contributing Partners:	JSI, UGOE, IIT, ECYC

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Contents

Executive summary

Deliverable **D5.2** is a demonstration deliverable that contains videos showing the implementation of the first exemplar archetypical solution for use case 1, i.e. the disassembly process for the Kalo 1.5 heat cost allocator. The possible disassembly workflow has been first analyzed in deliverable **D5.1**. The implemented approaches are presented in three separate videos that can be viewed on YouTuble.

- Video 1: The ReconCycle modular robotic workcell performing the disassembly of the Kalo 1.5 heat cost allocator:

  YouTube link: https://youtu.be/ltYug8picbI

- Video 2: The implementation of different disassembly operations using soft five-finger hand:

  YouTube link: https://youtu.be/GdiGyVSDhz4

- Video 3: Object recognition and localization for the disassembly of the Kalo 1.5 heat cost allocator using deep neural networks:

  YouTube link: https://youtu.be/nGdObEXEZv8

These initial implementations demonstrate how the current ReconCycle system can be applied to disassemble specific electronic devices (Kalo 1.5 heat cost allocator) for the purpose of electronic waste recycling. While the proposed solutions have not yet been fully integrated, they provide all the necessary functions to fully automate the complete disassembly process. Thus they provide a solid basis for further developments of the ReconCycle system, not only to be used in new, different use cases, but especially to automatically reconfigure the workcell and adapt the operations for the disassembly of different electronic devices.

1 Introduction

The goal of the ReconCycle project is to introduce the concept of robotic self-reconfiguration to the field of electronic waste recycling, which is still largely dominated by manual labor. Before the project can focus on self-reconfigurable hardware and software, we need to realize the basic (reconfigurable) system to automate the disassembly processes that typically take place in the recycling of electronic waste. In this deliverable, we present the implementation of the disassembly of the Kalo 1.5 heat cost allocator to demonstrate that our framework can be applied for disassembly tasks in the recycling of electronic waste.

The complete disassembly process for the Kalo 1.5 heat cost allocator was implemented in the ReconCycle reconfigurable robotic workcell implemented at JSI. The designed disassembly process and the workcell setup are shown in Video 1, which is described in more detail in Section 2. The qb SoftHand Research developed by the project partners QB and IIT was used to grasp various objects in the disassembly process. In Video 2 and Section 3 we show how qb SoftHand Research can be used for other parts of the disassembly process. The aim is to evaluate the efficiency and flexibility of adding more devices as opposed to performing more operations with a robotic system itself. To grasp an object at different locations, we need to be able to detect its pose. UGOE developed a vision system to detect different parts during the disassembly process. Due to the epidemiological situation, the system has not yet been integrated with the rest of the ReconCycle system. For this reason, in Video 1 where we show the complete disassembly process carried out in the ReconCycle workcell, we manually put the objects at the fixed locations. Nevertheless, in Video 3 and Section 4 we show how each of these process steps can be solved with the developed vision system.

2 Disassembly process implementation

The goal of the disassembly process in use case 1 is to remove the battery from the Kalo 1.5 heat cost allocator (shown in Figure 1). To achieve this, we have to remove the PCB containing

Figure 1: Kalo 1.5 heat cost allocator

the soldered battery from the plastic housing and then cut the battery from the extracted PCB. The implementation of this process is shown in Video 1. The first robot starts by picking up the Kalo 1.5 heat cost allocator using qb SoftHand Research gripper and places it into a pneumatic vise. The vise clamps the housing firmly so that the second robot can use the lever tool to break the PCB out of the housing. When the PCB is released, the vise is rotated upside down, allowing the PCB to fall onto the tray below. When the vise returns to the upwards position, the tray extends out from underneath it, allowing for the unobstructed pick-up of PCB in the next step. At the same time, vise jaws are opened, allowing the first robot to pick up the empty housing using qb SoftHand and transfer it to the designated container. When the cell operates continuously, after the housing disposal, the first robot is used again to insert the next heat cost allocator into the vise.

After breaking of the circuit board from the plastic housing, the second robot changes its tool. It leaves the lever tool in the tool storage and takes the vacuum gripper which it uses to picks up the circuit board from the tray and places it into the cutter. When the battery is cut from the PCB, the second robot uses the same vacuum tool to pick up the battery and places it into the container designated for the removed batteries. When the cell operates continuously, the second robot exchanges the vacuum gripper back for the lever tool and the disassembly process is repeated.

The robotic workcell required for the designed disassembly process was implemented using archetypical ReconCycle modules presented in Section 2.1. The high-level specification of the disassembly process was programmed using the FlexBE state machine, as presented in Section 2.3. The poses and trajectories needed to execute the FlexBE state machines were acquired by kinesthetic teaching, as described in Section 2.2. We used qb SoftHand Research to pick up the heat allocator and its housing. The full functionalities of qb SoftHand Research gripper are presented in Section 3 and Video 2. Because at this point the vision system is not yet fully integrated into the workcell, we used predetermined fixed positions where objects were placed at different stages of the disassembly process. These objects are 1. heat cost allocator entering the workcell, 2. removed PCB positioned on the tray, and 3. the battery placed at the bottom of the cutter ramp. After the vision system is fully integrated, it will be used to perform object recognition and localization, thus there will be no fixed locations where objects should be placed. The vision system is presented in more detail in Section 4 and Video 3.

2.1 ReconCycle modules for the disassembly of Kalo 1.5

Six ReconCycle modules were used to implement the disassembly process for the Kalo 1.5 heat cost allocator. The basis for all six modules is the archetypal ReconCycle module described in deliverable D.1.1. The "Material input" module and "Tool storage" module don't require any external power or data inputs and are used in their archetypical configuration. These two modules are simply plugged into the system via the developed Plug-and-Produce connectors (see deliverable **D1.1**), which in these cases provide only mechanical coupling.

For the implementation of the complete disassembly process, we also needed additional auxiliary devices, which are installed on two archetypical modules. One module was equipped with a vise that holds the heat cost allocator housing during PCB removal. For additional handling of the disassembled parts, this module was also equipped with a pneumatic motor and a pneumatic cylinder. The second module is equipped with a cutting device used to cut the battery from the PCB. These auxiliary devices are controlled by the modules' microcomputers.

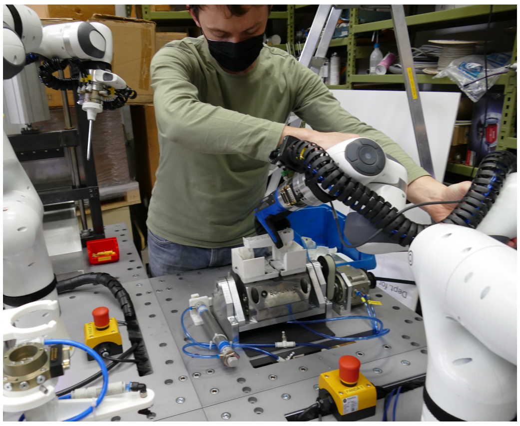
When the designed module is connected to the ROS network for the first time, the "Equipment Manager" allows easy configuration of the new equipment, which can then be controlled via the "Equipment Server".

The last two modules serve as a mounting platform for the two Franka Emika Panda robots. When the module with the robot is connected to the ReconCycle cell via Plug-and-Produce connectors, the robot control computer mounted in the module launches the robot control action servers, which are needed to control the robot via the ReconCycle cell ROS network. The auxiliary devices on the robot modules, such as tool changers and tools mounted on the robot, are controlled by the module's microcomputer, just like the auxiliary equipment on the other two modules.

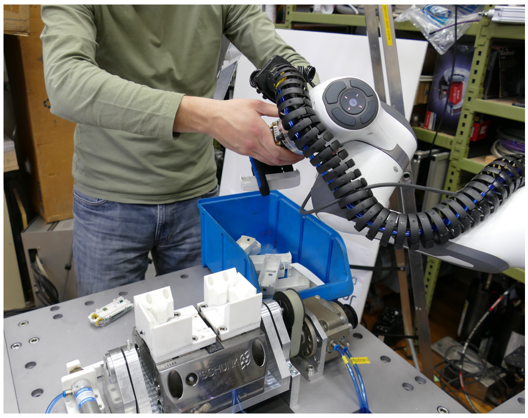
2.2 Teaching robot poses and movements with kinesthetic guidance

During the disassembly process, the robots need to move to several locations that do not change during the disassembly cycles. For example, robots must always place objects in the vise (Figure 2a) and dispose the plastic housing (Figure 2b) at the defined location. we use kinesthetic guidance to easily acquire these locations. We kinesthetically guide the robots to the desired poses in the workspace and, using our Helping Hand GUI, store the acquired poses in the MongoDB database, from where they are later read by the FlexBE state machine. See deliverable **D1.1** for more details about Helping Hand and MongoDB.

In order to detach the PCB from the plastic cover, the robot must execute a suitable end-effector trajectory. The generation of such trajectories using conventional robot programming methods is quite difficult. Using the Helping Hand GUI, we kinesthetically guided the robot's end effector while performing the detaching task and recorded the executed robot trajectory (Figure 3). The recorded trajectory was then encoded using Dynamic Movement Primitives and stored in the MongoDB database, from where the FlexBE state machine can read it when the robot needs to execute the movement.



(a) Recording the robot pose for placing Kalo 1.5 heat cost allocator in the vise



(b) Recording the robot pose for the plastic housing disposal in the bin

Figure 2: Teaching the desired robot poses by kinesthetic guidance

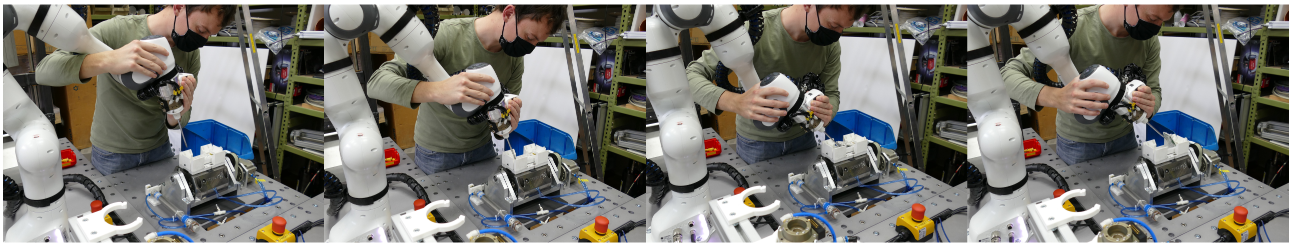


Figure 3: Kinesthetically guiding the robot's end-effector while performing the PCB detaching task and recording the executed robot trajectory

2.3 Implementation of state machines for the disassembly of Kalo 1.5 in FlexBE

The disassembly program was implemented using the FlexBE state machines. We used the standard FlexBE states for grouping and parallel execution of states and to program flow control. In FlexBE terminology, the programs generated from FlexBE state machines are called behaviors. The grouping of FlexBE states allows reuse of behavior parts at different places in the program. This allows us to quickly implement code and reuse old behaviors.

The developed FlexBE states were used to control the robots through the associated action servers. The first state machine reads the desired pose or DMP-encoded trajectory from the MongoDB database. The next state uses the acquired parameters and sends them to the robot's action server. The qb SoftHand Research gripper is controlled in a similar way. We also implemented a state that reads inputs and outputs from simple devices that support only open/close commands. This is a universal state that can control any auxiliary equipment by the defined ROS service name.

3 Object and tool handling with qb SoftHand in disassembly operations

Video 2 shows the execution of the various steps in the disassembly of the heat cost allocator with qb SoftHand Research. The similarity of the qb SoftHand Research to the human hand enables human-like operation. Moreover, the intrinsic control simplicity together with its embodied intelligence (which allows for self adaptation tasks), and the intrinsic robustness allow for high flexibility in task execution and tool handling. In the video, it is shown that the qb SoftHand Research is able to pick up and place various objects and use tools in contact with the environment. Furthermore, the video shows how the hand can be used in different steps of the complete disassembly process, enabling also the separation of discrete components and sub-assemblies. The ongoing work focuses on the generalization of trajectories, execution of a complete disassembly task in integration with the vision and planning framework developed in the ReconCycle project. Since the qb SoftHand Research can perform different tasks with different task parameters, it is suitable as a universal tool in a reconfigurable cell.

4 Object recognition and localization in the disassembly process

At three different steps in the disassembly process, we need to be able to grasp object at unknown locations. A vision system is thus needed to detect and compute the poses of the parts. Due to the epidemiological situation, the system has not yet been integrated into the ReconCycle cell. However, in Video 3, we show that this vision system can detect the required object poses in each of the required steps.

The first part of the video shows that the vision system is able to detect the position and orientation of multiple still assembled heat cost allocators and even determine if the battery is still attached to the circuit board. The cell will use these data to pick up the object and insert it into the vise. After separating the PCB from the plastic housing, we need to pick up the PCB at an undefined location in the tray. The second part of the video shows that the vision system is able to detect the position and orientation of the PCB and whether the internal plastic housing or the battery is still attached to the PCB. This data will be used by the robotic cell to pick up the PCB with the battery and place it in the cutter. After the battery is separated from the PCB, the robot picks up the battery from the other shredded parts and disposes of it separately. The third part of the video shows that the vision system is capable to classify the battery and detect its pose even when other shredded parts are present. The robotic cell will use these data to pick up the battery and dispose of it separately from the other shredded parts.

5 Conclusion

With videos in this deliverable, we present the first exemplar archetypical solution for the disassembly of Kalo 1.5 heat cost allocator. Video 1 demonstrates that the ReconCycle workcell based on reconfigurable hardware and software design principles, can performing all the required disassembly tasks. The operation of the yet not integrated vision system is shown in Video 3. The next step is to integrate the vision system into the cell to enable autonomous and continuous execution of the disassembly processes. The qb SoftHand Research manipulation capabilities are presented in Video 2. This implementation provides us with an alternative solution for the disassembly steps that could be more flexible when switching from one disassembly process to another.

The main goal of the project is to use the designed workcell for disassembly of different objects. With this work, we demonstrate that our reconfigurable software is capable of solving all steps of the disassembly process for a given use case. In future work, we will continue to develop and test the ReconCycle system reconfiguration and adaptation capabilities for other use cases.