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Automation in Remanufacturing: Applying Sealant on a Car Component

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Abstract. The remanufacturing industry currently relies significantly on manual work when, for example, sorting and disassembling. Due to several issues, including process time and sequence, operations number, disassembly planning and scheduling, process cost, and performance measurement, it is challenging to stay competitive. Based on this, it is assumed that more extensive use of robots and automation in these industries can facilitate higher efficiency and better work conditions. This research paper aims to explore how remanufacturing of car components can be made automatic. The paper describes a case where a specific car component was selected and a specific step in its remanufacturing process explored from the perspective of automating that task. When conducting remanufacturing of the selected car component, some machines are used for the testing, cleaning, and grinding of materials. However, all assembly work is done manually. In collaboration with the case company, the process step of applying sealant for the assembling of a lid that covers electronic components was selected. The demonstrator shows that it is possible to apply sealant with a human-robot layout with a good result. One of the advantages of using a robot for this step is that a high-quality result was achieved.

Keywords. Circular Economy, Automotive, Automation, Remanufacturing, Collaborative Robots, HRC, SME

1. Introduction

There is a trend within the manufacturing industry to become more circular by the reuse, repair, and remanufacturing of pre-owned products. Remanufacturing has been shown in many studies to salvage product value to a larger extent than, for example, recycling and new manufacturing; see, for example, [1] and [2]. To make the remanufacturing processes more efficient (for example, shorter process lead times) while also improving the work environment (hazardous work) and improving quality (in, for example, assembly), automation can be a solution [3]).

However, automation is not easily implemented in remanufacturing due to the large variation of pre-owned products (a.k.a. cores) that are used for remanufacturing. In addition, the volumes of cores entering the remanufacturing processes also affect the possibilities for automation in remanufacturing.

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When setting up and developing the remanufacturing process for a certain product, there are several things to consider. For example, which process steps are needed to achieve a remanufactured product that meets the new customer demands? Which spare parts are needed? And, what kind of production layout is it possible to have?

This research paper focuses on remanufacturing a car component that today is manually remanufactured, besides using some machines to clean and grind materials. However, all assembly work in the re-assembly stage of the remanufacturing process is done manually. The goal was to identify the potential automation of a single remanufacturing process step and develop an automation demonstrator to see if it was possible to automate.

1.1. Aim

The aim of this research paper is to explore how the remanufacturing of car components can be made automatic. The paper describes a case where a specific car component was selected and a specific step in its remanufacturing process explored from the perspective of automating that task. In addition, the methodology approach and individual data collections steps are also described.

2. Methodology

The identification of the task was done through a study visit at the case company, where the researchers walked through the remanufacturing line and made observations. These observations, semi-structured discussions, and personal experience based on testing to perform the remanufacturing task, as well as the case company's interest in evaluating if it was possible to automate in a flexible way, contributed to a decision to develop a demonstrator. The requirements for the demonstrator were developed by the researchers based on the company's interest in evaluating the possibility of using a human-robot collaboration layout.

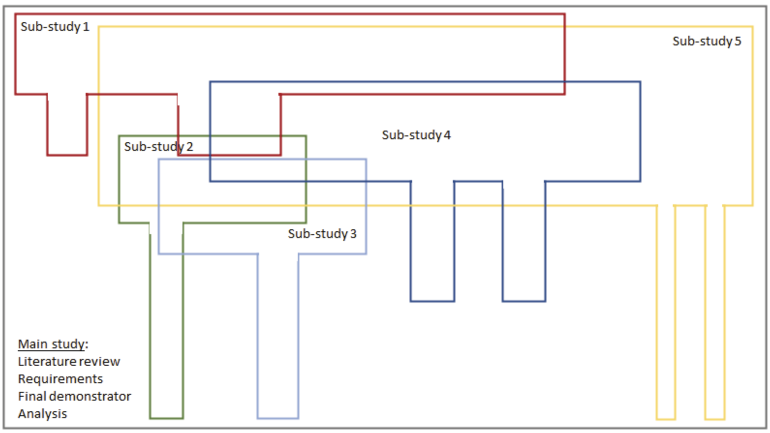

Figure 1. Overall organization of included activities for developing the demonstrator.

The overall process of developing the demonstrator was organized into several steps inspired by the demonstrator-based research methodology [4]. From this method, the researchers performed the first steps related to exploring the company's manual disassembly/reassembly cells through a case study, literature review, data collection, and analysis, including observations (see the main study in Figure 1, gray-colored frame). Thereafter, the demonstrator outline was designed, and different sub-studies were defined for interactions with students. Between each new sub-study, the researchers evaluated, analyzed, and thereafter defined the next activities. The student projects were executed as T-shaped projects, defined as projects with a wider scope than it is realistic to solve in detail. During each sub-study, the various areas of the scope are worked on in varying levels of detail and fidelity. At least one area is investigated in more depth, detail, and fidelity, while still considering the other areas of the scope.

The overall demonstrator requirements were coordinated and adjusted if needed after analyzing the results from each sub-project by the main author of this research paper. Finally, the main author organized an overall fine-tuning of the demonstrator before the demonstrator acceptance test (DAT), all of this illustrated as the main study (gray frame around all sub-studies) in Figure 1. The following sub-studies were designed and supervised within the main study (see Figure 1):

Sub-study 1: This study was performed by four students aiming to benchmark technologies relevant for an automated cell based on requirements defined based on the researcher's analysis of needs from the company case study data collection (red-colored frame).

Sub-study 2 and 3: The researchers defined two in-depth studies for two groups with three students each related to dispensing – one group focused on the dispensing process and the other group on the robot cell / application (green/light-blue-colored frames).

Sub-study 4: This study was designed as a master’s thesis project for one student aiming to evaluate different concepts for how to automate the dispensing process [5] (dark-blue-colored frame).

Sub-study 5: This study, performed as a project by four students, was characterized as in-depth work in realizing the functionality of the demonstrator through simulation, programming, and organizing the functionality of the demonstrator cell (yellow-colored frame).

To summarize, the development of the final demonstrator engaged fourteen different students (one student attended two sub-studies) in different courses during three semesters. The main author coordinated all studies and was responsible for the overall design and development of the final demonstrator function and layout.

2.1. Case description

The case considered in this work is the remanufacturing of a pre-owned electro-mechanical automotive component (in remanufacturing, a so-called core). This component is used in car engines of a major car manufacturer. The relevant car models are not produced anymore but will be in use for several more years. The remanufactured component is sold as spare parts. The core has a mass of a bit less than 2 kg, and the biggest dimension is around 200 mm. The casing is made of cast aluminum.

The production follows the typical remanufacturing process of inspection, cleaning, disassembly, reprocessing, assembly, and testing [6]. Most of the process steps are done manually, but a few use partial or fully automated machines. Internal logistics is handled manually by directly moving the cores or via manually handled trollies.

The selected component is remanufactured at a low volume of approximately 50 pieces per day in 1 shift. The remanufacturing company is an SME located in Sweden. At one of the workstations, a sealant is dispensed on the core to assemble the lid that covers the electronics components. It is important that the sealant is dispensed correctly so that the component becomes water and humidity-proof. For that, a daily production of this car component is placed in 3 rows of approximately 20 pieces on a simple fixture.

In collaboration with the case company, it has been decided that the process step of dispensing sealant for lids that cover the electronic components shall be investigated for potential automation solutions. A deeper understanding of the task was achieved through discussions with the production manager and operators, including testing the manual process of dispensing sealant (apprenticing).

In detail, the process for sealing can be summarized as follows: At the end of a workday, the following process steps are performed by hand on all prepared cores: A) first, primer is applied to connectors, and the B), C) areas are molded with two different resins. Then, D) sealant is applied, and E) the lids are closed. The cores are left overnight for curing.

3. Theoretical framework

3.1. Remanufacturing process development

Many automotive parts have been remanufactured since the 1950s, or even earlier, since spare parts were needed to keep cars running on the roads, as well as for other reasons, such as the repair shop found ways to offer competitive prices on its car services. During these years, the types of automotive parts being remanufactured have changed, and the remanufacturing industry had to adapt to new market demands. Currently, the industry is transitioning towards electrified vehicles, which will change the automotive remanufacturing industry as, for example, the number of moving parts will be reduced and new types of knowledge will be needed [7]. According to [8], it becomes interesting for car manufacturers to set up automotive part remanufacturing (or contract someone) if:

- there is large market demand,
- the car components have high value, and
- it is easy to obtain pre-owned car components.

This kind of knowledge is being gained as new cars are put on the market. In addition, the transition towards electrified vehicles also affects which attributes are useful to study when selecting parts for remanufacturing. Sundin et al. [8] have categorized these car component attributes into three categories, economy, technology, and environment, as seen in Table 1.

Table 1. Car component attributes used when identifying which components should be remanufactured [8].

Economy	Technology	Environment
Market	Remanufacturability:	Material scarcity
Price/Value	- Accessibility	Material and weight
Economic lifetime	- Disassemblability	Resource efficiency
Remanufacturing volumes	- Testability	Climate impact
Collaboration with:	- Robustness	Transport possibilities
- Part supplier (OEM)	- Affinity/Originality	
- Insurance company	- Backward compatibility	
Core collection costs	High quality / Technical lifetime	
	Access to spare parts	

The design of products and their manufacturing/remanufacturing processes are dependent on each other. Products can be designed for manufacturing/remanufacturing, but that is not the case for many products. However, the product design affects how remanufacturing could be conducted, for example, the required process steps and their sequence, as seen in Table 1 under Technology.

In a generic remanufacturing process, the cores must go through an industrial process containing process steps like *inspection*, *cleaning*, *disassembly*, *reprocessing* (i.e., taking away or adding material, replacing worn-out parts), *reassembly*, and *testing* [9]. This means that the cores need to be handled in and between all these steps without further damaging them. This is especially important to consider if the steps in the remanufacturing process shall be automated. One good example of how to use machines to disassemble cores is the one used by FUJI Film, which disassembles its single-use cameras with machines using built-in disassembly points where the machines hold and open up the cameras for the next step in the remanufacturing process, as shown in Figure 2 [10].

Figure 2. Camera design for automatic disassembly within remanufacturing [10].

As previous research stated, for example, [11], there are some trends that are not in line with automatic remanufacturing. Examples are cases where products are:

- becoming more complex and heterogeneous,
- becoming sleeker, and
- using more proprietary joining methods.

Many products are not designed for remanufacturing, for example, [12], and there are no feedback systems in place where remanufacturing requirements are fed into the product development process to make remanufacturing more efficient [13]. This leads to fewer opportunities to remanufacture products and lost economic and environmental value.

There are many guidelines stated regarding how to design products for circularity and remanufacturing; see, for example, [6, 12, 14, 15]. Nine guidelines have been found to be crucial by [16] when designing products for automated remanufacturing processes, as shown in Table 2.

Table 2. Nine design guidelines to follow when designing products for automatic remanufacturing (based on [16])

Design guideline for automated remanufacturing	Brief description
1. Make it easy to inspect the product and its components	Make it easy and safe to inspect the product and components, particularly exchanging components. Use indications and repair manuals for testing and inspections
2. Provide repair manuals and documentation	Provide user-friendly repair manuals and documentation on how to repair, upgrade, etc., with signs on how to open the product and exchange components
3. Make exchanging and faulty components easily accessible	Make disassembly points and components subject to break, wear, or fail easily accessible and preferably from one side
4. Make it easy to clean the product and its components	Avoid shapes and areas where dirt might collect, such as small holes, nooks, grooves, and sharp edges. Select materials that are easy to clean. All components should be able to withstand the same chemicals, mechanical cleaning processes, and temperatures
5. Use fasteners and connectors that can be easily opened and closed multiple times	Minimize the number of connectors and fasteners. Ensure the robustness and wear resistance of fasteners. Prioritize latch, snaps, clips, bolts, and screws over welding, rivets, folding, staples, and gluing, which make fasteners more difficult to demount
6. Design with standardized fasteners and components across different products and models	The compatibility and exchangeability of components are required across other models and products, e.g., the same type and size of screws
7. Design to use standard tools across different products and models	The compatibility and adaptability of tools are required across other models and products, e.g., the same type and size of a screwdriver to dismantle
8. Make spare parts and exchanging components easily available	Exchanging components of products must be easy to find on the market and preferably be inexpensive or 3D-printable with additive manufacturing technologies
9. Adapt a modular design	Divide the product into different modules and put all of the components that need to be exchanged or upgraded into one single module, thus lowering the effort

However, these guidelines are not commonly implemented in industrial products on the market today, and thus the products that are entering the remanufacturing process. Therefore, there seems to be a need to design a flexible remanufacturing process from today's perspective with products not designed for remanufacturing and one that can manage many different variants of products.

3.2. Flexibility

There are several definitions for flexibility. From a production point of view, a flexible production system contributes to the capability to reconfigure a production process fast, produce new products easily, and quickly react to changes in the market [17]. Flexibility variations can be grouped as (1) product flexibility, (2) capacity flexibility, (3) operations flexibility, and (4) machine flexibility [17, 18]. In the remanufacturing context, these variations can correspond to the need for (1) managing a variety of products, (2) changes in volumes, (3) variety in quality, and managing (4) different software/hardware configurations. This high variety of products in a remanufacturing line demands a flexible production system supported by automation solutions. The concept of flexible automation, designed to manage different types of products, has evolved significantly since the 1960s [19]. From a remanufacturing perspective, flexible automation seems to be beneficial due to the characteristics of a wide variety of incoming products.

3.3. Flexible automation

The combination of small batch sizes and high diversity in incoming products, which characterizes remanufacturing, demands flexibility where robots can be considered to have the potential of being deployed for high mix in low-volume manufacturing [20]. Some of the challenges of managing an automated assembly system that need to be adapted for flexibility are [21]:

- Managing complexity related to the integration of automation in assembly lines
- Integrating flexible and intelligent robots, including potential sensor systems
- Demands for human-robot interaction, including safety aspects

Human-robot interaction can be one way to manage the need for flexibility in a layout feasible for remanufacturing due to its definition to be highly inter- and multi-disciplinary [22]. This possibility to achieve flexibility can be managed by implementing a human-robot collaborative layout, where some human operations are replaced by robots [23]. Furthermore, repetitive tasks are also suitable for a human-robot collaborative layout [24], but it is important to perform a risk assessment to secure safety issues [25]. With careful layout planning, it may be possible to share tasks so that the robot manages hazardous and non-ergonomic operations and the operator contributes with skills related to challenging cognitive tasks [26]. However, when installing a human-robot collaborative layout, there are three main areas related to implementation challenges: safety, knowledge (skills), and functionality [27].

Flexible automation can be achieved by utilizing a robot, but end-effector managing the product is needed, often in the form of grippers. An overview of different grippers presents the following classification [28]:

- Configuration-based classification
  - Number of fingers
  - Functionality in the fingers/end-effector
- Actuation-based classification
  - Power source for the actuation
- Application-based classification
  - Surgical
  - Assistive
  - Industrial
  - Underwater
- Stiffness-based classification
  - Rigid
  - Soft

The combination of the robotic layout solution, the safety approach, and the gripper technology adapted to the variations of the incoming material, such as the products to be remanufactured, needs to be merged into a flexible production layout.

4. Case study results

In this case study, the remanufacturing of an automotive component in Figure 3 is investigated. In the existing manual process, the core is remanufactured in 9 steps [3]. The 7th step, after the electronics have been repaired, is dispensing sealant onto the core and reassembling the lid. The following step is the testing of the product. The sealing process has high quality demands as the product in use is placed in a harsh environment as part of the car's engine. As identified, the reason for automation of the sealing process is to increase efficiency and secure quality [3].

A robot cell solution has been investigated, and a demonstrator designed, built, and tested. The current solution is that the whole production of one day is buffered in a shelf-like structure, and at the end of the workday, a sealant is applied by hand to all cores, the lids are closed, and the cores are left overnight for curing.

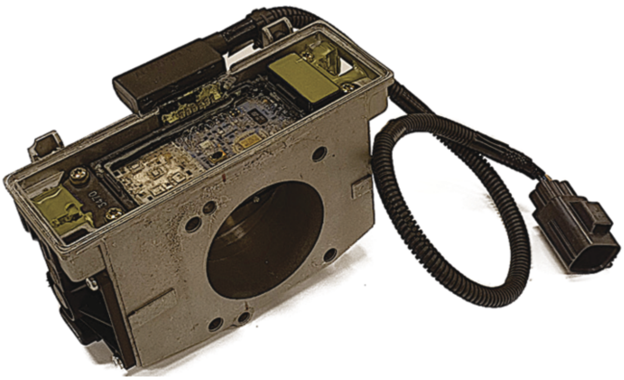

Figure 3. The core used in the case – An electro-mechanical throttle valve for car engines.

The different sub-studies contributed to defining requirements and testing ideas for dispensing sealant for the lids. For dispensing sealant, manually operated caulking guns are used. Manually operated caulking guns powered by muscle power, pressurized air, or electricity are available on the market. In this case, a caulking gun powered by pressurized air is employed. The provided flow of sealant can be adjusted to the operator's needs. The operator positions the nozzle and moves it along the line where the sealant shall be dispensed. The operator adjusts the orientation, position, and velocity of the nozzle to compensate for varying positioning of the core, varying state of the core, varying flow of sealant, and other influences by eye-hand feedback. During the dispensing and curing process, personnel are potentially exposed to airborne substances of the sealant and curing process. Therefore, active ventilation is used.

In the automated case, the dispenser shall provide a repeatable sealant flow controlled by the robot control system, which communicates the required sealant flow depending on TCP speed. Off-the-shelf equipment for dispensing in a robot application is intended for high-volume production. Due to the low production volume, only small amounts of sealants are used per day, and, therefore, the sealant is purchased in cartridges. Related is the challenge of potentially curing an opened cartridge and curing sealant in the dispenser. See Figure 4 for the physical mock-ups related to dispensing.

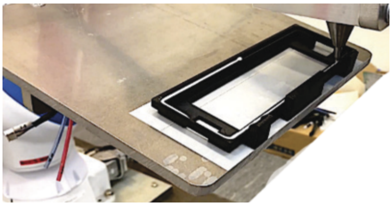

Figure 4. Mock-up for testing dispensing of sealant.

When designing the demonstrator, the most critical decision concerned if (I) the robot should carry the dispenser or if (II) the dispenser should be stationary and the robot moves the core relative to the dispenser's nozzle. An analysis conducted implies that solution (II) is advantageous. Some of the arguments are summarized here:

- no cables or similar needed for the dispenser need to move with the robot,
- several dispensers can easily be installed,
- the sealant flows vertically from the nozzle supporting its application, and
- the dispenser does not interfere with the payload or geometrical restrictions of the robot.

The next decision was related to the gripper technology – if the robot should grip the core directly or if an adapter should be designed for the core. Due to the core size and weight, a large gripper with large fingers was needed, which in the overall setting with the robot and layout was rejected. Instead, a carrier was designed as an interface on which the core can be mounted, and with a design adopted for simple gripping, as seen in Figure 5.

Figure 5: Carrier, without (left) and with mounted core (right).

Next, the final layout for the demonstrator was conceptualized. Here, there was a need for solving the transportation of the cores into and out of the robot cell; this is also safety-related. Further, the interaction with the workstation before and after the robot cell requires buffers. A passive transportation solution, such as the flow racks shown in Figure 6, fulfilled the requirements. Furthermore, the same passive solution allows the realization of curing buffers. Concepts and the final demonstrator were modeled, simulated, and analyzed, as seen in Figure 7, and finally physically realized, as seen in Figure 8.

This demonstrator realizes the automation of dispensing sealant for the outer lid. It is assumed that the cores have been mounted in the carriers of some workstations before and that the carriers support the work in the workstations before and after this automated station to be more useful.

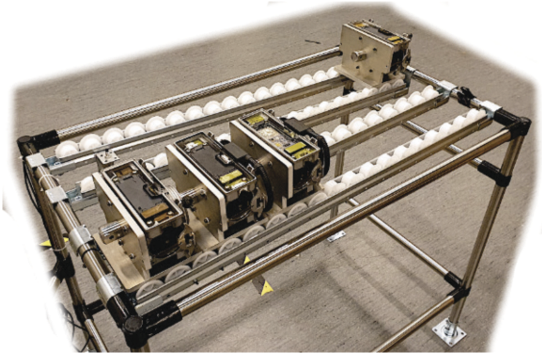

Figure 6: Flow rack implementing the inlet and outlet of the robot cell.

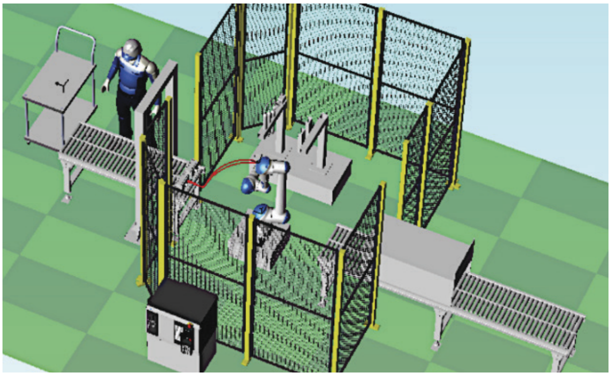

Figure 7: Concept for dispensing three sealants, mounting two lids, and curing in a tunnel [5].

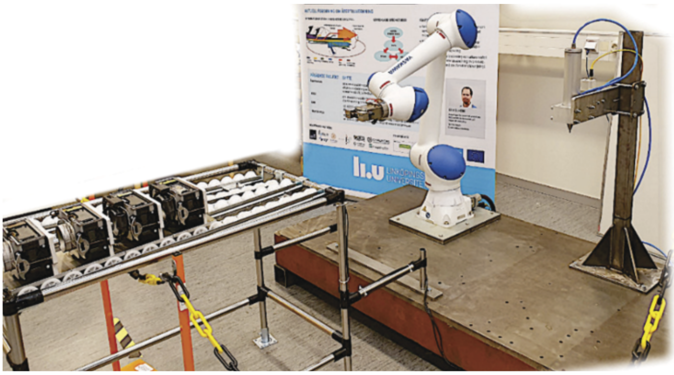

Figure 8: Final demonstrator of an automated sealant process for remanufacturing.

The operator of the previous process step places the core on the flow rack leading from that workstation into the robot cell. The flow rack works as a buffer so the operator and robot can work independently. Additionally, the workpieces cross the safety guard on the flow rack. The guard, which may be a physical fence, was not realized in the demonstrator but is indicated by the yellow-black chain in the picture. A safety concept has been considered but not fully developed. A sensor is located at the end of the flow rack, signaling to the control system that the next workpiece is available. Not realized has been an identification system required for handling different products or variants or for traceability. The robot grabs the workpiece at the coupling of the carrier and removes it from the flow rack. Sealant is applied by the robot and dispenser, and then the workpieces are placed at the outgoing flow rack for curing and transport towards further workstations. The final realized demonstrator is also presented as a short video at https://www.youtube.com/watch?v=sb4vZvaRmts.

5. Concluding remarks

The demonstrator shows that it is possible to apply sealant with a robot in a remanufacturing situation with a good result. One of the advantages of using a robot for this step is that a high-quality result is achieved. A positive side effect of realizing demonstrators like the one in this project at a university by researchers with teaching duties is that it yields relevant student projects. In this case, 14 students had the opportunity to work on industry-relevant topics to solve real industrial problems and investigate new tools. This has been shown to be a fruitful way of integrating education with research to facilitate the need to prepare and train students in new emerging technologies that support the industrial challenges and potential needs for developing knowledge about and skills in new technologies.

6. Future research

Many things could be studied regarding this topic, for example, how to integrate the automatic sealant application with the rest of the remanufacturing process steps. Other studies could also be conducted on the economic and environmental effects of this kind of automation.

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