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Possibilities for Robotics in theElectrical and electronic appliance (EEE) refurbishment

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Abstract. The term "remanufacturing" refers to the industrial process of restoring previously utilized items (cores) to a functional state. Inspection, disassembly, cleaning, reprocessing (repairs), storage, reassembly, and final testing are only some of the phases that the cores through during this industrial process. Many manufacturers also see remanufacturing as a means to greater economic, environmental, and social sustainability. Recently, the remanufacturing of electric and electronic equipment (EEE) has developed all over the globe, and technological breakthroughs in the robot industry have boosted the potential for applying greater automation inside the remanufacturing business. The purpose of this article is to catalog the many opportunities for robotics in EEE refurbishment. To achieve this goal, a multiple case study was done at four EEE remanufacturing businesses. The case study, together with the prior research, illustrates instances of the manual processes involved in EEE remanufacturing. This study's findings highlight the potential for automation in the cleaning, disassembly, and reassembly processes across the four remanufacturing case firms.

Keywords. Automation, Remanufacturing, Work environment, HRC, SME

Introduction

The circular economy is a means towards sustainable development, and it is estimated that a shift from a linear to a circular economy would generate total annual benefits for Europe of around €1.8 trillion [1]. Remanufacturing has an essential role within the circular economy [2], one which enables the shift to a circular economy, as this activity gets used products back on the market instead of being scrapped. Remanufacturing is an industrial process whereby products are restored to like-new condition. According to the World Economic Forum [3], advanced remanufacturing is one of the production areas that industry should focus on in the near future. In addition, the remanufacturing industry

council in Europe foresees a potential increase in the remanufacturing industry, from its current turnover of €30 billion a year to €90 billion by the year 2030 [2]. These two insights bring thoughts on how industry and research now jointly need to change focus.

There are numerous different definitions of remanufacturing; for examples, see [4] and [5]. According to the concept of remanufacturing used in this work, "an industrial process whereby products, referred to as cores," are returned to useable life, remanufacturing is broadly defined in stlin [6], which is based on Sundin [7]. The core goes through a series of steps—including inspection, disassembly, component reprocessing, reassembly, and testing—to guarantee it will be of sufficient quality for final use.

There are three distinct kinds of remanufacturing businesses operating today, differentiated by their relationship to the OEM from whom they get their components. The Original Equipment Manufacturer (OEM) may be the one doing the remanufacturing, the OEM may hire another firm to do the work for them, or the remanufacturing company may be completely separate from the OEM.

It is generally agreed that remanufacturing is better for the environment than making brand-new parts, since much of the work that goes into making new components can be reused in the remanufacturing process [8]. According to Sundin and Lee [8], who reviewed seven studies from the EEE industry, remanufacturing is more environmentally preferable than manufacturing brand new products because it reduces environmental effects by 14-60% in terms of resource efficiency and CO2 equivalent emissions.

Currently, the remanufacturing business depends heavily on physical labor, especially when it comes to tasks like sorting and dismantling. Several problems, such as process time and sequence, the number of operations, disassembly planning and scheduling, process cost, and performance assessment [9], make it difficult for many businesses, especially small and medium-sized firms (SMEs), to remain competitive. More widespread use of robots and automation in these sectors is thus expected to promote increased efficiency and better working conditions, gradually contributing to an enhanced remanufacturing sector capable of handling difficult problems. Furthermore, automation solutions provide settings in which robots and people collaborate closely. According to Dautenhahn [10], the field of human-robot interaction is both interdisciplinary and cross-disciplinary. This is particularly crucial in a field like electronics remanufacturing, where robots and humans work side by side. After conducting risk assessments, a human-robot cooperation (HRC) makes it feasible to delegate routine and potentially dangerous procedures to a robot while freeing up human workers to focus on more creative and mentally taxing endeavors [11]. Since the publication of ISO/TS15066 in February 2016, robot manufacturers have diversified their offerings to include collaboratively designed robots with varying degrees of safety features, such as FANUC's CR-7 and Yaskawa's HC10.

Automation in remanufacturing is challenging to perform cheaply, as shown by prior studies (see, for example, Kernbaum et al. [12]). However, recent advancements in robot technology and growing demands for automation in remanufacturing have sparked renewed interest in revisiting the topic. Therefore, the purpose of this article is to investigate the scope of the automation opportunities present in EEE remanufacturing.

1. Techniques of Research

This paper's goal was attained by a multiple case study of four Swedish remanufacturing firms. Table 1 shows that the investigated firms are SMEs operating in the EEE market. The repair and remanufacturing methods, product volumes, and company sizes of these businesses all range widely. Inspection, cleaning, disassembly, reprocessing (repair), reassembly, testing, and packaging are the primary phases of their operations.

Table 1. The characteristics of the companies included in the multiple case study of this paper.

Company	Product	Type of remanufacturer	Experience
Company A	IT equipment	Independent	21 years
Company B	Photocopiers	Contracted	36 years
Company C	Toner cartridges	Independent	26 years
Company D	Car electronics	Contracted	43 years

Companies took part in this study because they wanted to learn more about a Swedish research project called Automated Repair and Remanufacturing (ARR) and how it may help them enhance their own repair and remanufacturing procedures. The proposed case study methodology [13] was deemed to be adequate in light of the current state of knowledge about the potential for automation in remanufacturing processes in order to research and grasp the applicability of automation on the repair and remanufacturing processes of the case firms. Direct observations, unstructured interviews, and focus groups were used to collect qualitative empirical data. The authors took part in a tour at each organization as part of their observation, learning about things including repair and remanufacturing procedures, internal logistics, product movement within processes, and remanufacturing difficulties. Notes and photographs were collected throughout the inspections and walks around to capture the findings. Furthermore, a contact person led the way, provided details about the procedures, and fielded inquiries. Several people from both the business and academic sectors participated in the focus groups, where they addressed a predetermined issue facing the organization. Each participant in the industrial project had a broad requirement that led to the identification of the issues addressed in the focus groups. The empirical data were then contrasted and analyzed in an iterative and exploratory fashion to improve their clarity and applicability.

Research papers outside this area tackling either automation or remanufacturing were included (e.g., Kurilova-Palisaitiene et al [9]), and a literature search focused on papers addressing automation within the repair and remanufacturing processes (e.g., Kernbaum et al [12]). We also did an upstream and downstream qualitative search for pertinent references. Theory in this field was also based in part on the authors' prior research experiences in remanufacturing and automation.

1. Theoretical framework

Electrical and electronic product refurbishment 1.1

Recent years have seen an increase in the remanufacturing of EEE, following in the footsteps of the aerospace and automotive industries. Several EEE remanufacturers were studied as part of a European Union initiative called the European Remanufacturing Network [14]. This study looked at the specific remanufacturing processes that each company used.

Table 2. Examples of process steps at European EEE remanufacturing companies (modified from [14]).

Comp.	Borg Automotive	Büroservice Hübner	IT Lyftet	Leapp	ATP	ARP
Product	Electric steering racks	Printers	Laptops	MacBook	Trans-missions	Toner cartridges
Reman steps	Disassembly, Cleaning, Inspection, Recondition, Replenishing, Reassembly, & Testing.	Testing, Cleaning, Part changing, & Testing.	Inspection, Cleaning, Inspection, Data wiping, Testing, Replacing, Reconfig., & Assembly.	Quality screen, Decompose, Inspection, Repair, Data wiping, & Packing.	Inspection, Teardown, Cleaning, Renewing, Assembly, & Testing.	Disassembly, Cleaning, Assemble toner, Refilling, Assemble cartridge, & Testing.

At the EEE remanufacturing companies, there is little or no automation ongoing within the process steps exemplified in Table 2 above [14]. As one can see from the examples in Table 2, there are several steps in different orders, depending on what kind of EEE is being remanufactured. However, according to Sundin and Bras [15], there are seven generic steps that a used product (a.k.a., core) goes through in order to become a remanufactured product (Figure 1).

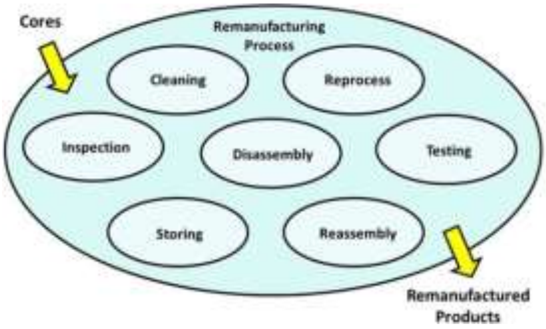

Figure 1. The seven generic steps included in a generic remanufacturing process [15].

1.1. 1.1 Industrial Robot Collaboration Use Cases

Safety fencing is commonplace for industrial robots, which often do heavy lifting and other tedious activities with great consistency and efficiency over extended periods of time [16, 17]. In such an application, the processing stages tend to follow a predictable

Quality, placement, and output parameters: a set number of processes are performed for a given input, yielding a fixed number of products.

Such input criteria are not always obvious at the outset when dealing with the repair and remanufacturing of EEE; for instance, the screws used to remove a product may be unclean, rusted, or broken. Humans in the EEE business are responsible for practically all of these duties since they are the only ones able to recognize uncertainty and make product-specific decisions.

Human-robot cooperation (HRC) is necessary to combine the strengths of robots, such as endurance, suppleness, and accuracy, with those of humans, such as intuition, adaptability, and problem solving [18]. Human-robot collaboration (HRC) makes it possible to build applications in which people and robots interact closely together. Figure 2 shows the many degrees of collaboration that exist. On the far left, we see a typical industrial robot housed in a cage where the human worker has no access to the robot. The other four setups depict varying degrees of robot-human collaboration. After doing a risk assessment, Gopinath and Johansen [11] state that repetitive and potentially dangerous jobs may be delegated to a robot so that people can focus on more creative and mentally taxing work.

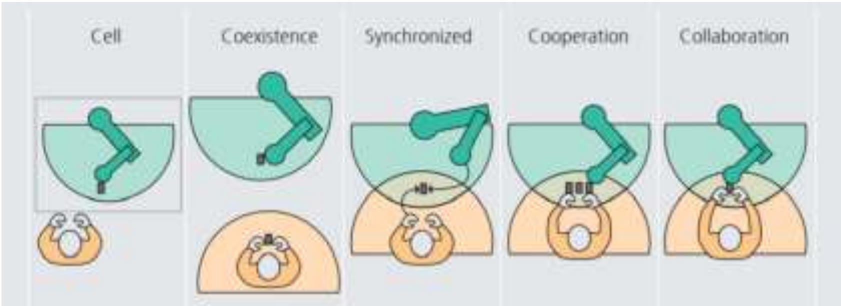

Figure 2. Various levels of cooperation between a human worker and a robot [19].

2. Case study results

2.1 Firm A

Company A is a remanufacturer of electronic devices, such as computers, tablets, displays, and cellphones, with the mission of promoting more efficient use of this technology. After consulting with the firm and considering the number of remanufactured computers, it was agreed to limit efforts to laptops alone. Customers, such as businesses, donate laptops, which are then stored in cabinets (Figure 3a). Depending on the client, the contents of these cabinets may vary. The wires, for instance, may be stored on a separate shelf from the rest of the IT hardware. The following procedures were identified in the process map created for laptop refurbishment:
First, we empty the cabinets of laptops.
a) Each laptop has a unique serial number and has been registered.
b) The cables are rewound, untangled, and organized.
Third, a pause is made while laptops and cables are buffered.
The system signals and the non-erasable hard disc drives are removed and physically destroyed if wiping the data is impossible at the business to which the laptops are transferred (Figure 3b).

1. Laptops are visually controlled and cleaned if needed or possible, and thereafter sorted into different classes before being moved to ready-to-sell storage.

Figure 3. a) An example of a cabinet used to collect IT equipment for remanufacturing at Company A. b) Workplace for erasing data from laptops at Company A.

The computers are then put into storage until they are ready to be sold. The last touches on a product's individuality are applied at the point of sale. This process typically consists of the two phases for a typical customer: Laptops will be sent to the client after (1) being re-configured and (2) having the operating system installed.

Potential for automation at Company A

The entire remanufacturing process at company A is currently manual. The potentials for automation in this remanufacturing process are identified and presented in Table 3.

Table 3. The identified potential processes for automation at Company A, where the source and the automation reasons are described. WE=Work Environment, O=Observations, I=Interviews, F=Focus group discussion. The source of data and automation reasons are given in order of appearance.

Process step	Reason for automation	Source of data
Rewinding of laptop cables (strenuous for hand wrists)	WE and Efficiency	I, O and F
Placing, connecting and setting up laptops for data erasing	Efficiency	O, I and F
Accessing laptops for data erasing	Efficiency	O and F
Disconnecting and picking up laptops for buffering classification (sorting)	Efficiency	O, I and F
Destruction of non-erasable hard disc drives	Efficiency	I and O
Raising boxes for packing the remanufactured laptops	Efficiency	O and I

2.2. Company B

Company B is a major European photocopier remanufacturer. Typically sourcing from European markets through logistical hubs in Sweden and Germany, the company remanufactures items that are then exported to 60 nations. Company B remanufactures a wide variety of photocopiers from various manufacturers.

at the tune of 6,000-7,000 metric tons annually. It is also mostly concerned with monochrome photocopiers. Having a steady flow of arriving items, which significantly changes seasonally, and a diversity of incoming products, which are typically unknown when the firm is acquiring, are regarded as the major obstacles of its whole operation.

The basic steps in its repair and remanufacturing are: tagging and labeling, inspection and testing, wiping hard drives, sorting and separating, disassembling, repairing and exchanging components, final testing, cleaning and packing. Materials recycling is the destination for broken or worn out parts and components that can't be fixed or remade.

The studied process at the company for this research is the *toner cartridges refilling process*, which is currently mainly carried out manually, with an average of 60 refills per day. The refilling is conducted based on model and colour. The toner cartridges refilling process includes (1) emptying, (2) sorting, (3) refilling toner cartridges with the help of a machine (Figure 6c), (4) sealing, (5) cleaning, (6) marking and (7) packing (Figure 4).

Figure 4. Equipment used for emptying and refilling toner cartridges at Company B: a) storage of sorted toner cartridges, b) barrel for recovered toner and c) refilling machine.

Potential for automation at Company B

Based on the data collected at Company B, the potentials for automation in this remanufacturing process are identified and presented in Table 4.

Table 4. The identified potential processes for automation at Company B, where the source and the automation reasons are described. WE=Work Environment, O=Observations, I=Interviews, F=Focus group discussion. The source of data is mentioned in order of appearance.

Process step	Reason for automation	Source of data

Emptying toner cartridges (recovering the toner) – a workenvironment issue in the form of powder contamination (hazardousness)

Refilling toner cartridges

- a work environment issue in the form of ergonomicissues and repetitive work

- a precision requirement, as colours and toners must notbe mixed. In addition, toner cost is high, and toner waste has economic drawbacksWE and Efficiency O and F

WE and Efficiency I, O and F

Process step	Reason for automation	Source of data

Cleaning toner cartridges (on the outside after being refilled) – a customer requirement to have a clean toner cartridge (quality issue)Quality and WE O and F

2.3. Company C

Company C remanufactures and distributes printer cartridges throughout Europe. It is the market leader in the Nordic countries. Toner cartridges of almost every brand and model may be remanufactured by Company C. Insufficient time is spent preparing for production of lower amounts of a wide range of incoming goods, which is the company's primary issue.

Collecting, sorting, disassembling, inspecting, emptying, cleaning, drilling (if necessary), repairing, refilling, reassembling, testing, resetting, and coding toner cartridges is a lengthy process before they are ready for shipment. A materials recycling center receives items that are broken beyond repair or otherwise unusable.

Due to the great variety of cartridge types and the unique procedures utilized to deconstruct and refill them, Company C's current remanufacturing process is performed completely by hand. The stages of emptying and cleaning, as well as the phases of refilling, were identified as having the highest potential for automation after studying and mapping the remanufacturing processes (see Figure 5).

Figure 5. Cleaning and disassembling toner cartridges at Company C.

Potential for automation at Company C

Based on the data collected at Company C, the potentials for automation in this remanufacturing process are identified and presented in Table 5.

Table 5. The identified potential processes for automation at Company C, where the source and the automation reasons are described. WE=Work Environment, O=Observations, I=Interviews, F=Focus group discussion. The source of data is mentioned in order of appearance.

Process step	Reason for automation	Source of data
Cleaning toner cartridges – a work environment issue inthe form of noise from the fume hood space, ergonomic issues and repetitive work for the operator	WE and Efficiency	I, O and F
Refilling toner cartridges - a work environment issue in the form of ergonomicissues and repetitive work - a precision requirement, as colours and toners must notbe mixed. In addition, toner cost is high, and toner waste has economic drawbacks	WE and Efficiency	O, I and F

2.4. Company D

When it comes to automotive electronics, such as infotainment systems and engine electronics, Company D is an industry leader in repair and remanufacturing. The value chain of Company D includes a major automaker. The service network for the automaker then sells the remanufactured product after collecting the damaged parts.

This study focuses on an electro-mechanical component of an engine (Figure 6). Other components with similar characteristics that are currently manufactured or are planned to be remanufactured are also considered. The component consists of a mechanical structure, mechanisms and integrated electronics. Automation is facilitated as the components are mechanically robust and dimensionally stable, which supports handling and fixturing. The process of remanufacturing the electro-mechanical components was mapped and contained the following nine steps:

1) Inspecting and testing
2) Cleaning
3) Machining off lid
4) Disassembling and cleaning
5) Removing sealant
6) Repairing electronics
7) Applying sealant
8) Assembling new lid
9) Testing

Figure 6. The electro-mechanicalcomponent remanufactured at Company D.

The examined components, like the engine compartment of a vehicle, need to be sealed to prevent the harmful elements from getting inside. Therefore, when remanufacturing, it is necessary to reseal the components. In these contexts, sealants are often utilized. This necessitates the recurrence of processes such as component separation (which may be achieved by severing the seal), residual cured sealant removal, and sealant dispensing and curing. These procedures are now carried out by hand, which may be a time-consuming operation.

Potential for automation at Company D

Based on the data collected at Company D, the potentials for automation in this remanufacturing process are identified and presented in Table 6.

Table 6. The identified potential processes for automation at Company C, where the source and the automation reasons are described. WE=Work Environment, O=Observations, I=Interviews, F=Focus group discussion. The source of data is mentioned in order of appearance.

Process step	Reason for automation	Source of data
Cleaning electro-mechanical component	WE and Quality	O, I and F
Removing the sealant from the electro-mechanical component	Efficiency and WE	O, I and F
Sealing the electro-mechanical component – mainly precision work	Efficiency and Quality	O, I and F

3. Cross-case analysis

This section summarizes the potential for automation at the studied remanufacturing companies by combining a theoretical framework based on the seven generic process steps of remanufacturing [15] and the levels of HRC [19] with empirical data collected from the case companies (Section 3), as well as the authors' varied prior experiences with various aspects of automation and remanufacturing, such as their environmental and production system challenges. The basic process phases (Figure 1) are linked to the empirically discovered applications in each case firm (Tables 3-6) and to the levels of HRC (Figure 2) in the cross-case study shown in Table 7 below. Applications in the current production system where human operators may engage in novel robot-human interaction are reflected in the identified automation potentials. This report, however, is the main product of our ongoing discussion with our industrial partners on the potential for further automation in the remanufacturing sector.

Table 7. The identified potential for automation at the case companies of this research. Potential levels of HRC are given in parentheses.

Remanufacturing step	Company A	Company B	Company C	Company D
Inspection				
Cleaning	Data erasing *(N/A)*			
Disassembly	Disconnect laptops *(N/A)*			
Reprocess				
Reassembly *(Coexistence)*	Connect laptops fordata erasing *(N/A)*	Sealing		
Testing				
Packing	Raising boxes *(Cell)*			

Table 7 shows that the most promising areas for automation are cleaning, disassembly, and reassembly. The primary potential benefit of automating these remanufacturing operations is improved worker safety, particularly during the cleaning and refilling of toner throughout the assembly phases (Companies B and C). The other opportunities are motivated either by the need for greater process efficiency (Company A) or by the need for greater accuracy (Company D). Companies B and D found that quality was a key factor in their decision to use automation.

4. Discussion and conclusion

Reasons for automating remanufacturing are found in the case study and the literature, and they are comparable to those found in traditional manufacturing, such as the need for more efficient procedures and shorter lead times. However, the examples showed a lot of promise in the cleaning procedures for reasons related to the workplace environment. This is a critical remanufacturing procedure since it may take a long time and accounts for a large percentage of the whole lead time (see, for example, Sundin and Bras [15]).

In addition, prior studies have indicated that lengthy process durations might make it challenging to incorporate robots in remanufacturing (e.g., Kernbaum et al [12]). Nonetheless, there are prospects and installations that work well, such as Autocraft's cleaning and assembling of automobile components [20]. We have uncovered opportunities for automation in the cleaning and assembling processes of EEE items via our research.

To create an effective HRC, however, it is necessary to weigh the benefits of robots against those of humans, as stated by Wang et al. [18], and to consider the five varying degrees of cooperation, as stated by Bauer [19]. These gradations suggest that the optimal arrangement is directly related to the specific requirements of each work. As an example, in our cleaning procedure for Company D, we may require an extremely sharp instrument to remove sealant. If the tool is located in the robot's end-effector, the risk assessment [11] will show an increase in dangers, recommending a cell layout philosophy for safety reasons, which may be connected to difficulties in the workplace.

5. Future research

Our EEE remanufacturing industry mapping effort has revealed numerous unanswered research questions. We can see the need for more research and development of technology demonstrators to determine the best and most efficient means of increasing automation in remanufacturing applications. While each of the case study organizations has its own unique challenges—low product quantities, a large number of variations to handle, and a wide range of incoming quality—they all have a similar problem: the requirement for technological flexibility while investing in increasingly automated solutions. It's also crucial to put money towards automated solutions that can have a positive impact on the economy and the environment. Small and medium-sized enterprises (SMEs) were the focus of this study, however a big remanufacturer may be included in future studies. Further research is required to understand the relationship between the remanufacturing process phases and the possible degrees of automation of HRC. Three of the case firms (B, D, and E) follow a pattern in which they can only utilize coexistence HRC for their reassembly processes, but the fourth remanufacturing company (A) deviates from this trend.

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