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Smart disassembly cell for circularity: Turn industry 4.0 technologies for disassembly and recovery of components.

S.Parthasarathi[a]*, U.Eibar[a], T.Alix[a,b], R.Chavanne[a], M.Cherif[a,b], N.Perry[a,b]

a Arts et Metiers Institute of Technology, CNRS, Bordeaux INP, Hesam Universite, I2M, UMR 5295, F-33400 Talence, France.
b Univ. Bordeaux, CNRS, Bordeaux INP, I2M, UMR 5295, F-33400, Talence, France.

* Corresponding author. Tel.:+33752155373. *E-mail address:* siddharth.parthasarathi@ensam.eu.

Abstract

Circular Economy initiatives have introduced a solution demand for the treatment of End of Life (EoL) products, switching from shredding and material recycling to the recovery of modules/components that remain functional. The process needs product recovery and diagnostic, disassembly, and requalification. These tasks are today carried out by human labour due to their complexity and uncertainties concerning the working conditions of the received product. But it implies time and costs that hardly balance the economical balance in developed countries context. Human – Cobot collaborative disassembly are promising solution to overcome the uncertainties without compromising the flexibility and the rate of disassembly operation. The Smart Disassembly Cell for Circularity (SDC2) project aims to provide a semi–automated disassembly solution for EoL electronic products. This paper portrays the requirements for the implementation of a Human-Cobot collaborative cell for electronic products. The goal of this project is to implement a shared workplace where the robot and the worker can work in parallel or share a common task with safe interaction. A literature study on available solutions was made. From there, the study and implementation of the decision system, database and service platform started. This document describes the function of the database and decision system as well as the service platform to establish global communication. MySQL and Python with the FLASK package were used to frame the database and service platform, Genetic algorithm was implemented for providing the robotic disassembly planning solution. A case study using a personal computer and a Power inverter was conducted to verify the development in each stage. The systems are under development with an aim to provide a global disassembly cell which will be able to disassemble various products rather than focusing on a specific product.

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Keywords: Circular Economy; Disassembly; Human–Robot collaboration; Service Platform; Database; Genetic Algorithm.

1. Introduction

As innovation advances and new electronic gadgets become accessible, the generation of electronic waste is escalating rapidly. Waste Electronic and Electrical Equipment (WEEE) incorporates devices such as cell phones, home machines, and PCs, which are disposed of as waste. Despite only 17.4% of electronic waste being documented, the generation reached 53.6 million metric tonnes in 2019 [1]. Existing recycling facilities use mass recovery techniques, such as shredding, crushing, and magnetic separation [2]. These manual procedures demand skilled labour, leading to increased costs and safety concerns [3]. However, the mass recycling approach falls short of ensuring efficient recovery, managing to reclaim only 28% of metals from the total weight of a printed circuit board [4]. Such techniques are not meant to accommodate Circular Economy (CE) principles. The CE aims to extend the lifespan of products through reuse, repair, refurbishing, remanufacturing, and repurposing [5]. Applying reuse and repair strategies to a laptop, extending its service life by two years, exhibits a diminished global warming potential, and reduced human toxicity potential when compared to recycling [6]. Beyond laptops, electric motors and gearboxes in washing machines last around 30 years, while the appliance's lifespan

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is 10-15 years [7]. Components at the Printed Circuit Board (PCB) level house precious and hazardous materials [8]. The extraction requires desoldering and for reuse scenarios, the component needs to be desoldered without any damage. To do so, human operators require a higher level of experience and the process itself is intense, time-consuming and even hazardous depending on the product [9]. Robots excel in executing repetitive tasks with consistency and can function in hazardous environments but require cognitive ability and logical decision systems to disassemble End of Life (EoL) products. Robots also lack human adaptability in uncertain situations. The key is to have efficient human decision skills and increase operation speed by including the human and cobot to share the decision and the operation. Based on the studies of available automated disassembly solutions, Human-Robot collaboration (HRC) and the supporting systems for developing such collaborative cells, this project focuses on adopting flexible collaborative disassembly solutions to build a methodology to overcome product variability. Studies on industries that adopted robotic disassembly widely explain the limitations and uncertainties. This paper is organized as follows a short literature review on human-robot disassembly cells in section 2. Section 3 will give a short description of the project plan and the techniques employed. The implementation and the case study are reported in section 4. Section 5 with a conclusion and future works finishes the paper.

2. Related Works

A detailed study of the integration of robots within the framework of Circular Economy principles, undertaken by the authors, provides insights into the trends in automation and collaboration between humans and robots [10]. An automated disassembly cell, employing destructive techniques for dismantling a Liquid Crystal Display (LCD) screen, was executed. The cell incorporates an industrial robot coupled with a circular saw for the disassembly process, thereby precluding the option of human collaboration within the cell [11]. This cell focuses on recovery for recycling scenario thus the decision system for task sequencing or component selection is not discussed. Disassembly of Compact Disk drives from the PC was introduced where the disassembly tasks were allotted to robots using a decision tree [12] and robotic recovery of high-value materials from an Electronic Control Unit (ECU) of an electric vehicle [13] showed better automation solutions in practice. However, the studies failed to address the uncertainties as a component in a PC is most likely to be upgraded or changed by the users, in terms of electric vehicles, the accessibility of the component itself is uncertain considering the state of the received vehicle. An automated disassembly system incorporates a vision system to determine component coordinates and the type of washing machine motor. Additionally, an eddy current system is integrated to verify the remaining copper after disassembly, coupled with a functionality test for classifying motors with defects [14]. Another disassembly cell, utilizing two collaborative robots and a human, successfully dismantles a water pump and a turbocharger. The authors also implemented a decision system that sequences the disassembly operations [15]. The above-mentioned works are research-based; Apple managed to construct a fully automatic disassembly cell named Daisy for their iPhones. Daisy demonstrated the capability to disassemble nine different iPhone versions at a rate of 200 phones per hour [16]. Fujifilm also implemented a remanufacturing system for their cameras [17]. These systems have limitations, and the uncertainties get higher with the new-age products. These machines were not updated or expanded as the product type keeps on changing, which adds complexity and lowers the cost-effectiveness of the industry. In formulating a decision system, a comprehensive study of the disassembly sequence and its representation plays a vital role. Methods such as and/or graphs, Petri nets and disassembly precedence matrices are used to represent the component relation and its precedence. The survey on different representation approaches helps in understanding and selecting a feasible approach [18]. The application of and/or graphs for products like fuel pump which has several components makes it the best fit for understanding the planning of complete disassembly and selective disassembly scenarios [19], [20], [21], [22]. The tree-like representation of the sequence and relation between the components used in and/or method helps to simplify the understanding and the operation planning. Some used Perti-Nets and fuzzy logic, all these methods include the conversion of tasks to matrix form and are used by optimization methods [23]. A detailed study of different indicators tailored for disassembly decision-making and optimization algorithms provides better clarity for adopting the rightful tools [24], [25]. Apart from the decision and other supporting systems, a service platform which connects the software systems with the hardware units is crucial. A platform comprising a database and a user interface where the operator can access the data and the disassembly tasks can be instructed to the cobots [26], the evolution of this platform may ensure the automation of the disassembly cell. The reviews show that disassembly is not the reverse operation of an assembly, it requires different approaches, techniques and tools. The human brain can easily adapt to the situation and can overcome uncertainties, but designing a decision system which acts similarly to the human brain is an outsider. Disassembly of one type of product itself is complex, adding the different types of products increases the complexity and uncertainties. From the review, it is evident that a complete disassembly cell comprising vision system, identification and decision system and collaborative robot system for different types of products is not implemented. The SDC2 project aims to build such a disassembly cell by adapting available solutions.

3. Description of the methodology

The steps planned for the development and implementation of this proposed smart disassembly cell project are expressed in Fig. 1. The key element of this disassembly cell is the vision system that provides the functionality termed as the analysis, which can be further distinguished as product and process analysis. With the product analysis, technical data can be obtained by scanning barcodes; the required disassembly process is then obtained from the commercial values and the received product’s state. To carry out the disassembly, its process needs to be classified into recovery operation and the tasks required to complete that recovery operation. The disassembly operation is sequenced, and the collaborative model is then planned considering feasibility, safety, commercial, and uncertainty conditions. From those various value studies, the task allocation between the human and robot can be assigned. The product information and disassembly process data are stored in a database, and the process sequencing and allocation are done using a genetic algorithm. The database and decision system demand communication, which is provided by a web interface. The operator also requires an interface to read the allocated task and to override the process when necessary. The interface will also establish communication with the vision system to ensure the overall disassembly process analysis and workflow.

Once the recovery of the desired component is done, the component then enters the validation stage for reuse purposes, as the component might be faulty or might have experienced damage during recovery. The decision between scrapping or storing the component depends on the market value, demand, and economic values defined by the user. The commencement of the project was done on the Database, Decision system, and interface; the study and the implementation are detailed in order. Revalidation is not discussed in this paper, as the control for validating the recovered product requires a tailored test bed, decision systems, and a database for determining the condition of the component after disassembly, service life, and operational compliance before reusing.

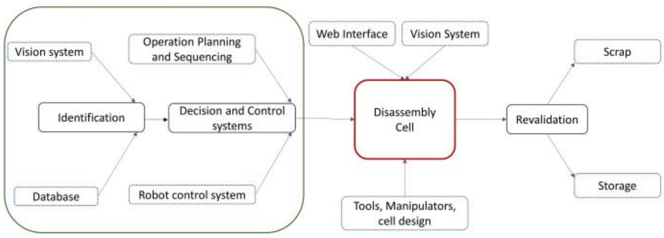

Fig. 1. The outline for the development of the proposed disassembly cell.

3.1 Database

The disassembly instructions for the products are not readily available; the information is limited to the type of product and the manufacturer. Thus, it was necessary to create a database with disassembly operation instructions and tasks specific to the products and the type of components to be retrieved. The disassembly operation and tasks solely depend on the selection of the component to be retrieved under consideration of various factors such as economics, product market, etc. The MySQL database used in this work is an open-source Relational Database Management System (RDBMS). It is preferred because of its ability to store various kinds of data in the form of tables, and its relational-based system eases communication between different tables. MySQL uses Structured Query Language (SQL) to access the data from the tables.

The database is multi-purpose for disassembly data and for the web interface, thus it comprises a user table, product table, subassembly table, tools, and disassembly operation tables. The data type and the content of each table are mentioned in Fig. 2, and its legends are Primary Key (PK), Not Null (NN), Unique values (UQ), Bit values (B), Unassigned datatype (UN), Zero Fill (ZF), Auto Increment (AI), Generated Columns (G).

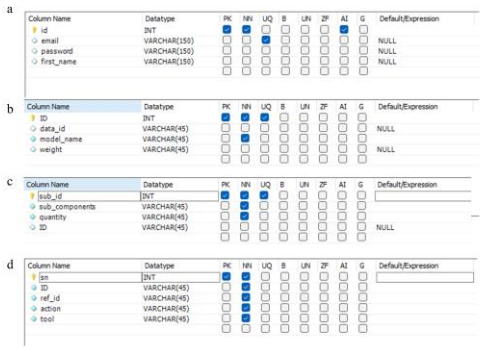

Fig. 2. (a) User login table; (b) Products table; (c) Components table; (d) Disassembly operation and tasks table.

The user and product tables are utilized by the web interface to track user details and output available products. The subassembly and operation tables provide components and their disassembly data. All the tables are related to each other using the primary key, and individual products are related using sub ID.

Each component in a product will require a different approach, considering the uncertainty of the received product. To address the unavailability of data, a disassembly sheet was introduced to provide input to the database. The received products will undergo manual disassembly to study feasibility, tools, approach requirements, and uncertainties. This manual study is crucial as it serves as the data points and training set for the automation of this process.

3.2 Disassembly Decision System

Disassembly is hindered from automation by its uncertainties, necessitating the development of a decision tool capable of managing various scenarios that may arise during the process. Among the crucial decisions to be made are:

- To determine the extent to which disassembly is going to be performed.
- To identify which components are to be recovered and what will be done with them, whether they will be sold or recycled.
- To decide who will perform the disassembly operation, whether it will be done by a robot, or an operator based on factors such as difficulty, time consumption, and safety.

The deciding factors are flexible and can be tailored to satisfy the user's needs. Finally, the sequence of these operations must be determined to be as optimized as possible with respect to time. The first three decisions are made based on the information available in the database. For the last one, a genetic algorithm has been generated for optimization. The indicators for enabling the decision systems were adopted from similar research works [19], [27]. The scale for the indicators was revised and adopted to fulfill the requirements.

3.3. Service platform

The ideology behind the platform is to facilitate communication between the user, the cobot, and the disassembly cell. Fig. 3 simplifies the framework of the proposed platform. The web interface is created using the Python Flask framework, which utilizes HTML and JavaScript to display contents. The interface is an aggregation of multiple modules, such as user login, product information, and decision module. These modules are user-assigned so that the interface can be expanded when further updates or the addition of new features are introduced. The Flask package comprises the user login module; it uses get and post command lines to receive and render inputs from the user. The queries are executed as functions in a Python file, and the functions are called inside an HTML file, which is rendered as the output in the interface.

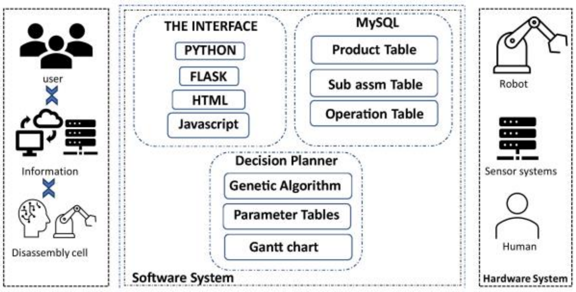

Fig. 3. Framework of the service platform.

4. Case Study

As the disassembly cell is proposed to offer a disassembly solution for various products, a personal computer and a power inverter are taken into study. Power inverters are used for converting direct current from solar panels to alternating current in households. In this project, a power inverter with a 3 to 6 kW power output range was chosen. Inverters in this range are compact and smaller in size than the tower computer. These power inverters pack very valuable electrical components such as capacitors, transformers, and inductors. However, the disassembly process to acquire such components is challenging.

The disassembly is divided into two streams: mechanical and electrical systems. The robot tools, planning, and other disassembly parameters need to be tuned according to these two streams. The goal of mechanical disassembly is to gain access to the valuable component by unscrewing, unplugging, etc. Electrical disassembly is the second step where specific components from the PCB are disassembled using targeted techniques such as desoldering. The data collection, decision system and the interface implementation for the two products are discussed below.

4.1 Disassembly and data extraction

As mentioned, the disassembly data is limited, so fashioning the relevant data using manual methods is effective. A DELL OptiPlex 380 tower and a Huawei SUN 2000 Power inverter are taken for this study. The technical information of the components of a PC can be obtained from a common web service provider. An in-depth study on the precious material contents of the motherboards and other components of a PC is published [28]. Planning the component recovery operation and feasible tool application is the predominant study in this case. On the other hand, the technical information of the electronic components used in an inverter is not readily available compared to the PC. During the manual disassembly, the data of the electronic components on the PCB also needs to be collected to classify them according to their market value, precious material content, and reusability. This data creation can also be used by the decision system as a factor for classifying which components need to be disassembled.

Once the technical data from the barcodes and web providers are collected, the manual disassembly is carried out under a timed environment. The same operator undergoes the disassembly of the same product several times to gain experience, as the time difference between before and after experience was significant. Each step is noted as a detailed description in the disassembly sheet and recovered components/fasteners are counted and noted in a sequence to ease task planning. Time, tool requirements, and uncertainties in the form of remarks are documented in detail, as shown in Fig. 4.

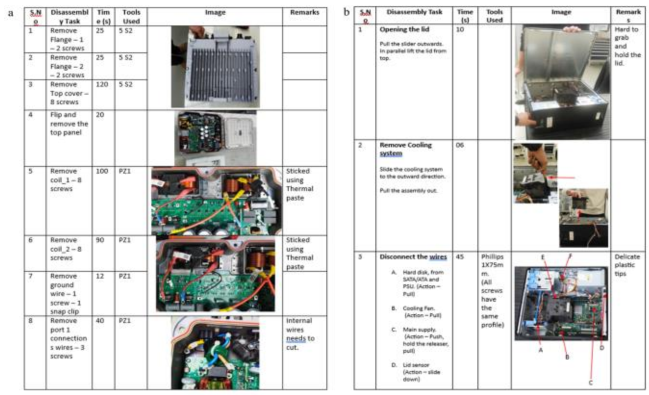

Fig. 4. (a) Manual disassembly table of the Power inverter; (b). Manual disassembly table of the PC.

The manual operation is attempted using a Doosan A0912 series 6-degree-of-freedom collaborative robotic arm with a reach of 1200 mm. The payload capacity of the robot is 9 Kg, which is sufficient, as the robot is not commanded to pick and place the entire product. The robot is paired with a 2F-85 series two-finger gripper from Robotiq to analyze the limitations, as a feasible task for a human might be difficult for a robot. The unscrewing tasks were not carried out, as a wide range of industrial solutions is readily available for such low torque conditions. Different end effectors were not installed initially to reduce the number of tools and frequent tool-changing scenarios, instead, focused on enabling multi-purpose tool heads. The design study to accommodate various functionalities using add-ons to a gripper head is in progress.

With the gripper connected, the waypoints and manipulation are simulated and implemented using Doosan's programming and simulation tool named DART platform. The cobot mimic study of the manual process is highly recommended to construct the indicators for the decision system. The completed datasheet is then fed into the database, and in the meantime, the indicators of disassembly actions and the operation sequence for the genetic algorithm are also generated using the time and remarks data from the manual disassembly datasheet. The remarks data is used to determine the difficulty of the task, which helps in allocating tasks between the robot and human.

4.2. Decision System

Once the physical constraints between components, the operating time of each process, and the possibility of robot and operator coexistence have been defined, the genetic algorithm can be launched to obtain the most efficient sequence from the point of view of total disassembly time. Based on Charles Darwin's theory of natural evolution, the genetic algorithm reflects the process of natural selection in which the fittest individuals are selected to reproduce and obtain the next generation. A chromosome (sequence) is characterized by different genes (disassembly operations), and along with other chromosomes, a population is created. In each generation, different operations between chromosomes are carried out, and new chromosomes are generated. After this step, the best ones (the fastest sequences) are selected, and in each generation, the population is improved.

As for the operation of the algorithm, the restrictions of order and coexistence between different disassembly operations are defined in matrix form to program the algorithm, and the values of each component of the matrix vary between the Boolean values 1 and 0. As the program runs, these restrictions disappear until a null matrix is obtained. In the general case of total disassembly, the genetic algorithm was programmed to perform the entire disassembly in the shortest possible time without regard to the components obtained. In reality, it is not interesting to obtain all the components, as it is not economically or temporally productive. Therefore, a new constraint was added to the database defining the value of each component from an economic and ecological point of view. The task allocation was done using the constraints made using the remarks from the datasheet.

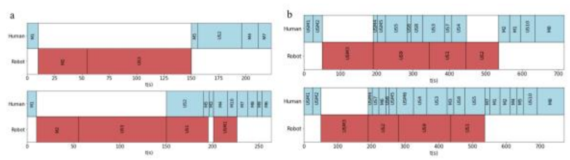

Fig. 5. (a) Disassembly task sequence for PC; (b) Disassembly task sequence for Power inverter

After applying this constraint, a component is set as a target so that the algorithm stops running once this component is obtained. The differences in the disassembly sequences of both cases can be seen in Fig. 5 for the PC and Power inverter cases. The tasks were renamed in the form of codes with numbering to facilitate the formation of indicators, these code names are used to define and can be redefined at any time.

4.3. Software systems

The web interface, database, and decision system are grouped as software systems. Initially, the components table gets filled, then the tasks required by that component are filled in the operation table. The data input to these tables is done manually. Once the tables get updated, the data needs to be transferred to the web interface. This transmission needs to be in the form of a query initiated by the user through the interface. This communication is done using the MySQL - cursor function. It uses command line management to process the user query and fetch the data from the data tables. The calculation and output from the genetic algorithm are also rendered in the same method. The general flow as a user is pictured in Fig. 6.

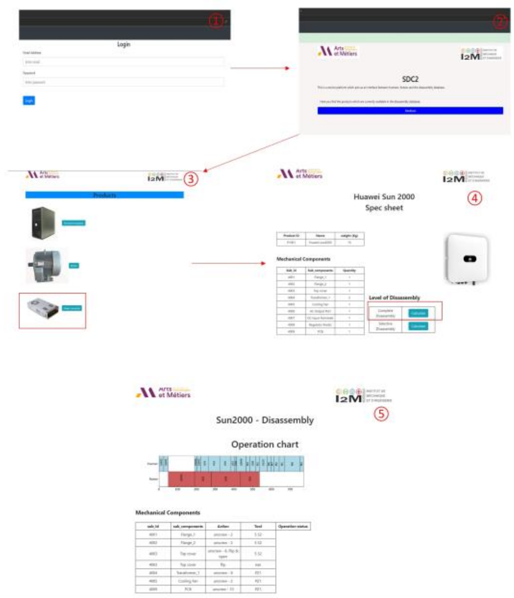

Fig. 6. The interface walkthrough from user login to selecting a product and generating the disassembly sequence chart.

The above-mentioned walkthrough is explained as follows:

1. The user needs to create an account using his email; if already created, he/she can log in to the interface.
2. Once the user gets logged in, he/she can access the product list from the database.
3. The desired product can be selected from the products page. In this case, the power inverter is selected.
4. By selecting the product, the component list of the selected product will be displayed and the option for the level of disassembly.
5. After choosing the required disassembly level, the interface will deploy the decision algorithm and renders the operation sequence and the components to disassemble table.

This interface is operated manually. The vision system is not combined with these modules. With the vision system, the product selection will be automated, and the level of disassembly will be carried out by the user after validating the condition of the received product.

5. Conclusion

This paper introduces the studies and initiation of a human-robot collaborative disassembly cell for two different products, currently under development and requiring studies on various topics. The database and web interface introduction enables the cell to store disassembly operation data with remarks, supporting the overcoming of uncertainties. The decision system defines indicators, operation sequence, and task allocation using a genetic algorithm, with indicators updatable based on requirement. The project's continuation involves adding a vision system with recognition capabilities for cobots, enhancing the web interface for direct communication with the robot, increasing automation, and allowing operator intervention in case of uncertainty. The inclusion of digital twin solutions automates the disassembly process, aiding in finding optimal solutions by simulating various uncertainty scenarios, and assists in planning and configuring the optimal disassembly cell. The initial focus of the project's development will be on vision systems and manipulator design and implementation.

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References

[1] V. Forti, C. P. Baldé, R. Kuehr, and G. Bel, "The Global E-waste Monitor 2020".
[2] S. Vongbunyong and W. H. Chen, "Disassembly Automation," in *Disassembly Automation*, in Sustainable Production, Life Cycle Engineering and Management. , Cham: Springer International Publishing, 2015, pp. 25–54. doi: 10.1007/978-3-319-15183-0_3.
[3] G. F. Cardamone, F. Ardolino, and U. Arena, "About the environmental sustainability of the European management of WEEE plastics," *Waste Manag.*, vol. 126, pp. 119–132, May 2021, doi: 10.1016/j.wasman.2021.02.040.
[4] Zong Gao, Jianzhi Li, and H. C. Zhang, "Printed circuit board recycling: a state-of-art survey," in *Conference Record 2002 IEEE International Symposium on Electronics and the Environment (Cat. No.02CH37273)*, San Francisco, CA, USA: IEEE, 2002, pp. 234–241. doi: 10.1109/ISEE.2002.1003272.
[5] X. Pan, C. W. Y. Wong, and C. Li, "Circular economy practices in the waste electrical and electronic equipment (WEEE) industry: A systematic review and future research agendas," *J. Clean. Prod.*, vol. 365, p. 132671, Sep. 2022, doi: 10.1016/j.jclepro.2022.132671.
[6] E. Bracquené, J. Peeters, J. Duflou, and W. Dewulf, "Sustainability assessment of product lifetime extension through increased repair and reuse".
[7] B. Lu, B. Li, L. Wang, J. Yang, J. Liu, and X. V. Wang, "Reusability based on Life Cycle Sustainability Assessment: Case Study on WEEE," *Procedia CIRP*, vol. 15, pp. 473–478, 2014, doi: 10.1016/j.procir.2014.06.046.
[8] X. Wang and G. Gaustad, "Prioritizing material recovery for end-of-life printed circuit boards," *Waste Manag.*, vol. 32, no. 10, pp. 1903–1913, Oct. 2012, doi: 10.1016/j.wasman.2012.05.005.
[9] M.-L. Lee, X. Liang, B. Hu, G. Onel, S. Behdad, and M. Zheng, "A Review of Prospects and Opportunities in Disassembly with Human-Robot Collaboration." arXiv, Oct. 20, 2023. Accessed: Jan. 08, 2024. [Online]. Available: http://arxiv.org/abs/2310.13643
[10] H. Poschmann, H. Brüggemann, and D. Goldmann, "Disassembly 4.0: A Review on Using Robotics in Disassembly Tasks as a Way of Automation," *Chem. Ing. Tech.*, vol. 92, no. 4, pp. 341–359, Apr. 2020, doi: 10.1002/cite.201900107.
[11] K. Elo and E. Sundin, "Process Concepts for Semi-automatic Dismantling of LCD Televisions," *Procedia CIRP*, vol. 23, pp. 270–275, 2014, doi: 10.1016/j.procir.2014.10.104.
[12] F. Torres, S. Puente, and C. Díaz, "Automatic cooperative disassembly robotic system: Task planner to distribute tasks among robots," *Control Eng. Pract.*, vol. 17, no. 1, pp. 112–121, Jan. 2009, doi: 10.1016/j.conengprac.2008.05.013.
[13] J. Li, M. Barwood, and S. Rahimifard, "An automated approach for disassembly and recycling of Electric Vehicle components," in *2014 IEEE International Electric Vehicle Conference (IEVC)*, Florence: IEEE, Dec. 2014, pp. 1–6. doi: 10.1109/IEVC.2014.7056158.
[14] B. Karlsson and J.-O. Järrhed, "Recycling of electrical motors by automatic disassembly," *Meas. Sci. Technol.*, vol. 11, no. 4, pp. 350–357, Apr. 2000, doi: 10.1088/0957-0233/11/4/303.
[15] J. Huang *et al.*, "An experimental human-robot collaborative disassembly cell," *Comput. Ind. Eng.*, vol. 155, p. 107189, May 2021, doi: 10.1016/j.cie.2021.107189.
[16] "K. Young, 'Apple adds Earth Day donations to trade-in and recycling program,' New Robot, Daisy, Disassembles iPhone to Reclaim Precious Materials, Apr. 2018 [Online]. Available: https://www.apple.com/au/newsroom/2018/04/apple-adds-earth-daydonations- to-trade-in-and-recycling-program/."
[17] J. R. Duflou, G. Seliger, S. Kara, Y. Umeda, A. Ometto, and B. Willems, "Efficiency and feasibility of product disassembly: A case-based study," *CIRP Ann.*, vol. 57, no. 2, pp. 583–600, 2008, doi: 10.1016/j.cirp.2008.09.009.
[18] A. J. D. Lambert, "Disassembly sequencing: A survey," *Int. J. Prod. Res.*, vol. 41, no. 16, pp. 3721–3759, Jan. 2003, doi: 10.1080/0020754031000120078.
[19] M.-L. Bentaha, A. Voisin, and P. Marangé, "A decision tool for disassembly process planning under end-of-life product quality," *Int. J. Prod. Econ.*, vol. 219, pp. 386–401, Jan. 2020, doi: 10.1016/j.ijpe.2019.07.015.
[20] S. Parsa and M. Saadat, "Human-robot collaboration disassembly planning for end-of-life product disassembly process," *Robot. Comput.-Integr. Manuf.*, vol. 71, p. 102170, Oct. 2021, doi: 10.1016/j.rcim.2021.102170.
[21] R. C. W. Sung, J. R. Corney, and D. E. R. Clark, "Automatic Assembly Feature Recognition and Disassembly Sequence Generation," *J. Comput. Inf. Sci. Eng.*, vol. 1, no. 4, pp. 291–299, Dec. 2001, doi: 10.1115/1.1429931.
[22] Y. Ren, G. Tian, F. Zhao, D. Yu, and C. Zhang, "Selective cooperative disassembly planning based on multi-objective discrete artificial bee colony algorithm," *Eng. Appl. Artif. Intell.*, vol. 64, pp. 415–431, Sep. 2017, doi: 10.1016/j.engappai.2017.06.025.
[23] Meimei Gao, M. Zhou, and Ying Tang, "Intelligent decision making in disassembly process based on fuzzy reasoning Petri nets," *IEEE Trans. Syst. Man Cybern. Part B Cybern.*, vol. 34, no. 5, pp. 2029–2034, Oct. 2004, doi: 10.1109/TSMCB.2004.833331.
[24] X. Guo, M. Zhou, A. Abusorrah, F. Alsokhiry, and K. Sedraoui, "Disassembly Sequence Planning: A Survey," *IEEECAA J. Autom. Sin.*, vol. 8, no. 7, pp. 1308–1324, Jul. 2021, doi: 10.1109/JAS.2020.1003515.
[25] P. Vanegas *et al.*, "Ease of disassembly of products to support circular economy strategies," *Resour. Conserv. Recycl.*, vol. 135, pp. 323–334, Aug. 2018, doi: 10.1016/j.resconrec.2017.06.022.
[26] J. Liu, Z. Zhou, D. T. Pham, W. Xu, J. Cui, and C. Yang, "Service Platform for Robotic Disassembly Planning in Remanufacturing," *J. Manuf. Syst.*, vol. 57, pp. 338–356, Oct. 2020, doi: 10.1016/j.jmsy.2020.10.005.
[27] H. Wang, D. Xiang, Y. Rong, and L. Zhang, "Intelligent disassembly planning: a review on its fundamental methodology," *Assem. Autom.*, vol. 33, no. 1, pp. 78–85, Feb. 2013, doi: 10.1108/01445151311294801.
[28] M. Kaya, *Electronic Waste and Printed Circuit Board Recycling Technologies*. in The Minerals, Metals & Materials Series. Cham: Springer International Publishing, 2019. doi: 10.1007/978-3-030-26593-9.