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Selective cooperative disassembly planning based on multi-objective discrete artificial bee colony algorithm

Yaping Ren [a,b], Guangdong Tian [c,a,b,*], Fu Zhao [d], Daoyuan Yu [a,b], Chaoyong Zhang [a,b,**]

[a] School of Mechanical Science and Engineering, Huazhong University of Science & Technology, Wuhan, 430074, Hubei, China
[b] The State Key Laboratory of Digital Manufacturing Equipment & Technology, Huazhong University of Science & Technology, Wuhan, 430074, Hubei, China
[c] Transportation College, Jilin University, Changchun, 130022, China
[d] School of Mechanical Engineering, Division of Environmental and Ecological Engineering, Purdue University, West Lafayette, IN 47907, USA

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ABSTRACT

Disassembly sequencing has significant effects on the performance of remanufacturing and recycling of used or discarded products. Studies on disassembly sequence optimization have largely focused on sequential disassembly. However, for large or complex products sequential disassembly takes long time to complete and is rather inefficient since it removes only one part or subassembly at a time with only one operator assigned to disassemble a product. This work studies selective cooperative disassembly sequence planning (SCDSP) problem which is essential to disassemble large or complex products in an efficient way. Similar to sequential disassembly planning, SCDSP aims at finding the optimal disassembly task sequence, but is more complicated. SCDSP is a nonlinear NP-complete combinatorial optimization problem, and evolutionary algorithms can be adopted to solve it. In this paper exclusive and cooperative relationships are introduced as additional constraints besides the common precedence relationship. A novel procedure to generate feasible cooperative disassembly sequences (GFCDS) is proposed. A mathematical programming model of SCDSP is developed based on the parallel disassembly characteristics with two optimization objectives i.e. disassembly time and profit, considered. A multi-objective evolutionary algorithm (MOEA), i.e., multi-objective discrete artificial bee colony optimization (MODABC), is adopted to solve the problem to create the Pareto frontier. This approach is applied to real-world disassembly processes of two products (a small product and a medium/large one) to verify its feasibility and effectiveness. Also, the proposed method is compared with the well-known NSGA-II. For our comparative study, the nondominated solutions of the two MOEAs are compared in both cases, and two quantitative metrics, i.e., inverted generational distance (*IGD*) and spacing (*SP*), are adopted to further measure the algorithm performance. Results indicate that the set of nondominated solutions from MODABC are better for each instance tested, and the Pareto front is overall superior to that from NSGA-II. For both cases, *IGD* and *SP* are decreased by up to 81.5% and 62.2%, respectively.

1. Introduction

Due to growing concerns on resource depletion and environmental degradation, the recovery and management of obsolete or used products have attracted world-wide attention. These products contain a large number of mineral resources, e.g., gold, iron, and aluminum. However, they often also contain harmful and toxic elements, e.g., lead and chromium. To promote recycling and remanufacturing, finding a way to carry out safe and efficient disassembly is critical (Gungor and Gupta, 1997; Ren et al., 2017; Tang et al., 2002; Zhang et al., 1997). As a result, disassembly modeling and planning has been a topic of great interest.

Disassembly modeling methods mainly include undirected graph, disassembly tree, directed graph, AND/OR graph, and Petri net (Bentaha et al., 2015; Gao et al., 2003, 2004; Tang et al., 2001; Zussman and Zhou, 1999; Liu et al., 2017). Using disassembly model, the goal of disassembly planning is to determine the best disassembly sequence i.e. the order for separating a product into its constituent parts, components, or subassemblies.

Generally, disassembly can be classified into complete disassembly and selective disassembly (Smith and Hung, 2015). A complete

* Corresponding author at: Transportation College, Jilin University, Changchun 130022, China.
** Corresponding author.
E-mail addresses: tiangd2013@163.com (G. Tian), zcyhust@hust.edu.cn (C. Zhang).

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disassembly requires disassembling all high-value parts and all low-value parts (Desai and Mital, 2003), while a selective disassembly only removes specific high-value or high-impact parts (Smith et al., 2012). Hence, selective disassembly can minimize disassembly cost and maximize profit. In term of the logical disassembly sequence, disassembly can also be categorized into sequential disassembly and parallel disassembly (Dutta and Woo, 1995). For sequential disassembly, only one part or subassembly is disassembled at a time, i.e., one disassembly operation is performed at any given time. Different from a sequential disassembly, in parallel disassembly (also called cooperative disassembly) more than one disassembly tasks can be done at the same time and two or more subassemblies or parts can be removed simultaneously. That is, several operators can perform different operations in parallel. Comparing with one operator in sequential disassembly (Zhang and Zhang, 2010), collaborative division among multiple operators to disassemble some large or complex products can significantly shorten disassembly time and improve efficiency. In practice, several performance indicators are used to evaluate the performance of a disassembly sequence, with the two common indicators being disassembly time and profit. Accordingly, disassembly planning becomes a single objective or multi-objective optimization problem.

Similar to sequential disassembly planning (SDP), cooperative disassembly planning (CDP) is a NP-complete problem. When the problem size (i.e., the number of components in the product to be disassembled) increases, the solution space exponentially increases, and it is difficult to find the optimum solution in reasonable time. Further, CDP is more complex than SDP since CDP is a nonlinear programming problem which allows that more than one operator removes cooperative disassembly tasks at the same time (Zhang and Zhang, 2010). Finding the global optimal becomes challenging and may not be possible. In this work, a hierarchical assembly tree is transformed into an operation-dependent hierarchical disassembly tree (OHDT) to illustrate the relationships between subassemblies and operations in which three restricted relationships are defined for cooperative/parallel disassembly planning (CDP), i.e., precedence, exclusive and cooperative relationships. A selective CDP considering two optimization objectives i.e. disassembly time and profit is established and a multi-objective discrete artificial bee colony algorithm (MODABC) is developed to solve this complex problem. Two real-world cases are investigated to demonstrate the feasibility of the proposed approach. Also, the comparisons with the well-known NSGA-II are given to further verify the performance of MODABC. In the current research, a quantitative performance comparison is implemented by two metrics, i.e., inverted generational distance (*IGD*) and spacing (*SP*), which effectively indicates the superiority of the proposed approach.

The rest of this paper is organized as follows. Section 2 reviews the related work. Section 3 describes SCDSP and Section 4 establishes its mathematical model. Section 5 shows MODABC. Section 6 presents the Pareto solutions for two real cases and comparison. Finally, Section 7 concludes our work and describes some future research issues.

2. Related work

Many approaches have been developed for disassembly planning (Tang et al., 2002; Zhang et al., 1997; Tian et al., 2017a), e.g., two-commodity network flow method (Lambert, 1999), and rule-based recursive approach (Smith and Chen, 2011). Due to the complexity of the problem, heuristic algorithms are usually adopted to determine the "optimal" disassembly sequence, e.g., rapidly-growing random tree-based algorithm (Aguinaga et al., 2008), genetic algorithm (GA) (Li et al., 2005), improved max–min ant system (Liu et al., 2012), self-adaptive simplified swarm optimization method (Yeh, 2012), path-relinking approach (Adenso-Diaz et al., 2008), and neural networks (Cook et al., 2000; Tian et al., 2011).

It is noted that the above research focuses on sequential disassembly, while CDP has received much less attention. This is especially true for the selective cooperative disassembly process. Behdad et al. and El-Sayed et al. adopt transition matrices to describe a selective disassembly and use mixed integer linear programming and genetic algorithms (GAs) to obtain sequential disassembly plans (Behdad et al., 2009; El-Sayed et al., 2012). Smith et al. use disassembly sequence structure graphs (DSSGs) and expert rules to determine the subassemblies/parts to be selectively dismantled. The DSSGs depict how to establish a set which comprises minimum removed parts to reach selected (target) parts. The disassembly process is conducted by the expert rules which can create the sequences of removed parts subjected to some physical constraints in practice. Likewise, this method cannot deal with disassembling multiple parts at the same time (Smith et al., 2012). Han et al. obtain selective disassembly sequences via a disassembly precedence graph and linear programming method. The approach can solve multi-objective selective disassembly sequence problems. However, it remains a SDP i.e. removing only one part at a time. Thus, the total disassembly time and cost cannot be reduced effectively (Han et al., 2013).

Recently, parallel disassembly has been explored due to the necessity of recycling large and complex products. Kang et al. transform a AND/OR graph into an extended process graph to describe the precedence relationship among subassemblies/parts, and disassemble subassemblies/parts in parallel based on precedence relationship. Unfortunately, this method cannot guarantee the final parallel disassembly sequences are definitely feasible since not all the constraints in parallel disassembly are considered (Kang et al., 2001). Zhang and Zhang propose a disassembly hybrid graph model (DHGM) to explain the connection structure between parts, and calculate the minimum work time via branch-and-bound algorithm. However, this research focuses on producing complete cooperative disassembly sequences without considering disassembly costs (Zhang and Zhang, 2010). Smith and Hung use modular design theory to transform parts into modules, and disassemble parts according to recursive rules. Then an optimized selective parallel disassembly sequence is created via GA. The method only considers a single target i.e. disassembly cost, which is not the same as the profit gained from recycling end-of-life (EOL) products (Smith and Hung, 2015).

Analyzing the current state of the art, we can see that a selective cooperative disassembly sequence planning (SCDSP) considering the total disassembly time and profit is of great significance for repair, reuse, remanufacturing, or recycling but not well studied. Furthermore, previous research has mainly focused on disassembly sequence optimization with a single target, i.e., disassembly time, or cost. In practice, a decision-maker may consider more than one objective, thus multi-objective optimization is needed. This work aims to establish a multi-objective optimization model for SCDSP based on OHDT from both economical and efficient perspectives.

3. Description of selective cooperative disassembly planning

A regular sequential disassembly is well noted and has been studied for decades (Dutta and Woo, 1995), in which only one part or subassembly is disassembled at a time, i.e., a single disassembly operation is performed at one point. On the contrary, two or more disassembly tasks can be done simultaneously in the parallel disassembly procedure. Obviously, it can take less disassembly time than a sequential one to obtain the same parts or subassemblies from one product especially for some complex and large products. Moreover, time is crucial to a disassembly sequence which indicates disassembly efficiency and has great impact on the cost or revenue of a disassembly process. Hence, minimizing the total time for SCDSP is determined as one optimization goal.

In general, the disassembly process is labor-intensive and thus more expensive compared with destructive processes such as dismantling and shredding. However, because disassembly leaves components intact, it also offers an opportunity for obtaining higher revenues compared with materials recycling. Additionally, end-of-life disassembly is encouraged for its economical benefit and appropriate processing of discarded complex products aims at the recovery of as much as possible of their