Computers in Industry 75 (2016) 13–26

Contents lists available at ScienceDirect

Computers in Industry

journal homepage: www.elsevier.com/locate/compind

Integrated multi-layer representation and ant colony search for product selective disassembly planning

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ARTICLE INFO

Article history:
Received 10 April 2015
Received in revised form 27 August 2015
Accepted 28 October 2015
Available online 13 November 2015

Keywords:
Selective disassembly
Product representation
Sequence optimization
Product maintenance

ABSTRACT

Selective disassembly plays an important role in product life cycle to meet requirements of the product repairing, reusing and recycling. An efficient disassembly plan is essential to minimize processing time in product maintenance for cost saving. This paper introduces a method for integration of the multi-layer product representation and the optimal search in product selective disassembly planning. The multi-layer representation is based on the product structure formed in product design. The method enables an efficient search for the disassembly sequence. Unlike the existing product representation methods, the multi-layer representation is a dynamic product data model integrated with an ant colony search process for a near optimal solution. Industrial applications have proven the method effectiveness.

1. Introduction

Disassembly is an operation in either product maintenance to replace the failed part of the product, or for recycling reusable parts of an end-of-life product to reduce the impact on environments and maximize the utilization of resources [1,2]. A product has to be separated into individual components in the repairing or recycling process, which is called the disassembly operation. Disassembly is a key operation to divide a product into separated parts [3]. Disassembly planning ensures feasible operations of a disassembly based on criteria of the solution search [4].

Generally, a final product consists of several subassemblies, each subassembly contains different components to meet variant requirements of the product function. Disassembly planning searches for feasible disassembly sequences based on product structure. The product structure is decided in the product design stage including product components and subassemblies. Usually, a product can be disassembled in different sequences with different time and cost [5]. Optimization is used to find an optimal solution of disassembly plans. Since the cost can be measured by time used to complete an operation, an optimal plan is commonly measured based on the minimum time of the product disassembly [6].

Based on disassembly tasks in a product life cycle, disassembly requirements can be classified into complete disassembly and selective disassembly. The complete disassembly separates an entire product into subassemblies, then components, which is similar to the reverse processing of an assembly. In contrast, the goal of a selective disassembly is to separate only target components in a product, which is used to obtain reusable components of an end-of-life product, or for component repairing in the product maintenance. Compared to the entire components disassembled in a complete disassembly, the target component in a selective disassembly is uncertain depending on the product state and applications. Considering the importance of the selective disassembly in product maintenance and reuse, this research discusses process planning for the selective disassembly.

Selective disassembly planning decides the sequence of a product disassembly to remove a target component, which has more challenges than an assembly and complete disassembly as its final goal may not be known in the product design stage. The failure part can be any component in a product depending on the product usage. It is normally not sure in the product design stage for components to be reusable or recyclable at the end of the product life [7].

As both complete and selective disassembly planning methods are based on the same structure of a product, a product representation and plan search method may be used for both planning processes. However, the search efficiency is different. For example, most of the disassembly planning methods generate all

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http://dx.doi.org/10.1016/j.compind.2015.10.011
0166-3615/

feasible sequences first, then search for an optimal solution using optimization algorithms with some criteria, such as Zhu et al. [8] searched an optimal solution in all available feasible disassembly sequences using a linear programming model. Wang and Xiang reviewed different methods of disassembly planning [9]. Different methods for disassembly planning have been proposed for the efficient generation of disassembly sequences [10], such as using the lowest level of a product graph for the feasible disassembly sequence of selective disassembly [11], and the product data update in the selective disassembly operation [12]. However, some of these methods are only effective for a certain type of product models. Some of them have problems of computation-intensive and time-consuming. There is not an effective method for the product representation and optimal sequence search for selective disassembly planning.

This paper proposes the integration of the sequence search and plan optimization to improve the search efficiency of selective disassembly planning. An integrated method of the product representation and the optimal search is developed. Unlike the existing product representation methods, a multi-layer representation based on the product bill-of-material (BoM) introduced in this paper is a dynamic product data model, which is integrated with an ant colony-based search process for a near optimal solution. The efficiency of disassembly planning can be significantly improved.

Following section will first review research on product representation and disassembly planning. A method is then proposed to improve the existing methods. Section 3 introduces the proposed product representation that is a multi-layer matrix method based on the product BoM. In Section 4, an ant colony searching method is discussed for the optimal search. Criteria and evaluation methods are also introduced to find the near optimal sequence. Disassembly simulation is conducted to visualize the operation detail in Section 5. Industrial case studies are presented in Section 6 to verify the proposed method followed by conclusions and further research discussed in Section 7.

2. Related work

A process flow of selective disassembly planning is shown in Fig. 1. A feasible disassembly depends on product's geometric structure, components' relationships, constraints of the selected component for removing, tools required in the operation, space accessibility for the tool application, and complexity of components and fasteners to be removed in order to disassemble a target component. There are different factors considered for the feasibility of a disassembly plan. As disassembly planning is based on the product structure decided in product design, a representation of the product structure directly affects the plan search efficiency. The product representation and disassembly

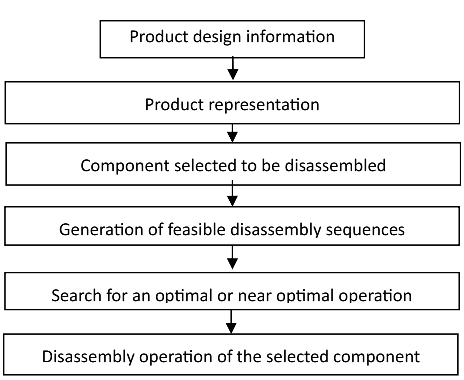

Fig. 1. Selective disassembly.

sequence search have a close relation [13]. The disassembly sequence search is conducted based on the product representation. There are three basic elements in a disassembly planning system including the product representation, sequence search, and solution optimization.

Product representation is essential for product disassembly modelling. Product representation describes details of the product structure, components, constraints and connections. There are different methods of product representations for disassembly planning [4,14,15]. Commonly used methods of the product representation are graph-based methods, disassembly Petri Nets, and matrix-based methods. The disassembly sequence can be searched based on these representations using either a complete search or heuristic algorithms.

2.1. Product representation

2.1.1. Graph-based representation

There are different forms of the graph-based product representation. AND/OR graph is a widely used product representation in disassembly planning [16]. An AND/OR graph consists of nodes and hyperarcs. The nodes stand for components or subassemblies in a product, while disassembly tasks are represented by the hyperarcs [17]. Two or more components or subassemblies can join together to form a more complicated subassembly [18]. The graph has a hierarchical structure. The nodes in the graph are labelled as either "AND" or "OR" branches. The vertical links are "AND" relations. "AND" successors are subassemblies that are split from the upper node, while nodes linked in the same level are "OR" relations. "OR" branches indicate alternative subassemblies, any of which can generate a sequence. An AND/OR graph can show all possible sequences of a product disassembly. It has been used in different applications such as the representation of the satellite equipment for increasing the planning flexibility [19]. Combining weights and the AND/OR graph, a weighted AND/OR graph was used to represent the product structure and element constraints for disassembly planning [20].

Another type of graph-based methods, the adjacent graph, is also used to represent component relationships of a product [21]. Nodes in the graph represent components or subassemblies of the product. Relationships between connected components or subassemblies are represented by directed lines or undirected lines. A directed line or undirected line in the adjacent graph usually represents relationships of two components. The adjacent graph can include more information of component constraints for product structure compared to AND/OR graphs. The adjacency graph has been used to represent the door of a dishwasher for disassembly planning [22].

Graph-based methods can represent relationships of different components or subassemblies in a product. But the graph is difficult to be generated from product design information automatically [20,23]. It can only be used for the product that has the simple structure with few components. Otherwise, the representation may become very complicated [24]. Graph-based methods also require a large search space and much time for achieving an optimal solution [25], which is computationally complex as it may cause combinatorial explosion problems for products with numerous elements [26,27].

2.1.2. Disassembly Petri Net

Petri Net (PN) is a graphical method to represent the structure relation of a product or system for analysis modelling. A disassembly PN consists of the token, places, transitions and arcs with operation rules. Token stands for a product, places represent subassemblies and/or components, while transitions are equal to actions, arcs are similar to hyperarcs in AND/OR graphs for