A Product Disassembly Model Based on Hybrid Directed Graph

LI，Fang-Yi*
School of Mechanical Engineering, Shandong University, Jinan 250061, China
e-mail: lifangyi@sdu.edu.cn
LI, Jian-Feng
School of Mechanical Engineering, Shandong University, Jinan 250061, China
e-mail: ljf@sdu.edu.cn
LI, Jian-Zhi
Department of Manufacturing, the University of Texas, Edinburg, TX 78541, USA
e-mail: jianzhili@utpa.edu
DUAN, Guang-Hong
Department of Precision Instruments and Mechanology, Tsinghua University, Beijing 100084, China
e-mail: duangh@tsinghua.edu.cn

Abstract

Effective product disassembly modeling is a key problem in products disassembly analysis. A hybrid directed graph disassembly analysis model is proposed based on graph theory, constraint, and assembly topology concept. While the vertices of the graph represent the parts or components of a product, the directed edges (arcs) represent the component disassembly topological constraints, disassembly sequence precedence, and required disassembly operations. The various constraints including directed constraints, virtual constraints and undirected constraints are introduced to describe the complex disassembly relationships between or among subassemblies. Furthermore, pre-constraint and post-constraint group model are proposed to describe the multiple disassembly scenarios problem and the incomplete disassembly problem. Therefore, the restricting and restricted relationships between subassemblies can be described by constraint chains mentioned above clearly. Finally, the model's application is illustrated with a disassembly example.

Keywords: Disassembly; Green Manufacturing; Directed Graph; Disassembly constraints; Constraint chain

1 Introduction

Product disassembly is one of the most extensively addressed research fields in green product design and manufacturing, maintenance, and remanufacturing. An important problem in product disassembly is product structure modeling and its application in product disassembly process planning, which are required in product disassembly analysis and decision making [1,2].

Most popular product structure modeling methods include Directed Graph [3,4,5], Undirected Graph [6], AND/OR Graph, Petri net[7], and Disassembly Tree[6]. In a Directed Graph model, a vertex is used to represent a part, a component, or a subassembly of a product under study, and the edge (or arc) between vertexes is generally used to describe the disassembly constraints and disassembly sequence. The disassembly sequence can be easily presented by the directed graph model. Comparing with Directed Graph model, Undirected Graph model is simpler; however, it is difficult for it to describe disassembly sequences clearly.

Sanderson and Homem de Mello[8] describe products assembly and disassembly relationship by use of AND/OR graph[9,10]. AND/OR graph can represent all possible disassembly paths with fewer vertexes comparatively. However, there are usually too many cut sets in the analyzing process because of combination explosion, and it is also very difficult to reduce the cut sets number.

Another widely used model is product disassembly tree [11] in which the parts or components are represented as vertices of a tree, and the relationships between vertices represent the disassembly constraints. Ishii proposed a fish-bone graph to represent product's disassembly structure [12], which is also a kind of tree-like structure. Product tree can be easily imported from PDM or other product file, and then revised according to the disassembly demand to get the product disassembly tree. Disassembly tree is simple and easy to understand, but difficult to describe complicated disassembly constraints and their relationships.

In general, current literature review shows that Graph theory is the mainly modeling method, and the most of the modeling methods focus on how to disassemble vertices but not corresponding constraints, and thus lack of measures to describe the spatial constraints, constraints interference and other complicated concurrent and combining disassembly constraints.

In this paper, a hybrid directed graph disassembly model is proposed which focus on the following issues,

1) On the basis of directed graph, undirected constraints and virtual constraints are introduced to describe the complicated constraint relationships between or among parts and components, furthermore, the concept of AND/OR graph is applied to describe the group, concurrent and parallel relationships between or among disassembly operations.

2) Assembly information such as topology, connection and contact, et cetera should be used in product disassembly modeling process.

3) Strong and weak subassembly concept is introduced to describe materials, parts, components group relationships in order to solve the disassembly depth problem more efficiently.

2 Hybrid directed graph model based on constraints

In fact, the disassembly problems are the processes of removing constraints, and there are several constraint relationships between parts and components as follows,

1) Real constraints and virtual constraints: according to spatial relationships between parts and components, disassembly constraints can be presented as,

- Real constraint: the constraints such as contact, connection and fit are explicit, and reflect real constraint relationships between subassemblies. The subassemblies correspondent with the real constraints must be contact.
- Virtual constraint: Although some subassemblies don't contact, connect, or fit to each other, there are still interfere relationships when disassembling them, we call this kind of relationships as virtual constraint.

2) Precedence relationship: There are usually precedence relationship between disassembly constraints, such as only if constraint A is removed then constraint B can be removed, therefore we define that there is precedence relationship between constraints a and b, and denote it by P (A, B).

3) Group relationship: More than one constraint usually forms group, and only after the constraint group removed, subassembly can be disassembled further. We define the relationship between or among subassemblies in each group as "AND". Considering sometimes there are more than one constraints group, and removing either constraint group can make the disassembly process going on, then we define the relationship between or among these groups as "OR". For example, in figure 1(B), constraints a and b together form a disassembly constraint group I, and c alone can form another group II, therefore the relationship between a and b is "AND", which can be denoted as "$a \cap b$", and the relationship between $a \cap b$ and c is "OR", which can be denoted as $(a \cap b) \cup c$ and means that disassembly process can continue after either constraint group $(a \cap b)$ or c is removed.

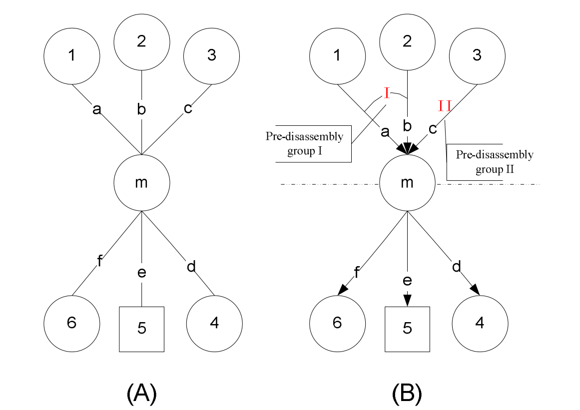

Fig. 1 Disassembly constraints (A) undirected graph

(B) directed graph and disassembly constraints groups

4) Pre-constraints and Post-constraints: Disassembling a subassembly usually need two steps, first some constraints need to be removed to get disassembly operation space, and we define these constraints as pre-constraints like a, b, c showed in figure 1. Secondly, other constraints need to be removed to release the parts or components, and we define these constraints as post-constraints like d, e, f showed in figure 1. By the definition, it is easy to know that pre-constraints always should be disassembled earlier than post-constraints.

5) Parallel relationship: if there is no special notification, there is no precedence relationship between or among pre-constraints, and there is also no precedence relationship between or among post-constraints.

6) Constraint chain: As mentioned above, there are precedence relationships between pre-constraints and post-constraints; moreover, there may be precedence relationships between or among pre-constraints or post-constraints themselves, which can be illustrated in graph as dashed arcs from constraining arc to arcs be constrained. We will discuss this further in detail in the following section.

7) Undirected constraint relationships: If there is no definite precedence relationship between two subassemblies correspondence with a constraint, then, undirected constraint can be used to describe this kind of relationship. Sometimes, destructive disassembly can be described by undirected constraints.

8) Combination relationships: Product parts and components can be combined into group as subassembly and be disassembled together. Subassembly can be classified as strong subassembly and weak subassembly. Some subassembly must be disassembled as a whole module firstly, and then parts or components in it can be disassembled further. We call this kind of subassembly as strong subassembly; otherwise, we call it weak subassembly. In contrast with Strong subassembly, we can disassembly weak subassembly as a whole at first or disassemble parts or components in it at first.

In general, hybrid directed graph extends the application of directed graph and improves its modeling ability.

The concept and application of the model can be further illustrated by an example shown in figure 2.

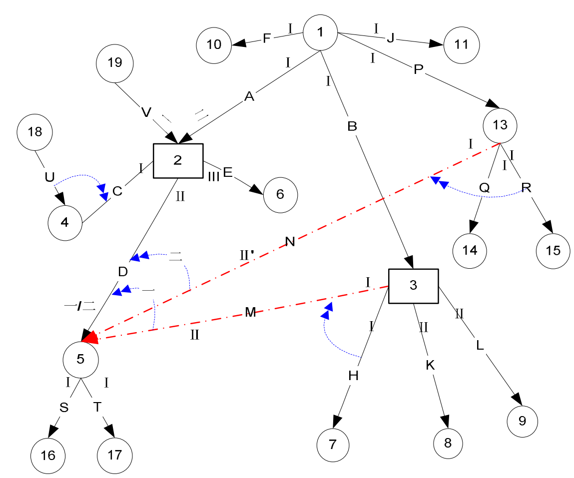

Fig. 2 A hybrid directed graph model

Arabic numerals 1, 2, etc denote the subassemblies, circle vertices denote product parts and rectangular vertices denote components. A, B, C marked on the arcs denote the disassembly constraints. Roman numerals I, II denote disassembly constraint groups. If no definite specification, all arcs directing into a vertex form a pre-constraint group and all arcs leaving from a vertex form a post-constraint group.

In figure 2, part 1 connects with part 10, 11, 13 and component 2, 3. If we want to disassembly 10, 11, 13, 2, or 3, we need remove constrains between 1 and them at first. These constraints are real constraints such as contact, connection, or fit. Moreover, there are also virtual constraints in it, for example, constraint M is a virtual constraint, which means part 3 must be disassembled before part 5 although they don't contact, connect or fit to each other. Considering constraints of part 5, M and D form a pre-constraint group I of it, at the same time, constraint D and another virtual constraint N form another pre-constraint group II, moreover, there is "OR" relationship between group I and II, which means removing either group can make disassembling 5 be possible.

Moreover, the constraint between component 2 and 4 should be undirected constraint because there are no definite disassembly precedence relationship between them, which means either 2 or 4 can be disassembled at first.

Hybrid directed graph can be used to describe product complete disassembly and selective disassembly problems easily, which can also be shown in figure 2,

- Disassemble component 2 completely: Then, all post-constraints need to be disassembled, however, there are two different pre-constraint removing scenarios I and II, so there are two scenarios to disassemble component 2 completely. One is removing constraints V and C, D, E; the other is removing constraints A and C, D, E.
- Disassembly component 2 incompletely: For example considering to disassembly part 6, there are two scenarios, one is removing constraints V and E, in this case, 2 still connects with 1, 4, and 5; The other is removing constraints A and E, in this case, 2 still connects with 19, 4 and 5.

Now, it can be easily understood that disassembling parts/components and disassembling constraints are two different concepts. The model can describe product selective disassembly problem easily because of the introduction of the constraint removing/disassembling concept.

3 Application of hybrid directed graph model

In this section, a simple product is used to illustrate the hybrid directed graph modeling and analyzing process.

Fig 3 is a simplified assembly graph of a computer graphics card. It is mainly includes main case 8, display card subassembly, system board subassembly, bolt 1 and 7. The graph display card subassembly includes card 4, fixing bar 2 and bolt 3. The system board subassembly includes system board 6 and card slot 5.

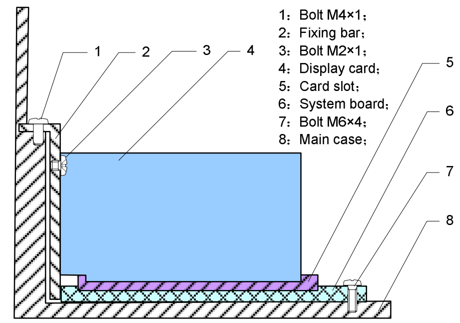

Fig. 3 Assembly structure of a computer display card

Based on the discussion above, the computer graph display card disassembly model can be built step by step as follows:

1) According to product assembly structure, analyze parts and components information and topology relationship;
2) Construct the undirected graph model layer by layer as shown as step 2 and 3 in figure 4.
3) Analyze the constraints between or among parts and components, identify the precedence relationship between or among constraints, find out the virtual constraints and undirected constraints, and build the preliminary hybrid directed graph model, as shown as the step 4 in figure 4. Doubled arrowed arc denotes the restriction relationship between constraints, such as the arc from constraint i to a which means a is restricted by i, and removing i should be in advance of removing a;

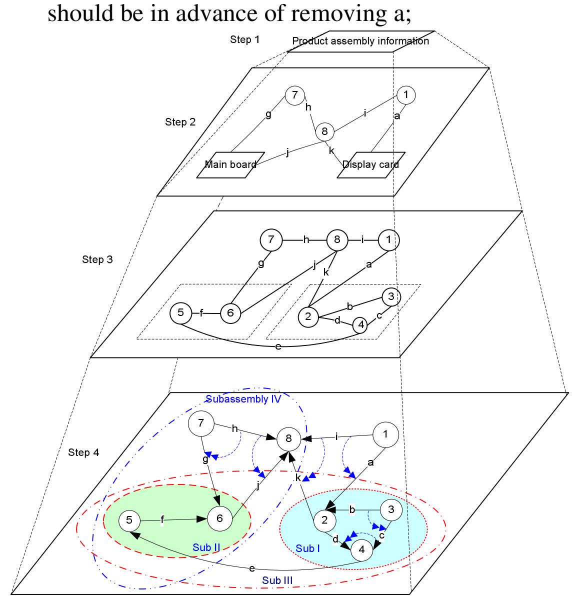

Fig. 4 Disassembly modeling processes of the display card

based on hybrid directed graph

4) Find out the strong subassemblies and possible weak subassemblies, such as strong subassembly I, II, and weak subassembly III, IV shown in figure 4. Subassembly I includes parts 4, 2 and 3. Subassembly II includes 6 and 5. Meanwhile, 5, 6, 7, 8 can also form weak subassembly IV, and 2, 3, 4, 5, 6 can form weak subassembly III. How to

disassemble and recycle should be determined according to economic or environmental analysis, or sometimes decided by people.

5) According to different group relationship, improve and finish the graph model as shown in figure 4.
6) Finally, construct the hierarchic hybrid directed graph model as shown in figure 5 based on strong subassembly I and II.

Considering part 4 as selective disassembly target in figure 4: Because part 3 belongs to strong subassembly I{2,3,4}, thus the disassembly sequence should be i→a→k→e, and thus get subassembly I, then remove constraints b, c, d, and thus get part 4. To sum up, the final disassembly sequence is i→a→k→e→b→c→d.

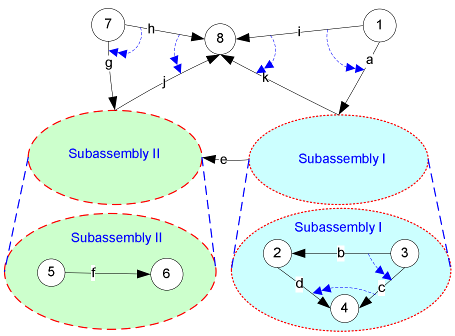

Fig. 5 Hierarchic hybrid directed graph model

If part 8 is the disassembly target, then {2，3，4，5，6} can be viewed as a subassembly as shown in figure 6. If this is the case, only need to disassemble bolts 1, 7, and move away the subassembly {2，3，4，5，6}. Therefore, in order to get part 8, the constraints removing sequence is i→a→k→h→g→j or h→g→j→i→a→k.

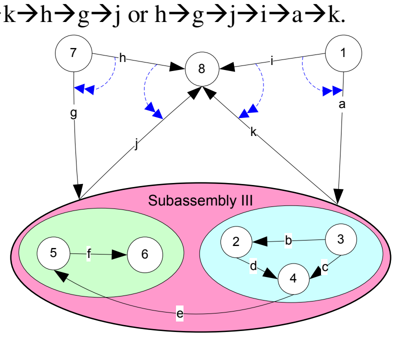

Fig. 6 Part 8 as the disassembly target

To disassemble the whole assembly completely, the hierarchic hybrid graph model (fig. 5 and 6) can be used. It is apparent that subassembly without in-arc and with out-arc only should be disassembled in advance, and considering to disassemble subassembly groups at first. Finally, we get the following feasible constraints removing sequence:

i, a: 1→h, g: 7→e, k {2, 3, 4} →j: {5, 6}, 8→b, c: 3→d: 2, 4→f: 5, 6

According to relevant recycle regulations, it is much more economical to disassemble {2, 3, 4} as a group, and the same with {5, 6}. Therefore, the corresponding constraints removing sequence is:

i，a：1→g，h：7→e，k：{2，3，4}→j：{5，6}，8

4 Conclusions

Based on constraint and hierarchy concept, this paper proposed a hybrid directed graph model in support of product disassembly analysis. The concept of constraints removing but not nodes removing is the essence of the model and furthermore the essence of disassembly problem. Directed, undirected and virtual constraints can describe the complicated disassembly constraint relationship between or among parts and components. Moreover, the concepts of pre-constraints, post-constraints and their group can describe the incomplete disassembly problem easily. Besides, the introduction of the concept of strong and weak subassembly can be of great help in disassembly sequence and depth decision process. Comparing with various models currently used, hybrid directed graph disassembly model is easy to understand, simple to apply and convenient to handle complicated products disassembly problem.

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*Contact author lifangyi@sdu.edu.cn;
phone 86-13805310890; School of Mechanical Engineering, Shandong University, 73# Jingshi Road, Jinan, 250061, China.