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Precedence Constraint Knowledge-based Assembly Sequence Planning for Open-Architecture Products

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Abstract

This paper discusses feasible assembly sequences for Open-architecture products (OAPs). A structure diagram of OAPs and a product assembly constraint matrix are proposed to represent the precedence constraint knowledge among parts and modules. Considering that an independent functional module may not be independent in its spatial structure, a module of OAPs is first evaluated for its possibility to be assembled as a single sub-assembly. If it cannot be assembled as a sub-assembly, it will be divided into several sub-assembles or parts to adjust the product hierarchical graph. Combining with module types of OAPs, feasible assembly sequences of modules and parts are finally generated using the hierarchical precedence method. An industrial paper-folding machine is used as an example to verify the proposed method.

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Keywords: Open-architecture product, assembly sequence planning, assembly modeling, assembly constraint matrix;

1. Introduction

Open-architecture products (OAPs) use adaptable design methods to meet different needs of users [1]. OAPs allow users to design, manufacture or purchase personalized functional modules added on an original product to meet changeable requirements in the product lifespan [2, 3], which requires that OAPs are assembled and disassembled easily when users update their personalized modules. Introduction of assembly sequence planning (ASP) can reduce the cost and improve the operation efficiency of OAPs. As OAPs use the modular structure [4], assembly sequence planning of OAPs has to consider both operations for modules of OAPs and for parts inside a module of OAPs.

One of the purposes of the OAP planning is to achieve independent functional modules to be operated separately. But due to restrictions of the function correlation, the space correlation and information interaction of components, OAP modules formed by module planning methods cannot guarantee that both functional independence and spatial structure independence are satisfied [5]. Therefore, one module with functional independence may not be assembled as a sub-assembly.

Assembly modeling needs product information, such as geometric constraints and connection relationships among parts from the 3D product model. Assembly model information includes product information, hierarchical relationships among parts in the assembly, the assembly location and directions [6]. These information details have to be represented in a property form for the assembly modeling [7, 8]. Compared to commonly used methods of the product representation, an assembly hierarchy semantic description is mostly used for retrieving the similar assembly model [9, 10]. Product bill of materials (BOM) includes parts information with a hierarchical structure of a product [11].

Assembly modeling for OAPs has to consider the connection and assembly precedence sequence in the relative space among modules of OAPs and parts in the modules. The BOM hierarchy graph can represent the hierarchical structure and parts list information, the product structure graph provides assembly constraint relations. For the ASP of OAPs, considering their characteristic and space constraints, a matrix

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model can be combined with the analytic hierarchy process proposed in the literature [12].

This paper proposes a suitable modeling method for OAPs. The BOM hierarchy graph is used to describe OAP module hierarchies and parts information. Using the assembly constraint matrix, modules are analyzed if they can be assembled individually as sub-assemblies. Conditions of the serial assembly and parallel assembly are used to search the assembly level of parts and modules. Following definitions and assumptions are used to conduct the research discussed in this paper.

Definitions

- Support platform module: In a product assembly process, a module used as the assembly baseline is called the support platform module. Other modules are added in this module sequentially to complete the assembly of an entire product.
- Basic part: In a process of parts assembly inside a module, a part used as the assembly baseline is called the basic part. Other parts are connected to this part sequentially to complete the assembly of an entire module.

Assumptions

- Modules that cannot be assembled as a sub-assembly are divided into several sub-assemblies or parts. They still belong to the same BOM module layer. After a module is divided, a separated part is considered as a module to plan the assembly sequence with other modules.
- If several assemblies have same part numbers, shape and materials, they can be divided from the module to be an independent assembly, called alike-type assemblies. Each of them should have more than two parts.
- Module types of OAPs are known from the product design.

2. ASP for OAPs

An assembly is composed of sub-assemblies and parts. However, sub-assemblies of an OAP may be sets of parts as well as modules. ASP steps are: (a) Modules of an OAP are first evaluated for their possibility to be assembled in a single sub-assembly. (b) ASP for parts in each module. (c) ASP for modules of the OAP based on the BOM layer.

A structure diagram, assembly constraint matrix and direction matrix are established based on the product design and BOM. A module of the OAP is evaluated for its possibility to be assembled as a sub-assembly based on the simplification matrix, alike-type assembly and direction matrix. If a module cannot be assembled in a sub-assembly, it will be divided, and the BOM hierarchy graph is adjusted. Then the assembly sequence of parts inside modules is generated based on the assembly constraint matrix and conditions of sub-assemblies.

2.1 Alike-type assembly

As described in the assumptions, if several assemblies have same number of parts, similar shape and materials, they are called alike-type assemblies. They can be treated as independent modules to simplify the assembly constraint matrix.

2.2 Bill of materials (BOM)

A hierarchical graph can be established based on the product to describe hierarchies of OAPs. If M_k is a module, P_b^k is a part of M_k, and b^k is the total number of parts in M_k while k is the total number of modules.

2.3. Product structure diagram and assembly constraint matrix

A product structure diagram G = {E, V, W} is used to describe the precedence constraint knowledge of OAPs. Where E = {E_1, E_2, ..., E_n}, E is a set of non-null nodes. V = {V_1, V_2, ... , V_m}, W is a set of undirected edges used to connect nodes, W = { W_1, W_2,... , W_q}, W is a set of directed edges used to connect nodes. In this paper, Assembly = {P, WS}. P = {P_1, P_2, ..., P_n } to represent the parts of OAPs. WS=[WS_{ij}] represents the assembly constraint relationship defined as follows:

- ws_{ij} =1: a connection relation exists between P_i and P_j but P_i must be assembled before P_j;
- ws_{ij} =-1: a connection relation exists between P_i and P_j but P_i must be assembled after P_j;
- ws_{ij} =2: a connection relation exists between P_i and P_j but P_i can be assembled before or after P_j;
- ws_{ij} =9: there is no connection between P_i and P_j, but P_i must be assembled before P_j;
- ws_{ij} = -9: there is no connection between P_i and P_j, but P_i must be assembled after P_j;

WS_k represents the assembly constraint relationship among the parts in M_k. Remaining parts except parts in M_k of OAPs are P_1, P_2, …, P_i. SM_k is a simplification matrix which represents the assembly constraint relations among P_1^k, P_2^k, …, P_b^k, and remaining parts P_1, P_2, …, P_i. BM^{ij} represents the assembly constraint relation between P_1^i, P_2^i, …, P_b^i of module M^i and P_1^j, P_2^j, …, P_b^j of module M^j.

2.4. Direction matrix

The direction matrix DM describes feasible assembly directions of parts. There are six assembly directions: x, -x, y, -y, z, –z in an x-y-z coordinate system. DM = [dm_{oj}], where o={x, -x, y, -y, z,-z}, represents the direction sets, j = {1^k, 2^k,…, b^k}, dm_{oj} = 0, 1 as follows.

- 0 represents that part b^k cannot be assembled.
- 1 represents that part b^k can be assembled.

2.5. Analysis of a module to be able to be assembled in a single sub-assembly

Following steps are applied in the analysis:

Step 1: Each part in a module is examined if it is embedded within two or several other parts belong to different modules;

Step 2: For column elements in SM_k, if they are not all positive or negative values but the element 0, M_k cannot be assembled in a sub-assembly.

Step 3: According to the direction matrix, if there exist one row where all elements are 1, this module can be assembled in a sub-assembly. Otherwise, it will be divided into several