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Disassembly information model incorporating dynamic capabilities for disassembly sequence generation

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ABSTRACT

Industrial recycling and reusing is becoming more and more important due to the environmental and economic pressures. It involves disassembly activities to retrieve all the parts or selected parts. An information modeling for the disassembly and optimal disassembly sequence generation based on the information model becomes critical. Unlike the traditional graph based representation of product structure, this paper introduces an efficient and machine readable disassembly information model and then discusses a linear programming based optimization model for obtaining the optimal disassembly sequence from the proposed disassembly information model. A key feature of this approach is the incorporation and use of dynamic capabilities in its information model processing technique. Dynamic capabilities are added into the information model to handle state-dependent information such as parts' disassembly directions which may change after each disassembly operation. The overall information model is built in UML, and dynamic capabilities are represented as events in UML. The proposed method has been illustrated using an electrical–mechanical device.

1. Introduction

Sustainable manufacturing is a key topic nowadays. One important issue is to extend the product life cycle, which means to send the disposed product back into the manufacturing chain for remanufacturing, recycling, or reuse. How to perform these EOL (End of Life) activities efficiently and economically is a significant research problem. Disassembly is the first step associated to all of these EOL activities.

The current design process concerns little about EOL issues such as disassembly. Even though there is some information about the disassembly process such as BOM (Bill of Material), flow chart, etc., it is scattered, disorganized and machine unreadable. This paper presents a disassembly information model which solves one major problem in the disassembly process, sequence generation, by adding dynamic capabilities into the model. Also, the model is extensible; other information regarding the disassembly process such as disassembly equipment, inspection, disassembly feature, etc. that may be required to develop a complete, open disassembly model, can be easily added as required.

The feasible disassembly sequences of a product could be numerous and their generation process could be complicated as the number of the parts in the product increases. A lot of redundant or inefficient sequences could be generated from the information model, although they are feasible. This paper presents a linear programming-based optimization model for finding the optimal sequences. The linear programming model will use all available feasible sequences (in the forms of an AND/OR graph and a task precedence graph) generated from the disassembly information model as the input in order to yield an optimal solution.

2. Literature review

In a product disassembly system, modeling the product topology and geometry information is important, especially for generating the disassembly sequences. A number of graph based modeling strategies have been used before, such as AND/OR graph [1,9], directed graph [1,9], disassembly petri net (DPN) [2,3,9], and so on. These graph-based representations work well for mathematical analysis, like system optimization. However, the graph-based techniques do not consider product's geometrical and topological information data bases to start with. To build an automated system, a complete and comprehensive product information model must be included, which will represent concepts, relationships, constraints, rules, and operations (along with product's structural information) to specify data semantics for the required disassembly domain. It can provide sharable, stable, and organized structure of information requirements as needed in the context of a given domain. Some works related to the product information model have already been carried out by NIST, like CPM (Core Product Model) [5,6], OAM

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(Open Assembly Model) [7], and disassembly information model [8]. These models are intended to capture the engineering information commonly shared in product development with different focus. In the following paragraphs, some significant research works have been briefly discussed in two areas: (i) the graph-based assembly structure modeling, and (ii) the complete product information modeling.

2.1. Graph-based assembly structure modeling

2.1.1. AND/OR graph

An AND/OR graph is a directed graph G=(N, D), where N stands for nodes that denotes a product, part or subassembly. D stands for hyper arcs which represents the set of feasible disassembly operations. Each node i can have k ($k>=1$) disassembly methods, forming an OR-relation; if an operation disassembles node i into m ($m>2$) nodes, m arcs link node i to these m-nodes, and form an AND-relation. Fig. 1 is a simple example of the AND/OR graph of a product. Arc 1 in the figure represents disassembly operation 1 and assembly ABCDE can be disassembled into subassembly ABCD and part E (which is not shown in Fig. 1) through disassembly operation 1. Similarly, operation 3 disassembles subassembly ABCD into subassembly AB and subassembly CD. Each path in the AND/OR graph forms a feasible disassembly sequence. In Fig. 1 for example, path 1–3 is one of the feasible disassembly sequences.

2.1.2. Task precedence graph

Instead of representing nodes as parts and sub-assemblies, in task precedence graph nodes represent disassembly operations. Two disassembly operations are represented by two nodes connected by a directed arc signifying one operation proceeded by the other. If the AND/OR graph in Fig. 1 is translated into a task precedence graph, it will look as Fig. 2 above.

Please note that the Operation 0 has been considered as a pseudo operation. It is the initialization of the disassembly process. After initialization, either operation 1 or operation 2 can be executed. The doubly directed arc means either one operation can be done before or after the other one, e.g. operation 1 can be done after operation 2 and vice versa.

Though the task precedence graph is a derivative of an AND/OR graph, it is needed for our proposed optimization model, because

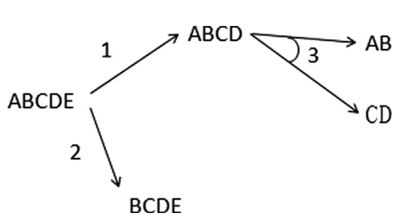

Fig. 1. An example of AND/OR graph.

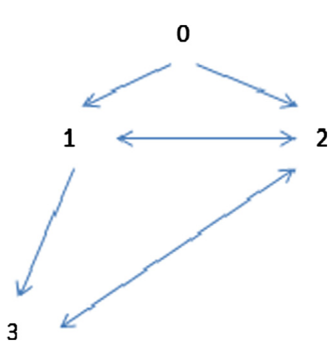

Fig. 2. The task precedence graph of Fig. 1.

in our formulations, the cost of a particular disassembly operation is directly dependent on its previous operation. This sequence-related information (Any goal node could be arrived at following more than one path from a given starting node) is not explicit in the AND/OR graph, but it is easily observable in the task precedence graph; for example, it is not clear from the AND/OR graph that operation 3 can be done after operation 2 (Fig. 1). It will be further discussed in details in the following sections.

2.2. The complete product information modeling

Information modeling [4] originally comes from software engineering for building system architecture. These years, it has been applied on domains like manufacturing. Before developing disassembly information model, a review of the product information model will be helpful. There are some efforts reported in the development of ontology-based models [17], but they are more concerned about the product life cycle management issues in generic terms and the capabilities of rule-based inference systems built in ontology are quite limited. Thus, complicated algorithms can be hardly implemented in ontology. The product information such as geometry, feature and assembly [16] has been standardized in ISO 10303-203 and ISO 10303-224, and some of them have been already implemented in commercial CAD packages. However, information related to design issues including sustainability and manufacturing processes is either missing or incomplete in these ISO-based models. As noted before, a notable development in this field is NIST's core product model (CPM). It is a unified modeling language (UML) based model intended to capture the full range of engineering information commonly shared in product development [5]. CPM focuses on modeling the general, common and generic product information and excludes the information which is domain specific. NIST developed another information model called "open assembly model" (OAM) [7,10] which extends CPM. Along with structural information, it represents the function, form, and behavior of the assembly, and defines a system level conceptual model.

Another disassembly information model [8] recently developed by NIST provides a general framework of disassembly process. The model consists of six major packages—(i) support data package, (ii) feature package, (iii) tolerance package, (iv) work piece package, (v) equipment package and (vi) workflow package. The information content in these packages could be used for disassembly sequence identification, feature modeling, equipment modeling and inspection process modeling.

The *process* class in the NIST disassembly information model could be used to represent information regarding one possible disassembly sequence (of the disassembly AND/OR graph). Each sequence has several process elements which are disassembly operations. Each operation comprises of several tasks.

In order to formulate disassembly sequence identification, NIST model assumes that the AND/OR graph is known and then translates the information into corresponding classes with constraints. They are not involved in disassembly sequence generation.

All the information models (Core product model, Open Assembly Model and NIST disassembly information model) described above focus on the static data set of the domain. These static natures are modeled into certain classes and class associations. However disassembly sequence generation process is a dynamic process and it needs the schema to be available for instance level, information organization and updating after each disassembly operation. It is crucial for disassembly process modeling. Kim et al. [18] has reported the development of a disassembly sequence generation algorithm taking actual disassembly system conditions into account. But their system conditions incorporate information regarding process selection, operation planning, control sequence