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Assembly unit partitioning for hull structure in shipbuilding

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HIGHLIGHTS

- A hull assembly model based on the attributed connection oriented graph is presented.
- Using the fuzzy assessment rule to establish the assembly relation matrix of hull.
- The fuzzy cluster method to analyze partition of assembly units is given out.
- To establish evaluation model on assembly ability of hull.
- Using the fuzzy synthetic evaluation to decide the optimal partitioning scheme.

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ABSTRACT

In order to solve the problem that low automatic degree to the block assembly process design will negatively influence construction cycle time and construction quality in shipbuilding, this paper presents a newly developed determination system of assembly units for the hull structure. Firstly, the assembly information model of a hull block which includes the part information and the linkage information between parts is proposed following the structural features and assembly process of the hull structure. Secondly, the assembly relation matrix is established on the basis of the fuzzy assessment rule and then the fuzzy clustering method to analyze partition of assembly units is given out. Thirdly, through analyzing the assembly ability of hull structures, the set of evaluating indexes is founded whose weights are decided by an analytic hierarchy process (AHP). Meanwhile, the model for the assessment is provided by fuzzy synthetic evaluation (FSE) and the comprehensive assessment values of assembly partition schemes can be computed to judge the final optimization scheme. A block assembly is taken as an example to verify the proposed method, and the results show that it is an effective method for solving the partition problem of hull structures.

1. Introduction

A ship is a huge structure which is constructed by a large number of hull structural parts through welding operation. To maximally utilize the process commonality, expand the work areas and improve the work conditions, the ship assembly abides by the principles of work-package breakdown in modern shipbuilding. The ship hull is divided into hundreds of building blocks (e.g. about 200 building blocks in the case of the 300000 ton VLCC), blocks are further segmented into of several unit blocks which can consist of two or more mid-assemblies and subassemblies. A mid-assembly is composed of a few subassemblies, and a subassembly consists of steel plates and sections. Considering the bottom-up assembly procedure, the levels of hull structure assembly to assemble steel plates and sections into the final hull should be classified into subassembly level, mid-assembly level, unit block assembly level, block assembly level and final hull assembly level. An assembly unit is a finished product at each assembly level and is used as a component part at the next level [1–3].

In assembly unit construction, since every unit is assembled by welding steel plate and sections with various sizes and shapes, determination of assembly units is very difficult, and it is still realized manually depending on the experiences and know-how of assembly engineers. So it is very important to realize the automation of assembly unit partitioning by means of concluding the experiences of skilled assembly engineers to form an effective decision method, and which can reduce cost, improve quality, and raise the productivity.

To reduce the number of independent parts or components in assembly sequence planning of complex mechanical products, the subassembly identification and extraction is widely studied by many researchers [4,5]. From the literatures, we can see that there are some basic methods for subassembly formation, such as the interactive component disassembly method, the "set-cut" method, and the relationship-map method. These methods establish the fundamentals for the automation of the assembly units partitioning, but they have some own disadvantages in actual

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production activities. The interactive component disassembly method is mainly concerned about formulating a necessary and sufficient set of questions to be answered by the human designer and is the relatively low degree of automation [6]. The "cut-set" method can generate all possible subassemblies of a product in theory, but this method always suffers from 'state explosion' with the increasing number of parts [7,8]. The relationship-map method employs the connection matrix on the assembly liaison graph to generate all geometrical feasible assembly units, but the method could lead to a complex matrix calculation that makes it difficult to generate an effective result [9,10].

In recent years, many scholars pay more attention to the exact assembly modeling method and mathematical subassembly patterns to implement a fully automated partition system. Wang et al. [11] pointed that the assembly constraints including the topological, geometrical, and process constraints should be considered and merged into the assembly model for the more effective subassembly identification. Xing et al. [12] presented an assembly modeling with adjacency matrix and three subassembly patterns, which are described by mathematical equations, respectively. And then the assembly tree can be created through selecting different subassemblies detected from the adjacency matrix and other constrains. Gao et al. [13] used a method of gray clustering based on gray system theory to perform subassembly identification. In this method, the clustered objects are part pairs with adjacency relation in a product, and the clustering indices consist of energy consumption of disassembly, disassembly time, disassembly direction and diameter of part pair. Jeonghan et al. [14] used the liaison graph of a product assembly to represent the assembly and subassemblies, and then they presented mixed-integer programming to model the partition of the assembly graph. Zhang et al. [15] used the aircraft assembly tree of type hierarchy to represent the main structure of assembly, and then they presented a fuzzy-clustering algorithm to find the desired disassembly scheme on the objects which are not included in main structure.

Although these scholars made great progress on generating assembly units, the proposed methods are not universal for all products and need sufficient domain-specific knowledge. As a result, the above methods are not suitable for shipbuilding because of their limits. Firstly, these methods emphasized the geometrical constraints and mechanical assembly process constraints, but the linkage characteristics between two components and design characteristics of a part within the welding structure were not considered. Secondly, the subassembly identification is NP-complete in mathematics and the computational efficiency of the algorithm mentioned above is still not satisfactory. Meanwhile, the computing result of each algorithm is unique and difficult to adjust according to change of production condition. Thirdly, the obtained assembly schemes can only match the assembly relationship in a product structure and lack the systematic analysis based on the assembly ability of products. Therefore, this paper presents the linkage graph model of a hull block which includes the part information and linkage information through considering the various assembly constraints for hull assembly. On the basis of the assembly model, a new assembly unit partition method is proposed to automatically gain decomposition schemes of the hull assembly structure based on the fuzzy clustering. All the feasible partition schemes are easily obtained through adjusting the threshold of fuzzy cut matrix. Furthermore, to effectively evaluate the generated partition schemes, we establish the assembly ability criterion and give the assembly ability evaluating method based on FSE.

The rest of this paper is organized as follows: In Section 2, we establish the framework of the solution. In Section 3, we present the representation method of block assembly information. A block partition method based on the fuzzy clustering is provided in Section 4. In Section 5, we present the evaluation method of assembly unit partition scheme based on FSE. In Section 6, we present a case of a block partition to show how to model, analyze and evaluate the system. Conclusions are given in Section 7.

2. The framework of the solution

The assembly unit partitioning in a shipyard defines the work strategy for the ship. In this process, the designer decides how to build the ship from the numerous hull parts available. Determination of appropriate assembly units makes the process of hull assembly more flexible, easier and faster. At present, this work is done manually by some skilled engineers in the production planning stage. However, because of time pressures and the limited know-how of designers, only a very few partitioning schemes can be optimized in the actual shipbuilding activities.

In this research, we build a decision system for assembly unit partition based on fuzzy mathematics. The overall system framework is shown in Fig. 1. First, BOM (bill of materials) data of the block model are extracted from the shipbuilding computer-aided design (CAD) system, with which the information of parts and the relations between parts are defined in the interface program. With the assembly model defined, we present a fuzzy clustering method to determine the assembly unit. For the existence of multiple feasible assembly schemes, we use the FSE method to select an optimal assembly unit partitioning scheme. Finally, the optimal assembly unit partitioning scheme will be input to the shipbuilding CAPP system in which the assembly sequences at each assembly level and welding process planning on these units should be decided.

3. Representation of hull assembly information

To enable automated assembly unit partitioning, all the related product information should be organized and represented as the product assembly model within a computer. In the traditional assembly model, a product is generally described by liaison graph proposed by De Fazio and Whitney [16]. The graph can be easily established by extracting the required information from the CAD models directly or/and indirectly, but it is designed to represent only geometric assembly information and assembly process information. Some partitions could be feasible from a geometric and process point of view for a mechanical product, but are impractical due to the special properties of part and connection within a welding structure. To support the decision and evaluation of good assembly partition plans and assembly process plans for the hull, the assembly representation used in this research integrates both geometric and non-geometrical assembly data and is represented in the form of an attributed connection oriented graph, which is termed the block assembly information model (BAIM).

This paper defines the BAIM as a 2-tuple $BAIM = \langle N, E \rangle$.

Where: N represents a set of nodes, E represents a set of edges. Each node is defined as a part of a block and each edge is defined as the geometric relation between two parts. The corresponding attributes meanings of the node and edge in BAIM are defined as follows:

(1) The attributes information of a node includes part number, part name, part type, corresponding block number, part area, part material, part gravity, number of parts connected to it, characteristic value of part base and so on.

The characteristic value of a part base is the very important non-geometrical information and it is determined by part area, part gravity and number of parts connected to the part. The