Research on Hull Assembly Process Planning Based on Rule Reasoning

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Abstract. Currently, hull assembly process is mainly dependent on experience, and lack of normative standard. In this paper, hull structure for assembly features is systematically studied, and an assembly sequence planning method based on Rule Reasoning is proposed. Firstly, assembly feature and sequence expression of hull structure is analyzed and the constraint relation of connection information is described. Secondly, the relationship between established structures and the constraint function is designed. Setting the double bottom of the ship as an example, hull assembly sequence is obtained based on geometric constraints and optimized by the fuzzy evaluation method and finally realized the computer aided evaluation of the hull assembly sequence.

1. Introduction
Hull assembly and welding are a core technology for the complicated systematic project of ship construction process, and greatly affect the efficiency and quality of ship building. However, hull assembly process is mainly dependent on the experience of technologists and lack of computer aided methods, which has seriously restricted the efficiency and quality of ship building.

With the development of computer information and intelligent technology, many scholars have carried out extensive research on the computer aided planning technology of ship assembly process. Cho set up a ship block assembly system, and realized the assembly sequence planning and scheduling by the technology of case-based reasoning [1]. Seo carried out the further research on the matching of similar instances [2]. Qu Shipeng combined the reasoning based on case with the reasoning based on geometric constraints and the optimization of assembly sequence was realized by genetic algorithm [3]. Li Peiyong applied demolition method and analytic hierarchy process to optimize the assembly sequence [4]. Wang Bo proposed a method of cut-set to generate assembly sequences, but it would bring combinatorial explosion problem for complex product combination [5]. Song Li-ping programmed the assembly sequence of the marine engine room with the interactive virtual assembly technology based on the demolition [6]; In addition, Wei Wei and Wang Jing pin used the ant colony algorithm to program the assembly sequence of the hull double floor [7-8]. However, because of the numerous of hull structures and the complexity of assembly process, modern intelligent algorithm is still difficult to meet the practical requirements. The method of case based reasoning and geometric reasoning own good practicability, However, they are obvious defects in the non-geometric information processing, which is difficult to meet the requirements of rationality and effectiveness of the hull assembly process planning.
In this paper, hull structure for assembly features are systematically studied, and an assembly sequence planning method based on rule reasoning is proposed, which realized the computer aided planning of hull assembly sequence.

2. Analysis of assembly feature and assembly sequence expression of hull structure

2.1. Structural analysis
The number of hull assembly structures is very large, but only a few of them will affect the planning process. In order to plan a better assembly sequence and reduce the difficulty of planning, the selection of the common structures is extremely essential. In practical applications, there are 8 types of common parts (A, B, C, K, L, P, S, W) according to the type of the shape and function[9].

Although the number of common part types is reduced through filtering, the difficulty of planning assembly sequence is not reduce because there may be many different shapes even the same type and function of the components. Therefore, based on the simplification principle, selecting several common components can greatly reduce the difficulty of the problem in practical production. By analyzing these ship hull parts, the assembly elements of different parts can be obtained as shown in Table 1:

| Part type | Classification | Function                | Assembly element       |
|-----------|----------------|-------------------------|------------------------|
| A         | A1             | T plate of web          | Four edges of the parts|
| B         | B1             | Square elbow plate      | Four edges of the parts|
| K         | K1             | Base plate              | Four sides and two surfaces|
| K         | K3             | Base ware               | Two surfaces           |
| L         | L1             | Stiffening bar          | Four edges of the parts|

By analyzing the assembly process of the hull, there are mainly four kinds of connection relation between ship structural components: basic part, strutting piece, reinforcing member and envelope part. The relation diagram of structural parts assembly is shown in Figure 1:

![Figure 1. Relation diagram of structural parts assembly](image)

2.2. Assembly sequence expression
The expression of assembly sequence should be concise and contain the main information of assembly. In this paper, four types of information (assembly code, initial information, terminal information and assembly type) are selected to express the assembly sequence. The assembly relationship can be expressed as: (Num, Sta, End, Lin). In which, Num is the order number of the assembly operation; Sta is the initial component information, including the initial component and its assembly elements; End is the information of the end component, including the end component and assembly elements; Lin is the type of connection.

For example: If the numbers of the structural are P3 and P4, the sequence is expressed as (2, (P3, 3), (P4, 2), (), 4). Its meaning is: in the whole assembly sequence, the assembly sequence number of P3
and P4 is 2 and the assembly elements 3 of P3 are assembled by elements 2 of P4. And the type of connection is fitting.

2.3. Constraint relation of connection information
The large number of rules and assembly elements may lead to the difficult of the assembly planning. Because not all the components of the assembly process will affect the assembly process, a lot of small components can be simplified such as reinforcing ribs, reinforcing plates. In addition, the method of rule based reasoning will incorporate all the possible connected components into the reasoning category. However, in practice, those components which have influence on the assembly planning are not necessarily in contact with each other, which will result in a dramatic increase in the number of reasoning results.

In this paper, a method of introducing the relation constraint as well as the connection information is proposed to plan the assembly sequence. This method is based on the connection relationship of the main components by means of information description. It can eliminate the connection relationship which may not exist in the space position and then reduce the difficulty of assembly sequence reasoning.

The expression of connection information constraint relation is: $(C_L, P_M, P_N)$, in which, $C_L$ is the connection number, $P_M$ is the $M_{th}$ component, $P_N$ is the $N_{th}$ component. In terms of the constraint information, the assembly sequence reasoning process can be carried out according to the assembly rules.

3. Inference of assembly sequence based on rules
The reasoning process of assembly sequence based on rules is shown in Figure 2:

![Figure 2. The reasoning process of assembly sequence planning](image)

(1) Arrange the sequence of component installation according to the assembly priority of component, that means, installation of structural parts according to priority level, and then find the relevant structure in the same level using the associated graph model.

(2) The assembly process structure of same assembly level can be considered as the matching process of assembly rules. The connecting assembly component element and assembly type are determined by matching rules.

(3) After completing the assembly of component, the assembly of sub-assembly and unit can be carried out which is similar to the component layer. The only difference is that the assembly priority of the sub-assembly layer is determined according to the relevant components of the component parts.

By analogy, the assembly of the whole hull is realized and the assembly sequence is obtained by the process above.

Compared to the other intelligent algorithms, Rule based reasoning (RBR) for the assembly sequence planning technology is more practical. At the same time, it would obtain more feasibility of assembly sequence by the increasing of the assembly rules, although the RBR has a higher requirement for the actual assembly experience. In this paper, the method of constraint reasoning combined with the rule based reasoning is proposed to complete the effective planning of assembly sequence. This method introduces the assembly constraints such as assembly contact and interference matrix, which can help RBR to complete the whole process of assembly sequence planning.
3.1. Establishment of relationship between structures

In order to express the logical relations between the components, an adjacent interference matrix is established to represent the contact and assembly interference of each structure.

Taking the double bottom of the ship as an example (shown in Figure 3), the six directions $(x, y, z, -x, -y, -z)$ of the three-dimensional space of the components is represented by the Descartes coordinates. Design variables $L(p, q)$ and $G(p, q)$ are used to represent the assembly relationship, the variables are defined as follows:

$$ L(p, q) = (L_1, L_2, L_3, \ldots, L_i), L_i \in \{0,1\} \quad i = 1 \sim 10 \quad (1) $$

$$ G(p, q) = (G_1, G_2, G_3, \ldots, G_j), G_j \in \{0,1\} \quad j = 1 \sim 10 \quad (2) $$

In which, $L_i$ represents the contact relation of any two structural elements in the $i_{th}$ directions, $L_i = 1$ means that the component $p$ and $q$ have contact relationship in the $i_{th}$ direction of $p$; $L_i = 0$ indicates that the component $p$ and $q$ do not have any contact in that direction. $G_j$ indicates that a component has an assembly interference relationship in the $j_{th}$ direction relative to another. $G_j = 1$ shows that the $q$ in the direction of the relative $i$ in the $p$ movement is not affected by any of its interference, and $G_j = 0$ means that there is no interference relationship.

The relationship of contact and interference can be obtained in the process of establishing a 3D model. In the establishment of contact and interference matrix, the influence caused by the sequence of assembly can also be directly identified, that is the difference of the turn over number. Because the outer and mainland components are similar, only the outer component is selected to establish the contact and interference matrix, which are shown as follows:

$$(3)$$

$$(4)$$
3.2. Design of constraint function

Assembly constraint relation can guide the reasoning of assembly sequence. In the process of ship assembly, the planning of the block assembly sequence can be simplified as the management of the constraint relation of different structures. The space constraint relation of the assembly structure can be called rigid constraint. In this paper, the rigid constraint function is used to describe the geometric relations of the segmented structures. In order to realize the geometric feasibility of assembly sequence, the relations of the contact and the interference of the assembly structure must be guaranteed and any assembly sequence must meet the following two conditions:

1) There is at least one connection relationship between the parts to be assembled and the previously installed structures.
2) When any structural member is assembled, at least one direction does not interfere with other structural elements.

The above two conditions are necessary to determine the geometric feasibility of assembly sequences. The formula (1) and the formula (2) define the contact relation and interference relation between any two components, respectively.

In order to verify whether the assembly sequence is satisfied with the first constraint condition, formula (5) and (6) are defined to make relevant judgments,

\[ (TL_k)_i = L_i(k, k-1) \lor L_i(k, k-2) \lor \cdots \lor L_i(k, 1) \] (5)
\[ (RTL)_k = (TL_1)_k \lor (TL_2)_k \lor (TL_3)_k \lor (TL_4)_k \lor (TL_5)_k \lor (TL_6)_k \] (6)

Similarly, formula (7) and (8) are given to verify whether the assembly sequence can satisfy the second constraint conditions, and i represent any direction in the Descartes coordinate. \((TG_i)_k\) is a six dimensional vector, which is used to indicate the presence of interference between the structural member and any other structural elements that have been assembled in the direction of movement to the specified position. \((TG_i)_k\) indicates the interference of a structural member when compared to other structural members during assembly. Symbolic "\(\land\)" is used to find the "and" operation of the vector. \((RTG)_k = 1\) indicates that it can move in a certain direction to the specified position without interference from other installed structures. Otherwise, the structure can not be effectively assembled, that is, the assembly sequence is unreasonable.

\[ (TG_i)_k = G_i(k, k-1) \land G_i(k, k-2) \land \cdots \land G_i(k, 1) \] (7)
\[ (RTL)_k = (TG_1)_k \land (TG_2)_k \land (TG_3)_k \land (TG_4)_k \land (TG_5)_k \land (TG_6)_k \] (8)

3.3. Hull assembly sequence reasoning based on geometric constraints

Taking the double floor as an example and it is divided into 10 components which can be seen as a new combination of components, according to the assembly rules, the Outsole component \(BS - L\) and the floor or stringer should be assembled first and the floor \(FR - B\) is selected. The assembly of the two components can be seen as an assembly sequence \((BS - L, FR - B)\). Then the assembly sequence \((BS - L, FR - B, LB2Q)\) can be analyzed as follows:

1) Judging the contact relationship
Considered the $(BS - L, FR - B)$ as a new sub assembly, and the contact relationship between the new sub assembly and the component $LB2Q$ is judged by formula (3):

\[
L( BS - L, LB2Q ) = (0, 0, 1, 0, 0, 0)
\]

\[
L( FR - B, LB2Q ) = (1, 0, 1, 0, 0, 1)
\]

According to formula (5), the value of $TL$ can be calculated as shown in Table 2.

| $L( BS - L, LB2Q )$ | $L( FR - B, LB2Q )$ | $TL$ |
|---------------------|---------------------|------|
| 0                   | 1                   | 0    |
| 0                   | 0                   | 0    |
| 1                   | 0                   | 1    |

Taking the "or" operation to $TL$ according to formula (6), it can obtain $RTL = 1$, which means there have contact relationship between $LB2Q$ and $(BS - L, FR - B)$.

(2) Determine the assembly direction of the new structure

This process is similar to the step of determining the relationship of structural parts. Firstly, it can obtain $G( BS - L, LB2Q ) = (1, 1, 1, 1, 1, 0)$ and $G( FR - B, LB2Q ) = (1, 1, 0, 1, 0, 1)$ according to the formula (4). Secondly, the value of $TG$ can be calculated according to formula (7) as shown in Table 3.

| $G( BS - L, LB2Q )$ | $G( FR - B, LB2Q )$ | $TG$ |
|---------------------|---------------------|------|
| 1                   | 0                   | 0    |
| 1                   | 1                   | 1    |
| 0                   | 0                   | 1    |
| 0                   | 1                   | 0    |

Continuing to carry on the "or" operation to $TG$ according to the formula (8), it can obtain that $RTG = 1$. According to table 3, $LB2Q$ own three assembly degrees of freedom, which means the component $LB2Q$ can be successfully installed on the sub assembly $(BS - L, FR - B)$ and it can meet the practical geometric conditions according to the sequence of $(BS - L, FR - B, LB2Q)$.

Because the number of the assembly sequence is great, Only 5 representative assembly sequences are selected and shown in Table 4:

| Initial component | Assembly sequence number | Assembly sequence |
|-------------------|--------------------------|-------------------|
| BS - L            | 1                        | $BS - L \rightarrow LB10B \rightarrow FR - E \rightarrow LB6B \rightarrow FR - C \rightarrow FR - A \rightarrow LB2B \rightarrow FR - B \rightarrow LB2Q$ |
|                   | 2                        | $BS - L \rightarrow FR - A \rightarrow LB6B \rightarrow FR - C \rightarrow LB10B \rightarrow FR - E \rightarrow LB2B \rightarrow FR - B \rightarrow LB2Q$ |
|                   | 3                        | $BS - L \rightarrow FR - B \rightarrow LB2Q \rightarrow LB2B \rightarrow FR - A \rightarrow LB6B \rightarrow FR - C \rightarrow LB10B \rightarrow FR - E$ |
| IB - L            | 4                        | $IB - L \rightarrow LB2B \rightarrow FR - B \rightarrow FR - A \rightarrow LB6B \rightarrow FR - C \rightarrow LB10B \rightarrow FR - E \rightarrow LB2Q$ |
|                   | 5                        | $IB - L \rightarrow LB10B \rightarrow FR - E \rightarrow LB6B \rightarrow FR - C \rightarrow FR - A \rightarrow LB2B \rightarrow FR - B \rightarrow LB2Q$ |

According to the above 5 feasible assembly sequences, the scheme can be optimized according to the fuzzy evaluation method. The index and the weight value of the evaluation model can be adjusted by the assembly process personnel according to the specific situation.
In addition, the assembly and dis-assembly process simulation can be carried out through dynamic interference inspection (shown in Figure 4), so as to avoid the collision interference problem in the assembly process, and to optimize the final assembly method.

4. Conclusions
This paper aims at the problems of low assembly efficiency and unstable product quality, which are mainly caused by manual and experience operation. A method of assembly sequence planning based on rule reasoning is presented based on the research on the assembly features of ship hull structures. Setting the double bottom of the ship as an example, hull assembly sequence is obtained based on geometric constraints, which realized the computer aided of the hull assembly sequence evaluation.

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