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DEVELOPMENT OF AN ASSEMBLY SEQUENCE PLANNING SYSTEM BASED ON ASSEMBLY FEATURES

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ABSTRACT

To meet the requirements of industries and support manufacturing planners to make decisions rapidly and accurately, the assembly features-based assembly sequence planning system is developed. The system employs a semantic technique for creating an assembly features model. And there are several functional modules in the assembly sequence planning system to make full use of assembly features. In the generation of assembly sequences for any product, the core technologies include the reasoning mechanism for matching assembly features, the algorithm proposed for automatic generation of assembly sequence and the evaluation method for obtaining the optimal assembly sequences. To verify the validity and efficiency of the developed system, the assembly features-based assembly sequence planning is applied to a practical problem, i.e. the assembly of an automotive module such as oil pump and the corresponding results are presented.

KEYWORDS

Assembly Feature Model, Assembly Sequence Planning, Reasoning mechanism, Evaluation Method

1. INTRODUTION

Assembly involves the integration of components and parts to produce a product or system (Chen et al., 2008). Assembly planning aims to identify and evaluate the different ways to build a functional module from its components. Assembly sequence planning (ASP) plays an important role in the assembly plan and affects several aspects of assembly process as well as assembly productivity and cost. The assembly sequence planning is the core problem in the development of computer-aided assembly planning system. In addition, good ASP has been recognized as a practical way to reduce operation difficulty, the number of tools, assembly product costs and working time, improvement of quality and shrinkage of time to market (Lai and Huang, 2004). Automating the generation of assembly sequences and their optimisation can ensure the competitiveness of manufactured goods and increase profit margins (Romeo M. et al., 2006). Currently, automatically generating feasible assembly sequences is still an extraordinarily difficult task due to the complexity increasing exponentially with the number of parts. Hence, it has been an objective for manufacturing industries to look for effective and suitable methods to overcome this challenge.

This paper focuses on the computer-aided ASP system, more specifically on assembly sequence planning and optimizing. An assembly feature-based ASP system is proposed by which all feasible assembly sequences can be reasoned out automatically and the optimal assembly sequences can be obtained easily according to the evaluation.

The arrangement of the paper is as follows. Section 2 gives literature view on ASP. Section 3 shows the strategy for developing ASP system. In Section 4, core technologies of assembly feature-based ASP system are elaborated. In Section 5, architecture of assembly features-based ASP system is designed, and the programming system is implemented and the functionality of the system is introduced. Section 6 demonstrates the application of the developed ASP system with the practical problem. Finally, the conclusions and further research directions are summarized in Section 7.

2. ASSEMBLY SEQUENCE PLANNING IN THE AREA OF ASSEMBLY

ASP has received much attention in manufacturing industries and research projects over the past two decades. There have been many attempts to solve and optimize the ASP using various approaches. These methods can be roughly classified into three kinds: human-interaction manual method, geometric feasibility reasoning approach and knowledge-based reasoning method.

The early assembly sequence planners were mainly interactive in nature (Priyadarshi and Gupta, 2009). Traditional ASP is manual according to the experience and knowledge of industrial engineers. And it mainly focuses on each user's query either on the connection between a pair of parts or the feasibility of a single assembly operation. However, if the product is complex, the planner needs to spend lots of time and energy to determine the sequence, and sometimes he cannot ensure this sequence is feasible or optimal. Therefore, traditional manual analysis does not allow the feasibility of assembly sequences to be easily verified and then it is far from automation.

Thereafter several authors proposed geometry-based reasoning approaches to generate assembly sequence. Niu et al. (2003) applied a hierarchical approach to generating precedence graphs for ASP. Gu et al. (2008) proposed the procedures to transform directed graph and AND/OR graph into symbolic ordered binary decision diagram (OBDD) for mechanical assembly sequences. Su et al. (2009) used the 3D geometric constraint analysis (3D-GCA) and algorithms for spatial ASP. Su (2009) also presented a hierarchical approach to ASP and optimal sequences based on geometric assembly precedence relations (APRs). However, geometry-based reasoning approach is prone to lead to combinatorial explosion problem. In order to reduce the searching space of ASP of complex product, numerous intelligent algorithms have been developed and used to generate assembly sequence, such as genetic algorithms (GAs) (G. Dini et al., 1999, Romeo M. et al., 2006), artificial neural network (ANN) (Chen et al., 2008), artificial immune systems (Chang et al., 2009), particle swarm optimization algorithm (Guo and Li, 2009; Wang and Liu, 2010), symbiotic evolutionary algorithm (Shin et al., 2011), and memetic algorithm (MA) (Gao et al., 2008, Tseng et al., 2007). Although most algorithms afore mentioned improved the efficiency of the process to search the assembly sequences and avoid the combinatorial explosion problem, these algorithms depended upon the influence of initial positions and relative parameters which limit the efficiency of finding global optimal solution for complex product. In addition, they may tend to converge prematurely at local optimal solutions frequently.

To implement the automation of generating assembly sequence, there is not enough to only consider the geometric information. The above methods do not consider much assembly knowledge, so they are short of enough assembly information to deal with ASP in practice. In this context, knowledge-based reasoning is put forward. Here, knowledge consists of geometric information, assembly method, assembly tools and machines, and other knowledge related to the assembly sequence. Dong et al. (2005) applied a collaborative approach to ASP, and knowledge-based approach is proposed to integrate geometry-based reasoning with knowledge-based reasoning. Chen et al. (2010) proposed three-stage integrated approach to promote the quality of assembly plan and facilitate assembly sequence optimization via a knowledge-based engineering system and a robust BPNN (Back Propagation Neural Network) engine. Park (2000) developed a knowledge-based system for generation of an optimal assembly sequence. The advantages of system are that assembly-oriented information can be grasped and used efficiently, and some difficult operation information can be used to evaluate assembly sequence. Therefore, knowledge-based method is feasible and available to generate assembly sequence automatically.

From the above literature analysis, it is known that information of components themselves is underutilized and there is no planning method based system for generating the assembly sequence. Therefore, it is necessary to develop a new planning strategy and algorithm to generate the appropriate information model for assembly sequence planning and apply the information model to plan assembly sequence at the same time.

3. STRATEGY FOR DEVELOPING ASP SYSTEM

In ASP, the primary step is to generate an assembly product model. The efficiency of an ASP depends heavily on it. Rationalization of an assembly product model is judged by its potential to directly use CAD data and its capability to effectively assist the generation of assembly sequences. Features which combine geometric and technological information are defined for modelling and planning. A feature-based product model is suitable for automatic generation of assembly sequences. From this viewpoint, the paper presents a novel assembly feature model which integrated single-part models and sub-assembly models, and assembly sequence can be generated based on assembly features model. Figure-1 shows the systematic procedure of ASP. In order to implementation of the ASP system, there are four main tasks to be studied.

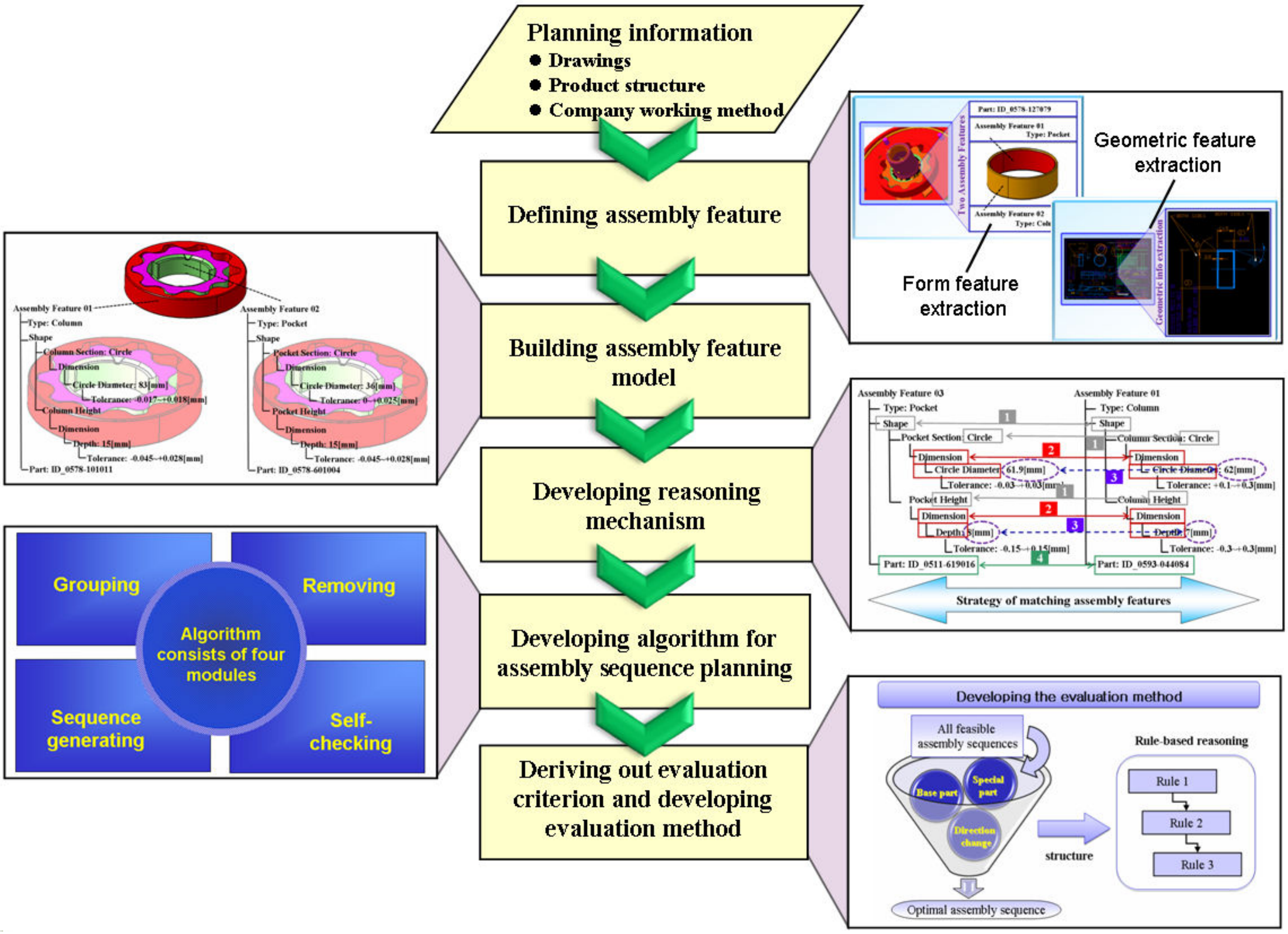


Figure 1 – Systematic procedure of ASP

1) Information model of assembly feature for parts: Assembly features are extracted from the analysis of parts and subassemblies to build the model of assembly feature attributes.
2) Strategy for realization of reasoning mechanism: reasoning mechanism is designed to match assembly features and determine the relationship among assembly features.
3) Algorithm for generating all feasible assembly sequences: The proposed algorithm is used to generate all feasible assembly sequences with the help of reasoning mechanism.
4) Evaluation method for obtaining the optimal assembly sequences: Evaluation method is used to select the optimal assembly sequences among all feasible assembly sequences.

4. DEVELOPMENT OF ASP SYSTEM

4.1. FORMING AN ASSEMBLY FEATURE

An assembly operation requires at least two parts, and the two parts are assembled through their respective assembly features. So an assembly feature is here defined as an assembling bridge between two parts, i.e. a contacting point. In other words, assembly of parts can be transformed into their assembly features matching. During the assembly process, there is lots of assembly-specific information which should be encapsulated in terms of assembly features. For better and clear utilization, assembly features can be divided into two types:

Type 1. Form features which are described semantically could be found from 3D drawings, i.e. pocket, column, etc. And form features are used to find their counter features assembly.

Type 2. Geometric features are expressed by traditional dimensional data which could be obtained from 2D drawings, i.e. 50.00mm, -0.06mm. And geometric features are used to determine whether two parts could be connected or not.

Generally, one part has many generic features, but not all of them are useful in assembly process. In order to have an accurate definition of assembly feature, assembly drawing is needed to analyse the assembly process of parts. Because the assembling process happens at contact surface and two parts interact with one another, assembly features should be defined in pairs. This concept is used to determine all assembly features.

Figure-2 illustrates an example of determination of assembly features. In Figure-2, part 2 can be assembled with part 1 using its outside feature, not the inside feature. So, the outside feature is considered as an assembly feature for part 2. Meanwhile, part 1 also uses one of its features to match part 2's outside feature, so the used feature is also defined as an assembly feature for part 1.

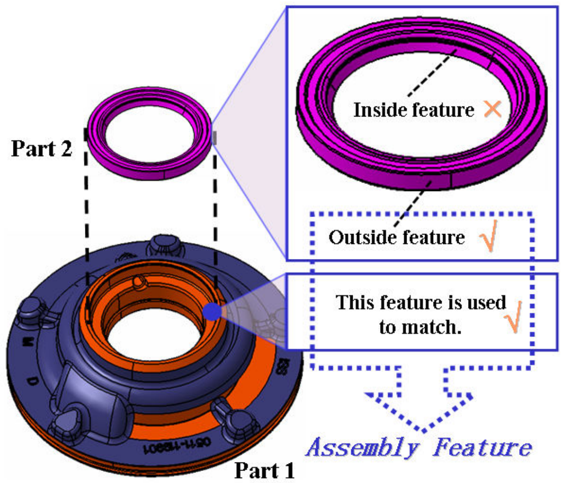


Figure 2 – Determination of assembly features

This kind of the definition has several advantages. The first advantage is that it provides purposeful and precise for determining assembly features because it was described in consideration of assembly process and prevents the insufficient or excessive definition. Another advantage is that all defined assembly features should be run out exactly after assembling all parts completely. And it ensures the accuracy and reliability of the results of an ASP.

4.2. GENERATING AN ASSEMBLY FEATURE MODEL

An assembly feature model includes all necessary information of ASP. In order to generate an assembly feature, form features and geometric features should be extracted respectively. Notably, form features must be determined firstly, and then geometric features will be added along with form features. For the given product, the first step is to decompose the whole product to determine the amount of parts in this product and analyze assembly relations among parts. The product could be decomposed easily under the environment of CATIA because there is a function to obtain the exploded view to make assembly analysis. The fundamental principle for determining form features is that there is at least a pair of form features (each part has one form feature) if two parts could be assembled. Each form feature should be defined using semantic way. Through assembly analysis, all form features could be found and extracted from 3D drawings. According to the fundamental principle, the minimum amount of form features could be determined. After determining all the form features, the geometric features should be generated with the help of 2D drawings and include not only dimension but also the technology data related assembly process such as tolerance and roughness, etc. After that, all assembly feature attributes could be obtained completely and they will be integrated into an assemble feature model.

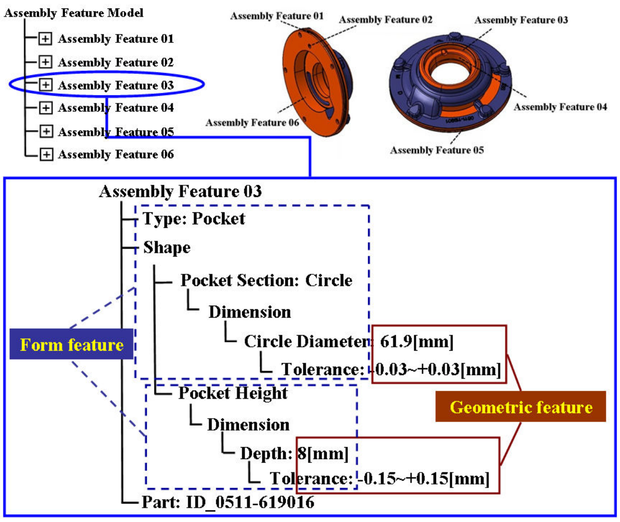


Figure 3 –Structure of an assembly feature model

Figure-3 illustrates an example of an assembly feature model. In Figure-3, Part possesses six assembly features which are integrated into an assembly feature model. Every assembly feature is expressed compactly and sufficiently using the same tree structure which is made up of form feature and geometric feature. Assembly feature 03 shows this tree structure in details.

4.3. DEVELOPMENT OF A REASONING MECHANISM

In order to build assembly relationship among parts, a reasoning mechanism is designed to determine the relations among assembly features. The relationship represents the assemble possibility between two parts. The reasoning mechanism is implemented based on the assembly feature model. Moreover, every assembly feature should be reasoned by item-by-item method due to the structure of an assembly feature model. In the course of each assembly feature reasoning, form features and geometric features should be matched respectively. Figure-4 shows the strategy of a reasoning mechanism. There are four steps in the reasoning mechanism.

Step 1. Shape matching: Shape describes the geometric cross section by specialised term, and it contains circle, ellipse, triangle, square, and rectangular and so on. Here, shape of each part should be compared firstly. If the shape is described using the same term, it meets the condition of shape matching.

Step 2. Dimension matching: After the previous step, the geometry information of cross section should be further checked. It contains diameter, depth, length, width, long axis, minor axis, bottom side, and height and so on. If the dimension is described using the same term, it meets the condition of dimension matching.

Step 3. Dimension value checking: In this step, the reasoning could be continued by the dimension value checking. Generally, if two parts are assembled, the clearance between two parts must be smaller than the maximal tolerance δ. For example, the assembly clearance between piston pin hole and piston pin should be 0.0025 ~ 0.0075mm under the cold assembly condition. So the δ could be 0.075mm. The condition of checking dimension value is that the clearance should abide by equation-1, where D_{part1} and D_{part2} are the dimension values for two compared parts, respectively.

$$\left| D_{part1} - D_{part2} \right| \leq \delta mm \qquad (1)$$

Step 4. Feature relationship determining: After the previous three steps, it is assured that both form features and geometric features meet each condition, so that these two assembly features satisfy the assembling conditions. If two assembly features could be matched by the reasoning mechanism, these two assembly features can be assembled.

In the reasoning mechanism, Step 1 and Step 2 belong to semantic reasoning, but Step 3 is a geometric reasoning. Step 4 is used to determine and save the assembly features relationship. Through repeatedly reasoning, all relations of assembly features will be obtained and they will be used in the next algorithm process.

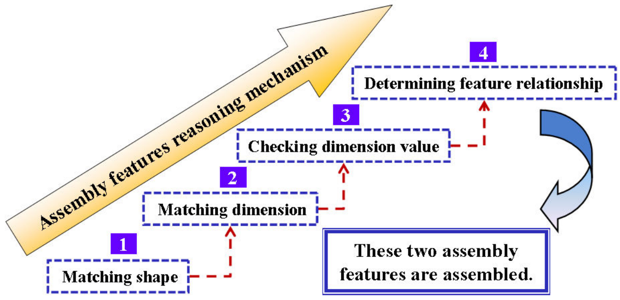


Figure 4 – Strategy of a reasoning mechanism

4.4. DEVELOPMENT OF AN ALGORITHM

An algorithm is used to generate all feasible assembly sequences with the help of reasoning mechanism, and it consists of backward reasoning and merging mechanism. The basic idea of an algorithm is to find the part to be assembled through the relationship of assembly features. So, the working procedure is part - feature - feature - part. There are four important modules in this algorithm and more details as follow.

Grouping module: This is a selection domain, which consist of two groups: Group Ⅰ and Group Ⅱ. At the beginning of algorithm, Group Ⅰ contains one part which is selected arbitrarily, and the rest parts are in Group Ⅱ. With the operation of iterative mechanism, the part will be moved continually from Group Ⅱ to Group Ⅰ. If the assembly process is completely finished, namely, all parts have been assembled through assembly features, Group Ⅰ will contain all parts and Group Ⅱ is empty. So, the end condition of this algorithm is Group Ⅱ is empty.

Removing module: To reduce the searching effort of assembly features, this module can reduce the number of parts of the product unceasingly via assembly part merging along the assembly sequence. In this module, after two parts are assembled, they are considered as one component and every assembled feature or part can be removed from Group Ⅱ. The new generated component has the rest features of the two assembled parts except the features used for assembling two parts. Using this module, the quantity of assembling parts will be reduced and the solution space will be compressed simultaneously.

Sequence generating module: This module is constructed according to the basic idea of algorithm, and it is a processing procedure. Every part has its own features and they are also assigned to their part. Using this module, one optional feature in a part tries to find its counter feature in another part according to the above reasoning mechanism. This process proceeds until all exiting features or parts are empty.

Self-checking module: In this algorithm, self-checking is indispensable procedure when two parts are assembled, because there may be some additional assembly features which should be deleted at assembling. Through assembly process, some assembly features could be matched automatically or covered by the assembled counterpart, i.e. the accessibility to those features is prevented. This happens due to the shape of a part. Such kind of information should be described in the database through analysing the assembly drawings. The automatically matched and covered features have to be removed from the features generated by assembling two parts.

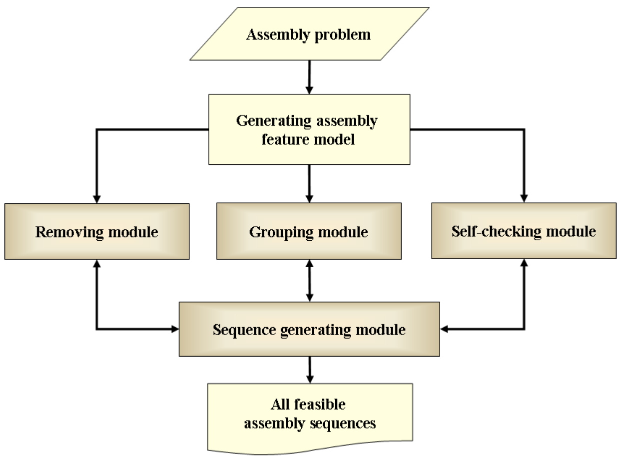


Figure 5 – Generation of assembly sequence by cooperating four modules

Figure-5 shows the relationship among four modules and presents how these modules cooperate to generate assembly sequence. As results of the cooperation of the modules, all feasible assembly sequences can be generated. They mean the sequences which have no left feature and parts in it after completing whole assembly processes.

4.5. DEVELOPMENT OF AN EVALUATION METHOD

Practical product can have lots of feasible assembly sequences with the increasing number of parts. There is a need to develop some procedures to reduce large quantities of sequences in order to select the optimal assembly sequence that most nearly meets planners' needs for a particular purpose in consideration of the practical conditions. So the evaluation method is designed to screen all feasible assembly sequences. In the evaluation method, three evaluation criteria are applied to obtain optimal assembly sequence, namely, base part, direction change, and special part. They should keep to the following basic principle:

1) Base part: If the part contains maximum quantity of assembly features and is heavier than other parts, this part is considered as a base part. Base part should be assembled firstly because it can take most parts and carry them.
2) Special part: In order to follow reasonable assembly sequence in terms of quality assurance and safety, the special part such as sensibility parts, e.g. high accuracy and surface roughness parts as well as easily broken parts such as glass etc. and dangerous parts such as explosive parts should be assembled as lately as possible.
3) Direction change: If the assembly direction is changed for meeting assembly requirements during the assembly process, this kind of operations will increase extra assembly effort, time and cost due to resetting part, turning part and assembly tools. This affects badly assembly efficiency. The fewer the direction change happen in assembly sequence, the better that assembly sequence is.

Based on the above principle and the developed assembly feature model, three rules are developed to select the optimal assembly sequence. Each principle forms one rule and three rules are derived out as follow.

Rule 1: Base part must be assembled firstly.
CHOOSE PART (a)-(Nf,W)
GET Nf %Nf - number of assembly feature%
GET W %W – weight of part%
IF MAX (Nf, W)
THEN BASEPART (TRUE, part (a), FIRST)
SELECT SEQUENCE (q)
IF BASEPART (FALSE, part (a), FIRST)
THEN SEQUENCE (FALSE, sequence (q))
DELETE SEQUENCE
END

Rule 2: Special part should be assembled lately.
CHOOSE PART (a)-(Attribute)
%Attribute – sensitive, dangerous%
GET SPECIALPART (TRUE, part (a), LATE)

SELECT SEQUENCE (q)
GET LOCATION NUMBER Nln
%Nln – location number of special part%
COUNT Np
%Np –sum of the whole location number%
IF MIN (Np)
THEN SEQUENCE (TRUE, sequence (q))
OBTAIN SEQUENCE
END

Rule 3: The few number of direction change in assembly sequence.
SELECT SEQUENCE (q)
DEFINE PART (a), PART (b)
%Two parts are successive in this sequence%
GET Ndc %Ndc- number of direction change%
IF MIN (Ndc)
THEN SEQUENCE (TRUE, sequence (q))
OBTAIN SEQUENCE
END

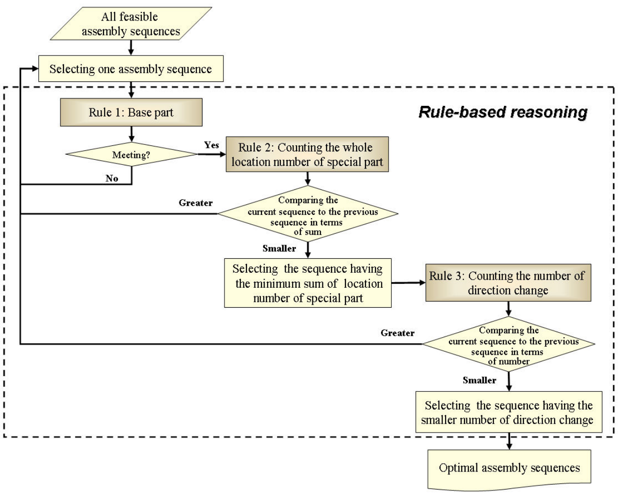


Figure 6 – Mechanism of the evaluation method

Figure-6 shows the mechanism of evaluation method. The given rules reduce searching time by eliminating unrealistic and uncommon solution. If an assembly sequence satisfies three rules, this assembly sequence is an optimal assembly sequence. Thus, the rule-based evaluation method can generate reasonable and near-optimal heuristic solutions efficiently.

5. IMPLEMENT OF ASP SYSTEM

5.1. SYSTEM ARCHITECHTURE

In order to develop the ASP system, system architecture and database are designed firstly. Figure-7 illustrates the architecture of ASP system and shows the flow of information. In the system architecture, there are six databases: product information database, assembly process database, assembly feature database, assembly method database, feasible assembly sequence database, and optimal assembly sequence database. Product information database and assembly process database are described from enterprise information database, and the other databases are generated with running the system. In addition, there are four functional modules that are the core modules of ASP system.

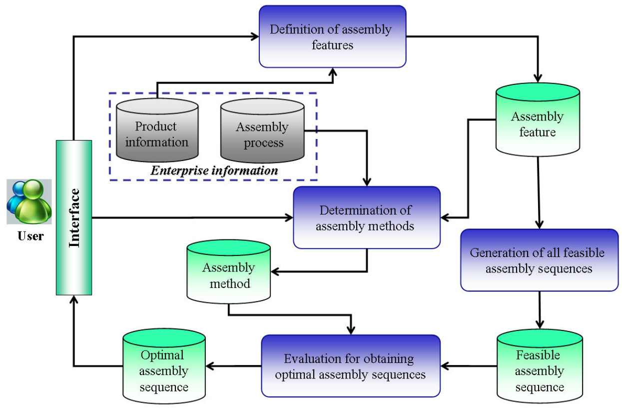


Figure 7 –Architecture of ASP system

Definition of assembly features module. This module is used to define assembly features for each part. Here, 3D drawings and 2D drawings are used to derive out assembly features and analyse assembly process.

Determination of assembly methods module. This module is applied to extract assembly method by examining assembly features. And company specific assembly methods are analysed and applied to assembly sequence planning.

Generation of all feasible assembly sequences model. This module is supported by reasoning mechanism and algorithm. All feasible assembly sequences can be generated by this model.

Evaluation for obtaining optimal assembly sequences module. This module is used to select the optimal assembly sequences. All alternative sequences are evaluated by the derived evaluation criteria.

Through the evaluation of all feasible assembly sequences, several optimal assembly sequences might be selected and the best one is determined among them by planner in consideration of planning conditions such as company organization and working behaviours and so on.

5.2. REALIZATION OF ASP SYSTEM

Based on the system architecture and holistic design concept, the ASP system has been implemented using C++ and Microsoft Foundation Classes (MFC) library in Windows XP Professional platform. Microsoft Visual C++ 6.0 is used as the integrated development environment (IDE) to build event-driven software. The MFC library provides the user interface (UI) module. All codes are programmed by C++. The developed whole ASP system is shown in Figure-8.

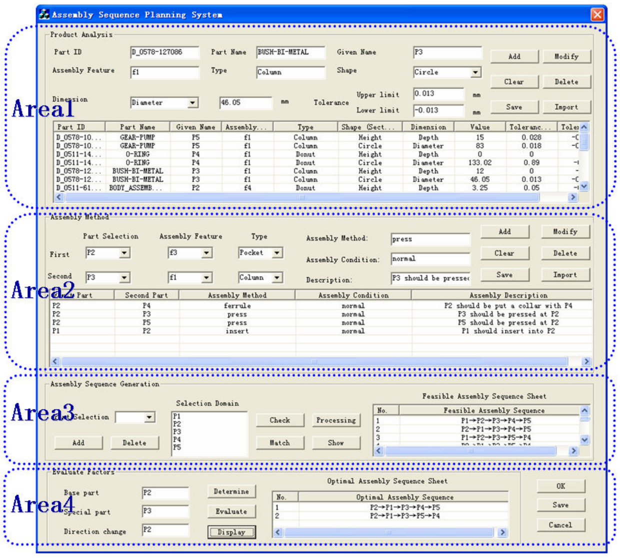


Figure 8 –The whole ASP system

From Figure-8, it is known that the ASP system consists of four modules: Area 1-product analysis module, Area 2-assembly method definition module, Area 3-assembly sequence generation module, and Area 4-evaluation module. These modules are integrated into one interface and the developed ASP system is easy for planner to operate due to the well designed interface.

5.3. FUNCTIONALITY OF ASP SYSTEM

5.3.1. Product analysis module

The functionality of this module is to analyse the whole product and define assembly features of each part. In Figure-8, Area 1 shows product analysis interface. There are two methods to input assembly feature information. One is to input data one by one, and the other is to import the assembly feature file. Six buttons manage assembly features. The list shows the results of product analysis and all assembly features will be displayed in the list. The input of this module is each part of product and the output is assembly features for each part which should be stored in the assembly feature database.

5.3.2. Assembly method definition module

The roll of this module is to define the assembly method between two parts. In Figure-8, Area 2 shows assembly method definition interface. Assembly method is auxiliary information from enterprise database. The input is two parts and each assembly feature and the output is assembly method sheet. Thanks to product analysis module, part and assembly feature could be selected directly. From assembly features, assembly method, assembly condition and description of assembly operation will be added from enterprise database. In case of the difficulty of deriving assembly method directly from assembly feature model such as surface contact, four buttons including add, modify, clear and delete are used to define assembly methods. The list shows assembly method between two parts and it could be saved in the assembly method database.

5.3.3. Assembly sequence generation module

This is a core module in the developed system. The functionality of this module is to generate all feasible assembly sequences based on the assembly feature model. There are two sub-modules: reasoning module and processing module. Reasoning module determines the relationship among assembly features. All feasible assembly sequences are generated automatically by processing module. In Figure-8, Area 3 shows interface of this module. The selection domain confirms assembly parts. Two buttons are used to add or delete the part. Check button and match button are used to operate reasoning mechanism. Processing button is used to generate all feasible assembly sequences. Several pop-up dialog boxes will be applied to prompt the operating results. The results will be shown in the list of feasible assemble sequence and be stored in the feasible assembly sequence database.

5.3.4. Evaluation module

The evaluation module is to select optimal assembly sequences. In Figure-8, Area 4 shows the interface of evaluation module. Determine button is used to generate the evaluation factors automatically based on three rules. Evaluate button is used to sift all feasible assembly sequences and obtain optimal assembly sequences from them. If there is no evaluation result, it means that there is at least one position conflict among designated parts, and the evaluation factors should be modified. Two pop-up dialog boxes will be used to prompt the operating results. The results can be shown in the list of optimal assembly sequence and be saved in the optimal assembly sequence database.

6. APPLICATION OF THE DEVELOPED SYSTEM TO A PRACTICAL PROBLEM

To verify the validity and efficiency of the developed system, assembly features-based ASP system is applied to a practical problem, i.e. the assembly of an automotive module such as oil pump. The assembly structure of oil pump is shown in Figure-9. Because the product is made up of 17 parts, the maximum number of assembly sequence is 17! = 355687428096000 in theory.

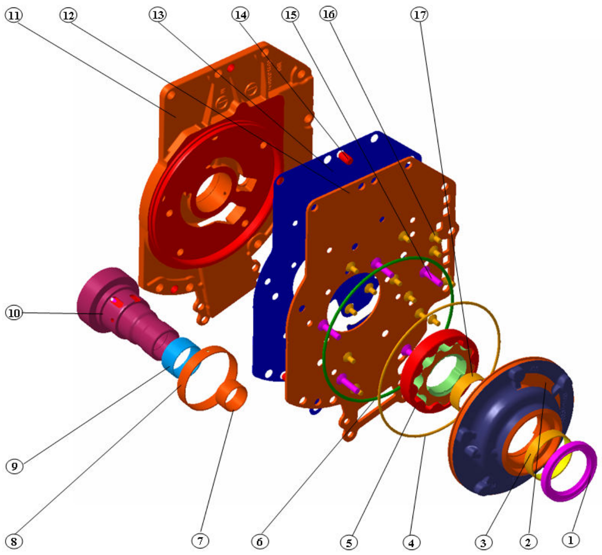
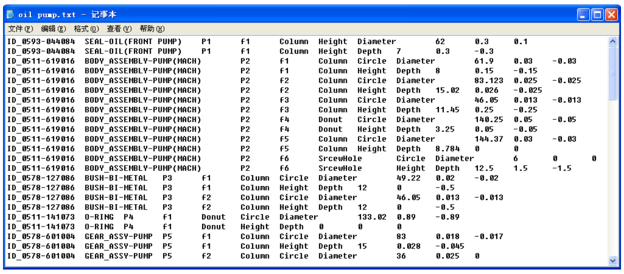


Figure 9 – Whole product structure of oil pump



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oil pump.txt - 记事本
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ID_0578-127086  BUSH-BI-METAL   P3   f2   Column  Height  Depth   12   0   -0.5
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ID_0511-141073  O-RING   P4   f1   Donut   Height  Depth   0   0   0
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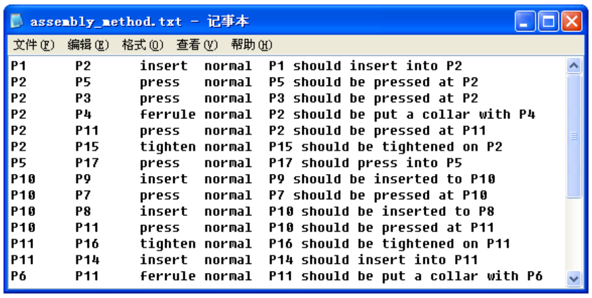
(a)



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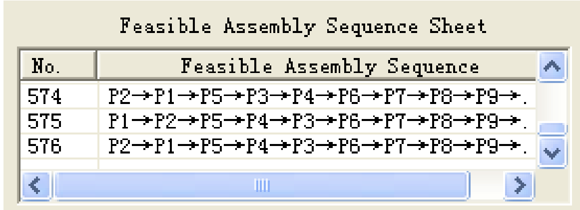
assembly_method.txt - 记事本
文件(F) 编辑(E) 格式(O) 查看(V) 帮助(H)
P1    P2    insert   normal  P1 should insert into P2
P2    P5    press    normal  P5 should be pressed at P2
P2    P3    press    normal  P3 should be pressed at P2
P2    P4    ferrule  normal  P2 should be put a collar with P4
P2    P11   press    normal  P2 should be pressed at P11
P2    P15   tighten  normal  P15 should be tightened on P2
P5    P17   press    normal  P17 should press into P5
P10   P9    insert   normal  P9 should be inserted to P10
P10   P7    press    normal  P7 should be pressed at P10
P10   P8    insert   normal  P10 should be inserted to P8
P10   P11   press    normal  P10 should be pressed at P11
P11   P16   tighten  normal  P16 should be tightened on P11
P11   P14   insert   normal  P14 should insert into P11
P6    P11   ferrule  normal  P11 should be put a collar with P6
```

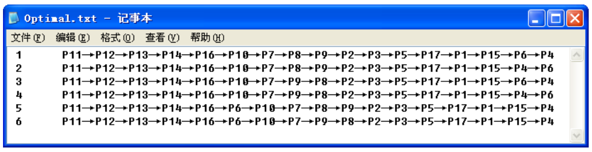
(b)

Figure 10 – (a) Assembly feature file and (b) Assembly method file



```
Feasible Assembly Sequence Sheet
No.   Feasible Assembly Sequence
574   P2→P1→P5→P3→P4→P6→P7→P8→P9→.
575   P1→P2→P5→P4→P3→P6→P7→P8→P9→.
576   P2→P1→P5→P4→P3→P6→P7→P8→P9→.
```

(a)



```
Optimal.txt - 记事本
文件(F) 编辑(E) 格式(O) 查看(V) 帮助(H)
1   P11→P12→P13→P14→P16→P10→P7→P8→P9→P2→P3→P5→P17→P1→P15→P6→P4
2   P11→P12→P13→P14→P16→P10→P7→P8→P9→P2→P3→P5→P17→P1→P15→P4→P6
3   P11→P12→P13→P14→P16→P10→P7→P9→P8→P2→P3→P5→P17→P1→P15→P6→P4
4   P11→P12→P13→P14→P16→P10→P7→P9→P8→P2→P3→P5→P17→P1→P15→P4→P6
5   P11→P12→P13→P14→P16→P6→P10→P7→P8→P9→P2→P3→P5→P17→P1→P15→P4
6   P11→P12→P13→P14→P16→P6→P10→P7→P9→P8→P2→P3→P5→P17→P1→P15→P4
```

(b)

Figure 11 – (a) The sheet of all feasible assembly sequences and (b) Optimal assembly sequences file

First of all, assembly features are extracted from 2D drawings and 3D drawings through assembly analysis to build the assembly feature model. They will be stored in the assembly feature database as text formatting, see Figure-10 (a). Next, assembly method and assembly condition are added according to assembly features. Assembly methods will be stored in the assembly method database as text formatting, see Figure-10 (b). And then, 17 parts could be added into the selection domain one by one. Reasoning mechanism will be carried out based on the generated assembly feature model. Assembly relationship among assembly features can be determined to find a counter feature. After that, 576 feasible assembly sequences are generated by adding process button and the results are shown in Figure-11 (a). Last, three evaluation criteria could be generated automatically by adding determine button. By applying the evaluate button, three optimal assembly sequences could be obtained. They should be stored in the assembly feature database as text formatting by adding save button. The final results are shown in Figure-11 (b).

The functionality of the developed system has been proved in practice. Through applying this ASP system, the assembly sequence planning was carried out effectively and efficiently. The solution space was markedly reduced by generating all feasible assembly sequences automatically and selecting the optimal assembly sequence finally.

7. CONCLUSIONS

This paper proposed an assembly feature model for encapsulating assembly-oriented information. Assembly operation can be transformed into their assembly features matching mechanism. Based on this model, a systematic ASP approach including reasoning mechanism, algorithm and evaluation method is applied to generate all feasible assembly sequences automatically and obtain the optimal assembly sequences finally. On the basis of the proposed strategy, assembly features-based ASP system was developed using Microsoft Visual C++ 6.0. In order to demonstrate the functionality of ASP system, a practical problem is applied to validate the reliability of the developed system. In another word, the developed ASP system supports a lot of assembly planners to complete the assembly sequence planning task.

Further development work will aim to extend the assembly feature model for whole assembly planning works such as the selection of the appropriate resources, e.g. person, assembly machine and jig/fixture, the calculation of assembly time and focus on the further development of a whole assembly planning system based on this assembly feature model.

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REFERENCES

Alok K. Priyadarshi and Satyandra K. Gupta, "Algorithms for generating multi-stage molding plans for articulated assemblies", *Robotics and Computer-Integrated Manufacturing*, Vol. 25, No. 1, 2009, pp 91-106

Chien-Cheng Chang, Hwai-En Tseng and Ling-Peng Meng, "Artificial immune systems for assembly sequence planning exploration", *Engineering Applications of Artificial Intelligence*, Vol. 22, No. 8, 2009, pp 1218-1232

G. Dini, F. Failli, B. Lazzerini and F. Marcelloni, "Generation of Optimized Assembly Sequences Using Genetic Algorithms", *CIRP Annals-Manufacturing Technology*, Vol. 48, No.1, 1999, pp 17-20

Hong-Seok. Park, "A Knowledge-Based System for Assembly Sequence Planning", *International Journal of the Korean Society of Precision Engineering*, Vol. 1, No. 2, 2000, pp 35-42

Hwai-En Tseng, Wen-Pai Wang and Hsun-Yi Shih, "Using memetic algorithms with guided local search to solve assembly sequence planning", *Expert Systems with Applications*, Vol. 33, No. 2, 2007, pp 451-467

Lai, H. Y. and Huang, C. T., "A systematic approach for automatic assembly sequence plan generation", *International Journal of Advanced Manufacturing Technology*, Vol. 24, No. 9-10, 2004, pp 752-763

Liang Gao, Weirong Qian, Xinyun Li and Junfen Wang, "Application of memetic algorithm in assembly sequence planning", *International Journal of Advanced Manufacturing Technology*, Vol. 49, No. 9-12, 2010, pp 1175-1184

Qiang Su, "A hierarchical approach on assembly sequence planning and optimal sequences analyzing", *Robotics and Computer-Integrated Manufacturing*, Vol. 25, No. 1, 2009, pp 224-234

Qiang Su, Sheng-jie Lai and Jun Liu, "Geometric computation based assembly sequencing and evaluating in terms of assembly angle, direction, reorientation, and stability", *Computer-Aided Design*, Vol. 41, No. 7, 2009, pp 479-489

Romeo M. Marian, Lee H.S. Luong and Kazem Abhary, "A genetic algorithm for the optimization of assembly sequences", *Computers & Industrial Engineering*, Vol. 50, No. 4, 2006, pp 503-527

Tianlong Gu, Zhoubo Xu and Zhifei Yang, "Symbolic OBDD representations for mechanical assembly sequences", *Computer-Aided Design*, Vol. 40, No. 4, 2008, pp 411-421

Tianyang Dong, Ruofeng Tong, Ling Zhang and Jinxiang Dong, "A collaborative approach to assembly sequence planning", *Advanced Engineering Informatics*, Vol. 19, No. 2, 2005, pp 155-168

Wen-Chin Chen, Pei-Hao Tai, Wei-Jaw Deng and Ling-Feng Hsieh, "A three-stage integrated approach for assembly sequence planning using neural networks", *Expert Systems with Applications*, Vol. 34, No. 3, 2008, pp 1777-1786

Wen-Chin Chen, Yung-Yuan Hsu, Ling-Feng Hsieh and Pei-Hao Tai, "A systematic optimization approach for assembly sequence planning using Taguchi method, DOE, and BPNN", *Expert Systems with Applications*, Vol. 37, No. 1, 2010, pp 716-726

Xinwen Niu, Han Ding and Youlun Xiong, "A hierarchical approach to generating precedence graphs for assembly planning", *International Journal of Machine Tools & Manufacture*, Vol. 43, No. 14, 2003, pp 1473-1486

Y.W. Guo, W.D. Li, A.R. Mileham, and G.W. Owen, "Application of particle swarm optimisation in integrated process planning and scheduling", *Robotics and Computer-Integrated Manufacturing*, Vol. 25, No. 2, 2009, pp 280-288