

A Real-Virtual Mapping Method for Mechanical Product Assembly Process Planning in Virtual Assembly Environment

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Abstract. In order to realize assembly process planning in virtual reality environment, an assembly process planning generation method based on real-virtual mapping of basic motion sequence is proposed. Based on the analysis of current assembly process content from enterprise, assembly process information is modeled; standard assembly operations and basic assembly motion are defined. The mapping matrix among standard assembly operations and basic assembly motions are set up. A method to get basic motion sequence in virtual environment during virtual assembling process by real user is put forward. A prototype system is developed based on these research results, and the system function is demonstrated through assembly process of automobile engine components. It shows that this assembly process generation method based on real-virtual mapping of motion sequence is feasible, and it also provides a new idea for the application of virtual assembly technique for product manufacturing process.

Keywords: Virtual reality; Virtual assembly; Assembly process planning; Standard assembly operation; Assembly basic motion; Real-virtual mapping.

1 Introduction

Mechanical product assembly belongs to the latter part of production work during the manufacturing process, it is a key link for product formation[1]. Mechanical assembly is a process to assemble components into subassembly, until the whole product. Mechanical assembly process plan is the reification of assembly process based on the product structure, manufacturing precision, and other factors. Assembly process planning includes information about assembly components and their assembly sequence, assembly tools and fixtures, assembly operation and assembly time and so on.

Assembly process plan is usually fulfilled by manufacturing engineer manually, and this procedure is depended on person's experience and knowledge to a large extent, and physical try out based on real prototype is necessary to check the process plan from time to time, it is inevitable low efficiency of this kind of assembly process planning. Therefore, computer aided assembly process planning can improve the efficiency of assembly planning, cut down the assembly cost and increase the degree of planning automation.

In research area of computer aided assembly process planning, it focuses on two common problems: assembly path planning and assembly sequence planning. Literature [2] presented a model based on features for assembly sequence planning automatically. The basic assembly modeling strategy was based on the matching features of components, and a group of standards based on assembly feasibility, maneuverability, assembly direction, cost and stability were used to check whether the assembly sequence is good or not. Literature [3] built a model with three-layer assembly information, and presented assembly sequence reasoning method within layered structure model, which solving assembly sequence planning problem for complicated product, and the prototype system FVAPP was developed based on UG. There are shortcomings of the above methods, such as easy of leading combination explosion, assembly experience and knowledge of individual people in assembly process can not be considered fully.

In virtual assembly research area, VRCIM laboratory of Washington State University and American National Institute of Standards and Technology developed Virtual Assembly Design Environment (VADE) together, which integrated with commercial CAD system tightly, and fed virtual assembly results back to CAD system. Virtual Reality Applications Center (VRCA) of Iowa State University built an assembly planning and evaluation system IVY [5], where assembly planning and evaluation could be performed based on geometric models and assembly hierarchical structure data directly. CIM Research Institute from Shanghai Jiao Tong University developed a software system named Integrated Virtual Assembly Environment (IVAE) [6]. It is a general application system for virtual assembly of general mechanical products based on geometrical constraints and degree of freedom analysis, where users can assemble products through various interactive devices such as data glove, 3D mouse, voice command, virtual menu, etc.

Although computer aided assembly process planning has made great development, process plan generated by totally computer automatic reasoning is not so easy to put into real practical use. While research on virtual assembly at present is mainly focused on assembleability evaluation for product design. Virtual prototyping and virtual reality technology provide a new and effective approach for assembly process planning. With the characteristics of immersion, interaction and imagination from virtual reality, through the use of virtual reality peripherals, assembly planner can manipulate components and tools and fixtures more naturally, and do assembly process planning in a visualized, perceivable and traceable manner, so as to obtain process plan which is reasonable, practical, and meets ergonomic requirement.

For assembly process planning with virtual reality, as assembly planner conducts product assembly operation in virtual environment, a very important problem is how to capture all necessary information automatically by computer software system and map the information to assembly process plan.

2 General Idea for Virtual Assembly Process Planning

In order to solve the automatically mapping problem for mechanical product assembly process plan, a real-virtual operation mapping method based on Basic-motion-Sequence is proposed. The general idea includes following aspects, as shown in Fig.1.

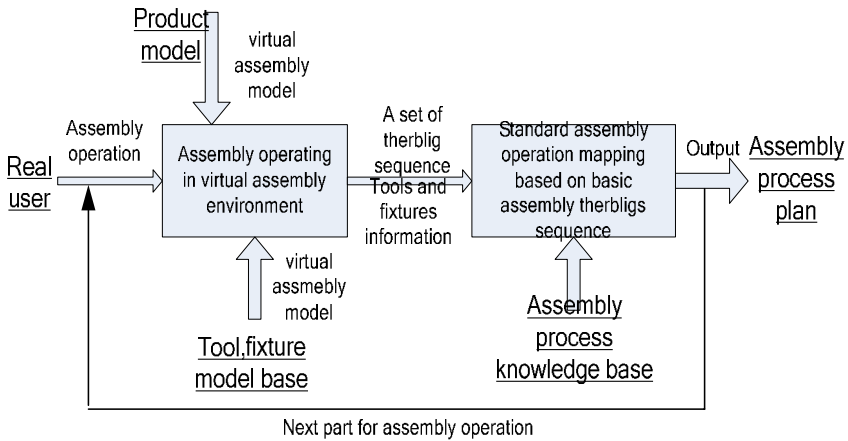


Fig. 1. General idea for assembly process planning based virtual assembly technology

A virtual assembly experimental environment is built where component assembly can be performed according to the mating constraint between each connected component. Assembly tools and fixtures database and Standard Assembly Process Knowledge base are built, and they act as support to do process planning. Product assembly tree model converted from CAD software system acts as input to the virtual assembly environment. With data glove and position tracking device, assembly planner can manipulate component with hand or with suitable assembly tool and fixture, and assemble components together to form the final product according to component's mating relation. During the assembly operation process for each component, software system can automatically record every set of complete virtual assembly operations in the form of basic-motion-sequence, together with information about operated component and assembly tool. Based on the mapping relation between basic-motion-sequence and Standard Assembly Operation, together with the type of component and type of assembly tool and so on, assembly process description information for each component and assembly time consumed for each assembly process can be generated automatically by searching in the standard assembly process knowledge base. After all the components have been assembled together, the software system will generate the final product assembly process plan. The key points of this basic idea are modeling of Standard Assembly Operation, modeling of Assembly Basic Motion, mapping between Standard Assembly Operation and Basic Motion Sequence, and acquisition of basic-motion-sequence during the virtual assembly operation. These key points are discussed in detail as follows.

3 Real-Virtual Mapping Method Based on Basic Motion Sequence

3.1 Modeling of Standard Assembly Operation

With the detail analysis of composition information about auto engine assembly process card from real industrial use, an assembly process information model is put

forward which includes information about assembled component, assembly tool, assembly operation motion, assembly operation time, weight of assembled object and moving distance of assembly operation.

Among these information, assembled component, assembly tool and assembly operation motion are the most basic ones. Only when virtual assembly operations on components are described exactly and associated with real assembly operations that complete assembly process could be obtained, so as to generate assembly process plan. Therefore, the description of virtual assembly operation motion model is the base to build the description model of assembly process information.

With the analysis of assembly operation motion from real manufacturing process plan, assembly operation motions can be simplified and classified into 9 types, they are Prepare, Put-on, Insert, Screw, Fasten, Press, Knock-in, Load and Unload, which act as Standard Assembly Operation (SAO) in assembly process plan information model. These 9 types of Standard Assembly Operations cover most of the operation motion types in auto engine assembly work and with out any overlapping from the operation motion meaning point of view.

3.2 Modeling of Assembly Basic Motion

Taking the Method Time Measurement (MTM) [7] as reference, it shows that current feasible MTM therbligs includes 18 types, which can be classified into three categories as follows:

1. Effective therbligs, they are necessary motions during task operation, such as Reach, Grasp, Move, Position, Assemble, Disassemble, Use, Release, Inspect.
2. Assistant therbligs, they are necessary therbligs in order to complete task operation therbligs, and they will make task be delayed and consume much more time, and lead to low working efficiency, such as Search, Find, Select, Plan, Pre-position.
3. Ineffective therbligs, they are therbligs which have no any effect on task working operation, and should be managed to acquire in therblig analysis: Hold, Unavoidable Delay, Avoidable Delay, Rest.

In our research, Standard Assembly Operations and body motion can be described with the reference to MTM. But the description of MTM therbligs is too basic, how to make MTM therbligs aggregation to meet the requirement of practicability and applicability in virtual assembly should be well considered. Currently, subjective therbligs can not be defined easily in virtual reality environment, such as Search, Find, think, etc. And some therbligs are not necessary for virtual assembly, such as Hold, Unavoidable Delay, and Avoidable Delay. So, with reference to the uniform definition of basic therblig element from MTM standard criterion, 9 types of Assembly Basic Motion elements have been proposed for necessary used in virtual assembly environment, they are Reach, Grasp, Move, Turn, Apply Pressure, Disengage, Position, Position-Z, Release. The definition of Assembly Basic Motion element based on MTM is the foundation of aggregating Assembly Basic Motion to form Standard Assembly Operation.

The meaning of the above 9 Assembly Basic Motion Element which could be recorded in virtual assembly environment is described in detailed as follows:

1. **Reach:** Move empty hand to touch component object. Take the moment when the hand has the orientation of moving forward to destination object as the starting point of **Reach** motion, and the moment when the hand arrives at the destination object as the ending point of **Reach** motion.
2. **Grasp:** Use fingers or palm to fully control component object. Take the moment when fingers surround an object and try to control it as the starting point of **Grasp** motion, and the moment when the object has been fully controlled as the ending point of **Grasp** motion.
3. **Move:** Use hand or any other part of body moves an object from one place to another. Take the moment when hand with load has the orientation of moving forward to destination place as the starting point of **Move** motion, and the moment when hand with load arrives destination place as the ending point of **Move** motion.
4. **Turn:** Take forearm as rotation axis and rotate hand, wrist and forearm. This basic motion has two variation factors, the rotating angle and rotating weight or resistance force.
5. **Apply Pressure:** Append force to overcome resistance. Apply extra force when meeting larger resistance during assembly process.
6. **Disengage:** Make object disengage from other objects. Take the moment when object is under controlled (**Grasp**) and is ready to be disassembled as the starting point of **Disengage** motion, and the moment when the object has been disassembled completely as the ending point.
7. **Position:** Put object on a certain orientation. Take the moment when virtual hand with object in operation begins to sway, turn and slide to a certain orientation as the starting point of **Position** motion, and the moment when object has been put at a correct orientation as the ending point.
8. **Position-z:** Put an object on a given position. If the given orientation where the object is required to be positioned is an unambiguous point, the object should be allowed to be put anywhere within a certain range.
9. **Release:** Release grasped object. Take the moment when fingers begin to leave the grasped object as the starting point of **Release** motion, and the moment when fingers leave the object completely.

The definition of Assembly Basic Motion based on MTM method is the basis to aggregate Standard Assembly Operation from Assembly Basic Motion, and virtual assembly operation motion should be mapped according to these Assembly Basic Motion strictly.

3.3 Mapping between Standard Assembly Operation and Basic Motion Sequence

According to assembly operation motion in real assembly process, all operations can be classified into 9 basic ones without any overlapping in meaning, which are Prepare, Put-on, Insert, Screw, Fasten, Press, Knock-in, Load and Unload.

In virtual environment, Standard Assembly Operations could be aggregated according the combinations Assembly Basic Motion. In other words, a Standard Assembly Operation can be decomposed into Basic Motion sequence, and the Standard Assembly Operation and Assembly Basic Motion sequence has a unique mapping relationship with each other. During virtual assembly process, Basic Motion sequences in assembly

Table 1. Standard Assembly Operations and Basic Motion Mapping Matrix

Basic Motion \ Standard Assembly Operation	Reach	Grasp	Move	Turn	Apply Pressure	Disengage	Position	Position-z	Release	Mapping code
1. Prepare	X	X	X						X	111000001
2. Put-on	X	X	X					X	X	111000011
3. Insert	X	X	X				X		X	111000101
4. Screw	X	X	X	X			X		X	111100101
5. Fasten	X	X	X	X	X		X	X	X	111110111
6. Press	X	X	X		X		X	X	X	111010111
7. Knock-in	X	X	X		X		X		X	111010101
8. Load	X	X	X				X	X	X	111000111
9. Unload	X	X	X			X			X	111001001

operations are recorded according to virtual operation order, and then the Basic Motion sequences can be mapped to corresponding Standard Assembly Operation. The mapping matrix is shown in table 1, each row indicates a type of Standard Assembly Operation, and each column indicates a type of Basic Motion. Each Standard Assembly Operation is corresponding to a set of Basic Motions which forms a motion sequence; these corresponding Basic Motions are marked with letter ‘X’. A 9 digital code is used to indicate the mapping relationship. For each row of Standard Assembly Operation, if the Basic Motion cell is marked with ‘X’, ‘1’ is signed as the digital code number; if the Basic Motion cell is blank, ‘0’ is signed as the digital code number. By this meaning, for each row, there is a 9 digital code, which is indicated at ‘Mapping code’ column.

The Standard Assembly Operation and Basic Motion mapping matrix acts as the basis of Standard Assembly Operation’s acquisition. During virtual assembly, when user manipulating some components, all Basic Motions are recorded. If a Basic Motion is applied during operating process, the digital code bit representing this Basic Motion will be signed as ‘1’. After operations completed, Basic Motion sequences are generated from recorded Basic Motions, and mapped into unique Standard Assembly Operations separately.

3.4 Acquisition of Basic Motion Sequence during Virtual Assembly Operation

During virtual assembly, components are manipulated by virtual hand, Basic Motion sequence information for assembly operation is recorded, where basic motion **Reach** is set as the starting motion of basic motion sequence and **Release** as the end motion of basic motion sequence. As assembly operation in virtual assembly environment is quite different from that of real assembly operation, each Basic Motion digital code is set according to following rules:

Reach code: Reach acts as the beginning motion of each assembly operation during virtual assembly. When virtual hand touches component or tool, which can be determined with collision diction model, the operation motion is considered as Reach,

and the **Reach** code is signed as ‘1’. As ineffective touch might occur between virtual hand and components from time to time during the virtual assembly procedure, only when Reach motion is combined with other basic motion (such as **Grasp** etc.), and only if the position of operated component has been changed, that the previous motion Reach is considered as effective motion.

Grasp code: If the virtual hand and component or tool is in the touch status, when operator sends a signal to grasp component or assembly tool, the **Grasp** motion code is set to ‘1’.

Release code: Release acts as the end motion of each assembly operation during virtual assembly, when operator sends a signal to release grasped object and the virtual hand leaves operated objects, the **Release** motion code is set to ‘1’. And all basic motions after **Reach** motion being recorded should be saved to get a mapping code, this mapping code is the basic information for motions-operation mapping.

Move code: when virtual hand is at state of grasping object, supposed that the object’s position at beginning is $P1$, and the object’s position at the end is $P2$, if $P1 \neq P2$, the **Move** motion code is set to ‘1’.

Turn code: when virtual hand is grasping objects, supposed that the object’s orientation at beginning is $R1$, and the object’s position at the end is $R2$, if $R1 \neq R2$, the **Turn** motion code is set to ‘1’.

Apply Pressure code: In virtual assembly, **Apply Pressure** can not be determined through signals sent by operator, but it can be determined by the final status of objects together with assembly process information. That is, check the object’s ID to find out whether the object should be pressed during the assembly process, if yes, and then check whether the object is completely constrained, and if all the answers are yes, the **Apply Pressure** motion code is set to ‘1’.

Disengage code: By checking the status of operated component at the beginning and the end of operation separately, if the total number of parts of the assembled components is decreased, it means Disengage motion happens, the **Disengage** motion code is set to ‘1’.

Position code: When virtual hand is assembling a grasped object, if line-align-line constraint is confirmed, the **Position** motion code is set to ‘1’.

Position-z code: When virtual hand is assembling a grasped object, and if face-to-face constraint is confirmed, the **Position-z** motion code is set to ‘1’.

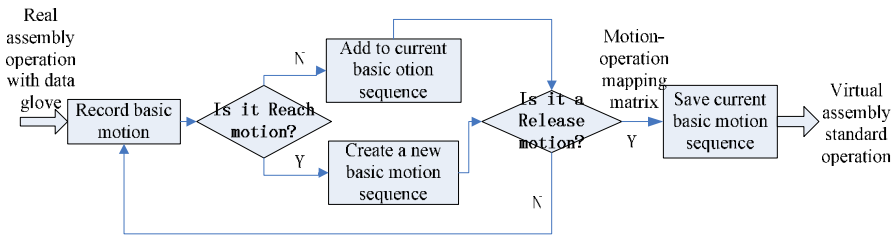


Fig. 2. Virtual assembly operation generating process

After virtual assembly operations, all basic motion sequences would be recorded as mapping codes, and Standard Assembly Operation could be acquired through mapping relationship shown in the motion-operation mapping matrix. The flow chat of real-virtual mapping process is shown in Fig.2. With these Standard Assembly Operations together with other assembly process information which are acquired at the same time during virtual assembly procedure, assembly process plan can be generated.

4 Example

The method mentioned above has been integrated into computer aided software named Virtual Assembly Process Planning Environment (VAPPE) which is developed by our research group. A type of auto engine has been selected as an example to verify the above method. Assembly tool and assembly fixture have been modeled and saved into database, standard assembly process knowledge for auto-engine assembly has also been modeled. After running the software system, VAPPE will read some initial files, such as product information and production environment information files, and set up virtual assembly environment, just as shown in Fig.3.

With data gloves, mouse or keyboard, operator can control virtual hand in the virtual environment to grasp and move components, and assemble components through constraint recognition and confirmation, so as to realize the assembly simulation function of virtual assembly system. Fig. 4 shows the assembling process of

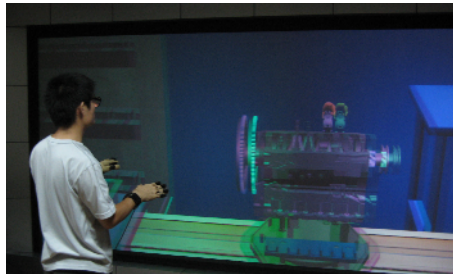


Fig. 3. Auto engine virtual assembly operating simulation scene

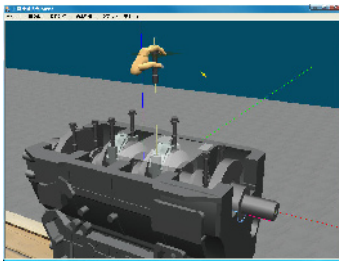


Fig. 4. Assembly process without tools

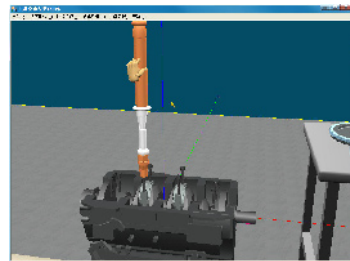


Fig. 5. Fasten bolts with semiautomatic tool

screwing 8 bolts into corresponding holes in bearing covers without tools. When the bolt is getting close enough to the mating hole, the system will highlight the potential constraints and prompt to operator with highlight line and/or face, and then operator can confirm these constraints in order to assemble components. After all the bolts are screwed to the right place, a semi-automatic tool is used to screw and fasten them, just as shown in Fig. 5.

During the virtual assembly operation, VAPPE system records all the basic motion sequences for every assembly operations and other assembly process information. After the virtual assembly operation completed, the software system runs the assembly process plan generation module. The module reads all virtual assembly basic motion sequence, and maps them into standard assembly operations according to motion-operation mapping matrix, as shown in table 2.

Table 2. Recorded assembly operation information

No.	Motion-operation mapping code	SAO	Component name	Tool name
1	111100101	screw	bolt CC4105Q-052004_2	No(hand)
9	111110111	Fasten	bolt CC4105Q-052004_2	Semi-automatic screwdriver

Table 3. Assembly process information corresponding to Table 2

No.	Content of process	time /s
1	Screw bolt CC4105Q-052004_2 with hand	2.2
9	Fasten bolt CC4105Q-052004_2 with semi-automatic screwdriver	2.7

Together with other assembly process information recorded during virtual assembly operation, VAPPE system will search corresponding standard assembly process in assembly process knowledge base to obtain standard assembly time, and shows the results in the interface. The processes corresponding to above standard assembly operations are shown in table 3. With this computer aided software, it is obvious that the assembly process plan efficiency can be increased. All the information about assembly process plan and workplaces can be saved into database and served for real assembly manufacturing process.

5 Conclusions

In order to realize assembly process planning in virtual reality environment, an assembly process planning generation method based on real-virtual mapping of basic motion sequence is proposed. In this paper, assembly process information is modeled; standard assembly operations and basic assembly motion are defined. The mapping matrix among standard assembly operations and basic assembly motions are set up. A method to get basic motion sequence in virtual environment during virtual assembling

process by real user is put forward. A prototype system is developed based on these research results, and the system function is demonstrated through assembly process of automobile engine components. The application illustrates the feasibility of the proposed method; it also provides a new and effective approach for assembly process planning through operator's real experiencing in the virtual reality environment.

Acknowledgments

The work is supported by the National High-Tech Program of China (Grant No. 2006AA04Z141) and the Key Project from NSFC of China (Grant No. 90612017). The authors are also grateful to the editors and the anonymous reviewers for helpful comments.

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